NSP

Pathfinder Decommissioning

Application for Type A Container — Reactor Vessel

APPLICATION FOR APPROVAL OF PACKAGING FOR LSA MATERIAL IN TYPE A PACKAGING

DECOMMISSIONING OF THE PATHFINDER ATOMIC POWER PLANT

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for

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EXECUTIVE SUMMARY

The Pathfinder Atomic Power Plant is being decommissioned. The reactor vessel and internals will be removed in one piece and shipped for disposal at Richland, WA, using the reactor vessel as the shipping container. The reactor vessel package includes two inches of steel circumferential shielding around the core region to maintain exposures with NRC and DOT shipping requirements. The package uses a honeycomb structure external impact limiter to meet the Normal Conditions of Transport free drop analyses. The package will be shipped by rail from Sioux Falls, SD to Richland, WA.

This application by Northern States Power Company (NSP) to the Nuclear Regulatory Commission (NRC) contains the necessary information identified in NRC Regulatory Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packaging of Type B, Large Quantity, and Fissile Radioactive Material" (Ref. 1.1) to qualify the vessel as a Type A container for Low Specific Activity (LSA) material. The application contains no exceptions to the NRC regulations identified in Title 10 CFR Part 71, "Packaging and Transportation of Radioactive Materials", (Ref. 1.2).

1.0 GENERAL INFORMATION

1.1 Introduction

Northern States Power Company (NSP) plans to decommission the Pathfinder Atomic Power Plant's (Pathfinder) fuel handling building (FHB) and reactor building (RB). Pathfinder is located in South Dakota, approximately 5.5 miles northeast of the city of Sioux Falls. It is owned and was operated as a nuclear facility by NSP of Minneapolis, Minnesota. The nuclear steam supply system (NSSS) was a 66 MWe boiling water type nuclear reactor designed by Allis-Chalmers Manufacturing Company of Milwaukee, Wisconsin.

Pathfinder was operated as a nuclear facility by NSP from 1964 through 1967. Starting in 1968, the plant was repowered with fossil fueled boilers and the nuclear portions of the plant were partially decommissioned and placed in a safe storage (SAFSTOR) configuration. Decommissioning was accomplished under an amendment to the original nuclear plant operating license, DPR-11. Following completion of the partial decommissioning program in 1971, the 10 CFR Part 50 license was surrendered upon amendment of a by-product material possession license under the provisions of 10 CFR Part 30.

During the SAFSTOR decommissioning program, the NSSS was dismantled to the extent necessary to render it inoperable and incapable of being restored to service. The reactor vessel was drained and connected to a vacuum pump to remove all residual water from non-drainable cavities. The control rods and blades were placed in the vessel for disposal, and the reactor vessel was filled with gravel. The internals were left in place. The vessel head was reinstalled and bolted to the vessel flange using the vessel head bolts.

Two vessel removal alternatives were considered; segmentation of the vessel and internals and transport for disposal in shielded shipping containers, and one-piece removal and disposal. The segmentation alternative would require extensive remote tooling and individual segment handling to cut and load the shipping casks for disposal. The cutting process would generate large quantities of smoke and debris which would require extensive contamination control measures such as control access tents, high efficiency particulate air (HEPA) filters and remote handling devices. There would be additional exposure to workers owing to the extensive time required to segment, load and ship each piece. The selected alternative of one-piece shipment does not require extensive tooling, handling contamination controls or high worker radiation exposure. The vessel and internals package contains 476 curies of radioactivity as activated and contaminated material. This number of curies does not warrant the effort to segment and package the vessel and internals. Based on the vessel activation and shielding analysis, the vessel and internals qualify as Low Specific Activity material and the package qualifies as a Type A container.

To prepare the vessel for shipment, the vessel will be filled with grout to fix the gravel in place, lifted from the reactor cavity, moved through the open reactor building dome and laid on its side within a temporary enclosure. The external asbestos insulation will be removed and the vessel certified clean of asbestos. A cylindrical steel shield will be welded to the vessel shell. An impact limiter consisting of Hexcel energy absorbing material will be installed on the vessel shell surface to protect the vessel during normal condition of transport. The vessel package will be lifted horizontally and placed on saddles installed on a flatbed railcar for transport to the US Ecology, Inc. burial facility near Richland, WA.

When fully prepared the vessel package will weigh 291 tons not including tie-downs or other supports. The package will be transported by rail from the Pathfinder site to Richland, WA. The Type A container package will be shipped in an exclusive use vehicle (railcar), but does not require a special carrier; therefore the package will be transported as normal mixed freight. The reactor vessel package will be unloaded from the railcar and transported a short distance to the burial site.

This shipping package application report evaluates the adequacy of the Pathfinder vessel package to meet the applicable requirements of the NRC contained in Title 10 CFR Part 71 (Ref. 1.2). Authorization is requested to approve this package for a one-time, single trip shipment between the Pathfinder site in Sioux Falls, SD and Richland, WA.

1.2 Package Description

The Pathfinder package is shown on Figure No. 1.1, and is based on TLG Engineering, Inc. Drawing No. N04-22B-001, Pathfinder Vessel Transport Package. The package is essentially a cylindrical container and will consist of the reactor vessel, internals, internal grout, steel shielding and impact limiter. The internal steel components of the package are neutron activated and include a variety of radionuclides, primarily cobalt-60 (Co-60), iron-55 (Fe-55), nickel-63 (Ni-63) and nickel-59 (Ni-59). A small amount of surface contamination exists on the interior surfaces of the vessel, but will be generally bound to the surfaces by the grout.

The total radioactivity is 476 Curies. However, the majority of the package source term consists of activated base metal that is not readily dispersible. The remaining source term is estimated to be 95 millicuries consisting of a thin corrosion film that is bound to the surfaces of the Pathfinder vessel and internals and is further bound by the grout. The maximum specific activity of the package is approximately 0.248 millicuries per gram. Since this value is less than 0.3 millicuries per gram the package qualifies as a Low Specific Activity (LSA) package. In accordance with 10 CFR 71.52, the package is exempt from the additional requirements for Type B packages, and will be qualified as a Type A package.

1.2.1 Vessel and Internals

The major components of the reactor vessel and internals are shown in Figure 1.2. The reactor vessel is fabricated from 3-inch thick carbon steel ASME A212 Grade B plate with integrally bonded (Lukens clad) 304L stainless steel cladding. The flanges and nozzle forgings conform to the ASTM A105 Grade II and are weld overlaid with stainless steel having a chemistry similar to Type 304 except that maximum free carbon content at the clad surface is below 0.050 per cent. The overlay is stabilized with a small amount of niobium.

The vessel head is fabricated from the same carbon and stainless steel cladding materials as the vessel shell. The head is secured to the vessel flange by the original 48 head studs and nuts.

The vessel internals are all fabricated from Type 304L stainless steel with the exception of the boiler boxes which are Zircaloy-2. The other principal contents of the vessel are the control rods and blades that were disposed of in the reactor vessel. These components were fabricated from boron stainless steel and contain boron pellets.

At the recommendation of the Atomic Energy Commission at the time of the initial Pathfinder decommissioning, the vessel was filled with one-quarter inch diameter pea gravel. The pea gravel apparently filled all cavities uniformly with the exception of one area at the side of the vessel. At this location there is a "hot spot" with a radiation reading of about 600 mR/hour, whereas all other areas at the same elevation are about 150 mR/hour. To stabilize the gravel and to fill the apparent void spot, the vessel will be pumped full with a grout. Other than the filling of the apparent void, no direct credit was taken for the shielding effectiveness of the grout in the shielding analysis.

1.2.2 Shielding, Impact Limiter and Tie-downs

Based on the shielding analysis of the vessel package with a 25 per cent void fraction in the gravel (no credit for the grout), two inches of steel shielding will be added to the vessel package to meet the NRC and DOT transport regulations. The shielding will be made up from a 1-3/4 inch thick shell plate welded to the vessel shell outside diameter, extending three feet below the elevation of the core bottom and five feet above the elevation of the core top. Figure 1.1 shows the shield extending six feet below and eight feet above the core midplane. The remaining 1/4 inch of steel shielding will be fabricated in a cylindrical shape to form the outer shell for the Hexcel impact limiter. The two inches of steel shielding is sufficient to reduce the external exposure rate to less than 10 mRem/hour at two meters (without credit for the grout), assuming a 25 percent void fraction in the gravel.

The impact limiter is used to absorb the energy of impact from the postulated one foot drop during normal conditions of transport. The impact limiter will be fabricated from pre-crushed Hexcel (TM of the Hexcel Corporation, Dublin, CA); a honeycomb configuration of aluminum bonded to the vessel surface. Two types of Hexcel will be used; a low density Hexcel configuration bonded to the vessel shell region extending over the entire length of the vessel. In the region where the 12 inch wide vessel support saddles will be located (at the vessel upper and lower shell spring lines), a higher density Hexcel will be used to compensate for the loss of low density Hexcel in that area. The Hexcel will be bonded to the vessel, and then covered by a one-quarter inch thick steel cylindrical plate to protect the Hexcel from inadvertent damage. The minimum Hexcel thickness is 8 inches located at the center region of the shell, surrounding the 1-3/4 in thick shielding section. The Hexcel thickens to approximately 11 inches for the remaining region of the vessel shell.

The tie-downs used for the package shipment will consist of two hoop straps fabricated from wire rope or steel bands. The hoop straps will be attached to the support saddles or to the railcar floor structural member supports to ensure there will be adequate support during transport. The vessel will rest on the two circumferential saddles located at the vessel shell spring lines. There will be no direct attachments to the vessel shell or Hexcel material for vessel tie-down except for the circumferential weld of the shield to the vessel.

1.2.3 Package Weight and Dimensions

The overall package weight of the vessel, internals, gravel, grout, shield, and impact limiter is 582,000 lbs, or 291 tons. Since the saddles and tie-downs are not attached to the package directly, no additional weight is included herein. The weights of the individual major components are shown in Table 1.1.

The overall package dimensions are shown on Figure 1.1, and are based on TLG Engineering, Inc. Drawing No. N04-22B-001. The overall length is 35ft-4 1/2in, and the overall diameter is 13ft-2in. The other principal dimensions are shown in Figure 1.1.

1.2.4 Total Curie Content

The Pathfinder package contains both activated and contaminated materials. The reactor vessel and internals activated inventory constitute most of the radioactivity of the package. The total activation inventory is 476 curies, consisting primarily of Co-60, Fe-55, Ni-59 and Ni-63. In addition, approximately 95 millicuries of the same radionuclides are present in the form of surface contamination on the interior surfaces of the internals. Table 1.2 lists the major components of the vessel and internals and their activity (in Curies) by radionuclide.

The principal radionuclide of interior surface contamination is Co-60 based on data taken of scraping samples from the feedwater system piping attached to the vessel. This sample point was judged to be a conservative representation of the vessel source of surface contamination. The individual quantities of surface contamination are not shown on Table 1.2 because the amounts are so small relative to the activation inventory.

1.2.5 Decay Heat Generation

The total amount of decay heat generation for the vessel and internals package was calculated from the activation analysis to be 4.67 watts. This amount of decay heat is insignificant, and need not be considered further in this analysis.

APPENDIX 1.3

References

1.1 NRC Regulatory Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packaging of Type B, Large Quantity, and Fissile Radioactive Material", Revision 1, January, 1980.

1.2 Title 10 Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Materials", January 1, 1989.

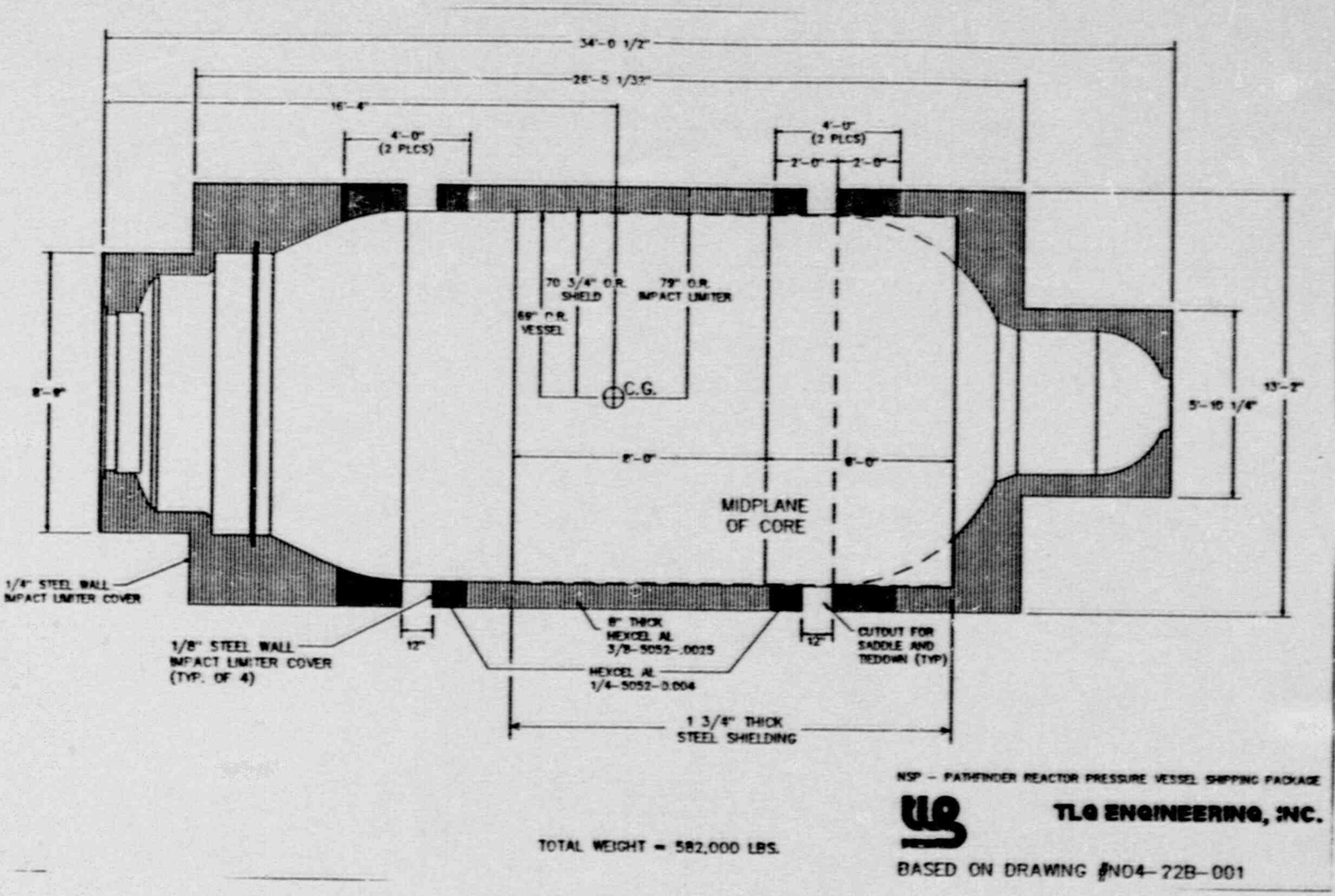

Figure 1.1
Pathfinder Vessel Transport Package

Figure 1.2
Pathfinder Vessel and Internals

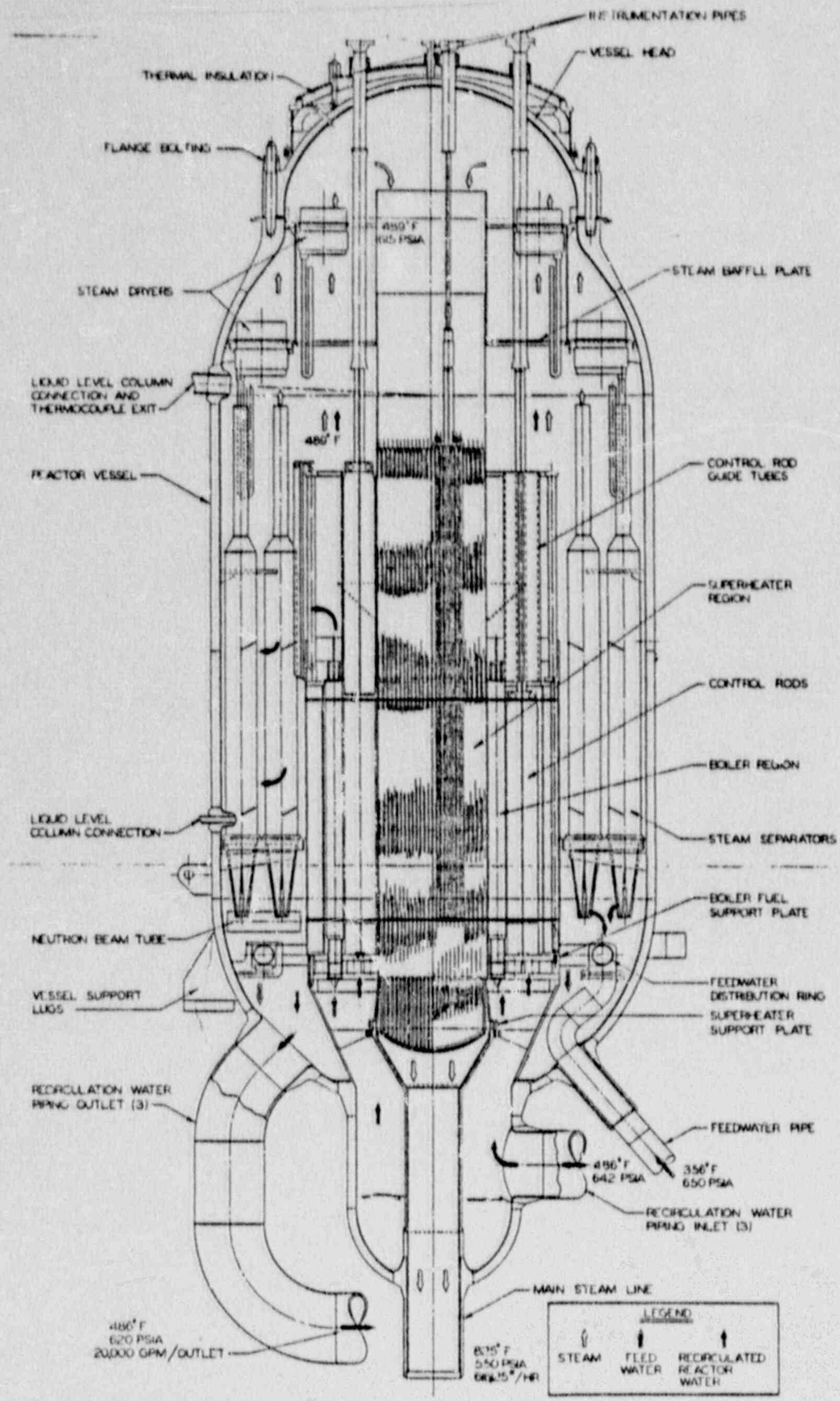

TABLE 1.1
PATHFINDER PACKAGE CALCULATED WEIGHTS

Component	Calculated Weight, lbs
Reactor Vessel	155,000
Vessel Internals	43,000
Shielding/Impact Limiter	64,000
Gravel and Grout	320,000
GROSS WEIGHT	582,000 lbs 291 tons

TABLE 1.2
ESTIMATED INVENTORY OF RADIONUCLIDES ON JANUARY 1, 1990

Component	H3	C14	Fe55	Co60	Ni59	Ni63	Nb94	Tc99	Eu152	Eu154	Others	Total Curies
Superheater baffle	0.08	0.03	4.58	34.40	0.19	21.97	---	---	0.02	---	---	61.3
Superheater fuel insul. tubes	0.15	0.06	8.77	65.92	0.35	42.11	---	---	0.05	---	---	117.4
Superheater support plate	---	---	---	---	---	---	---	---	---	---	---	<0.01
Superheater control rods	---	---	0.04	0.32	---	0.21	---	---	---	---	---	0.6
Boiler fuel boxes	0.01	0.03	0.84	7.19	0.04	4.35	---	---	---	---	0.86	13.3
Boiler shroud	0.15	0.06	9.59	51.61	0.39	46.84	---	---	---	---	0.01	108.6
Boiler hold down structure	0.01	---	0.61	4.58	0.02	2.93	---	---	---	---	---	8.1
Boiler CR tubes/remain. struct.	---	---	0.49	3.69	0.02	2.36	---	---	---	---	0.01	6.6
Boiler element poison shims	0.03	0.01	1.88	14.14	0.08	9.03	---	---	0.01	---	---	25.2
Boiler control blades	0.11	0.04	6.39	48.03	0.26	30.68	---	---	0.03	---	---	85.5
Instrumentation/sample holders	---	---	0.48	3.58	0.02	2.29	---	---	---	---	0.01	6.4
Boiler grid plate	0.04	0.02	2.52	18.96	0.10	12.11	---	---	0.01	---	---	33.8
Steam separators & supports	---	---	0.54	2.93	0.02	2.66	---	---	---	---	0.01	6.2
Feedwater ring & supports	---	---	0.15	0.83	---	0.75	---	---	---	---	0.01	1.7
Vessel cladding	---	---	0.06	0.34	---	0.31	---	---	---	---	---	0.7
Vessel	---	---	0.41	0.14	---	0.09	---	---	---	---	---	0.6
Total by isotope (curies)	0.59	0.25	37.36	256.66	1.49	178.68	<0.01	<0.01	0.13	<0.01	0.93	476.1
Percent of total by isotope	0.12%	0.05%	7.85%	53.91%	0.31%	37.53%	<0.01%	<0.01%	0.03%	<0.01%	0.19%	

2.0 STRUCTURAL EVALUATION

2.1 Structural Design

The purpose of this chapter is to describe and evaluate the structural aspects of the Pathfinder package for compliance with the requirements specified in 10 CFR 71 (Ref. 1.2). The principal structural engineering design features are identified, and the packaging components and systems important to safety are described and evaluated. Analyses results are presented which demonstrate that adequate protection measures are being taken to assure safe transport of the Pathfinder package for Normal Conditions of Transport.

The basic acceptance criteria for this package are that it must meet the external radiation requirements of the NRC as defined in 10 CFR 71 paragraph 71.47 (a) through (d). The structural criteria for this package are that it must meet the requirements of the NRC as defined in 10 CFR Part 71.71, paragraphs (a) through (c). The package must be shown to maintain integrity under the Normal Conditions of Transport, and not breach containment and lose its contents under these postulated test conditions. The radioactivity contained in the Pathfinder package is in the form of activated materials and internal surface contamination, further bound to the surface by grout pumped inside the vessel under pressure to fill voids. The package contains no contaminated liquids, explosive mixtures or potential aerosol particulates that could be considered radiological hazards. The analyses presented in this chapter show that the Pathfinder package can be safely transported from Sioux Falls, SD to Richland, WA without loss of integrity of the container.

The containment boundary consists of the thick reactor vessel shell, reactor closure head and nozzle closure plates. An outer 1/4 inch thick shell is included to contain the Hexcel.

Based on the finite element analysis performed on the Pathfinder package with the Hexcel impact limiter, the vessel shell will not deform plastically during the one foot free drop case. The elastic deformation that occurs is well within the allowable stress limits of the vessel materials. There will be no loss of the external shielding during the one foot drop, although the outer Hexcel 1/4 inch thick shell will deform plastically. Nevertheless, this outer shell will retain its shielding capability and protect the public from exposure.

The primary method of energy dissipation for the drop events is the crushing of the pre-crushed Hexcel impact limiter. Analyses show that the Hexcel will absorb the drop impact and protect the vessel shell from damage. The analyses consisted of finite element ANSYS (Ref. 2.1) computer runs to determine the maximum stresses in the vessel and hand calculations to verify the results.

The analytically determined margins of safety for each of the transport conditions are summarized in Table 2.1 for the Normal Conditions of Transport.

2.1.1 Structural Description

The principal structural elements of the Pathfinder package are the reactor vessel, vessel head and the Hexcel impact limiter. The steel shield surrounding the vessel does not have a structural role in the package design. The circumferential weld of the shield to the vessel is used as part of the package tie-down.

Vessel, Nozzles and Lower Head

The 3-inch thick reactor vessel has a lower hemispherical head to which is welded a lower cylinder assembly. The hemispherical head contains three pump suction nozzles and one feedwater nozzle. The lower cylinder assembly contains three pump discharge nozzles and one steam outlet nozzle extending through the bottom of the cylinder assembly. There is a liquid level nozzle and an instrument nozzle connected to the shell of the vessel. All nozzles will be cut close to the vessel shell, and nozzle cover plates will be welded over the openings. In addition, there are five pad assemblies welded to the vessel shell which support the vessel vertically within the vessel cavity and four plates for lateral support. These pads and plates will be cut close to the vessel prior to the installation of the steel shielding. The reactor vessel is fabricated from ASTM A212 Grade B plate with integrally bonded 304L stainless steel cladding 1/4-inch thick. The flanges and nozzle forgings conform to the ASTM A105 Grade II specification and are weld overlayed with stainless steel having a chemistry similar to Type 304 except that maximum free carbon content at the clad surface is below 0.050 per cent. The overlay is stabilized with a small amount of niobium. The original design pressure and temperature for the vessel were 700 psi and 500 deg F, respectively. The vessel and internal components were designed and constructed in accordance with the ASME Boiler and Pressure Vessel Code Section VIII and applicable special nuclear code cases.

Closure Head

The closure head is fabricated from the same material as the vessel shell and lower head. The head is secured to the reactor vessel with 48 closure studs fabricated from ASTM A437 Grade B4B, and the nuts fabricated from ASTM A437 Grade C4C. There are 20 control rod drive nozzles in the upper closure head, four lifting pipes used for head removal, one liquid level nozzle and one instrumentation nozzle. Each of these nozzles will be capped and seal welded closed prior to lifting the vessel from the reactor cavity.

Gravel and Grout

As noted earlier, the vessel was filled with 1/4 inch diameter pea gravel during the decommissioning activities associated with placing the facility in safe storage. Approximately 66 cubic yards of gravel, weighing 214,000 lbs (average density of 120 lbs/cu ft) were placed in the vessel. The gravel therefore has a void fraction of 23.4 percent based a theoretical solid density of 156.9 lbs/cu ft, or a void volume of 15.44 cu yds (.234 X 66 cu yds = 15.44 cu yds).

The estimated empty volume of the vessel less the internals is approximately 75.6 cubic yards. The gravel occupies only 66 cu yds of the 75.6 cu yds, leaving 9.6 cu yds empty. Approximately 25.04 cubic yards of grout needs to be added to the vessel to fill all available voids in the vessel and the gravel. This grout will be pumped in under pressure.

Impact Limiter

The impact limiter is constructed from Hexcel. Hexcel is a honeycomb energy absorbing material to absorb the impact of the one foot drop of the vessel. The honeycomb material will be fabricated from aluminum, and will be pre-crushed to eliminate any initial impact force peaks being transmitted to the vessel shell. The Hexcel will be bonded to the vessel shell and a 1/4 inch thick plate shell attached on the outside of the package to contain the Hexcel. All closure seams of the 1/4 inch thick shell will be welded closed. A minimum of 8 inches of Hexcel will be used around the cylindrical shell of the vessel. In the region where the two vessel saddle cutouts are located, high density Hexcel will be used to compensate for the loss of energy absorbing capacity at the saddles. The Hexcel material selected for this area will be 1/4-5052-0.004 with a crush strength of 725 psi (Ref. 2.2). In the remainder of the impact limiter, 3/8-5052-0.0025 Hexcel will be used with a crush strength of 180 psi.

The Hexcel thickness will vary to match the outside diameter of the vessel and steel shield so as to create a smooth package exterior. The configuration of the Hexcel arrangement is shown in Figure 1.1.

2.1.2 Design Criteria

Regulatory Requirements

The design criteria for the Pathfinder package are specified in NRC regulations Title 10 CFR Part 71. The activation inventory in the package is 476 curies. No individual vessel or internals component exceeds 0.3 millicuries per gram of material. Therefore, in accordance with paragraph 71.4 the package qualifies as Low Specific Activity (LSA) waste. The quantities of individual radionuclides exceed the limits for Type A packages specified in Table A-1 of Part

71 for special form and normal form values of A1 and A2, respectively. However, in accordance with paragraph 71.52 a package need not satisfy the requirements of paragraph 71.51 (Additional requirements for Type B packages) if it contains only Low Specific Activity material and is transported as exclusive use, but is subject to paragraph 71.41 through 71.47 of this part, including paragraph 71.43(f). Therefore, the package will be designed as a Type A package with contents that meet LSA quantity materials. Paragraph 71.43(f) requires the package be designed, constructed and prepared for shipment so that under the tests specified in paragraph 71.71 (Normal Conditions of Transport) there would be no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.

Type A Package Requirements

To meet the requirements for a Type A package, the Pathfinder package must be evaluated in accordance with the Normal Conditions of Transport identified in paragraph 71.71 (a) through (c). Paragraph (a) identifies the test specimens and sequence for the tests specified in this section. Paragraph (b) identifies the initial conditions for all tests, namely that the ambient temperature must be between -29 deg C (-20 deg F) and +38 deg C (100 deg F) which is most unfavorable for the feature under consideration. The initial internal pressure must be considered to be the maximum normal operating pressure, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable. Paragraph (c) provides the conditions and tests. These conditions and tests are as follows:

(c)(1) Heat
An ambient temperature of 38 deg C (100 deg F) in still air, and insolation of 400 g cal/cm^2 for a 12-hour period (curved surfaces).

(c)(2) Cold
An ambient temperature of -40 deg C (-40 deg F) in still air and shade.

(c)(3) Reduced External Pressure
An external pressure of 24.5 kilopascal (3.5 psi) absolute.

(c)(4) Increased External Pressure
An external pressure of 140 kilopascal (20 psi) absolute.

(c)(5) Vibration
Vibration normally incident to transport.

(c)(6) Water Spray
A water spray that simulates exposure to rainfall of approximately five cm (two in.) per hour for at least one hour.

(c)(7) Free Drop
A free drop through a distance of 0.3 meters (1 foot) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

(c)(8) Corner Drop
This test does not apply.

(c)(9) Compression
This test does not apply.

(c)(10) Penetration
Impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1 1/4 in.) diameter and six kg (13 lb) mass, dropped from a height of one m (40 in.) onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the package surface.

ASME Code

The ASME Boiler and Pressure Vessel Code (ASME), Section III (Ref. 2.3) design requirements will be used to evaluate the Pathfinder package integrity for internal or external pressure and temperature effects during Normal Conditions of Transport.

Welding Research Council Bulletin WRC 107

The Welding Research Council Bulletin (WRC) 107 (Ref. 2.4) will be used to verify the Pathfinder package analysis performed by finite element methods.

Brittle Fracture

Brittle fracture analysis will be evaluated in accordance with "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick", NUREG/CR-1815 (Ref. 2.5).

Penetration Analysis

The penetration analysis will be performed in accordance with the Ballistic Research Lab (BRL) and Stanford Research Lab (SRL) equations. These equations are described in Bechtel Topical Report 9A, Revision 2, "Topical Report - Design of Structures for Missile Impact", Bechtel Power Corporation, San Francisco, CA, September, 1974 (Ref. 2.6).

Impact Limiter Requirements

The impact limiter will be designed in accordance with Hexcel Design Bulletin TSB122 (Ref. 2.7). No more than 70 per cent of the Hexcel honeycomb thickness is available for crushing. This provides a factor of safety to ensure the honeycomb material does not bottom out and transfer the impact load to the vessel shell. The total depth of crushing should not approach any nozzle or vessel attachment projections from the vessel surface.

2.2 Weights and Center of Gravity

The total weight of the vessel, internals, grout, shield and impact limiter is 582,000 lbs, or 291 tons. The distribution of the weights calculated in one foot increments along the package length, and center of gravity calculations are shown in Appendix 2.10.1. The total weights of the individual components is shown in Table 1.1. The center of gravity (CG) of the package has been determined to be located on the longitudinal centerline, approximately 16ft-4in. from the outside face of the package at the reactor vessel head.

2.3 Mechanical Properties of Materials

The primary structural materials of the Pathfinder package are the carbon steel vessel and the Hexcel aluminum honeycomb. The gravel and grout materials are not relied upon for their structural characteristics and will not be described here. The mechanical properties of the materials used for the analyses of the Pathfinder package are discussed in the following sections.

2.3.1 Steel Materials

Various types and grades of steels were used for fabrication of components of the Pathfinder vessel and heads. A tabulation of the specific types of steel materials used, their application and their material properties is shown in Tables 2.2 and 2.3. These tables were reproduced from the Allis-Chalmers Report No. ACNP-62025 (Ref. 2.8) which describes the reactor vessel materials, fabrication and inspection.

Figure 2.1 shows the Allis-Chalmers Manufacturers' Data Report For Unfired Pressure Vessels, Form U-1A. This form identifies the materials and thicknesses of the vessel and head materials and provides the certificate of shop inspection.

Table 2.4 shows the specified minimum mechanical properties and design stress intensity values, respectively, of steel materials for ASME and ASTM materials specifications. Table 2.5 shows the actual design stress intensity values for the vessel and associated component steels for the Pathfinder vessel. Because there was only 83 effective full power days (EFPD) the shift of the nil deductibility transition (NDT) temperature is negligible.

2.3.2 Impact Limiter

The impact force deformation curve is based on the Hexcel information bulletins for the various products available. The crushing strength and other structural characteristics for Hexcel type 1/4-5052-0.0015 and 3/8-5052-0.0025 (Ref. 2.2) is given in Table 2.6. A typical force-deformation curve for Hexcel is shown in Figure 2.2.

2.3.3 Brittle Fracture Evaluation

The requirements for brittle fracture evaluation are identified in NUREG/CR-1815, UCRL-53013, RT, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick", (Ref. 2.5). Table 6 of NUREG/CR-1815 shows the fracture toughness requirements for Category III required degree of safety. Category III provides for "Adequate margin of safety" with the required amount of fracture toughness "Sufficient to prevent fracture initiation at minor defects typical of good fabrication practices". Since the Pathfinder vessel was designed and fabricated for high pressure power reactor application, it is reasonable to assume it was fabricated in accordance with "good fabrication practices".

The NUREG/CR-1815 criteria for meeting toughness requirements is identified in Table 6, therein. Table 6 criteria for meeting toughness requirements are that if the vessel steel up to 4 inches thick was tested to show the Charpy impact test data Cv was greater than 15 ft-lb at 10 deg F test temperature, the steel has sufficient fracture toughness and adequate margin of safety. Based on the ACNP Report 62025 (Ref. 2.8) Table II, therein, as reproduced in Table 2.3, herein, the Charpy impact test for all components of the vessel and internals exceeded 15 ft-lb at 10 deg F. Therefore, the Pathfinder package has sufficient fracture toughness to provide adequate margin of safety. The results of the brittle fracture evaluation are shown in Appendix 2.10.6-A.

2.4 General Standards for All Packages

The general package standards in 10 CFR 71, Subpart E, Paragraph 71.43 (a) through (h), have been complied with as demonstrated in the following paragraphs.

2.4.1 Minimum Package Size

The Pathfinder package meets the package size criterion of minimum overall dimension not less than 4 in.

2.4.2 Tamper-Proof Feature

The containment system of the package consists of the welded nozzle closure plates and the 48 head closure studs and nuts. In addition the 1/4 inch Hexcel outer enclosure is welded at all joints and as such, no tamper-proof features are required.

2.4.3 Positive Closure

The outer boundary of the package (the 1/4 inch Hexcel enclosure) is welded at all joints so the system can not be inadvertently opened.

2.4.4 Chemical and Galvanic Reactions

The materials used in the package will not cause any significant chemical galvanic or other reactions. Since this is a one-time shipment, the long-term interactions of the materials are not of concern.

2.4.5 Package Valves

The package does not include any valves. There is no pathway for radioactive material to escape.

2.4.6 Accessible Surface Temperature

The package has a negligible internal heat source of 4.67 watts. Accordingly, accessible surface temperatures are not expected to be greater than the railcar surfaces on which the package is loaded.

2.4.7 Continuous Venting

There are no vents in the package.

2.4.8 Lifting Devices

The reactor vessel will be lifted from the biological shield cavity using a temporary lifting rig. Six of the existing head studs and nuts will be removed and replaced with longer studs. A temporary lifting fixture will be attached with the new studs and nuts, the vessel lifted from the cavity and placed on its side outside the reactor building to prepare it for shipment. Prior to placement on the railcar, the temporary lifting rig will be removed and the vessel head studs retorqued and welded for a strong closure. All subsequent lifts will be made by lifting slings with the package in the horizontal position.

2.4.9 Tie-Down Devices

Tie-downs are not a part of the Pathfinder structural package. The package will be held in saddles with tie downs. Axial loads will be reacted by a key welded to the shield plate which will fit in a keyway in the saddles. The shield plate will be welded to the vessel shell using a continuous 11/16-inch circumferential fillet weld. This weld will be designed for a 10 g axial load.

2.5 Standards for Type B and Large Quantity Packaging

Not applicable.

2.6 Normal Conditions of Transport

This section demonstrates that the Pathfinder package is structurally adequate for the Normal Conditions of Transport as defined in Section 71.71 of 10 CFR 71. The 10 CFR 71 definition of structural adequacy is addressed in paragraph 71.51 (a)(1) which states that, "there would be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A2 per Hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging". To assure that this qualitative definition is met, the criteria, as discussed in Section 2.1.2, have been applied.

2.6.1 Heat

For Normal Conditions of Transport, hot environment, 10 CFR 71 specifies exposure to an ambient temperature of 100 deg F in still air, with insolation of 400 g cal/cm^2 for a 12 hour period (for curved surfaces). Since there is negligible internal heat source, and there are no constraints to the vessel expansion and contraction the vessel stresses are assumed to be low. No calculations are provided.

2.6.2 Cold

For Normal Conditions of Transport, cold environment , 10 CFR 71 specifies an ambient temperature of -40 deg F in still air and shade. Since there is negligible internal heat source, and there are no constraints to the vessel expansion and contraction, the temperature gradient is small and the stresses are assumed to be low. There is no liquid that could freeze.

A worst case scenario is evaluated in Section 3.0 for an instantaneous reduction in temperature from 100 deg F to -40 deg F. The vessel stresses are within the design stress intensity limits for the vessel material.

2.6.3 Reduced External Pressure

The bounding case for this normal condition of transport is specified in 10 CFR 71.71 (c)(3), which indicates a 3.5 psi absolute pressure. A finite element analysis of the reactor vessel as an axisymmetric shell model indicated maximum stress intensity of 248.0 psi, as compared to a vessel material allowable stress intensity of 17,875 psi. Therefore, the margin of safety (based on the finite element analysis and ASME Code calculations) is (17,875/248) -1 = 71.08. The detailed ASME Code calculations and finite element analysis are shown in Appendix 2.10.2.

2.6.4 Increased External Pressure

The 10 CFR 71 Subpart F, paragraph 71.71 (c)(4) requires evaluation for an external pressure equal to 20 psi absolute. Using the ASME Code, Section III, paragraph NB-3133 (Ref. 2.10), the minimum allowable external pressure is 437.0 psi versus the required external pressure of 20.0 psi. Therefore, the margin of safety is 437/20 - 1 = 20.9. The ASME Code evaluation for external pressure is shown in Appendix 2.10.3.

2.6.5 Vibration

The design criterion for rail transport vibration loads was based on discussions with Burlington Northern Railroad wherein the railcar structure is designed for maximum buff and draft loads of 500,000 lbs and impact loads of 1,250,000 lbs. These criteria are based on the Association of American Railroad requirements. Accordingly, the g force would be 2.2 longitudinal.

10 CFR 71 paragraph 71.45(b)(1) requires tie-down devices attached to the package to be designed for 2g's vertical, 5g's transverse and 10g's longitudinal.

The only tie-down attachment to the package is the circumferential weld between the shield plate and the vessel shell. This weld will be designed for a 10g axial load.

2.6.6 Water Spray

The water spray condition will not have a significant effect on the Pathfinder package.

2.6.7 Free Drop

The Pathfinder package weighs 291 tons. Subsection F of 10 CFR 71 requires that a package of this mass be analyzed for a drop of one foot onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. During transport the package will always be oriented in the horizontal position; i.e., the centerline axis of the package will be horizontal. Because of the unique size, weight, mass and bulk of the package, no other orientation is considered feasible during normal transport conditions. Consequently, the free drop condition is a one-foot side drop of the package on an essentially unyielding horizontal surface.

Two cases were evaluated: (1) drop of the package along its length, and (2) impact of the package at its edge, wherein 50 per cent of the package weight and kinetic energy is transmitted to one edge of the package. Drop of the package at its lower edge was considered to be more critical as it is heavier due to the core internals weight. For Case 1, the effective weight is taken as that of the heaviest one-foot wide section of the vessel and its internals along its length. It should be noted that for the side drop (Case 1), the weight of the protruding parts of the package (the upper and lower vessel heads) will be transmitted to the impact limiter at the edge of the vessel. The impact limiter end sections are analyzed for a significantly larger weight and kinetic energy in Case 2. Therefore, the maximum tributory (effective) weight for Drop Case 1 will be that of the heaviest one-foot wide section of the vessel and internals along its length. Figure 2.3 shows the orientation of these two drop cases. Maximum tributary weight, velocity and kinetic energy of impact associated with the two cases are given in Table 2.7. Refer to Appendix 2.10.4 for basis of the calculations.

2.6.7.1 Analytical Methods

This section describes the analytical methodology used to demonstrate the structural adequacy of the package during a side or edge drop event. The analytical method is based on a step-by-step evaluation of external energy, resistance offered and energy absorbed by the impact limiter. The maximum stresses in the reactor vessel wall are evaluated at each incremental depth of crushing. The Section 2.6.7.2 describes the calculation of deformation and forces generated during the drop event. Section 2.6.7.3 describes the ANSYS three dimensional finite element models used for the detailed evaluation of maximum stresses in the package.

2.6.7.2 Impact Limiter Resistance/Deformation Behavior

As described in Section 1.2, the package includes a circular energy absorbing impact limiter surrounding the vessel. This impact limiter is designed to protect the package during a one-foot drop event. The impact limiter consists of pre-crushed Hexcel energy absorbing material. For purposes of analysis, the impact limiter is assumed to absorb, in plastic deformation of Hexcel, the potential energy of the drop event. That is, the analyses assume that none of the drop potential energy is transferred to kinetic energy or strain energy of the target (the "unyielding surface" assumption of 10 CFR 71) nor strain energy in the vessel itself.

For each drop orientation, the prediction of overpack behavior can be approached from straight forward energy balance principles:

$$E = W(h+c) = \int_0^c Fx\, dx$$

Where: W = package weight

h = Drop height

c = maximum overpack deformation, or crushing

Fx = Force imposed upon target and package by the overpack at a deflection equal to x.

The left-hand term represents the potential energy of the drop. The right-hand term represents the strain energy of the deformed overpack.

Figure 2.4 shows the tributary area of resistance at incremental depths of crushing. Using the effective area of resistance at each incremental depth of crushing, effective load-deformation (energy absorption) characteristics of the impact limiter have been developed for the two drop cases. These load-deformation characteristics for the two cases are shown in Figures 2.5 and 2.6, respectively. The detailed calculations are given in Appendices 2.10.1. The maximum depth of crushing, peak deceleration and reaction loads generated are shown on Table 2.8.

2.6.7.3 ANSYS - Three Dimensional Finite Element Stress Analysis

Detailed three-dimensional finite element models of the critical sections of the vessel were prepared using eight node three-dimensional isoparametric solid elements (ANSYS element STIF 45). These models for the two cases are shown in Figures 2.7 and 2.8, respectively. For the side drop, a typical one-foot wide section of the vessel wall was modeled using three one-inch thick layers. The density of the vessel wall and gravel/grout (hereinafter, concrete) elements were selected to give proper distribution of weight of the vessel and that of the concrete and reactor vessel internals. The modulus of elasticity of concrete was conservatively taken as 28,000 psi (1/1000 of the modulus of steel) so that the concrete does not provide any stiffness to the reactor vessel wall. For the edge drop model, the vessel was modeled as two 1-1/2 inch thick layers. To account for the weakened section at nozzle openings, corresponding elements were removed. Appropriate boundary conditions were applied at the plane of symmetry.

At each incremental depth of crushing, appropriate boundary conditions and acceleration values were applied to depict the resistance offered by the impact limiter. For each model, ten load steps were applied at 1/2 inch increments in depth of crushing. Typical stress contours for primary membrane stress and membrane plus bending stress are shown in Figures 2.9 through 2.20. For the side drop cases the load is shown applied on the right side of the figure, and for the edge drop case the load is applied on the bottom of the figure. Maximum stresses for each incremental depth of crushing are summarized and compared against their allowable values in Table 2.9. The stresses in the vessel wall shown in Table 2.9 do not necessarily increase uniformly with increased depth of crushing. At lower depths of crushing, the effective resistance force and the width of support offered by the impact limiter is smaller. With lower resistance force the stress in the vessel wall is smaller. However, the smaller support width results in higher stress in the vessel wall. At increased depth of crushing the resistance force and effective support widths are larger so that the stress levels do not increase uniformly with depth of crushing. From these results, the margins of safety are shown in Table 2.10.

Results of finite element analyses were verified by hand calculations using analytical procedures given in Welding Research Council Bulletin WRC 107 (Ref. 2.4) which is widely used for the design of pressure vessels. The detailed design calculations for the impact limiter, finite element analysis results and WRC 107 calculations are given in Appendix 2.10.5.

2.6.8 Corner Drop

The corner drop evaluation, as specified in 10 CFR 71.71 (c)(8), applies only to fiberboard or wood rectangular packages not exceeding 110 lbs, and fiberboard or wooden cylindrical packages not exceeding 220 lbs. Therefore, the evaluation is not required for the Pathfinder package.

2.6.9 Compression

The compression evaluation as specified in 10 CFR 71.71 (C)(9), applies to packages weighing up to 11,000 lbs. Therefore, the evaluation is not required for the Pathfinder package.

2.6.10 Penetration

The penetration evaluation as specified in 10 CFR 71.71 (c)(10), requires an analysis of a 13 lb bar with a diameter of 1-1/4 in. dropped from a height of 40 in. onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the package surface. For a 40 in. drop the impact velocity is 14.7 ft/sec. Using the Ballistic Research Lab (BRL) analysis (Ref. 2.6), the thickness plate that will be perforated is 0.015 in. Since the reactor vessel wall is 3 inches thick, and the nozzle closure plates are 3/4 inch thick the bar will not penetrate the vessel. Similarly, the external kinetic energy is 43.33 ft lbs. Using the Stanford Research Institute (SRI) analysis (Ref. 2.6), the thickness of the plate that will be perforated is 0.0039 in. Therefore, there is adequate margin of safety to prevent penetration of the bar through the plate. Results of the penetration analysis is shown in Appendix 2.10.6-B.

2.6.11 Load Resistance

Routinely, packages have been evaluated with respect to structural standards for "load resistance". Specifically, it is usually required to regard the package as a simple beam supported at its ends with a loading equal to five times its fully loaded weight. Detailed structural calculations are given in Appendix 2.10.6-C. The maximum stress is 0.72 ksi in the bolts at the closure head. The margin of safety is (26.81/0.72) - 1 = 36.2.

2.7 Hypothetical Accident Conditions

This evaluation is not applicable.

2.8 Special Form

This evaluation is not applicable.

2.9 Fuel Rods

This evaluation is not applicable.

2.10 Appendix

Contents

APPENDIX 2.10.1

Calculations of Package Weight and Center of Gravity

Component	Length (FT)	Weight (LBS)	Distribution (LBS/FT)	Elev (FT) EL 1312-1311	Elev (FT) EL 1311-1310	Elev (FT) EL 1310-1309	Elev (FT) EL 1309-1308	Elev (FT) EL 1308-1307	Elev (FT) EL 1307-1306	Elev (FT) EL 1306-1305	Elev (FT) EL 1305-1304	Elev (FT) EL 1304-1303	Elev (FT) EL 1303-1302
*** Vessel ***													
Vessel Head	4.833	24029.500	4971.964	1655.664	4971.964	4971.964	- 4971.964	4971.964	2485.982				
Section 1	5.000	30546.450	6109.290						3054.645	6109.290	6109.290	6109.290	6109.290
Section 2	14.000	67354.650	4811.046										
Section 3	4.750	21540.200	4534.779										
Section 4	3.250	5935.050	1826.169										
Section 5	1.880	3136.320	1668.255										
Section 6	7.110	1742.400	245.063										
Vessel Totals:		154284.570		1655.664	4971.964	4971.964	4971.964	4971.964	5540.627	6109.290	6109.290	6109.290	6109.290
*** Internals ***													
Feedwater Ring Assembly	0.750	979.000	1305.333										
Hold Down Stud Assembly	6.250	213.000	34.080										
Boiler Poison Shim	6.920	483.000	69.798										
Shim	1.000	10.000	10.000										
Single Element Box Assy	7.333	2464.000	336.015										
Irrad. Sample Holder	9.000	42.000	4.667										
Irrad. Sample Container	9.000	26.000	2.889										
Four Element Cluster Box Assy	7.500	5200.000	693.333										
Feedwtr Ring Support Assy	0.750	48.000	64.000										
Superhtr Control Rod Assy	12.920	975.000	75.464										
Superhtr Control Rod Yoke	2.210	100.000	45.249										20.814
Steam Separ. Group Assy	14.420	5175.000	358.877										
Reactor Grid Plate	0.670	5600.000	8358.209										
Boiler Shroud Assembly	7.420	1460.000	196.765										
Steam Sep. Support Shaft	0.330	2310.000	7000.000										
Superheaters Shell Assy	20.520	4800.000	233.918								116.959	233.918	233.918
Boiler Control Rods	15.200	2624.000	172.632										91.495
Hold Down Assembly	5.670	7000.000	1234.568										
Steam Dryer	6.330	3400.000	537.125				236.335	537.125	537.125	537.125	537.125	537.125	478.041
Internal Totals:		42909.000		0.000	0.000	0.000	236.335	537.125	537.125	537.125	654.084	771.043	824.268
*** Shielding ***													
Interior cylinder	14.000	36764.000	2626.000										
Bottom Plate	0.146	3286.800	22538.572										
Outside Shell:													
Top Plate	0.020	620.110	31005.500	620.110									
Outside shell Upper Section	3.580	1012.210	282.740	282.740	282.740	282.740	163.989						
Upper Middle Plate	0.020	789.900	39495.000				789.900						
Outside shell Middle Section	26.380	11234.390	425.868	8.871			170.347	425.868	425.868	425.868	425.868	425.868	425.868
Lower Middle Plate	0.020	1130.530	56526.500										
Outside shell Lower Section	5.340	1017.040	190.457										
Bottom Plate	0.020	277.560	13878.000										
Fill Material:													
Top Section	3.58	389.675	108.848	108.848	108.848	108.848	63.132						
Middle Section	26.38	6520.134	247.162				98.865	247.162	247.162	247.162	247.162	247.162	247.162
Bottom Section	5.34	258.807	48.466										
Shielding Totals:		63301.156		1020.569	391.588	391.588	1286.233	673.030	673.030	673.630	673.030	673.030	673.030
*** Gravel & Grout ***													
Section 1	5.000	52565.583	10513.117						3598.114	8215.719	9635.171	11171.252	12844.159
Section 2	14.000	199383.608	14241.686										
Section 3	4.750	43084.628	9070.448										
Section 4	3.250	6406.273	1971.161										
Section 5	1.880	2252.447	1198.110										
Vessel Head	3.625	16388.619	4520.998		25.108	2077.932	4702.274	6202.144	3381.161				
Gravel & Grout Totals:		320081.158		0.000	25.108	2077.932	4702.274	6202.144	6979.275	8215.719	9635.171	11171.252	12844.159
TOTAL WEIGHT:		580575.883		2676.233	5388.659	7441.484	11196.805	12384.262	13730.056	15535.164	17071.574	18724.614	20450.747

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TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Container

Component	Elev (FT) EL 1302-1301	Elev (FT) EL 1301-1300	Elev (FT) EL 1300-1299	Elev (FT) EL 1299-1298	Elev (FT) EL 1298-1297	Elev (FT) EL 1?97-1296	Elev (FT) EL 1296-1295	Elev (FT) EL 1295-1294	Elev (FT) EL 1294-1293	Elev (FT) EL 1293-1292	Elev (FT) EL 1292-1291	Elev (FT) EL 1291-1290	Elev (FT) EL 1290-1289
*** Vessel ***													
Vessel Head													
Section 1	3054.645												
Section 2	2405.523	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046
Section 3													
Section 4													
Section 5													
Section 6													
Vessel Totals:	5460.168	4811.046	4811.045	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046	4811.046
*** Internals ***													
Feedwater Ring Assembly													
Hold Down Stud Assembly		2.726	34.080	34.080	34.080	34.080	34.080	34.080	5.794				
Boiler Poison Shim									40.483	69.798	69.798	69.798	69.798
Shim													
Single Element Box Assy									279.901	336.015	336.015	336.015	336.015
Irrad. Sample Holder				3.500	4.667	4.667	4.667	4.667	4.667	4.667	4.667	4.667	1.167
Irrad. Sample Container				2.167	2.889	2.889	2.889	2.889	2.88?	2.889	2.889	2.889	0.722
Four Element Cluster Box Assy									575.467	693.333	693.333	693.333	693.333
Feedwtr Ring Support Assy													
Superhtr Control Rod Assy		18.866	75.464	75.464	75.464	75.464	75.464	75.464	75.464	75.464	75.464	75.464	75.464
Superhtr Control Rod Yoke	45.249	33.937											
Steam Separ. Group Assy	315.811	358.877	358.877	358.877	358.877	358.877	358.877	358.8?7	358.877	358.877	358.877	358.877	358.877
Reactor Grid Plate													
Boiler Shroud Assembly									184.960	196.765	196.765	196.765	196.765
Steam Sep. Support Shaft													
Superheater Shell Assy	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918	233.918
Boiler Control Rods	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632	172.632
Hold Down Assembly			617.284	1234.568	1234.568	1234.568	1234.568	1234.568	209.877				
Steam Dryer													
Internal Totals:	767.610	820.955	1492.255	2115.205	2117.094	2117.094	2??7.094	2117.094	2144.926	2144.358	2144.358	2144.358	2138.691
*** Shielding ***													
Interior Cylinder				656.500	2626.000	2626.000	2626.000	2626.000	2526.000	2626.000	1626.000	2626.000	2626.000
Bottom Plate													
Outside Shell:													
Top Plate													
Outside Shell Upper Section													
Upper Middle Plate													
Outside Shell Middle Section	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868	425.868
Lower Middle Plate													
Outside Shell Lower Section													
Bottom Plate													
Fill Material:													
Top Section													
Middle Section	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162	247.162
Bottom Section													
Shielding Totals:	673.030	673.030	673.030	1329.530	3299.030	3799.030	3299.030	3299.030	3299.030	3299.030	3299.030	3299.030	3299.030
*** Gravel & Grout ***													
Section 1	7101.169												
Section 2	7331.829	14646.753	14434.025	14236.619	14236.021	14236.021	14236.021	14236.021	14227.201	14227.381	14227.381	14227.381	14229.177
Section 3													
Section 4													
Section 5													
Vessel Head													
Gravel & Grout Totals:	14432.997	14646.753	14434.025	14236.619	14236.021	14236.021	14236.021	14236.021	14227.201	14227.381	14227.38?	14227.381	14229.177
TOTAL WEIGHT:	21333.805	20951.784	21410.356	22492.401	24463.191	24463.191	24463.191	24463.191	24482.203	24481.815	24481.815	24481.815	24477.??4

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BY R.K DATE 9-14-89 SECTION 2.2-2

CHKD [signature] DATE 11/24/89 SUB-SECTION ______ OF ______

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TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Container

Component	Elev (FT) EL 1289-1288	Elev (FT) EL 1288-1287	Elev (FT) EL 1287-1286	Elev (FT) EL 1286-1285	Elev (FT) EL 1285-1284	Elev (FT) EL 1284-1283	Elev (FT) EL 1283-1282	Elev (FT) EL 1282-1281	Elev (FT) EL 1281-1280	Elev (FT) EL 1280-1279	Elev (FT) EL 1279-1278	Elev (FT) EL 1278-1277	Elev (FT) EL 1277-1276
*** Vessel ***													
Vessel Head													
Section 1													
Section 2	4811.046	2405.523											
Section 3		2267.389	4534.779	4534.779	4534.779	4534.779	1133.695						
Section 4							1369.627	1826.169	1826.169	913.085			
Section 5										834.128	1668.255	633.937	
Section 6					107.828	245.063	245.063	245.063	245.063	245.063	245.063	164.192	
Vessel Totals	4811.046	4672.913	4534.779	4534.779	4642.607	4779.842	2748.385	2071.233	2071.233	1992.276	1913.319	798.129	
*** Internals ***													
Feedwater Ring Assembly			979.000										
Hold Down Stud Assembly													
Boiler Poison Shim	69.798	69.798	23.731										
Shim					10.000								
Single Element Box Assy	336.015	336.015	168.008										
Irrad. Sample Holder													
Irrad. Sample Container													
Four Element Cluster Box Assy	693.333	693.333	464.533										
Feedwtr Ring Support Assy			48.000										
Superhtr Control Rod Assy	75.464	50.561											
Superhtr Control Rod Yoke													
Steam Separ. Group Assy	358.877	193.793											
Reactor Grid Plate			4179.104	1420.896									
Boiler Shroud Assembly	196.765	196.765	94.447										
Steam Sep. Support Shaft	2310.000												
Superheaters Shell Assy	233.918	233.918	233.918	233.918	233.918	4.678							
Boiler Control Rods	172.632	115.663											
Hold Down Assembly													
Steam Dryer													
Internal Totals	4446.802	1889.848	6190.742	1654.814	243.918	4.678	0.000	0.000	0.000	0.000	0.000	0.000	
*** Shielding ***													
Interior cylinder	2626.000	2626.000	2626.000	2626.000	1969.500								
Bottom Plate					3286.800								
Outside Shell													
Top Plate													
Outside shell Upper Section													
Upper Middle Plate													
Outside shell Middle Section	425.868	425.868	425.868	425.868	425.868	425.868	417.350						
Lower Middle Plate							1130.530						
Outside shell Lower Section								190.457	190.457	190.457	190.457	190.457	64.755
Bottom Plate													277.560
Fill Material													
Top Section													
Middle Section	247.162	247.162	247.162	247.162	247.162	247.162	242.219						
Bottom Section								48.466	48.466	48.466	48.466	48.466	16.478
Shielding Totals	3299.030	3299.030	3299.030	3299.030	5929.330	673.030	1790.099	238.923	238.923	238.923	238.923	238.923	358.794
*** Gravel & Grout ***													
Section 1													
Section 2	13497.762	7154.016											
Section 3		7080.066	12523.881	10996.825	7563.199	4427.867	492.790						
Section 4							1478.371	1971.161	1971.161	985.580			
Section 5										911.136	1212.913	59.099	69.299
Vessel Head													
Gravel & Grout Totals	13497.762	14234.082	12523.881	10996.825	7563.199	4427.867	1971.161	1971.161	1971.161	1896.717	1212.913	59.099	69.299
TOTAL WEIGHT	26054.641	24095.872	26548.432	20485.448	18379.054	9885.417	6509.645	4281.316	4281.316	4127.915	3365.154	1096.151	428.092

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BY RK DATE 9-14-89 SECTION 2.2-3

CHKD [illegible] DATE 10/25/89 SUB-SECTION ____ OF ____

PROJECT NO. 4-22B TASK NO. PH1584 PAGE ____ OF ____

TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Contain[er]

BY R.K DATE 9-14-89 SECTION 2.2-4

CHKD [signature] DATE 10/24/89 SUB-SECTION ______ OF ___

PROJECT NO. 4-22B TASK NO. PH1584 PAGE ______ OF ___

TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

Weight Distribution for the Pathfinder Vessel

Printed on 14-Sep-89

Component	TOTAL
*** Vessel ***	
Vessel Head	24029.500
Section 1	30546.450
Section 2	67354.650
Section 3	21540.200
Section 4	5935.050
Section 5	3136.320
Section 6	1742.400
Vessel Totals:	154284.570
*** Internals ***	
Feedwater Ring Assembly	979.000
Hold Down Stud Assembly	213.000
Boiler Poison Shim	483.000
Shim	10.000
Single Element Box Assy	2464.000
Irrad. Sample Holder	42.000
Irrad. Sample Container	26.000
Four Element Cluster Box Assy	5200.000
Feedwtr Ring Support Assy	48.000
Superhtr Control Rod Assy	975.000
Superhtr Control Rod Yoke	100.000
Steam Separ. Group Assy	5175.000
Reactor Grid Plate	5600.000
Boiler Shroud Assembly	1460.000
Steam Sep. Support Shaft	2310.000
Superheaters Shell Assy	4800.000
Boiler Control Rods	2624.000
Hold Down Assembly	7000.000
Steam Dryer	3400.000
Internal Totals:	42900.000
*** Shielding ***	
Interior cylinder	36764.000
Bottom Plate	3286.800
Outside Shell:	
Top Plate	620.110
Outside Shell Upper Section	1012.210
Upper Middle Plate	789.900
Outside Shell Middle Section	11243.261
Lower Middle Plate	1130.530
Outside Shell Lower Section	1017.040
Bottom Plate	277.560
Fill Material	
Top Section	389.675
Middle Section	6520.134
Bottom Section	258.807
Shielding Totals:	63310.02659
*** Gravel & Grout ***	
Section 1	52565.583
Section 2	199383.608
Section 3	43084.628
Section 4	6406.273
Section 5	2252.447
Vessel Head	16388.619
Gravel & Grout Totals:	320081.156
TOTAL WEIGHT:	580584.754

*** VOID ***	Length (FT)	Volume (CF)	Internals (CF)	Gravel/Grout (LB)
*** Volume of Vessel ***				
Section 1 - 1306.5-1301.5	1.000			
- Diameter (1)	7.560			
- Diameter (2)	7.904	23.481	0.543	3598.114
- Diameter (3)	8.592	53.461	1.085	8215.719
- Diameter (4)	9.280	62.747	1.321	9635.171
- Diameter (5)	9.968	72.776	1.558	11171.252
- Diameter (6)	10.656	83.548	1.665	12844.159
- Diameter (7)	11.000	46.046	0.775	7101.169
Section 1 Total:		342.059	6.947	52565.583
Section 2 - 1301.5-1287.5	1.000			
- Diameter	11.000	47.517	0.775	7331.829
		95.033	1.658	14646.753
		95.033	3.015	14434.025
		95.033	4.273	14236.619
		95.033	4.277	14236.021
		95.033	4.277	14236.021
		95.033	4.277	14236.021
		95.033	4.277	14236.021
		95.033	4.333	14227.201
		95.033	4.332	14227.381
		95.033	4.332	14227.381
		95.033	4.332	14227.381
		95.033	4.321	14229.177
		95.033	8.983	13497.762
		47.517	1.909	7154.016
Section 2 Total:		1330.464	59.372	199383.608
Section 3 - 1287.5-1282.7	1.000			
- Radius (1)	5.500			
- Radius (2)	5.438	47.045	1.909	7080.066
- Radius (3)	5.375	92.348	12.507	12523.881
- Radius (4)	4.188	73.449	3.343	10996.825
- Radius (5)	3.625	48.709	0.493	7563.199
- Radius (6)	2.125	28.258	0.030	4427.867
- Radius (7)	2.000	3.142	0.000	492.790
Section 3 Total:		292.950	18.281	43084.628
Section 4 - 1282.75-1279	1.000			
- Diameter	4.000	9.425	0.000	1478.371
		12.566	0.000	1971.161
		12.566	0.000	1971.161
		6.283	0.000	985.580
Section 4 Total:		40.841	0.000	6406.273
Section 5 - 1279.5-1277.6	1.000			
- Radius (1)	2.000			
- Radius (2)	1.820	5.809	0.000	911.136
- Radius (3)	1.130	7.732	0.000	1212.913
	0.750	0.377	0.000	59.099
		0.442	0.000	59.299
Section 5 Total:		14.360	0.000	2252.447
Section 6 - Height				
- Diameter				
Section 6 Total:		n/a		
Vessel Head - 1310.125-13	1.000			
- Radius (1)	0.900			
- Radius (2)	2.700	0.160	0.000	25.108
- Radius (3)	3.430	13.247	0.000	2077.932
- Radius (4)	3.710	30.455	0.477	4702.274
- Radius (5)	3.780	40.624	1.085	6202.144
		22.098	0.543	3381.161
Vessel Head Total:		106.584	2.105	16388.619
TOTAL VOID:		2127.258	86.705	320081.156
Gravel & Grout Density (LB/CF):		156.86		
Internals Density (LB/CF):		495.00		
Density of Hexcel (LB/CF):		5.00		
Volume of Hexcel needed		1433.66		

CENTER OF GRAVITY CALCULATIONS

With Origin at Top of Head EL. 1312.0',

$\bar{x} = \{3.7209\times0.5 + 5.6233\times1.5 + 7.675\times2.5 + 10.534\times3.5$
$+ 12.334\times4.5 + 13.680\times5.5 + 15.484\times6.5 + 17.02\times7.5$
$+ 18.672\times8.5 + 20.397\times9.5 + 21.280\times10.5 + 20.898\times11.5$
$+ 21.356\times12.5 + 22.438\times13.5 + 24.409\times14.5 +$
$24.409\times15.5 + 24.409\times16.5 + 24.409\times17.5 + 24.43\times18.5$
$+ 24.428\times19.5 + 24.428\times20.5 + 24.428\times21.5$
$+ 24.424\times22.5 + 26.00\times23.5 + 24.045\times24.5$
$+ 26.495\times25.5 + 20.433\times26.5 + 18.338\times27.5$
$+ 9.836\times28.5 + 5.345\times29.5 + 4.668\times30.5$
$+ 4.668\times31.5 + 4.514\times32.5 + 3.752\times33.5$
$+ 1.474\times34.5 + 1.747\times35.5\} \dfrac{1}{582.2}$

$= \dfrac{9911.68}{582.2} = 17.0245'$

APPENDIX 2.10.2

Reduced External Pressure Calculations and Finite Element Analysis

BY I Hudais DATE 8/31/89 SECTION 2.6.3-1
CHKD [illegible] DATE 10/22/89 SUB-SECTION ____ OF ____
PROJECT NO 4-22B TASK NO PH1584 PAGE ____ OF ____
TITLE NSP - PATHFINDER DECOMISSIONING STUDY
Reactor Vessel Analysis - Type A Shipping Container.

I OBJECTIVE - TO PERFORM ANALYSIS FOR REDUCED EXTERNAL PRESSURE.

II CRITERIA & METHOD OF APPROACH

The bounding case for this normal transport condition is specified in 10 CFR 71.71 (c) (3), which indicates a 3.5 psi absolute pressure.

The atmospheric pressure is 14.5 psi, the pressure across the shell wall would be 11.0 psi. Combining this pressure with the maximum internal pressure of 0 psi that can develop during the hot environment condition results in a maximum pressure differential of 11 psi. The membrane hoop stress associated with this pressure is equal to pr/t, which for a 3 in. thick and 66 in. radius cylinder, is 2 ksi. For an S_m allowable of 12.6 ksi, the resulting margin of safety is

$$M.S. = 12.6/0.242 - 1 = 51.07$$

NB-3324 Tentative Pressure Thickness

The following formulas are given as an aid to the designer for determining a tentative thickness for use in the design. They are not to be construed as formulas for acceptable thicknesses. However, except in local regions (NB-3221.2), the wall thickness of a vessel shall never be less than that obtained from the formulas in NB-3324.1 and NB-3324.2, in which:

t = thickness of shell or head, in. = 3.0"
P = Design Pressure, psi = 11.0
R = inside radius of shell or head, in. = 66.0
R_o = outside radius of shell or head, in.
S_m = design stress intensity values (Tables I-1.0), psi = 12,600.0 psi

NB-3324.1 Cylindrical Shells

$$t = \frac{PR}{S_m - 0.5P} \quad \text{or} \quad t = \frac{PR_o}{S_m + 0.5P}$$

NB-3324.2 Spherical Shells

$$t = \frac{PR}{2S_m - P} \quad \text{or} \quad t = \frac{PR_o}{2S_m}$$

Ref. 2.3

$$\therefore t_{req} = \frac{11.0 \times 66.0}{12{,}600 - 0.5 \times 11.0} = 0.0576''$$

$$\therefore M.S = \frac{3.0}{0.0576} - 1 = 51.04 \quad O.K$$

BY J. Hersans DATE 9/7/89 SECTION 2.6.3-2

CHKD JR DATE 10/24/89 SUB-SECTION ______ OF ______

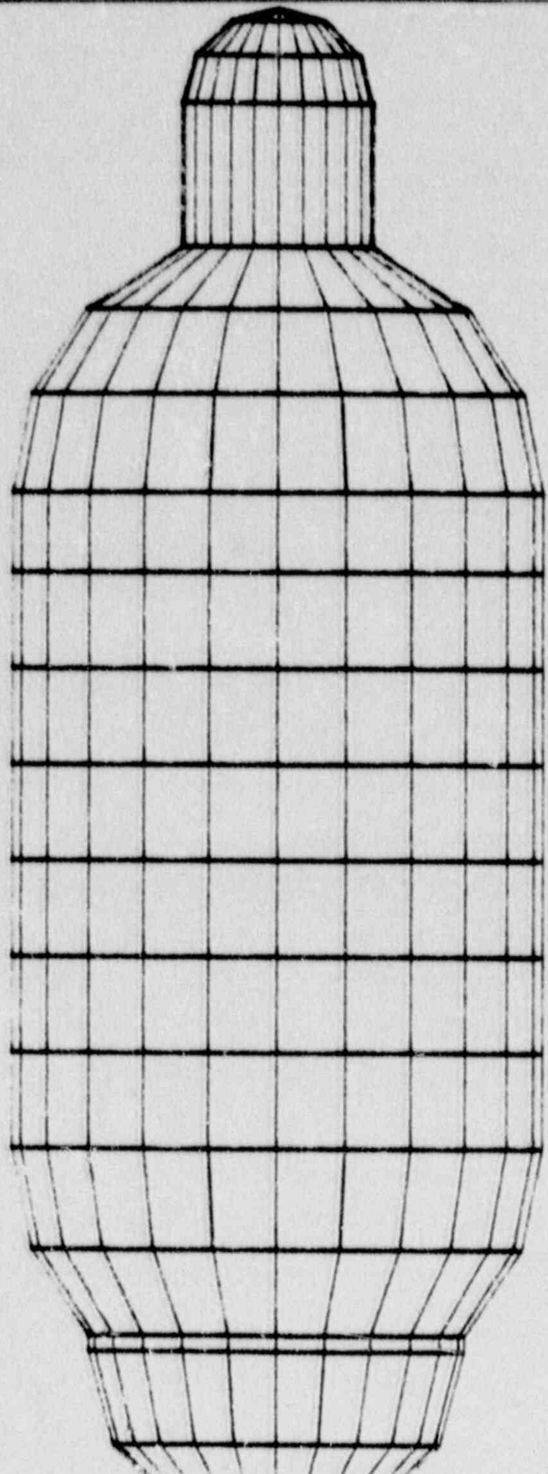
PROJECT NO. 4-22B TASK NO. PH1584 PAGE ______ OF ______

TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

Pressure Vessel Analysis Using Finite Element Model

Using SUPERSAP Computer Code



FINITE ELEMENT MODEL OF THE VESSEL

tlg ENGINEERING

BY 1. Husain DATE 9/7/89 SECTION 2.6.3-3
CHKD [illegible] DATE 10/22/89 SUB-SECTION ______ OF ______
PROJECT NO 4-22B TASK NO PH1584 PAGE ______ OF ______
TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Container

RESULTS OF FINITE ELEMENT ANALYSIS

**** POST-PROCESSING OF PFV1.SO

**** OUTPUT FOR TYPE-6 ELEMENTS (GROUP 1)

LOAD CASE = 1 SCALE = 1.0000E+00

**** ALGEBRAIC MAXIMA

	TOP- S1	TOP- S2	S1-S2 (B)	S1-S2 (T)	MBRN S1-S2	MEMBRANE S1
ELEM	79	79	78	259	75	78
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	80	80	81	260	74	77
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	94	78	89	255	76	79
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	77	94	73	254	73	76
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	76	93	95	258	80	91
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	93	77	75	261	96	92
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	88	95	92	262	77	81
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	83	76	91	256	79	73
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	86	88	87	257	91	75
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02
ELEM	95	87	82	263	95	90
	2.7229E+02	1.7560E+02	2.3457E+02	1.1226E+02	1.6563E+02	2.4275E+02

Max. Primary Membrane Stress in Vessel wall = 242.8 psi

Allowable Stress = 12,600.0 psi

Margin of Safety $M.S = \frac{12600}{242.8} - 1 = 50.89$

$= 51$

tlg ENGINEERING

BY: I. Husain DATE: 10-16-89 SECTION: 2.6.3-4
CHKD: JH DATE: 10/22/89 SUB-SECTION ____ OF ____
PROJECT NO. 4-22B TASK NO. PH1584 PAGE ____ OF ____
TITLE: NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Container

EVALUATION OF THE STRESS AT THE NOZZLE COVER PLATE

NOZZLE DIAMETER = 22.0"
COVER PLATE THICKNESS = t = 0.75"

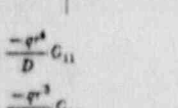
Stresses in the cover plate due to Pressure load will be evaluated using Formulas for Flat Plate with fixed Boundary conditions FROM R. J. ROARK'S FORMULAS FOR STRESS & STRAIN" 5th Edition, McGraw Hill Book Co.

TABLE 24 *Formulas for flat circular plates of constant thickness*

NOTATION: W = total applied load (pounds); w = unit line load (pounds per inch of circumference); q = load per unit area (pounds per square inch); M_0 = unit applied line moment loading (inch-pounds per inch of circumference); θ_0 = externally applied change in angular displacement (radians); y_0 = externally applied step in the normal displacement (inches); y = vertical deflection of plate (inches); θ = slope of plate measured from the horizontal (radians); M_r = unit radial bending moment (inch-pounds per inch of circumference); M_t = unit tangential bending moment (inch-pounds per inch of radius); Q = unit shear force (pounds per inch of circumference); E = modulus of elasticity (pounds per square inch); ν = Poisson's ratio; γ = temperature coefficient of expansion (inches per inch per degree); a = outer radius (inches); b = inner radius for annular plate (inches); t = plate thickness (inches); r = radial location of quantity being evaluated (inches); r_0 = radial location of unit line loading or the start of a distributed load (inches). F_1 to F_9 and G_1 to G_{19} are the several functions of the radial location r. C_1 to C_9 are plate constants dependent upon the ratio a/b. L_1 to L_{19} are loading constants dependent upon the ratio a/r_0. When used as subscripts, r and t refer to radial and tangential directions, respectively. When used as subscripts, a and b refer to an evaluation of the quantity subscripted at the outer edge and inner edge, respectively. When used as a subscript, c refers to the subscripted quantity evaluated at the center of the plate

Positive signs are associated with the several quantities in the following manner: Deflections y and y_0 are positive upward; slopes θ and θ_0 are positive when the deflection y increases positively as r increases; moments M_r, M_t, and M_0 are positive when creating compression on the top surface; and the shear force Q is positive when acting upward on the inner edge of a given annular section

Bending stresses can be found from the moments M_r and M_t by the expression $\sigma = 6M/t^2$. The plate constant $D = Et^3/12(1 - \nu^2)$. The singularity function brackets $\langle\ \rangle$ indicate that the expression contained within the brackets must be equated to zero unless $r > r_0$, after which they are treated as any other brackets.

Case no., loading, load terms	Edge restraint	Boundary values	
10. Uniformly distributed load from r_0 to a  $LT_y = \frac{-qr^4}{D} G_{11}$ $LT_\theta = \frac{-qr^3}{D} G_{14}$ $LT_M = -qr^2 G_{17}$ $LT_Q = \frac{-q}{2r}(r^2 - r_0^2)\langle r - r_0\rangle^0$	10a. Simply supported	$y_a = 0 \quad M_{ra} = 0$ $y_c = \frac{-qa^4}{2D}\left(\frac{L_{17}}{1+\nu} - 2L_{11}\right)$ $M_c = qa^2 L_{17}$ $\theta_a = \frac{q}{8Da(1+\nu)}(a^2 - r_0^2)^2$ $Q_a = \frac{-q}{2a}(a^2 - r_0^2)$	$y = K_y \frac{qa^4}{D} \quad \theta = K_\theta \frac{qa^3}{D} \quad M = K_M qa^2$ r_0/a: 0.0, 0.2, 0.4, 0.6, 0.8 K_{y_c}: −0.06370, −0.05767, −0.04221, −0.02303, −0.00677 K_{θ_a}: 0.09615, 0.08862, 0.06785, 0.03939, 0.01246 K_{M_c}: 0.20625, 0.17540, 0.11972, 0.06215, 0.01776 *Note*: If $r_0 = 0$, $G_{11} = \frac{1}{64}$ $G_{14} = \frac{1}{16}$ $G_{17} = \frac{(3+\nu)}{16}$ $y_c = \frac{-qa^4(5+\nu)}{64D(1+\nu)}$ $M_c = \frac{qa^2(3+\nu)}{16}$ $\theta_a = \frac{qa^3}{8D(1+\nu)}$
	10b. Fixed	$y_a = 0 \quad \theta_a = 0$ $y_c = \frac{-qa^4}{2D}(L_{14} - 2L_{11})$ $M_c = qa^2(1+\nu)L_{14}$ $M_{ra} = \frac{-q}{8a^2}(a^2 - r_0^2)^2$	r_0/a: 0.0, 0.2, 0.4, 0.6, 0.8 K_{y_c}: −0.01563, −0.01336, −0.00829, −0.00334, −0.00054 K_{M_c}: 0.08125, 0.06020, 0.03152, 0.01095, 0.00156 $K_{M_{ra}}$: −0.12500, −0.11520, −0.08820, −0.05120, −0.01620 *Note*: If $r_0 = 0$, $G_{11} = \frac{1}{64}$ $G_{14} = \frac{1}{16}$ $G_{17} = \frac{(3+\nu)}{16}$ $y_c = \frac{-qa^4}{64D}$ $M_c = \frac{qa^2(1+\nu)}{16}$ $M_{ra} = \frac{-qa^2}{8}$

Poisson's Ratio ν = 0.3 for Steel

EVALUATION OF STRESS @ THE NOZZLE COVER PLATE (Cont'd.)

- Max Moment $M_c = \frac{q a^2 (1+\nu)}{16}$

$$= \frac{q(11.0)^2(1+0.3)}{16}$$

$$= 9.83\, q$$

Max. Moment $M_{ra} = \frac{-q a^2}{8}$

$$= \frac{q(11.0)^2}{8} = 15.13\, q$$

For 11.0 psia external Pressure

Max Moment = 15.13x11.0 = 166.4 lbsin/in

For 3/4" thick Plate,

Max Bending Stress $= \frac{116.4 \times 6}{1(0.75)^2}$

$= 1,775.3$ psi

APPENDIX 2.10.3

Increased External Pressure Calculations

I OBJECTIVE: TO PERFORM ANALYSIS FOR INCREASE EXTERNAL PRESSURE

II CRITERIA & METHOD OF APPROACH

The 10CFR71 Subpart F, Paragraph 71.71(c) (4) requires evaluation for an external pressure equal to 20psi absolute. Allowable external pressures for ASME Code vessels are established by paragraph NB-3133 of ASME Code Section III (Ref. 2.3)

NB-3133 Components Under External Pressure

(REF. 2.3)

NB-3133.1 General. Rules are given in this paragraph for determining the stresses under external pressure loading in spherical and cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Appendix VII.

NB-3133.2 Nomenclature. The symbols used in this paragraph are defined as follows:

A = factor determined from Fig. VII-1100-1 in Appendix VII and used to enter the applicable material chart in Appendix VII. For the case of cylinders having D_o/T values less than 10, see NB-3133.3(b). Also, factor determined from the applicable chart in Appendix VII for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.

A_s = cross-sectional area of a stiffening ring, sq in.

B = factor determined from the applicable chart in Appendix VII for the material used in a shell or stiffening ring at the design metal temperature, psi

D_o = outside diameter of the cylindrical shell course or tube under consideration, in.

E = modulus of elasticity of material at design temperature, psi (for this value, see Table I-6.0). Use the curve with this value on the material/temperature line of the applicable chart in Appendix VII.

I = available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell, in.[4] The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_oT_n}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.

I_s = required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell, in.[4]

L = total length, in., of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:

(1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings;

(2) the greatest center-to-center distance between any two adjacent stiffening rings; or

(3) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, in.

L_s = one-half the distance, in., from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is:

(1) a stiffening ring that meets the requirements of this paragraph;

(2) a circumferential line on a head at one-third the depth of the head from the head tangent line; or

(3) circumferential connection to a jacket for a jacketed section of a cylindrical shell.

P = external design pressure, psi (gage or absolute, as required)

P_a = allowable external pressure, psi (gage or absolute, as required)

R = inside radius of spherical shell, in.

S = the lesser of 1.5 times the stress intensity at design metal temperature from Tables I-1.0 or 0.9 times the tabulated yield strength at design metal temperature from Tables I-2.0

T = minimum required thickness of cylindrical shell or tube, or spherical shell, in.

T_n = nominal thickness used, less corrosion allowance, of cylindrical shell or tube, in.

NB-3133.3 Cylindrical Shells and Tubular Products

(a) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values equal to or greater than 10 shall be determined by the procedure given in Steps 1 through 8 below.

Step 1: Assume a value for T. Determine the ratios L/D_o and D_o/T.

Step 2: Enter Fig. VII-1100-1 in Appendix VII at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T. From this intersection move vertically downward and read the value of factor A.

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Appendix VII for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see Step 7.

Step 5: From the intersection obtained in Step 4

2.6.4 Increased External Pressure (Cont'd.)

For Circular Cylinder:

Step 1. For $T = 3.0''$; $D_o = 2 \times 69.0 = 138.0''$

$$L = (13 \times 12 + 8) + \tfrac{1}{3} \times 69 \times 2 = 210.0''$$

$$= (21 \times 12 + 6.25) - 36.25 + 69.0 = 291.0''$$

$$= (21 \times 12 + 6.25) - 36.25 + \frac{69.0}{3} = 245.0''$$

$\therefore L = 291.0''$

$$\therefore L/D_o = \frac{291}{138} = 2.109 \quad ; \quad \frac{D_o}{T} = \frac{138.0}{3} = 46.0$$

Step 2 $A = 0.0019$

" 5 $B = 15{,}100.0$

" 6 $P_a = \dfrac{4B}{3 D_o/T} = \dfrac{4 \times 15{,}100.0}{3 \times 46.0}$

$= \underline{437.7}$ psi $\gg 20.0$ psi

For the spherical Head

$$A = \frac{0.125}{R/T} = \frac{0.125 \times 3.0}{69.0} = 0.0054$$

$\therefore B = 17{,}000.0$ from Figure VII-1100-2

$$\therefore P_a = \frac{B}{R/T} = \frac{17000 \times 3}{69.0} = 739.1 \text{ psi}$$

$\gg 20.0$ psi.

move horizontally to the right and read the value of B.

Step 6: Using this value of B, calculate the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{4B}{3D_o/T} \quad =$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3D_o/T}$$

Step 8: Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(b) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below.

Step 1: Using the same procedure as given in (a) above, obtain the value of B. For values of D_o/T less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10 use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left(\frac{2.167}{D_o/T} - 0.0833\right)B$$

Step 3: Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/T}\left(1 - \frac{1}{D_o/T}\right)$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NB-3133.4 Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6 below.

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R/T} \quad = 0.0054$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Appendix VII for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. = 17,000

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{R/T} \quad = \frac{17000}{69.0} \times 3 = 739.1 \text{ psi}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

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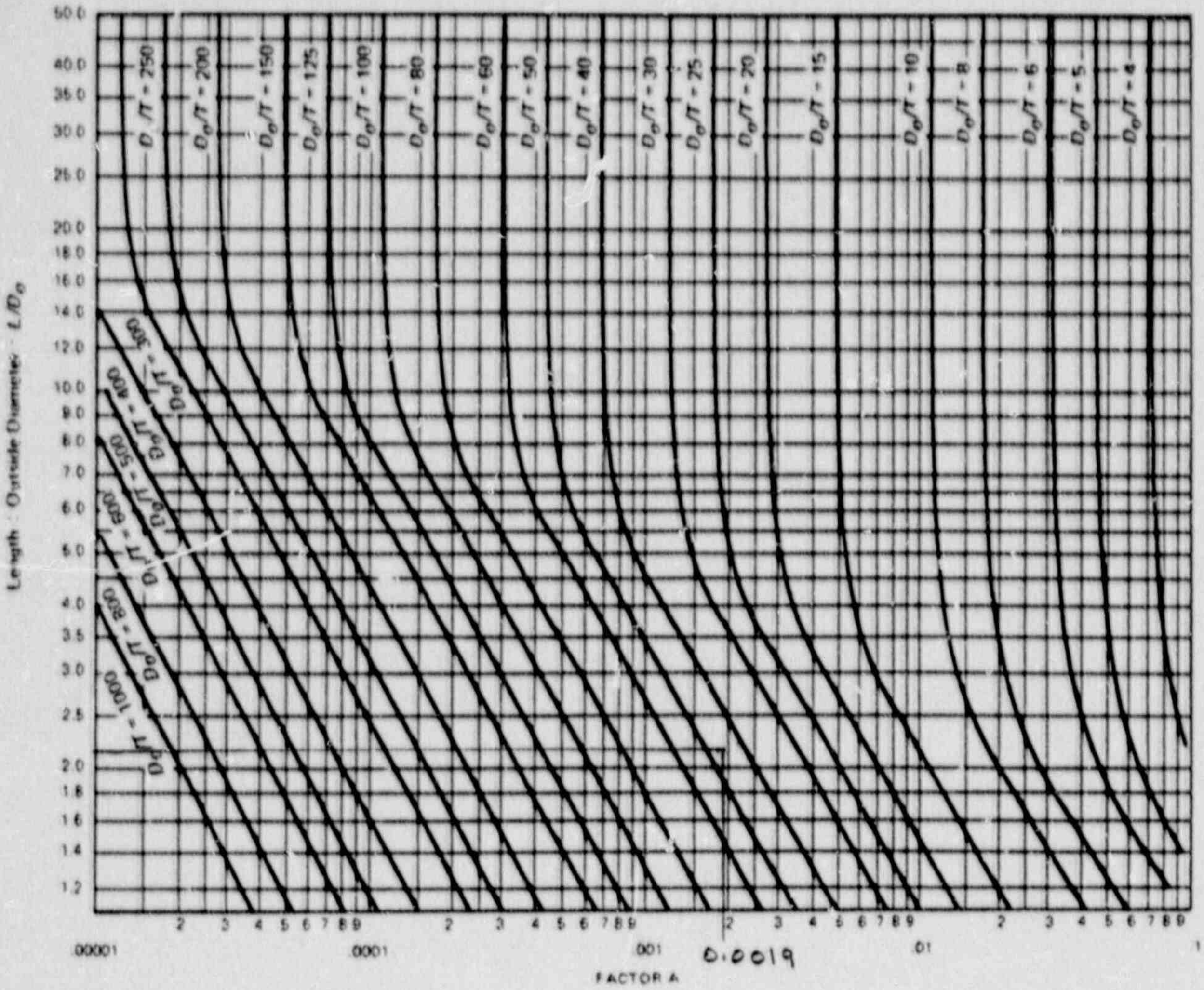

FIG. VII-1100-1 GEOMETRIC CHART FOR CYLINDERS UNDER EXTERNAL PRESSURE OR COMPRESSIVE LOADINGS

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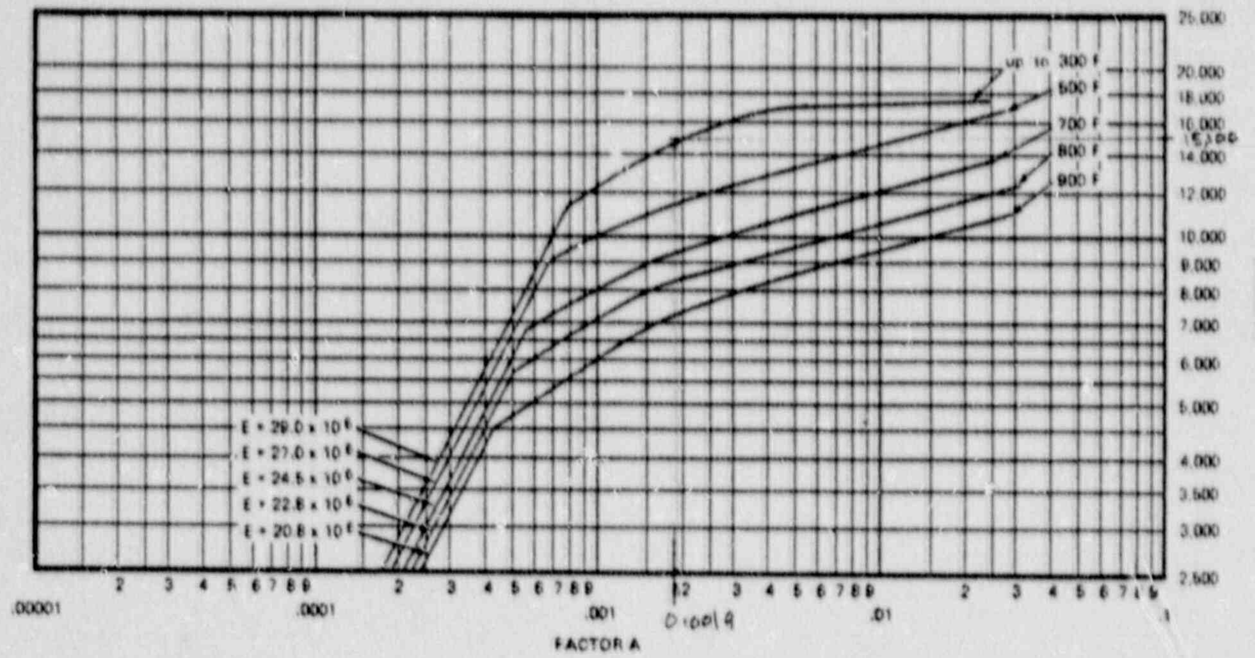

FIG. VII-1101-2 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CARBON STEEL (Specified Yield Strength 30,000 to 38,000 psi, inclusive) AND TYPE 405 AND TYPE 410 STAINLESS STEEL

Step 6: Compare P_a obtained in Step 4 or 5 with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NB-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of the combined ring-shell section is given by the formula:

$$I_s = \frac{D_o^2 L_s (T + A_s/L_s) A}{10.9}$$

The available moment of inertia I for a stiffening ring shall be determined by the procedure given in Steps 1 through 6 below.

Step 1: Assuming that the shell has been designed and D_o, L_s, and T_n are known, select a member to be used for the stiffening ring and determine its area A and the value of I defined in NB-3133.2. Then calculate B by the formula:

$$B = \frac{3}{4}\left(\frac{PD_o}{T_n + A_s/L_s}\right)$$

Step 2: Enter the right-hand side of the applicable material chart in Appendix VII for the material under consideration at the value of B determined in Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Steps 4 or 5 below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A.

Step 5: For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the following formula:

$$A = 2B/E^*$$

Step 6: If the required I_s is greater than the computed moment of inertia I for the combined-ring shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is smaller than the computed I for the section selected in Step 1, that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

NB-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

(a) the S_m value for the applicable material at design temperature given in Table I-1.1 or Table I-1.2;

(b) the value of the factor B determined from the applicable chart contained in Appendix VII, using the following definitions for the symbols on the charts:

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in.

R = inside radius of the cylindrical shell or tubular product, in.

The value of B shall be determined from the applicable chart contained in Appendix VII as given in Steps 1 through 5 below.

Step 1: Using the selected values of T and R, calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R/T}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Appendix VII for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the

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EVALUATION OF THE STRESS AT THE NOZZLE COVER PLATE

NOZZLE DIAMETER = 22.0"
COVER PLATE THICKNESS = $t = 0.75"$

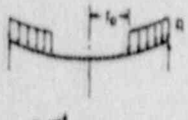
Stresses in the cover plate due to Pressure load will be evaluated using Formulas for Flat Plate with fixed Boundary Conditions
FROM R.J. ROARK'S FORMULAS FOR STRESS & STRAIN" 5th Edition, McGraw Hill Book Co.

TABLE 24 *Formulas for flat circular plates of constant thickness*

NOTATION: W = total applied load (pounds); w = unit line load (pounds per inch of circumference); q = load per unit area (pounds per square inch); M_o = unit applied line moment loading (inch-pounds per inch of circumference); θ_o = externally applied change in angular displacement (radians); y_o = externally applied step in the normal displacement (inches); y = vertical deflection of plate (inches); θ = slope of plate measured from the horizontal (radians); M_r = unit radial bending moment (inch-pounds per inch of circumference); M_t = unit tangential bending moment (inch-pounds per inch of radius); Q = unit shear force (pounds per inch of circumference); E = modulus of elasticity (pounds per square inch); ν = Poisson's ratio; γ = temperature coefficient of expansion (inches per inch per degree); a = outer radius (inches); b = inner radius for annular plate (inches); t = plate thickness (inches); r = radial location of quantity being evaluated (inches); r_o = radial location of unit line loading or the start of a distributed load (inches). F_1 to F_9 and G_1 to G_{19} are the several functions of the radial location r. C_1 to C_9 are plate constants dependent upon the ratio a/b. L_1 to L_{19} are loading constants dependent upon the ratio a/r_o. When used as subscripts, r and t refer to radial and tangential directions, respectively. When used as subscripts, a and b refer to an evaluation of the quantity subscripted at the outer edge and inner edge, respectively. When used as a subscript, c refers to the subscripted quantity evaluated at the center of the plate

Positive signs are associated with the several quantities in the following manner: Deflections y and y_o are positive upward; slopes θ and θ_o are positive when the deflection y increases positively as r increases; moments M_r, M_t, and M_o are positive when creating compression on the top surface; and the shear force Q is positive when acting upward on the inner edge of a given annular section

Bending stresses can be found from the moments M_r and M_t by the expression $\sigma = 6M/t^2$. The plate constant $D = Et^3/12(1-\nu^2)$. The singularity function brackets $\langle\ \rangle$ indicate that the expression contained within the brackets must be equated to zero unless $r > r_o$, after which they are treated as any other brackets.

Case no., loading, load terms	Edge restraint	Boundary values	
10. Uniformly distributed load from r_o to a  $LT_y = \frac{-qr^4}{D}G_{11}$; $LT_\theta = \frac{-qr^3}{D}G_{14}$; $LT_M = -qr^2G_{17}$; $LT_Q = \frac{-q}{2r}(r^2 - r_o^2)\langle r - r_o\rangle^0$	10a. Simply supported	$y_a = 0$ $M_{ra} = 0$; $y_c = \frac{-qa^4}{2D}\left(\frac{L_{17}}{1+\nu} - 2L_{11}\right)$; $M_c = qa^2L_{17}$; $\theta_a = \frac{q}{8Da(1+\nu)}(a^2 - r_o^2)^2$; $Q_a = \frac{-q}{2a}(a^2 - r_o^2)$	$y = K_y\frac{qa^4}{D}$ $\theta = K_\theta\frac{qa^3}{D}$ $M = K_Mqa^2$ (see K table 10a below). Note: If $r_o = 0$, $G_{11} = \frac{1}{64}$ $G_{14} = \frac{1}{16}$ $G_{17} = \frac{(3+\nu)}{16}$; $y_c = \frac{-qa^4(5+\nu)}{64D(1+\nu)}$ $M_c = \frac{qa^2(3+\nu)}{16}$ $\theta_a = \frac{qa^3}{8D(1+\nu)}$
	10b. Fixed	$y_a = 0$ $\theta_a = 0$; $y_c = \frac{-qa^4}{2D}(L_{14} - 2L_{11})$; $M_c = qa^2(1+\nu)L_{14}$; $M_{ra} = \frac{-q}{4a^2}(a^2 - r_o^2)^2$	(see K table 10b below). Note: If $r_o = 0$, $G_{11} = \frac{1}{64}$ $G_{14} = \frac{1}{16}$ $G_{17} = \frac{(3+\nu)}{16}$; $y_c = \frac{-qa^4}{64D}$ $M_c = \frac{qa^2(1+\nu)}{16}$ $M_{ra} = \frac{-qa^2}{8}$

10a:

r_o/a	0.0	0.2	0.4	0.6	0.8
K_{y_c}	−0.06370	−0.05767	−0.04221	−0.02303	−0.00677
K_{θ_a}	0.09615	0.08862	0.06785	0.03939	0.01246
K_{M_c}	0.20625	0.17540	0.11972	0.06215	0.01776

10b:

r_o/a	0.0	0.2	0.4	0.6	0.8
K_{y_c}	−0.01563	−0.01336	−0.00829	−0.00334	−0.00054
K_{M_c}	0.08125	0.06020	0.03152	0.01095	0.00156
$K_{M_{ra}}$	−0.12500	−0.11520	−0.08820	−0.05120	−0.01620

Poisson's Ratio $\nu = 0.3$ for Steel

EVALUATION OF STRESS @ THE NOZZLE COVER PLATE (Cont'd.)

Max. Moment $M_c = \frac{q a^2 (1+\nu)}{16}$

$= \frac{q(11.0)^2(1+0.3)}{16}$

$= 9.83\, q$

Max. Moment $M_{ra} = \frac{-q a^2}{8}$

$= \frac{q(11.0)^2}{8} = 15.13\, q$

For Increased External Pressure of 20.0 psi.

Max. Moment $= 15.13 \times 20 = 302.6$ lbs.in./in.

For 3/4" thick Cover plate, Section Modulus

$= S = \frac{1 (0.75)^2}{6}$ in³/in

∴ Max. Bending Stress $= \frac{302.6 \times 6}{1 \times (0.75)^2}$

$= 3,227.7$ psi

$= 3.23$ Ksi

APPENDIX 2.10.4

Side Drop and Edge Drop Finite Element Analysis

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I OBJECTIVE :- TO PERFORM PATHFINDER VESSEL DROP ANALYSIS FOR ONE FOOT DROP

II ASSUMPTIONS: ASSUMPTIONS ARE LISTED IN COMPUTATIONS WHERE THEY OCCUR

III REFERENCES :- GENERAL REFERENCES ARE GIVEN ON PAGE 36 OF THIS APPENDIX. SPECIFIC REFERENCES ARE PROVIDED WHERE EVER THEY OCCUR

IV DESCRIPTION

2.6.7 Free Drop

The Pathfinder package weighs 291 tons. Subsection F of 10 CFR 71 requires that a package of this mass be analyzed for a drop of one foot onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. During transport the package will always be oriented in the horizontal position; i.e., the centerline axis of the package will be horizontal. Because of the unique size, weight, mass and bulk of the package, no other orientation is considered feasible during normal transport conditions. Consequently, the free drop condition (which is expected to result in maximum damage) is a one-foot side drop of the package on an essentially unyielding horizontal surface.

Two cases were evaluated: (1) drop of the package along its length, and (2) impact of the package at its edge, wherein 50 per cent of the package weight and kinetic energy is transmitted to one edge of the package. Drop of the package at its lower edge was considered to be more critical as it is heavier due to the core internals weight. Figures 1 and 2 on page 2.6.7-4, shows the orientation of these two drop cases.

For Case 1, the effective weight is taken as that of a heaviest one foot wide section of the vessel and its internals along its length. It should be noted that for the vertical drop (case 1), the weight of the protruding parts of the package will be transmitted to the impact limiters at the edge of the vessel (which are analyzed for a significantly larger weight and kinetic energy in case 2). Therefore the maximum tributory (effective) weight for drop case 1 will be that of the heaviest one foot wide section of the vessel and internals along its length.

2.6.7.1 Analytical Methods

This section describes the analytical methodology used to demonstrate the structural adequacy of the package during a side or edge drop event. The analytical method is based on a step-by-step evaluation of external energy, resistance offered and energy absorbed by the impact limiter. The maximum stresses in the reactor vessel wall are evaluated at each incremental depth of crushing. The Section 2.6.7.2 describes the calculation of deformation and forces generated during the drop event. Section 2.6.7.3 describes the ANSYS three dimensional finite element models used for the detailed evaluation of maximum stresses in the package.

2.6.7.2 Impact Limiter Resistance/Deformation Behavior

As described in Section 1.2, the package includes a circular energy absorbing impact limiter surrounding the vessel. This impact limiter is designed to protect the package during a one-foot drop event. The impact limiter consists of precrushed Hexcel energy absorbing material. For purposes of analysis, the impact limiter is assumed to absorb, in plastic deformation of Hexcel, the potential energy of the drop event. That is, the analyses assume that none of the drop potential energy is transferred to kinetic energy or strain energy of the target (the "unyielding surface" assumption of 10 CFR 71) nor strain energy in the vessel itself.

For each drop orientation, the prediction of overpack behavior can be approached from straightforward energy balance principles:

$$E = W(h+c) = \int_0^c Fx\, dx$$

Where: W = package weight

h = Drop height

c = maximum overpack deformation, or crushing

Fx = Force imposed upon target and package by the overpack at a deflection equal to x.

The left-hand term represents the potential energy of the drop. The right-hand term represents the strain energy of the deformed overpack.

Figure 3 shows the tributary area of resistance at incremental depths of crushing. Using the effective area of resistance at each incremental depth of crushing, effective load-deformation (energy absorbtion) characteristics of the impact limiter have been developed for the two drop cases. These load-deformation characteristics for the two cases are shown in Figures 4 and 5 respectively.

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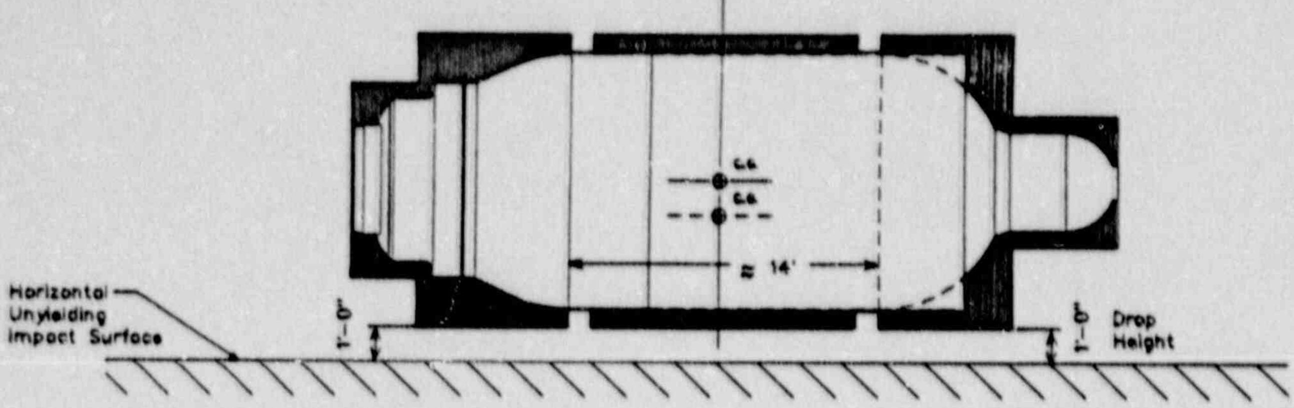
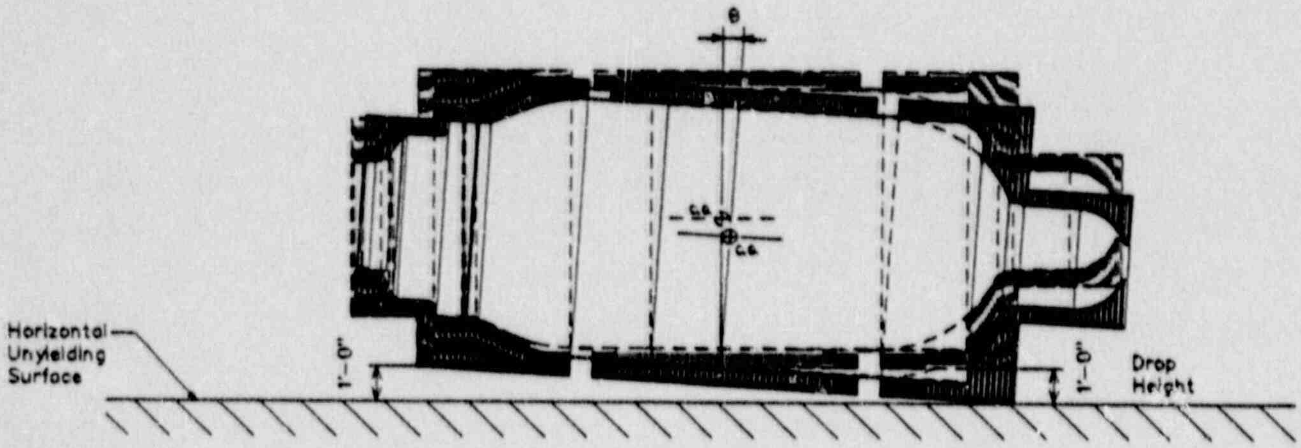


Case 1 – Side Drop

FIGURE 1



Case 2 – Edge Drop

Orientation Angle

FIGURE 2

APPENDIX 2.10.5

Design Calculations for Impact Limiter, Finite Element Analysis, and WRC 107

CASE I

DESIGN OF HEXCEL CORE FOR SIDE IMPACT

DROP HEIGHT = 1.0' = h

VELOCITY OF IMPACT = $V_i = \sqrt{2gh}$

$= \sqrt{2 \times 32.17 \times 1} = 8.021 \text{ ft/sec}^2$

Max. WEIGHT OF VESSEL & INTERNALS / FT. BETWEEN EL. 1312' TO 1277' = 24.5 K/ft

EXTERNAL KINETIC ENERGY OF IMPACT

$E_{xi} = \frac{1}{2} M V_i^2 = \frac{1}{2} \times \frac{24.5}{32.17} (8.021)^2 \times 12 = 294 \text{ in K/ft}$

Considering Total Deformation of Hexcel = 5.13 in.

TOTAL External Energy = 24.5(12+5.18) = 420.91 in K/ft = E_x

FOR HEXCEL 3/8-5052-.0025, 3.7 pcf.

Crushing strength f_{cr} = 180.0 psi (Page 2.67-12)

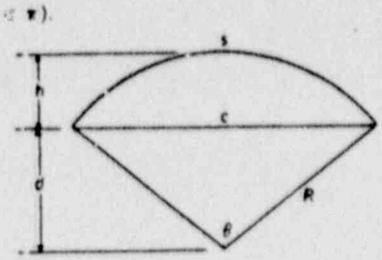
Internal Energy Absorbed by HEXCEL CORE

= Volume of Hexcel Crushed x Crushing Strength of Hexcel

From CRC Mathematical Tables, For Cylindrical Core

Sector and Segment of a Circle

Let the central angle θ be measured in radians ($\theta \leq \pi$).



$h = R - d, \quad d = R - h$

$s = R\theta$

$d = R\cos\frac{\theta}{2} = \frac{1}{2}c\cot\frac{\theta}{2}$

$= \frac{1}{2}\sqrt{4R^2 - c^2}$

$c = 2R\sin\frac{\theta}{2} = 2d\tan\frac{\theta}{2}$

$= 2\sqrt{R^2 - d^2} = \sqrt{4h(2R - h)}$

$\theta = \frac{s}{R} = 2\,\mathrm{Cos}^{-1}\frac{d}{R} = 2\,\mathrm{Tan}^{-1}\frac{c}{2d} = 2\,\mathrm{Sin}^{-1}\frac{c}{2R}$

$A\text{ (sector)} = \frac{1}{2}Rs = \frac{1}{2}R^2\theta$

$A\text{ (segment)} = \frac{1}{2}R^2(\theta - \sin\theta) = \frac{1}{2}(Rs - cd) = R^2\,\mathrm{Cos}^{-1}\frac{d}{R} - d\sqrt{R^2 - d^2}$

$= R^2\,\mathrm{Cos}^{-1}\frac{R-h}{R} - (R - h)\sqrt{2Rh - h^2}$

CASE 1
Design of HEXCEL CORE - SIDE IMPACT (Cont'd)

Area of Segment $= \frac{1}{2}R^2(\theta - \sin\theta)$

$R = 79.0 - 0.25 = 78.75$ in

For 12" wide cylinder,

Volume of Crushed Hexcel $= \frac{1}{2}(78.75)^2(\theta - \sin\theta)\,12 = V$

∴ Internal Energy Absorbed by HEXCEL

$= V \times f_{cr} = \frac{1}{2}(78.75)^2(\theta - \sin\theta)\,12 \times \frac{180}{1000}$ in.K/ft

$E_i = 6{,}697.7\ (\theta - \sin\theta)$ in K/ft

Equating External and Internal Energy.

$E_x = E_i$

$420.91 = 6697.7(\theta - \sin\theta)$

∴ $\theta - \sin\theta = 0.0628$

Solving by trial and error

$\theta = 41.75°$

∴ Depth of Crushing $= h = R - R\cos\theta/2$

$h = R(1 - \cos\frac{\theta}{2}) = 78.75(1 - \cos\frac{41.75}{2})$

$= 5.17$ in $< 5.18''$ O.K

% of Available Crushing thickness $= \frac{5.17}{8.0}$

$= 0.646 < 0.7$ O.K

width $C = 2R\sin\theta/2 = 2 \times 78.75 \times \sin\frac{41.75}{2} = 56.12$ in. $> 48''$ O.K used in Analy

∴ Max. Reaction Load Developed $= 56.12 \times 12 \times 180$

$= 121{,}223.5$ lbs

$= 121.22$ K

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CASE 1

Max. Acceleration from $V_f^2 = V_i^2 + 2as$

$V_f = 0$; impact Velocity $V_i = 8.02$ ft/sec

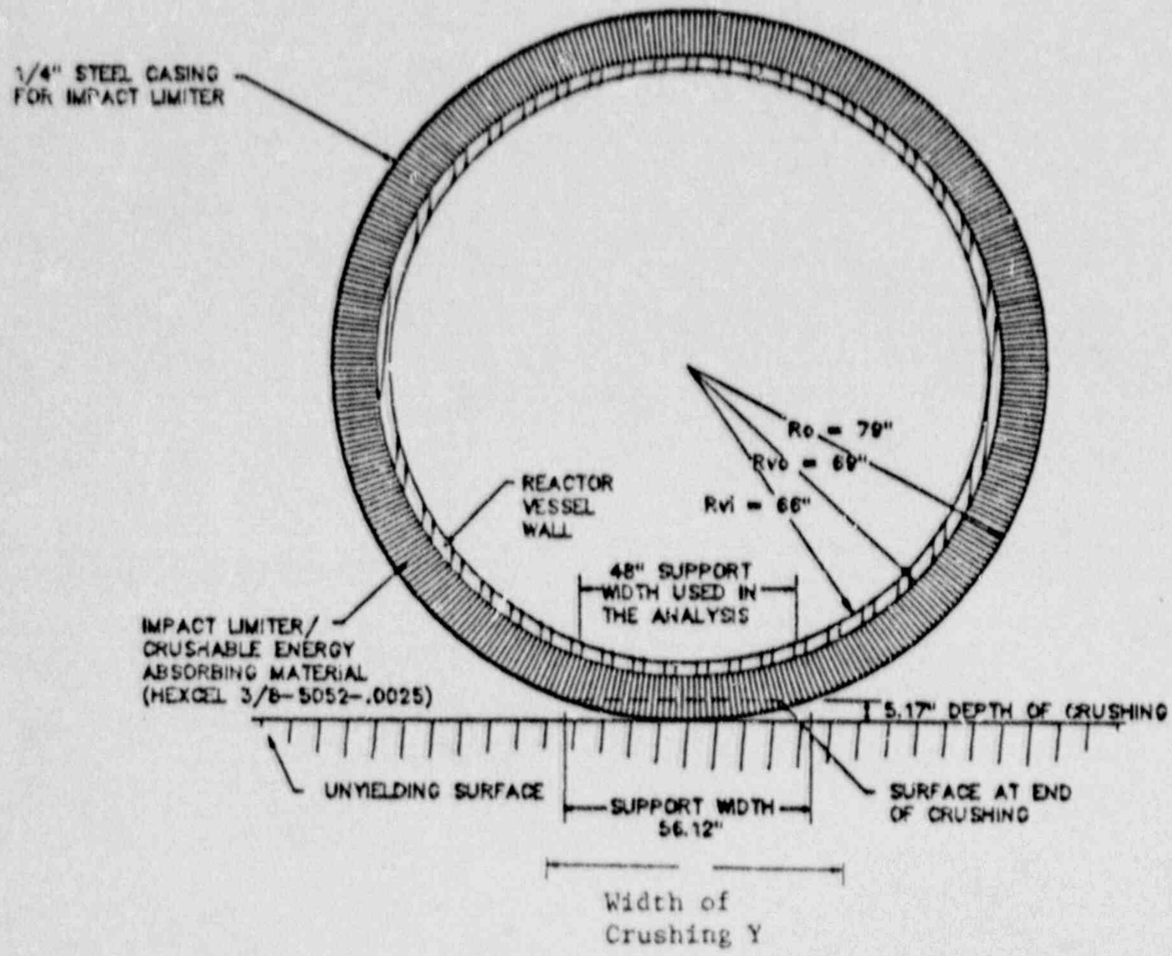
s = depth of crushing = 5.17 in

$\therefore$ acceleration $a = \frac{V_i^2}{2s} = \frac{(8.02)^2 \times 12}{2 \times 5.17} \frac{1}{32.17} = 2.32g$

Total Vertical Load = 24.5(1+2.32) = 81.4 K
< 121.22 K

FIGURE 3

HEXCEL PROPERTIES AND
WIDTH AND DEPTH OF CRUSHING



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SIDE DROP (Case 1)

Using the above Procedure, for various depth of crushing, θ and maximum resistance Load are

Depth of crushing (in)	θ (°)	Max. Resistance Load (K)
0	0	0
0.2	5°	29.65
0.5	6.46	38.3
1.0	9.14	54.04
1.2	10°	59.1
1.5	11.2	66.1
2.0	13.2	76.2
2.5	14.5	85.0
2.68	15	88.1
3.0	15.9	93.0
3.5	17.2	100.3
4.0	18.3	107.0
4.5	19.5	113.4
4.75	20	116.4
5.0	20.53	119.3
5.11	20.8	121.2

CASE 2.

DESIGN OF HEXCEL CORE FOR SIDE DROP AT EDGE

DROP HEIGHT = 1' = 12"

TOTAL WEIGHT = 582.2 K

CONSIDER 50% OF TOTAL WEIGHT DROP @ EDGE

MAX. VELOCITY OF IMPACT = V_i = 8.021 ft/sec

EXTERNAL KINETIC ENERGY OF IMPACT

$E_{xi} = 582.2 \times 0.5 \times 12 = 3,493.2$ in.K

FOR HEXCEL 1/4-5052-.004 7.9 pcf

CRUSHING STRENGTH f_{cr} = 725 psi (Page 2.6.7-12)

Total External Energy with HEXCEL Deformation of 5.18" = $\frac{582.2}{2}(12+5.18) = E_x$

For 3×12 = 36" wide Cylinder

Volume of Hexcel Crushed = $\frac{1}{2}(78.75)^2(\theta - \sin\theta)\, 36 = V$

∴ Internal Energy Absorbed by HEXCEL CORE

$E_i = V f_c = \frac{1}{2}(78.75)^2(\theta - \sin\theta)\, 36 \times \frac{725}{1000}$

$= 80,930.4\, (\theta - \sin\theta)$ in.K

Equating Internal & External Energy

$E_i = E_x$

$80,930.4(\theta - \sin\theta) = \frac{582.2}{2}(12+5.18) = 5001.1$

$\theta - \sin\theta = 0.0618$

∴ $\theta = 41.52°$

∴ Depth of Crushing = $h = R(1-\cos\frac{\theta}{2}) = 78.75(1-\cos\frac{41.52}{2})$

$= 5.11" < 5.18"$ O.K.

% of Total Thickness = $\frac{5.11}{8} = 0.639 < 0.7$ O.K.

CASE 2.

Design of HEXCEL CORE FOR SIDE DROP ON EDGE

Max. width $c = 2R \sin\frac{\theta}{2} = 2 \times 78.75 \sin\frac{41.57}{2}$

$= 55.83'' > 48''$ O.K used in the analysis

Max. REACTION LOAD DEVELOPED = 55.83 x 36 x 725
= 1,457,072.8 lbs = 1,457.1K

Max. Acceleration $= \frac{V_i^2}{2Sg} = \frac{(8.02)^2 \times 12}{2 \times 5.11 \times 32.17} = 2.35G$

Total Load $= \frac{582.2}{2} \times (1+2.35) = 974.7K < 1,457.1K$

Using the Above Procedure, Load-Deformation data for this case are

Depth of Crushing (in) h	θ (°)	Max. Resistance Load (K) Full Model	Symmetrical Model
0.3	5°	358.4	179.2
0.5	6.46	462.8	231.4
1.0	9.14	653.2	326.6
1.2	10°	714.0	357.
1.5	11.2	798.9	399.4
2.0	13.0	920.8	460.4
2.5	14.5	1028.0	514.0
2.68	15	1064.0	532.0
3.0	15.9	1124.0	561.9
3.5	17.2	1212.0	606.0
4.0	18.3	1293.0	646.5
4.5	19.5	1370.0	685.1
4.75	20	1406.0	703
5.0	20.53	1442.0	720.8
5.11	20.8	1457.0	728.6

BY I. Husain DATE 10/16/89 SECTION 2.6.7-11
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Reactor Vessel Analysis as Type 'A' Shipping Container

LOAD DEFORMATION CURVE
CASE 1 - SIDE DROP
(For Typical One foot Length of Package)

FIGURE 4

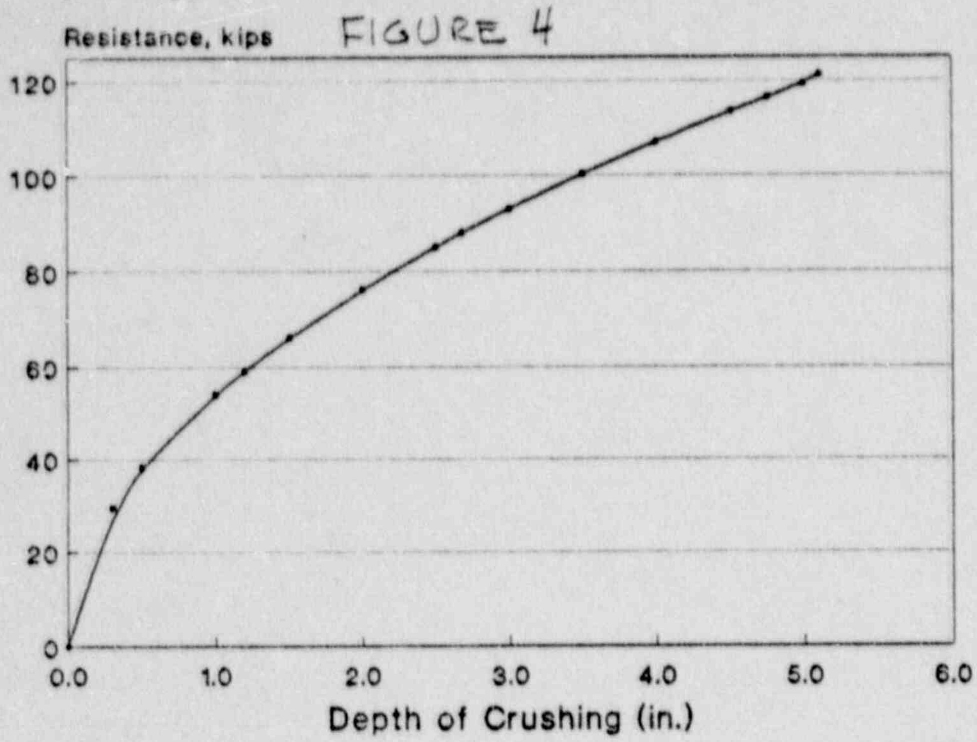
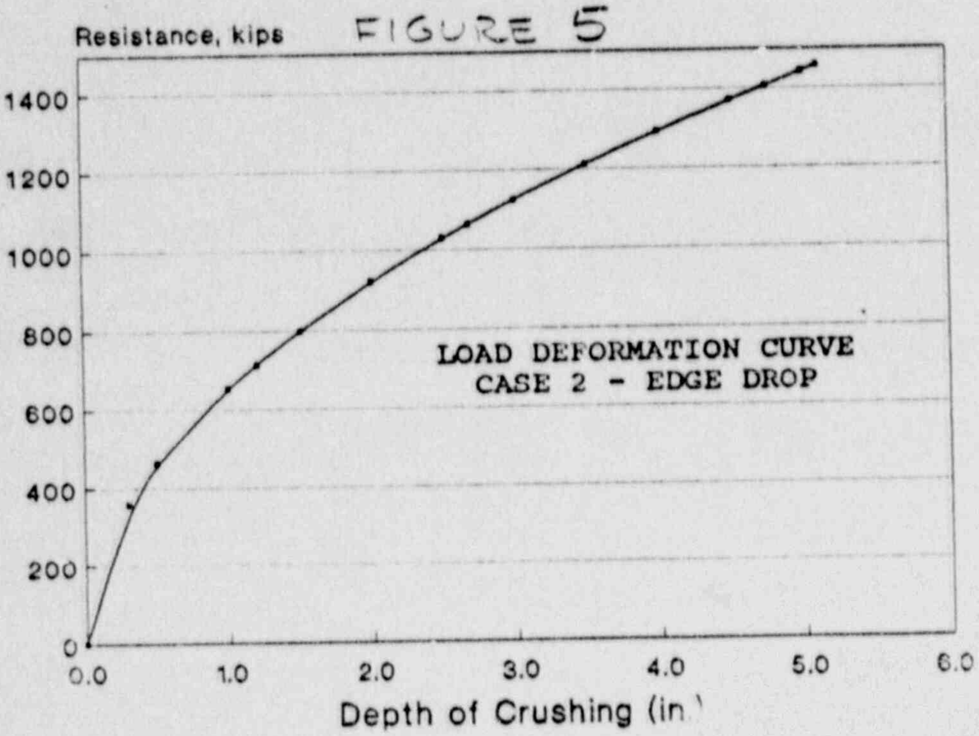


FIGURE 5



TLG ENGINEERING

BY: J. Husand DATE: 8/16/89 SECTION: 2.6.7-12
CHKD: JLP DATE: 10/22/89 SUB-SECTION: ____ OF ____
PROJECT NO. 4-22B TASK NO. PH1580 PAGE ____ OF ____
TITLE: NSP - PATHFINDER DECOMISSIONING STUDY
Reactor Vessel Analysis - Type A Shipping Container.

From Hexcel Catalog (Reference 2.2, 2.7)

5052 ALLOY HEXAGONAL ALUMINUM HONEYCOMB

SPECIFICATION GRADE

HEXCEL HONEYCOMB DESIGNATION	Nominal Density pcf	COMPRESSIVE					Crush Strength psi	PLATE SHEAR					
		Bare		Stabilized				"L" Direction			"W" Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
Cell-Material-Gage		typ	min	typ	min	typical	typ	typ	min	typical	typ	min	typical
1/16-5052-.0007	6.3	850p	–	900p	–	275p	—	600p	480p	90p	375p	300p	40p
1/16-5052-.001	9.0	1600p	–	1700p	–	420x	—	900p	835p	105x	545p	520p	53x
1/8-5052-.0007	**3.1**	**285**	**200**	**[illegible]**	**215**	**75**	**130**	**210**	**185**	**45.0**	**130**	**90**	**22.0**
1/8-5052-.001	**4.5**	**560**	**375**	**570**	**405**	**150**	**260**	**340**	**285**	**70.0**	**220**	**160**	**31.0**
1/8-5052-.0015	**6.1**	**1000**	**650**	**1040**	**680**	**240**	**450**	**580**	**465**	**98.0**	**320**	**272**	**41.0**
1/8-5052-.002	**8.1**	**1685**	**1000**	**1515**	**1100**	**350**	**750**	**725**	**670**	**135**	**455**	**400**	**54.0**
1/8-5052-.003	12.0	2800	2100	3050	2200	900p	—	1940p	1250p	—	1430p	1050p	—
5/32-5052-.0007	2.6	220	150	260	160	55	90	165	120	37.0	100	70	19.0
5/32-5052-.001	3.8	395	285	410	300	110	185	270	215	56.0	175	125	26.4
5/32-5052-.0015	5.3	690	490	720	535	195	340	420	370	84.0	270	215	36.0
5/32-5052-.002	6.9	1080	770	1130	800	285	575	590	540	114	375	328	46.4
5/32-5052-.0025	8.4	1530	1070	1600	1180	370	800	760	690	140	475	420	56.0
3/16-5052-.0007	2.0	160	90	175	100	34	60	120	80	27.0	70	46	14.3
3/16-5052-.001	**3.1**	**315**	**200**	**335**	**215**	**75**	**130**	**210**	**155**	**45.0**	**130**	**90**	**22.0**
3/16-5052-.0015	**4.4**	**560**	**360**	**590**	**385**	**145**	**250**	**330**	**280**	**68.0**	**215**	**160**	**30.0**
3/16-5052-.002	**5.7**	**820**	**560**	**860**	**600**	**220**	**390**	**460**	**410**	**90.0**	**300**	**244**	**38.5**
3/16-5052-.0025	6.9	1120	770	1175	800	285	575	590	540	114	375	328	46.4
3/16-5052-.003	8.1	1660	1000	1720	1100	350	750	725	670	135	455	400	54.0
1/4-5052-.0007	1.6	90	60	100	70	20	40	85	60	21.0	50	32	11.0
1/4-5052-.001	**2.3**	**210**	**120**	**230**	**130**	**45**	**75**	**140**	**100**	**32.0**	**85**	**57**	**16.2**
1/4-5052-.0015	**3.4**	**375**	**240**	**385**	**250**	**90**	**150**	**235**	**180**	**50.0**	**150**	**105**	**24.0**
1/4-5052-.002	**4.3**	**500**	**350**	**560**	**370**	**140**	**230**	**320**	**265**	**66.0**	**210**	**155**	**29.8**
1/4-5052-.0025	5.2	720	500	760	510	190	335	410	360	82.0	265	200	35.4
1/4-5052-.003	6.0	1050	630	1100	660	235	430	495	445	96.0	315	265	40.5
1/4-5052-.004	**7.9**	**1420**	**970**	**1490**	**1050**	**340**	**725**	**700**	**650**	**130**	**440**	**390**	**52.8**
3/8-5052-.0007	1.0	45	20	50	20	10	25	45	32	12.0	30	20	7.0
3/8-5052-.001	1.6	90	60	95	70	20	40	85	60	21.0	50	32	11.0
3/8-5052-.0015	2.3	190	120	200	130	45	75	140	100	32.0	85	57	16.2
3/8-5052-.002	3.0	300	190	315	200	70	120	200	145	43.0	125	85	21.2
3/8-5052-.0025	3.7	405	270	420	285	105	180	260	200	55.0	170	115	26.0
3/8-5052-.003	4.2	620	335	640	355	135	220	310	255	65.0	200	150	29.0
3/8-5052-.004	5.4	810	500	850	535	200	360	430	380	86.0	280	228	36.8
3/8-5052-.005	6.5	1000	700	1100	750	265	505	545	500	105	350	300	43.5

Notes:

1. Test data obtained at 0.625 inch thickness
2. p-Preliminaries (see page 11)
3. x-Predicted values
4. I-Beam shear for 12.0 pcf product

Additional information on Hexcel is found on Pages 30 though 35.

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BY I. Husain DATE 10/16/89 SECTION 3.6.7-13
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MAXIMUM STRESS SUMMARY

Depth of Crushing, in	Side Drop Max. Membrane Stress, ksi	Side Drop Max. Membrane + Bending, ksi	Edge Drop Max. Membrane Stress, ksi	Edge Drop Max. Membrane + Bending, ksi
0.5	2.56	5.33	3.03	13.06
1.0	2.74	5.54	3.79	13.45
1.5	3.35	6.77	4.63	16.44
2.0	1.91	6.25	4.49	17.11
2.5	2.13	6.97	5.01	19.10
3.0	2.33	7.63	5.47	19.27
3.5	2.52	8.23	5.90	20.78
4.0	2.39	7.27	5.00	20.26
4.5	2.54	7.77	5.30	21.47
5.11	2.71	8.23	5.63	22.83

MEMBRANE AND MEMBRANE PLUS BENDING MARGINS OF SAFETY

Maximum membrane stress = 5.90 ksi

Allowable membrane stress = Sm = 17.88 ksi

Margin of safety = 17.88/5.90 - 1 = 2.03

Membrane plus bending stress = 22.83 ksi

Allowable membrane plus bending = 1.5 Sm = 26.81 ksi

Margin of safety = 26.81/ 22.83 - 1 = 0.17

Maximum tensile stress in closure head bolts = 0.51 ksi

Allowable tensile stress in bolts = Sm = 17.88 ksi

Margin of safety = 17.88/0.51 -1 = 34.06

Maximum shear stress in bolts = 0.43 ksi

Allowable shear stress in the bolts = 0.6 X 38.0 = 22.80 ksi

Margin of safety = 22.8/0.43 -1 = 52.02

WELDING RESEARCH COUNCIL BULLETIN 107 (WRC 107) ANALYSIS (Ref. 2.4)

Results of finite element analyses were verified by hand calculations using analytical procedures given in Welding Research Council Bulletin WRC 107 (Ref. 2.4) which is widely used for the design of reactor vessels.

Detail Calculations and curves used in the calculations are given on pages 15 through 24.

From these results it can be seen that for

Case 1,

Maximum Stress in Cylindrical Vessel wall due to radial Load of 108 K = 6.83 Ksi

∴ For Max. Resistance Load of 121.2 K

Max. Membrane + Bending stress (Stress Intensity)

$$= 6.83 \times \frac{121.2}{108} = 7.66 \text{ Ksi}$$

Compared to ANSYS Analysis result of 8.23 Ksi.

For Case 2 -

Max Stress For Spherical Shell = 0.98 Ksi for Radial Load of 100.0 K

" " " " " $= \frac{0.98}{100.0} \times 1457.0 = 14.28$ Ksi.

As compare to ANSYS Analysis result of 22.83 Ksi. WRC 107 result for Case 2 are lower because they are for spherical shell rather than junction of spherical and cylindrical Shell

WRC 107 EVALUATION FOR SIDE DROP (CASE 1)

PARAMETERS:

For 12" x 36" NOZZEL DIMENSIONS.

$C_2 = 6"$; $C_1 = 18"$

$$\beta_1 = \frac{C_1}{R_M} = \frac{18}{70.5} = 0.255$$

$$\beta_2 = \frac{C_2}{R_M} = \frac{6}{70.5} = 0.0851$$

$$\frac{\beta_1}{\beta_2} = \frac{18}{6} = 3.0 > 1$$

$$\therefore \beta = \left[1 - \frac{1}{3}\left(\frac{\beta_1}{\beta_2} - 1\right)(1 - K_1)\right]\sqrt{\beta_1 \beta_2}$$

For N_ϕ, $K = 0.91$

$$\therefore \beta = \left[1 - \frac{1}{3} \times (3-1)(1-0.91)\right]\sqrt{0.255 \times 0.0851} = 0.139$$

For N_x, $K = 1.68$

$$\therefore \beta = \left[1 - \frac{2}{3}(1 - 1.68)\right] 0.1474 = 0.2142$$

For M_ϕ, $K_1 = 1.76$

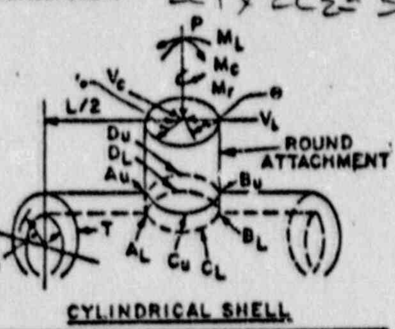
$$\therefore \beta = \left[1 - \frac{2}{3}(1 - 1.76)\right] 0.1474 = 0.2221$$

For M_x, $K_1 = 1.2$

$$\therefore \beta = \left[1 - \frac{2}{3}(1 - 1.2)\right] 0.1474 = 0.1671$$

WRC 107 EVALUATION FOR SIDE IMPACT - (CASE I) 2.6.7.-16

Table 5—Computation Sheet for Local Stresses in Cylindrical Shells $2C_1 \times 2C_2 = 36 \times 12$



1. Applied Loads* 108.0K
   - Radial load, P = —— lb.
   - Circ. Moment, Mc = —— in. lb.
   - Long. Moments, ML = —— in. lb.
   - Torsion Moment, MT = —— in. lb.
   - Shear Load, Vc = —— lb.
   - Shear Load, VL = —— lb.
2. Geometry
   - Vessel thickness, T = 3.0 in.
   - Attachment radius, r_o = —— in.
   - Vessel radius, Rm = 70.5 in.
3. Geometric Parameters
   - $\gamma = \frac{R_m}{T} = 23.5$
   - $\beta = (0.875)\frac{r_o}{R_m} =$ ——
   - Stress Concentration due to:
     - a) membrane load, Kn = ——
     - b) bending load, Kb = ——

*NOTE: Enter all force values in accordance with sign convention

From Fig.	Read curves for	Compute absolute values of stress and enter result—	Au	AL	Bu	BL	Cu	CL	Du	DL
			STRESSES — if load is opposite that shown, reverse signs shown							
3C	$\frac{N\phi}{P/R_m} = 2.8$	$K_n\left(\frac{N\phi}{P/R_m}\right)\cdot\frac{P}{R_mT} = \frac{2.8\times108}{3\times70.5}$	-1.43	-	-	-	-	-	-	-
1C	$\frac{M\phi}{P} = 0.075$	$K_b\left(\frac{M\phi}{P}\right)\cdot\frac{6P}{T^2} = \frac{0.075\times6\times108}{(3)^2}$	-5.4	+	-	+	-	+	-	+
3A	$\frac{N\phi}{M_c/R_m^2\beta} =$	$K_n\left(\frac{N\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T} =$					-	-	+	+
1A	$\frac{M\phi}{M_c/R_m\beta} =$	$K_b\left(\frac{M\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2} =$					-	+	+	-
3B	$\frac{N\phi}{M_L/R_m^2\beta} =$	$K_n\left(\frac{N\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T} =$	-	-	+	+				
1B or 1B-1	$\frac{M\phi}{M_L/R_m\beta} =$	$K_b\left(\frac{M\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2} =$	-	+	+	-				
Add algebraically for summation of φ stresses, σφ =			6.83							
4C	$\frac{N_x}{P/R_m} = 3.5$	$K_n\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_mT} = \frac{3.5\times108}{3\times70.5}$	-1.79	-	-	-	-	-	-	-
2C	$\frac{M_x}{P} = 0.066$	$K_b\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2} = \frac{0.066\times6\times108}{(3)^2}$	-4.75	+	-	+	-	+	-	+
4A	$\frac{N_x}{M_c/R_m^2\beta} =$	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T} =$					-	-	+	+
2A	$\frac{M_x}{M_c/R_m\beta} =$	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2} =$					-	+	+	-
4B	$\frac{N_x}{M_L/R_m^2\beta} =$	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T} =$	-	-	+	+				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta} =$	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2} =$	-	+	+	-				
Add algebraically for summation of X stresses, σx =			6.54							
Shear stress due to Torsion, MT		$\tau x\phi = \tau\phi x = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
Shear stress due to load, Vc		$\tau x\phi = \frac{V_c}{\pi r_o T}$	+	+	-	-				
Shear stress due to load, VL		$\tau x\phi = \frac{V_L}{\pi r_o T}$						-	+	+
Add Algebraically for summation of shear stresses, τ =										
COMBINED STRESS INTENSITY, S										
1) When σφ & σx have like signs		$S = ½\left[\sigma\phi + \sigma_x \pm \sqrt{(\sigma\phi - \sigma_x)^2 + 4\tau^2}\right]$	6.83							
2) When τ = 0		*S = largest of σφ, σx or $\lvert\sigma\phi - \sigma_x\rvert$	6.83							
3) When σφ & σx have unlike signs		$S = \sqrt{(\sigma\phi - \sigma_x)^2 + 4\tau^2}$								

$N_x/(M_L/R_m^2\beta)$ so determined by (C_L) from Table 3 (see para. 4.3).

4.2.2.5.2: When considering bending moment (M_L): $\beta = K_L\sqrt[3]{\beta_1\beta_2^2}$ where K_L is given in Table 8.

4.3 Calculation of Stresses

4.3.1 STRESSES RESULTING FROM RADIAL LOAD, P.

4.3.1.1 Circumferential Stresses (σ_ϕ):

Step 1. Using the applicable values of β and γ

Ref. 2.4

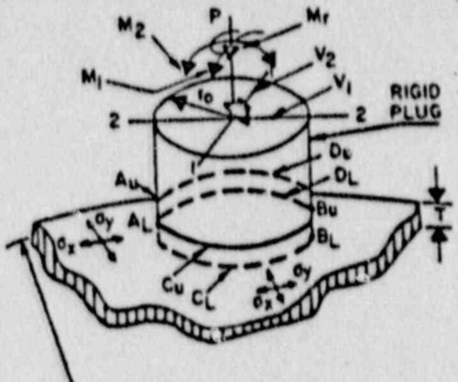
Checked by [initials] 10/21/85

WRC 107 EVALUATION FOR EDGE DROP (CASE 2)

Table 2—Computation Sheet for Local Stresses in Spherical Shells (Solid Attachment)

2.6.7.17

$$U_1 = \frac{C_1}{0.875\sqrt{R_m T}} = \frac{24}{0.875\sqrt{70.5 \times 3.0}} = 2.10$$



SPHERICAL SHELL

1. Applied Loads*
   - Radial Load, P = 100.0
   - Shear Load, V_1 = ——
   - Shear Load, V_2 = ——
   - Overturning Moment, M_1 = ——
   - Overturning Moment, M_2 = ——
   - Torsional Moment, M_T = ——
2. Geometry
   - Vessel Thickness, T = 3.0
   - Vessel Mean Radius, R_m = 70.5"
   - Attachment Outside Radius, r_o
3. Geometric Parameters
   - $U = \frac{r_o}{\sqrt{R_m T}}$ = —— = ——
   - $\sqrt{R_m T}$ = ——
   - $T\sqrt{R_m T}$ ——
4. Stress Concentration Factors due to:
   - membrane load, Kn ——
   - bending load, Kb ——

*NOTE: Enter all force values in accordance with sign convention

Reference Fig. Nos.	Read curves for	Calculate absolute values of stress and enter result :	STRESSES – if load is opposite that shown, reverse signs shown Au	AL	Bu	BL	Cu	CL	Du	DL
P. SR – 2	$\frac{N_x T}{P}$ = 0.023	$K_n \left(\frac{N_x T}{P}\right) \cdot \frac{P}{T^2}$ = $\frac{100 \times 0.023}{(3.0)^2}$	-0.26	-	-	-	-	-	-	-
P. ↓	$\frac{M_x}{P}$ = 0.0108	$K_b \left(\frac{M_x}{P}\right) \cdot \frac{6P}{T^2}$ = $\frac{0.0108 \times 6 \times 100}{(3)^2}$	-0.72	+	-	+	-	+	-	+
SR – 3	$\frac{N_x T\sqrt{R_m T}}{M_1}$	$K_n \left(\frac{N_x T\sqrt{R_m T}}{M_1}\right) \cdot \frac{M_1}{T^2\sqrt{R_m T}}$ =					-	-	+	+
	$\frac{M_x\sqrt{R_m T}}{M_1}$	$K_b \left(\frac{M_x\sqrt{R_m T}}{M_1}\right) \cdot \frac{6M_1}{T^2\sqrt{R_m T}}$ =						+	+	-
	$\frac{N_x T\sqrt{R_m T}}{M_2}$ =	$K_n \left(\frac{N_x T\sqrt{R_m T}}{M_2}\right) \cdot \frac{M_2}{T^2\sqrt{R_m T}}$ =	-	-	+	+				
↓	$\frac{M_x\sqrt{R_m T}}{M_2}$ =	$K_b \left(\frac{M_x\sqrt{R_m T}}{M_2}\right) \cdot \frac{6M_2}{T^2\sqrt{R_m T}}$ =	-	+	+					
Add algebraically for summation of radial stresses, σ_x		σ_x =	0.976							
P SR – 2	$\frac{N_y T}{P}$ = 0.007	$K_n \left(\frac{N_y T}{P}\right) \cdot \frac{P}{T^2}$ = $\frac{0.007 \times 100}{(3)^2}$	-0.078	-	-	-	-	-	-	-
P ↓	$\frac{M_y}{P}$ = 0.0033	$K_b \left(\frac{M_y}{P}\right) \cdot \frac{6P}{T^2}$ = $\frac{0.0033 \times 6 \times 100}{(3)^2}$	-0.22	+	-	+	-	+	+	+
SR – 3	$\frac{N_y T\sqrt{R_m T}}{M_1}$ =	$K_n \left(\frac{N_y T\sqrt{R_m T}}{M_1}\right) \cdot \frac{M_1}{T^2\sqrt{R_m T}}$ =					-	-	+	+
	$\frac{M_y\sqrt{R_m T}}{M_1}$ =	$K_b \left(\frac{M_y\sqrt{R_m T}}{M_1}\right) \cdot \frac{6M_1}{T^2\sqrt{R_m T}}$ =					-	+	+	-
	$\frac{N_y T\sqrt{R_m T}}{M_2}$	$K_n \left(\frac{N_y T\sqrt{R_m T}}{M_2}\right) \cdot \frac{M_2}{T^2\sqrt{R_m T}}$ =	-	-	+	+				
↓	$\frac{M_y\sqrt{R_m T}}{M_2}$	$K_b \left(\frac{M_y\sqrt{R_m T}}{M_2}\right) \cdot \frac{6M_2}{T^2\sqrt{R_m T}}$ =	-	+	+	-				
Add algebraically for summation of tangential stresses, σ_y		σ_y =	0.298							
Shear stress due to load, V_1		$\tau_1 = \frac{V_1}{\pi r_o T}$ = ——					-	-	+	+
Shear stress due to load, V_2		$\tau_2 = \frac{V_2}{\pi r_o T}$ = ——	+	+		-				
Shear stress due to Torsion, M_T		$\tau_1 = \tau_2 = \frac{M_T}{2\pi r_o^2 T}$ = ——	+	+	+	+	+	+	+	+
Add algebraically for summation of shear stresses, τ		τ								
COMBINED STRESS INTENSITY, S										
	1) When σ_x & σ_y have like signs:	$S = \frac{1}{2}\left[\sigma_x + \sigma_y + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}\right]$								
	2) When τ = 0	S = largest of σ_x, σ_y, or $\lvert\sigma_x - \sigma_y\rvert$	0.98							
	3) When σ_x & σ_y have unlike signs:	$S = \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$								

and radial bending stresses given in Figs. SR-2 and SR-3, so that the following simplified procedure for calculating maximum stresses has been developed.

3.6.1 Maximum Stress Resulting From Radial Load (P).

Step 1. Calculate the value of the applicable shell parameter (U) as given in para. 3.2.1.

Step 2. Enter Fig. SR-1 at the value of U found

Ref. 2.4

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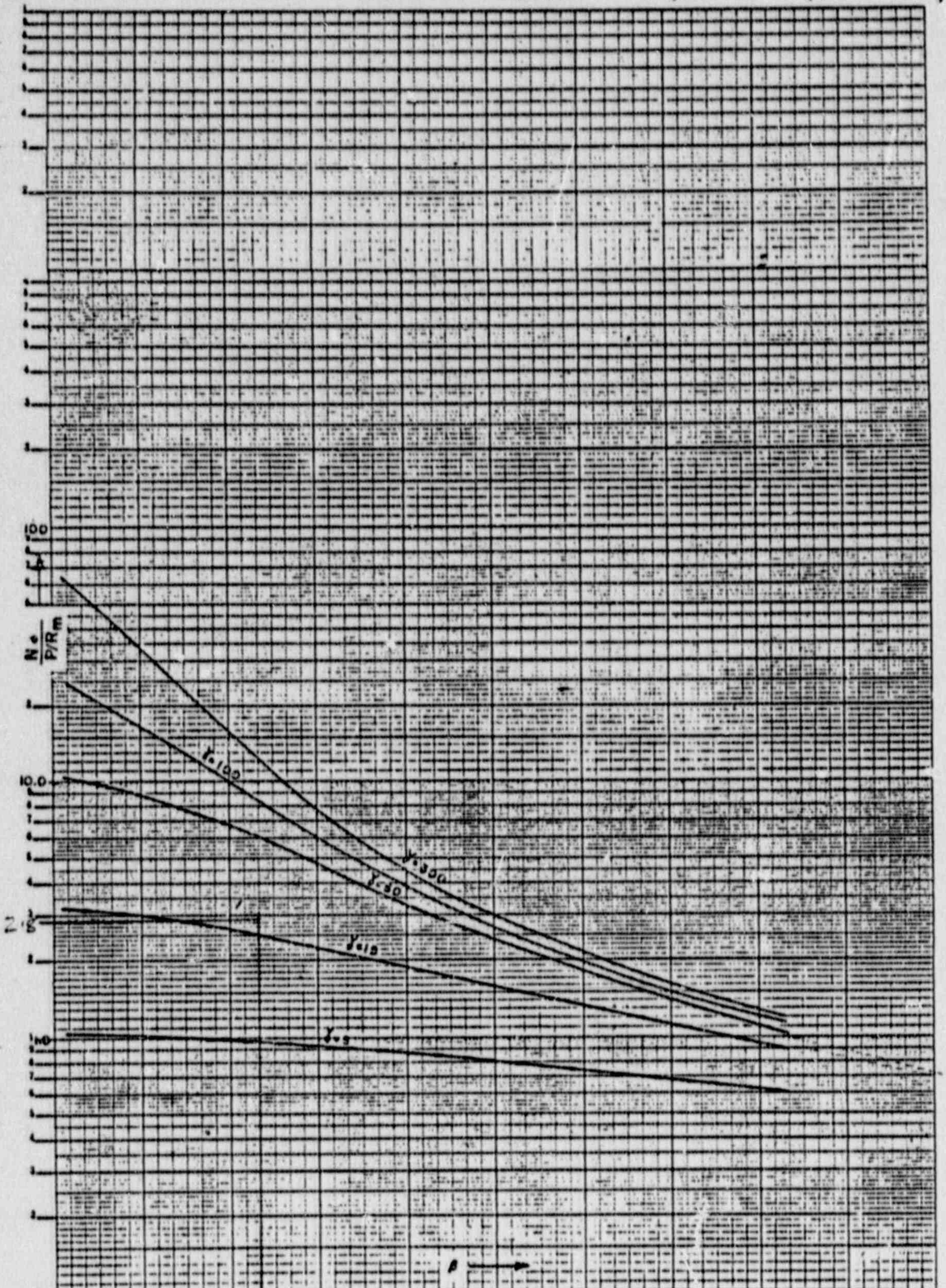
TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

For Case 1



Ref 24

Fig. 3C—Membrane force $N_\phi/(P/R_m)$ due to an external radial load P on a circular cylinder

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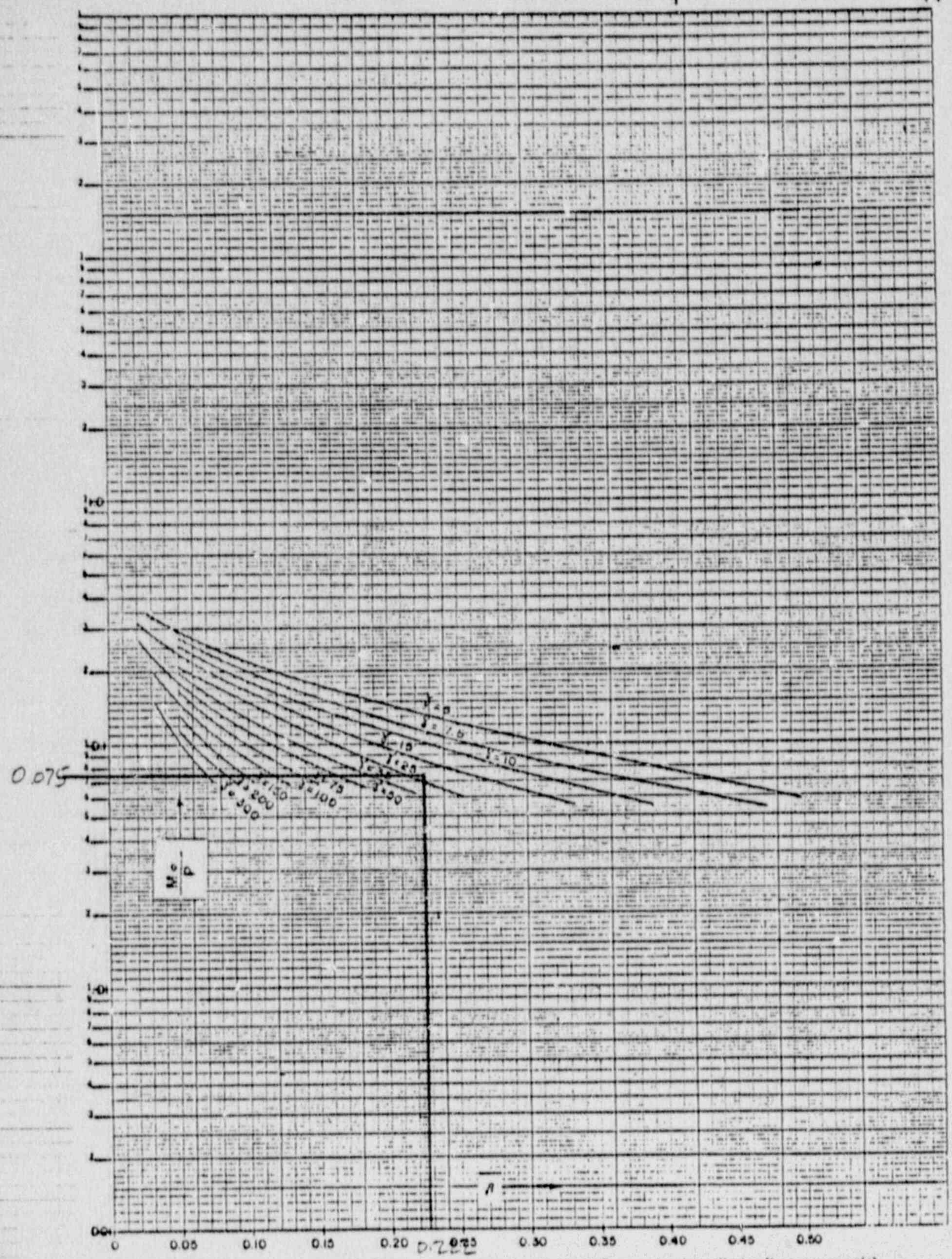
TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

For Case 1



Ref. 2.4

Fig. 1C—Bending moment M_ϕ/P due to an external radial load P on a circular cylinder (transverse axis)

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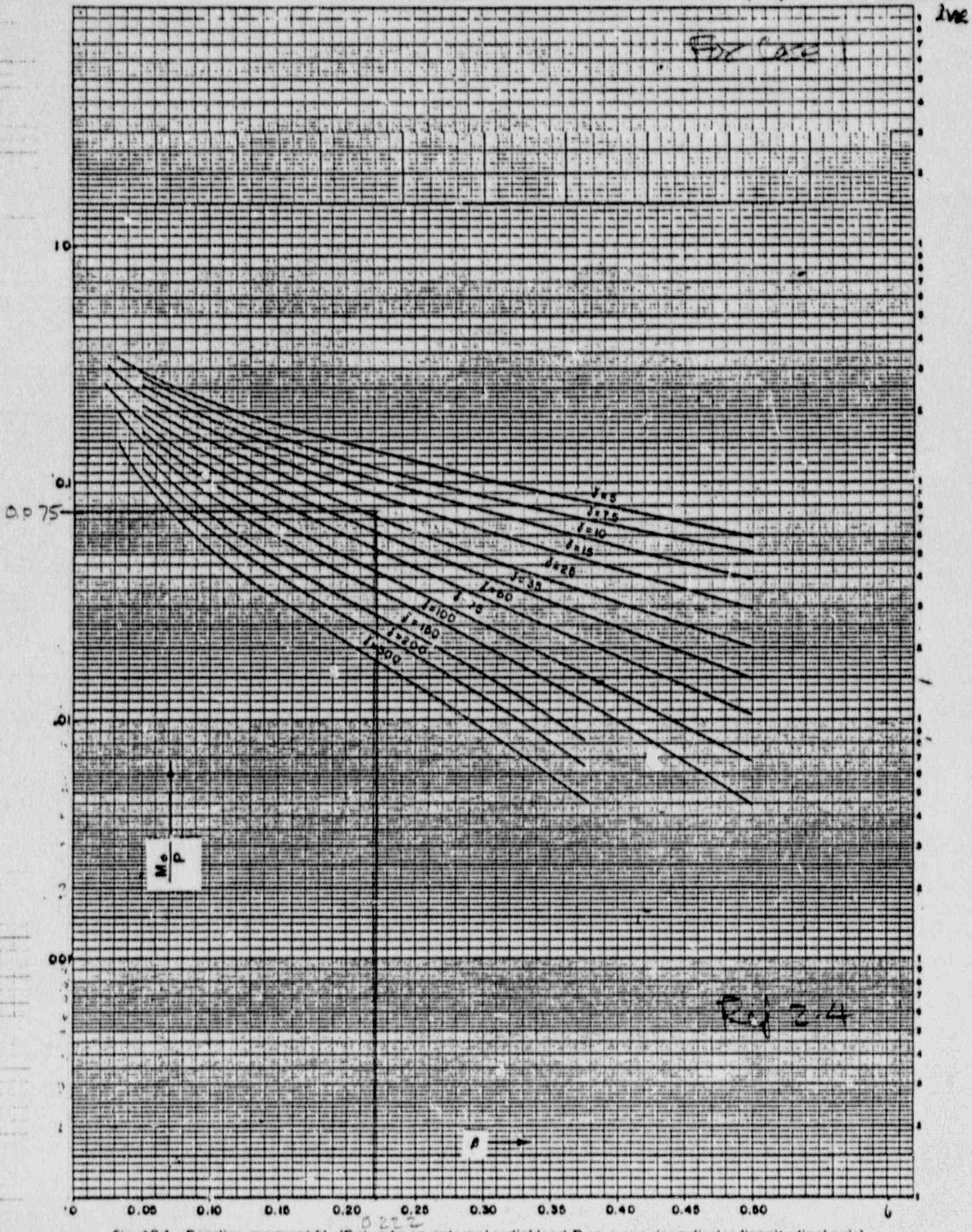

Fig. 1C-1—Bending moment M_ϕ/P due to an external radial load P on a circular cylinder (longitudinal axis)

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TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

For Case I

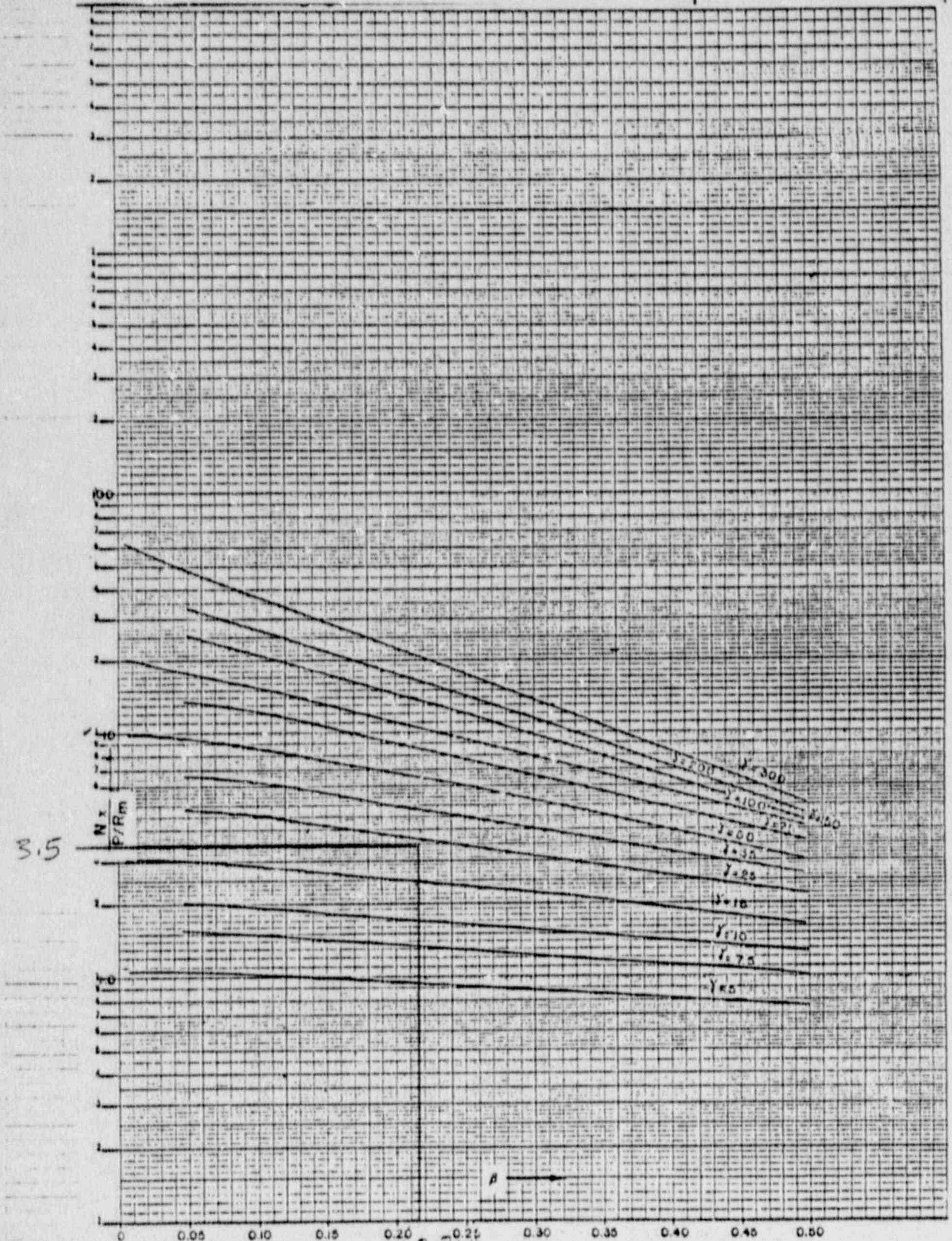

Fig. 4C—Membrane force $N_x/(P/R_m)$ due to an external radial load P on a circular cylinder

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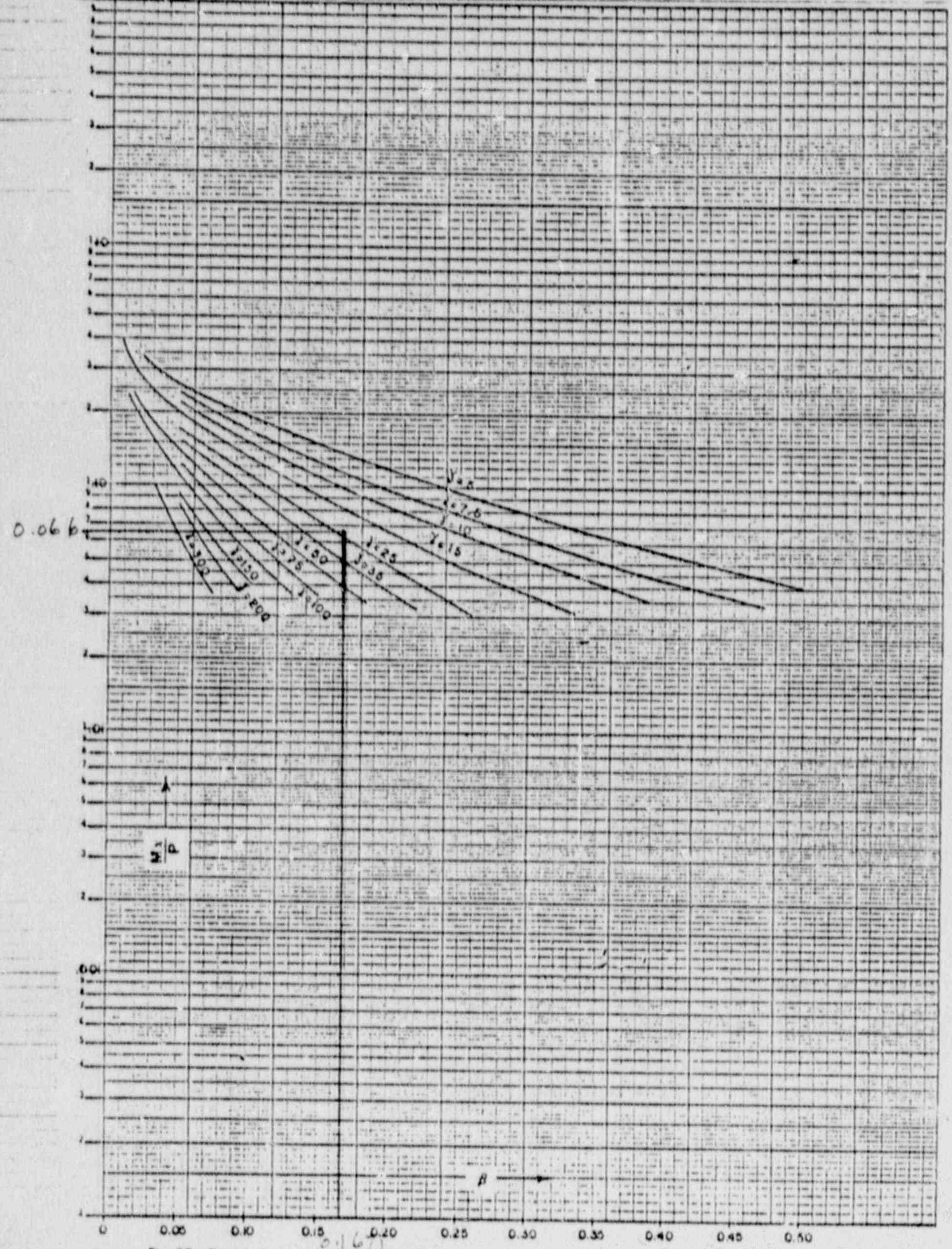

Fig. 2C—Bending moment M_x/P due to an external radial load P on a circular cylinder (transverse axis)

Ref. 2.4

tlg ENGINEERING

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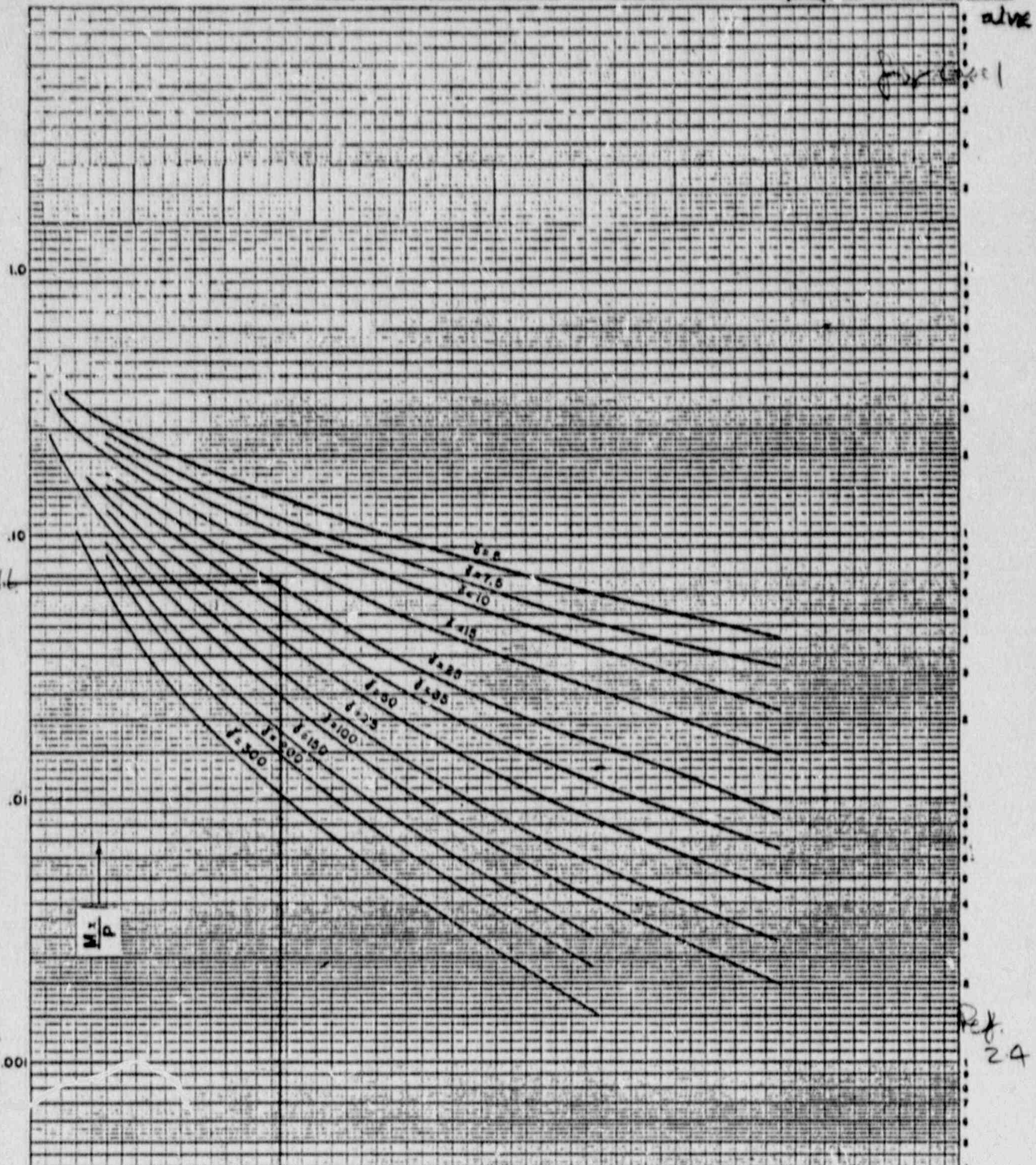

Fig. 2C-1—Bending moment M_x/P due to an external radial load P on a circular cylinder (longitudinal axis)

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TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

FOR CASE 2

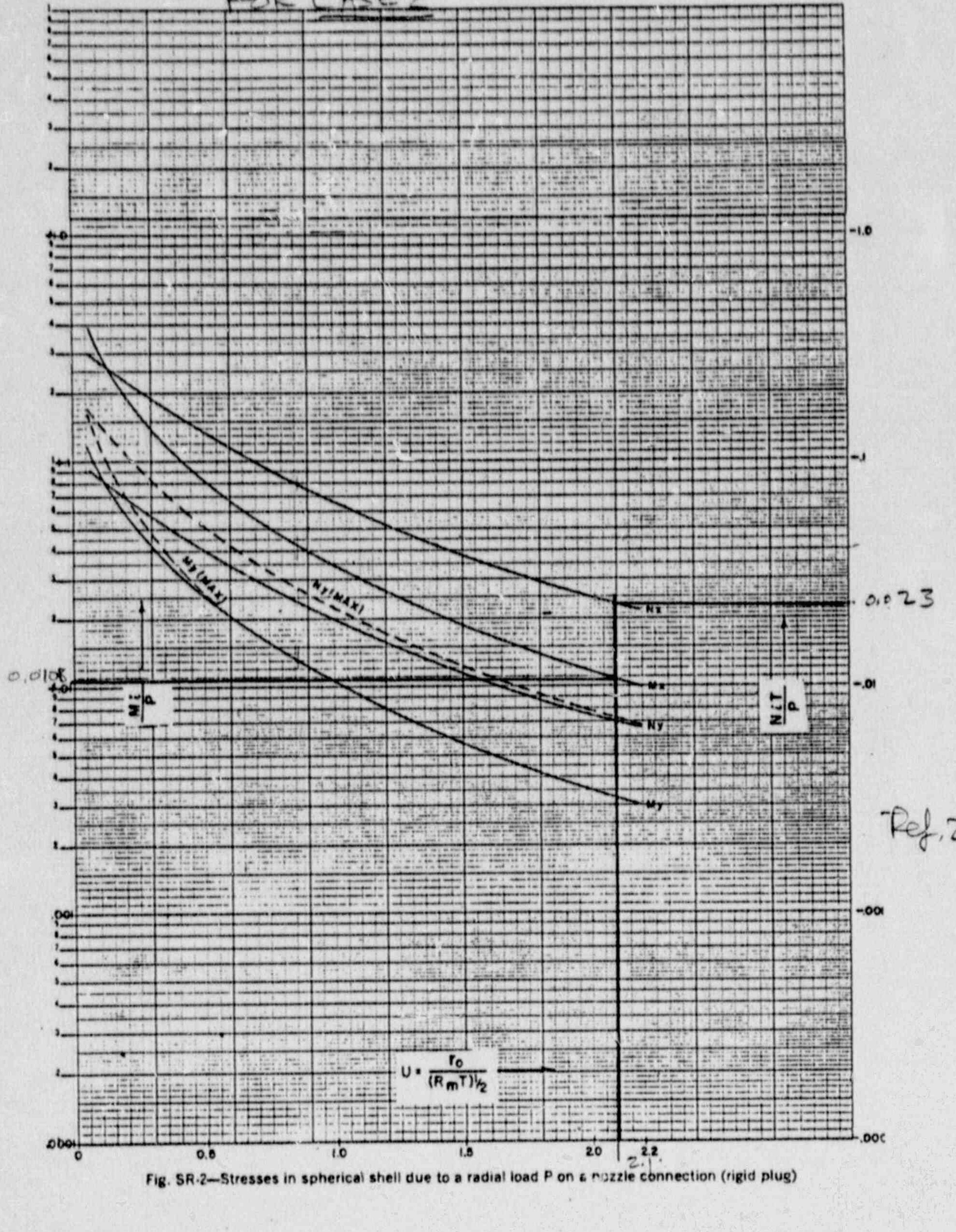

Fig. SR-2—Stresses in spherical shell due to a radial load P on a nozzle connection (rigid plug)

WRC 107 (Ref 24) Reactor Vessel Analysis as Type 'A' Shipping Container
ANALYTICAL COMPUTATIONS - INFORMATION

Local Stresses in Spherical and Cylindrical Shells due to External Loadings

T-24

1. Nomenclature

Symbols used in the formulas and equations in the text are listed below:

1.1 General Nomenclature

- σ_i = normal stress in the ith direction on the surface of the shell, psi
- = shear stress on the ith face of the jth direction
- S = stress intensity = twice maximum shear stress, psi
- N_i = membrane force per unit length in the ith direction, lb/in.
- M_i = bending moment per unit length in the ith direction, in. lb/in.
- K_n = membrane stress concentration factor (pure tension or compression)
- K_b = bending stress concentration factor
- i = denotes direction. In the case of spherical shells, this will refer to the tangential and radial directions with respect to an axis normal to the shell through the center of the attachment as shown in Fig. 1. In the case of cylindrical shells, this will refer to longitudinal and circumferential directions with respect to the axis of the cylinder as shown in Fig. 2.
- $+$ = denotes tensile stress (when associated with σ_i)
- = denotes compressive stress (when associated with σ_i)
- θ = angle around attachment, degrees (see Figs. 1 and 2)
- E = modulus of elasticity, psi
- P = concentrated radial load or total distributed radial load, lb
- V = concentrated external shear load, lb.
- M = concentrated external overturning moment, in lb
- M_T = concentrated external torsional moment, in. lb
- d_i, d_m = inside diameter and mean diameter, respectively, of the nozzle, in.
- D_i, D_m = inside diameter and mean diameter, respectively, of the shell, in.

1.2 Nomenclature Applicable to Spherical Shells

- V_1 = concentrated external shear load in 2-2 direction, lb
- V_2 = concentrated external shear load in 1-1 direction, lb
- M_1 = external overturning moment in 1-1 direction, in. lb
- M_2 = external overturning moment in 2-2 direction, in. lb
- R_m = mean radius of spherical shell, in.
- T = thickness of spherical shell, in.
- r_0 = outside radius of cylindrical attachment, in.
- r_m = mean radius of hollow cylindrical attachment, in.
- t = thickness of hollow cylindrical attachment, in.
- τ = r_m/t
- ρ = T/t
- U = $r_0/\sqrt{R_m T}$
- N_x, N_y = membrane force in shell wall in radial and circumferential directions, respectively, lb/in. (see Fig. 1)
- M_x, M_y = bending moment in shell wall in radial and circumferential directions, respectively, in. lb/in. (see Fig. 1)
- σ_x = normal stress in radial direction, psi (see Fig. 1)
- σ_y = normal stress in circumferential direction, psi (see Fig. 1)

K. R. WICHMAN is with the Navy Dept., Bureau of Ships, Washington, D. C. A. G. HOPPER is with All States Design and Development Co., Inc., Pittsburgh, Pa. J. L. MERSHON is with the Atomic Energy Commission, Washington, D. C.

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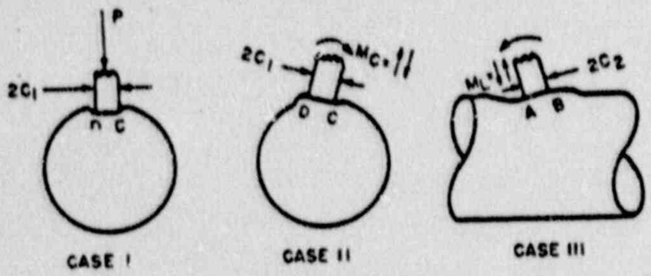
4. Cylindrical Shells

4.1 Sign Convention

Stresses will be considered in the shell at the attachment-to-shell juncture in both the circumferential and longitudinal directions as shown in Fig. 2. A knowledge of the shell deflections resulting from various modes of loading permits one to predict whether resulting stresses will be tensile (+) or compressive (−).



Consider Case I showing a direct radial inward load, P. Here P acts similar to a local external pressure on the shell causing compressive membrane stresses. Furthermore, local bending occurs so that tensile bending stresses result on the inside of the vessel at C and D while compressive bending stresses result on the outside.

In Cases II and III, the applied moments are considered to act as couples composed of equal and opposite radial forces. Hence, tensile membrane stresses result at B and D while compressive membrane stresses result at A and C. As in Case I

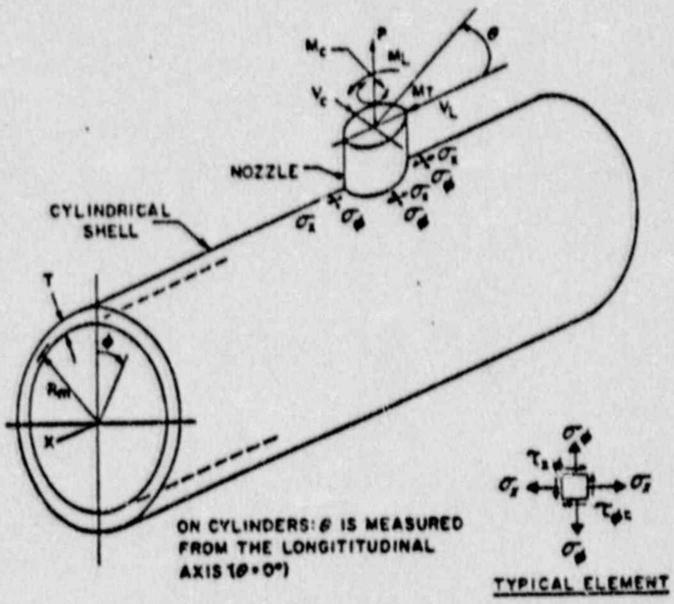


Fig. 2—Types of loading conditions at an attachment to a cylindrical shell

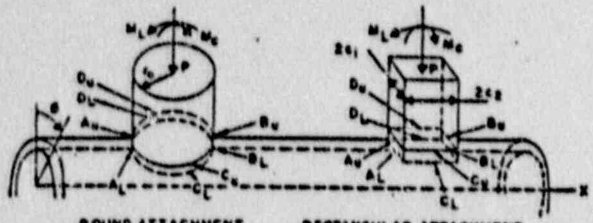
$$\left(\frac{\sigma_x T^2\sqrt{R_m T}}{M}\right)\left(\frac{M}{T^2\sqrt{R_m T}}\right)\Big]$$

In using this formula, the sign conventions established in Table 1 should be used.

Ref. 2.4

Ref. 2.7

Table 4—Sign Convention for Stresses Resulting from Radial and Moment Loading on a Cylindrical Shell



STRESS	LOCATION	LOADING P	LOADING M_c	LOADING M_L
[illegible]	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	

NOTE: [illegible]

tensile bending stresses result at A and C on the inside of the vessel, and B and D on the outside of the vessel. Similarly, compressive bending stresses result at A and C on the outside and B and D on the inside.

In this manner Table 4 has been developed to show the signs of stresses resulting from various external loading conditions. These stresses are located in the vessel wall at its juncture with the attachment. Use of Table 4 permits one to use the nondimensional curves presented in the following procedure with a minimum of encumbency and concern for sign convention.

The numerous stress components can be readily accounted for if a scheme similar to that shown in Table 5 is adopted. In using this scheme it is to be noted that the Maximum Shear Theory has been used to determine equivalent stress intensities. Also it is to be noted that evaluation of stresses resulting from internal pressure has been omitted.

Test work conducted by PVRC has shown that stresses attenuate rapidly at points removed from the attachment-to-shell juncture, the maximum stress usually being located at the juncture. However, in the general case of arbitrary loading, one has no assurance that the absolute maximum stress intensity will be located at one of the eight points considered in the above discussion. The maximum stress intensity could be located at some intermediate point around the juncture under an arbitrary load, or under a longitudinal moment with the circumstances outlined in para. 4.4 and Appendix A.

4.2 Parameters

The results of Bijlaard's work have been plotted in terms of nondimensional geometric parameters by use of an electronic computer. Hence, the first step in this procedure is to evaluate the applicable geometric parameters γ and β.

4.2.1 SHELL PARAMETER (γ). The shell parameter is given by the ratio of the shell mid-radius to shell thickness thus:

$$\gamma = R_m/T$$

4.2.2 ATTACHMENT PARAMETER (β). For cylindrical shells, either round or rectangular attachments may be considered in the following manner:

4.2.2.1 Round Attachment: For a round attachment the parameter β is evaluated using the expression:

$$\beta = \frac{0.875\, r_o}{R_m}$$

4.2.2.2 Square Attachment: For a square attachment the parameter is evaluated by:

$$\beta = \beta_1 = \beta_2 = \frac{c_1}{R_m} = \frac{c_2}{R_m}$$

4.2.2.3 Rectangular Attachment Subject to Radial Load (P): For this case β is evaluated as follows:

$$\beta_1 = \frac{c_1}{R_m} \qquad \beta_2 = \frac{c_2}{R_m}$$

If $\frac{\beta_1}{\beta_2} > 1$, $\beta =$

$$\left[1 - \frac{1}{3}\left(\frac{\beta_1}{\beta_2} - 1\right)\left(1 - K_1\right)\right]\sqrt{\beta_1 \beta_2}$$

If $\frac{\beta_1}{\beta_2} < 1$, $\beta =$

$$\left[1 - \frac{4}{3}\left(1 - \frac{\beta_1}{\beta_2}\right)\left(1 - K_2\right)\right]\sqrt{\beta_1 \beta_2}$$

where K values are obtained from Table 6.

4.2.2.4 Rectangular Attachment Subject to Circumferential Moment (M_c).

4.2.2.4.1: When considering membrane forces (N_i): $\beta = \sqrt[3]{\beta_1^2\ \beta_2}$. Then multiply values of $N_i/(M_c/R_m^2\beta)$ so determined by C_c from Table 7 (see para. 4.3).

4.2.2.4.2: When considering bending moment (M_i): $\beta = K_c\sqrt[3]{\beta_1^2\beta_2}$ where K_c is given in Table 7.

4.2.2.5 Rectangular Attachment Subject to Longitudinal Moment (M_L).

4.2.2.5.1: When considering membrane forces (N_i): $\beta = \sqrt[3]{\beta_1\ \beta_2^2}$. Then multiply values of

Ref. 2.4

Table 6—Radial Load (P)

	N_ϕ	N_x	M_ϕ	M_x
K_n	0.91	1.68	1.76	1.2
K_b	1.48	1.2	0.88	1.25

NOTE: Above holds approximately within limits $4 \geq \beta_1/\beta_2 \geq 1/4$.

calculated in para. 4.2, enter Fig. 3C and read off the dimensionless membrane force $[N_\phi/P/R_m]$.

Step 2. By the same procedure used in Step 1, enter Fig. 1C or 1C-1 and find the dimensionless bending moment $[M_\phi/P]$.

Step 3. Using applicable values of P, R_m, and T, find the circumferential membrane stress (N_ϕ/T) by:

$$\frac{N_\phi}{T} = \left[\frac{N_\phi}{P/R_m}\right] \cdot \left[\frac{P}{R_m T}\right]$$

Step 4. By a procedure similar to that used in Step 3, find the circumferential bending stress $(6M_\phi/T^2)$ thus:

$$\frac{6M_\phi}{T^2} = \left[\frac{M_\phi}{P}\right] \cdot \left[\frac{6P}{T^2}\right]$$

Step 5. Combine the circumferential membrane and bending stresses by use of the general stress equation (Section 2), together with the proper choice of sign (Table 4); i.e.:

$$\sigma_\phi = K_n \frac{N_\phi}{T} \pm K_b \frac{6M_\phi}{T^2}$$

4.3.1.2 Longitudinal Stresses (σ_x): Follow the 5 steps outlined in 4.3.1.1 except that $[N_x/P/R_m]$ is obtained using Fig. 4C; and $[M_x/P]$, using Fig. 2C or 2C-1. It follows that:

$$\frac{N_x}{T} = \left[\frac{N_x}{P/R_m}\right] \cdot \left[\frac{P}{R_m T}\right],$$

$$\frac{6M_x}{T^2} = \left[\frac{M_x}{P}\right] \cdot \left[\frac{6P}{T^2}\right] \text{ and}$$

$$\sigma_x = K_n \frac{N_x}{T} \pm K_b \frac{6M_x}{T^2}$$

4.3.2 STRESSES RESULTING FROM CIRCUMFERENTIAL MOMENT, M_c.

4.3.2.1 Circumferential Stresses (σ_ϕ):

Step 1. Using the applicable values of β and γ calculated in para. 4.2, enter Fig. 3A and read off the dimensionless membrane force $N_\phi/(M_c/R_m^2\beta)$.

Step 2. By the same procedure used in Step 1, enter Fig. 1A and find the dimensionless bending moment $M_\phi/(M_c/R_m\beta)$.

Step 3. Using applicable values of M_c, R_m, β

Table 7—Circumferential Moment (M_c)

β_1/β_2	γ	K_c for θ	K_c for M_ϕ	K_c for M_x	C_c for N_ϕ	C_c for M_x
1/4	15	1.09	1.31	1.84	0.31	0.49
	50	1.04	1.24	1.62	0.21	0.46
	100	0.97	1.16	1.45	0.15	0.44
	300	0.92	1.02	1.17	0.09	0.46
1/2	15	1.00	1.09	1.36	0.64	0.75
	50	0.98	1.08	1.31	0.57	0.75
	100	0.94	1.04	1.26	0.51	0.76
	300	0.95	0.99	1.13	0.39	0.77
2	15	(1.00)	(1.20)	(0.97)	(1.7)	(1.3)
	100	1.19	1.10	0.95	1.43	1.12
	300	...	(1.00)	(0.90)	(1.3)	(1.00)
4	15	(1.00)	(1.47)	(1.08)	(1.75)	(1.31)
	100	1.49	1.38	1.06	1.49	0.81
	300	...	(1.27)	(0.98)	(1.36)	(0.74)

NOTE: The values in parenthesis determined by an approximate solution.

Table 8—Longitudinal Moment (M_L)

β_1/β_2	γ	K_L for θ	K_L for M_ϕ	K_L for M_x	C_L for N_ϕ	C_L for N_x
1/4	15	1.14	1.80	1.24	0.75	0.43
	50	1.13	1.65	1.16	0.77	0.33
	100	1.18	1.59	1.11	0.80	0.24
	300	1.31	1.56	1.11	0.90	0.07
1/2	15	(1.00)	(1.08)	(1.04)	(0.90)	(0.76)
	100	1.00	1.07	1.02	0.97	0.68
	300	(1.00)	(1.05)	(1.02)	(1.10)	(0.60)
2	15	...	(0.94)	(1.12)	(0.87)	(1.30)
	100	1.09	0.89	1.07	0.81	1.15
	300	...	(0.79)	(0.90)	(0.80)	(1.50)
4	15	1.39	0.90	1.24	0.68	1.20
	100	1.18	0.81	1.12	0.51	1.03
	300	...	(0.64)	(0.83)	(0.50)	(1.33)

NOTE: The values in parenthesis determined by an approximate solution.

Ref. 2.4

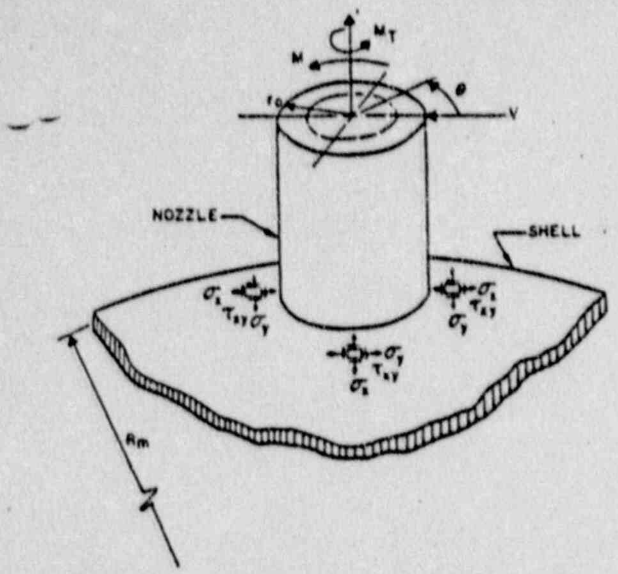


Fig. 1—Types of loading conditions at an attachment to a spherical shell

In Case II, the overturning moment may be considered to act as a couple composed of equal and opposite radial forces. Hence, tensile membrane stresses result at A while compressive membrane stresses result at B. As in Case I, local bending also occurs so that tensile bending stresses develop at A on the outside of the vessel and at B on the inside, while compressive bending stresses develop at A on the inside and B on the outside.

In this manner, the signs (tensile +, compressive −) of stresses resulting from various external loading conditions may be predicted. It is to be noted that these stresses are located in the vessel wall at its juncture with the attachment.

Table 1 shows the signs of stresses resulting from radial load and overturning moment. This table will facilitate the use of the nondimensional curves (presented in the following procedure) and minimize concern for the signs of the calculated stresses.

3.2 Parameters

The results of Bijlaard's work have been plotted in terms of nondimensional geometric parameters by use of an electronic computer. Hence, the first step in this procedure is to evaluate the applicable geometric parameters.

3.2.1 SHELL PARAMETER (U). The shell parameter is given by the ratio of the nozzle outside radius to the square root of the product of shell radius and thickness, thus:

$$U = \frac{r_o}{\sqrt{R_m T}}$$

If a square attachment is to be considered, U may be approximated as follows:

$$U = \frac{c_1}{0.875\sqrt{R_m T}}$$

3.2.2 ATTACHMENT PARAMETERS. For spherical shells, either round or square attachments may be considered.

3.2.2.1 Rigid Attachments: In the case of a rigid attachment, no attachment parameter is required to use the nondimensional curves.

3.2.2.2 Nozzles: For a hollow cylindrical attachment such as a nozzle, the following parameters must be evaluated:

$$T = \frac{r_m}{t}$$

$$\rho = \frac{T}{t}$$

3.2.2.3 Hollow Square Attachment: If a hollow square attachment such as a box beam is to be considered, the required parameters may be approximated as follows:

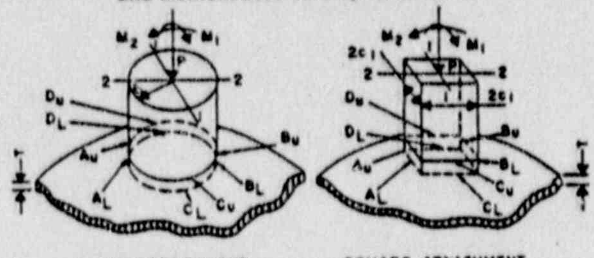
$$T = \frac{r_m}{0.875t}$$

$$\rho = \frac{T}{t}$$

3.3 Calculation of Stresses

3.3.1 STRESSES RESULTING FROM RADIAL LOAD, P

Table 1—Sign Convention for Stresses Resulting from Radial and Moment Load on a Spherical Shell



STRESS	LOCATION	LOADING P	LOADING M_1	LOADING M_2
Membrane $\frac{N_x}{T}$ & $\frac{N_y}{T}$	Au AL Bu BL	[illegible]		[illegible]
	Cu CL Du DL	[illegible]	[illegible]	
Bending $\frac{6M_x}{T^2}$	Au AL Bu BL	[illegible]		[illegible]
	Cu CL Du DL	[illegible]	[illegible]	
Bending $\frac{6M_y}{T^2}$	Au AL Bu BL	[illegible]		[illegible]
	Cu CL Du DL	[illegible]	[illegible]	

NOTE: 1) Sign convention for stresses: + tension, − compression.
2) If load P reverses, all signs in column P reverse.
3) If overturning moment M_i reverses, all signs in column M_i reverse.
4) For round attachment, overturning moments M_1 and M_2 may be combined vectorially, thus
$M = \sqrt{M_1^2 + M_2^2}$

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Reactor Vessel Analysis - Type A Shipping Container.

HEXCEL CORE DESIGN - ADDITIONAL INFORMATION FROM HEXCEL CATALOG

Refs. 2.2, 2.7

SYMBOLS

A	In^2	Impact Area
a	Ft/sec^2	Acceleration or Deceleration Rate
F	Lbs.	Impact Force
f_{cr}	PSI	Honeycomb Crush Strength
G	Dimensionless	Ratio a/g
g	Ft/sec^2	Acceleration due to Gravity
KE	In.-lb.	Kinetic Energy
m	Slugs	Mass
S	In.	Stopping or Falling Distance
t_c	In.	Honeycomb Core Thickness
t	Sec.	Time
v_0	Ft./Sec.	Initial Velocity
v_f	Ft/sec.	Final Velocity
v	Ft/sec.	Impact Velocity—Often equal to v_f
W	Lbs.	Impact Weight
ρ_c	$Lbs./Ft^3$	Honeycomb Core Density

BY I. Husain DATE 8/16/89 SECTION 2.6.7-31
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Reactor Vessel Analysis - Type A Shipping Container.

FORMULAS

Ref. 2.2, 2.7

The following formulas are those commonly encountered in simple energy absorption calculations.[1]

General: [2]

1. Kinetic Energy, $KE = \frac{1}{2} mv^2$
2. Mass, $m = W/g$
3. Dynamic Force, $F = ma$
4. $G = a/g$
5. Velocity, $v_f^2 = v_0^2 + 2aS$
6. Distance travelled, $S = v_0 t + \frac{1}{2} at^2$

Honeycomb Energy Absorption:

7. **Stopping Distance, S.** From 5. above for v_f equal to impact velocity and v_0 equal to zero,

$$v^2 = 2aS$$

and from 4. above, $a = Gg$. Therefore: $S = \frac{v^2}{2gG}$

8. **Minimum core thickness, t_c.** Assuming 70% of the total honeycomb thickness is available for crushing, then $S = 0.7t_c$ and therefore, from 7.

$$t_c = \frac{1}{0.7} \frac{v^2}{2gG}$$

This formula has been presented graphically on Page 3 of this bulletin.

9. **Crush strength, f_{cr}.** Since $f_{cr} = F/A$ and from 3. above:

$$F = ma = \frac{Wa}{g} = WG$$

$$\text{then } f_{cr} = \frac{WG}{A}$$

This formula has been presented graphically on Page 4 of this bulletin.

It can be shown that:

$$KE = f_{cr} AS$$

from 1. above

$$KE = \frac{1}{2} mv^2 = \frac{wv^2}{2g} = \frac{WGS}{2g} = WGS = FS = f_{cr} AS$$

Setting S equal to $0.7t_c$ and solving for t_c will produce the final check equation presented on Page 3.

1. Formulas based on acceleration being a constant
2. $g = 32.2$ ft/sec^2 for earth environment only

TLG ENGINEERING

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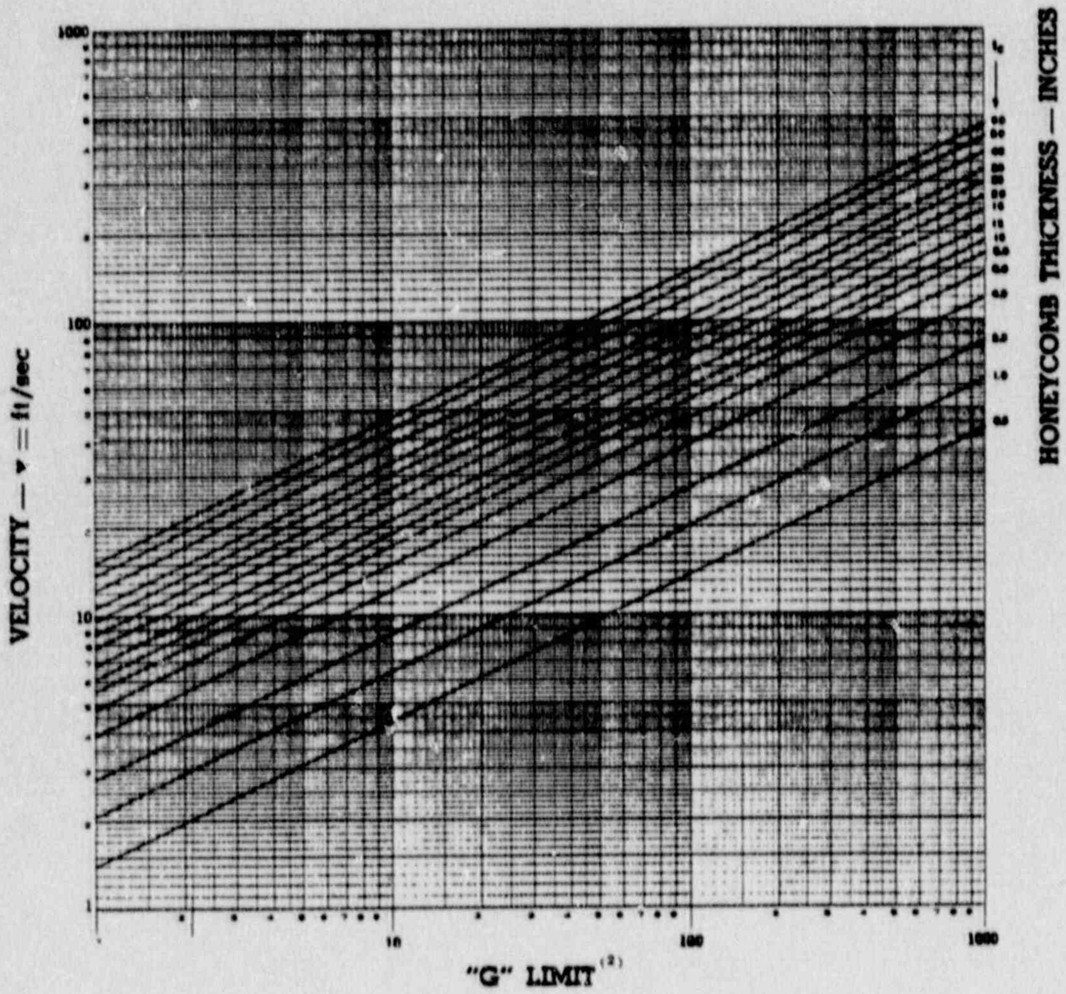
Reactor Vessel Analysis - Type A Shipping Container.

Ref. 2.2.2.7

PRELIMINARY SOLUTION

FOR

MINIMUM HONEYCOMB THICKNESS (1)



USE OF THIS CHART

GIVEN:

Impact velocity . . . v

G Limit . . . . . . G

(1) This solution takes into consideration the fact that only 70% of the honeycomb material is available for crushing.

(2) See Page 12 for the solution to problems in which G is not a design consideration.

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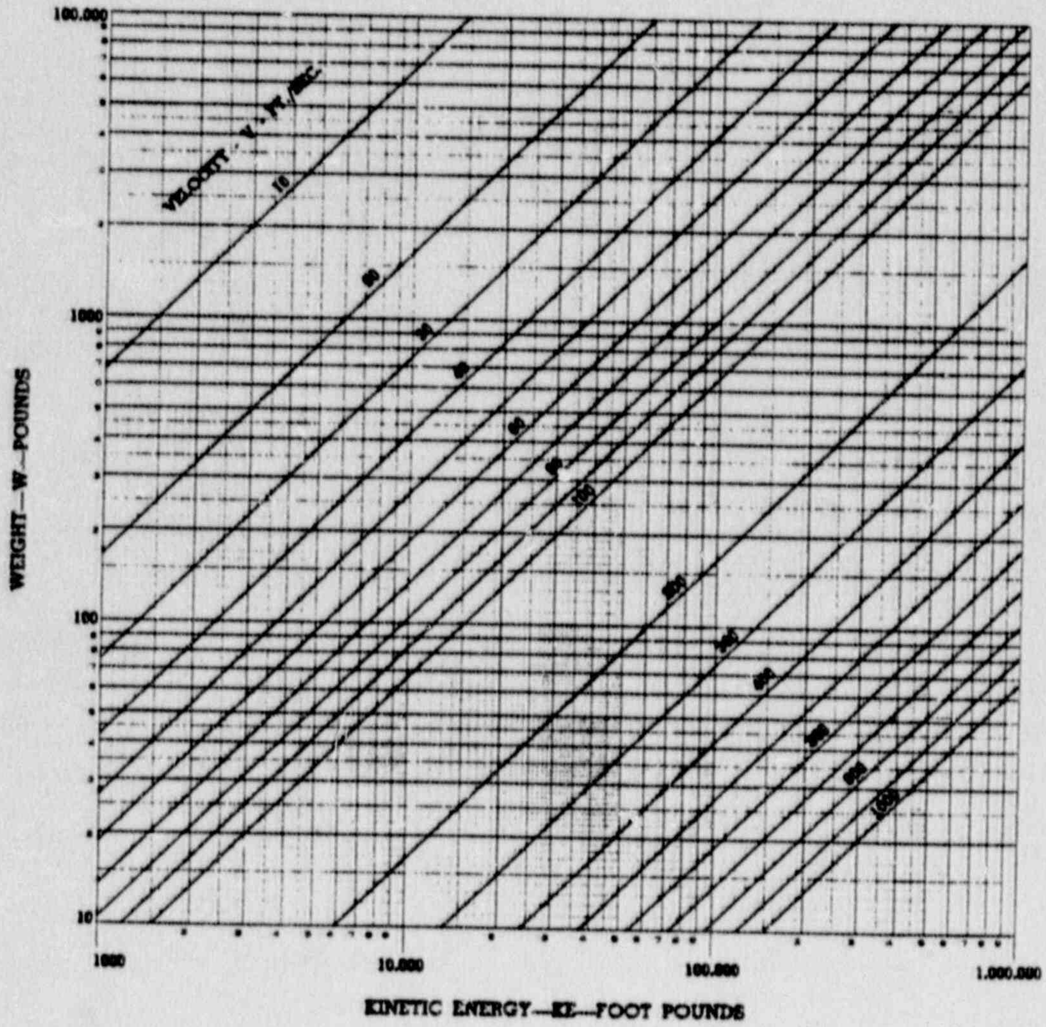
KINETIC ENERGY EQUATION SOLUTION

Ref. 2.7.2.7

This chart offers a rapid solution to the equation[1]:

$$KE = \frac{1}{2} mv^2 = \frac{1}{2} \frac{Wv^2}{g}$$



BY I. Husain DATE 8/17/89 SECTION 2.6.7-34
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KINETIC ENERGY ABSORPTION

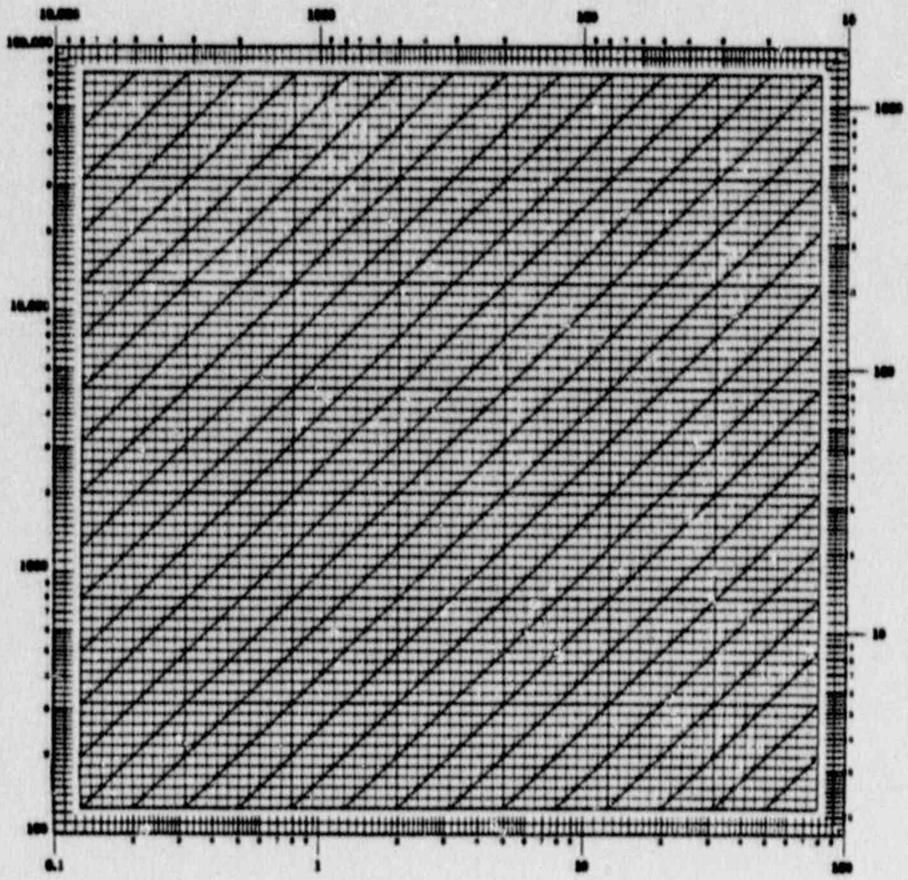
This chart offers a solution to energy absorption problems in which **no limiting G value is required** (i.e. stop a payload in a specific distance with no rebound · · · G not critical). The chart graphically solves the equation:

Ref. 2.7

$$KE = f_{cr}\ AS = f_{cr}\ A\ 0.7t_c$$

USE OF THIS CHART

1. Enter the chart with the known value of KE in foot-pounds and total core thickness t_c in inches. The intersection of the coordinates KE and t_c defines a diagonal line.
2. Move along this diagonal to the intersection of the horizontal line representing the impact area A being considered.
3. At this point on the diagonal, move vertically upward on the chart and read the crush strength f_{cr} required.



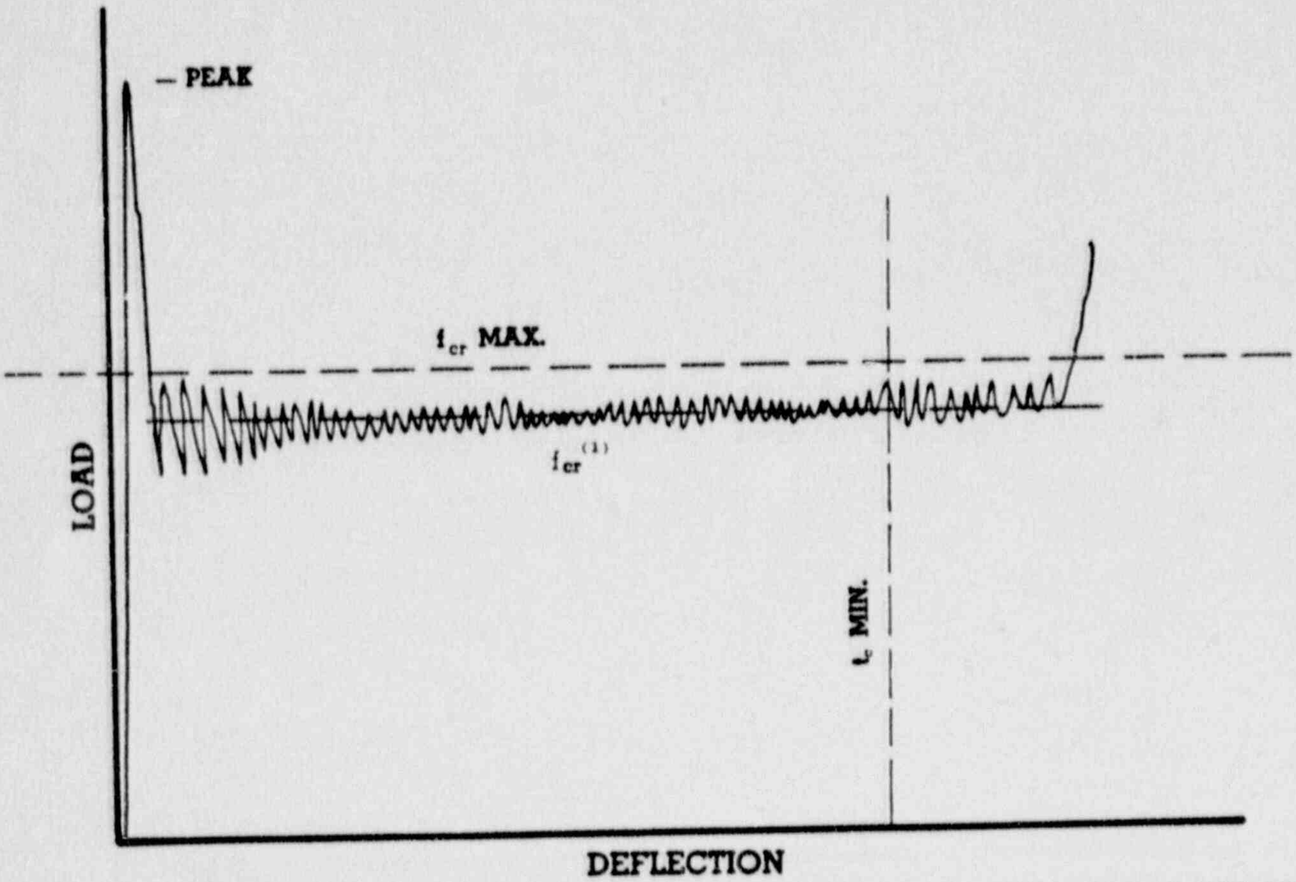
LOAD AND DEFLECTION

The load and deflection characteristics encountered in statically crushing honeycomb are graphically shown in the figure below. This curve indicates the value of the resistance to loading offered by the honeycomb as the compressive load is overcome and crushing starts and continues. Three items on this curve are of special interest:

A. COMPRESSIVE PEAK — Honeycomb systems which are not precrushed or in which the initial contact area has not been reduced exhibit this peak force level at impact. This undesirable peak can be easily eliminated by proper design. Ref. 2.7

B. MAXIMUM CRUSH LEVEL — A horizontal line has been drawn across this curve representing a maximum crush level. If this hypothetical line had been developed as a design maximum, then the actual honeycomb f_{cr} value must remain equal to or below this level for crushing to take place.

C. MINIMUM STOPPING DISTANCE — The vertical line drawn down this graph represents a hypothetical stopping distance minimum established in conjunction with the maximum crush level value. This value represents a minimum value for the maximum crush level line and any crush level selected below the maximum limit will require an increase in this minimum thickness.



(1) The actual crush strength of honeycomb is normally given as the average value of the load diagram inflections.

2.10.9 References

2.1 DeSalvo, G.J. and Stevenson, J.A., "ANSYS Engineering Analysis System User's Manual", Swanson Analysis System, Inc.,Houston,PA, Revision 4.4, March 1989

2.2 Technical Bulletin TSB120, "Mechanical Properties ofHexcel Honeycomb Materials", 1988, Hexcel, Dublin, CA

2.3 "ASME Boiler and Pressure Vessel Code", Section III, Division 1, 1983 Edition, and Addenda through 1985.

2.4 Welding Research Council Bulletin No. 107, August 1985, "Local Stresses in Spherical and Cylindrical Shells Due to External Laodings:, by K.R. Wichman, et.al.

2.5 NUREG/CR-1815 UCRL-53013, RT "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick".

2.6 Topical Report - "Design of Structures for Missile Impact", BC-TOP-9A Revision 2, Bechtel Power Corporation, San Francisco, CA, September 1974

2.7 Technical Bulletin TSB122, "Design Data for the Preliminary Selection of Honeycomb Energy Absorbtion systems", 1989, Hexcel, Dublin, CA

2.8 "Pathfinder Atomic Power Plant - Reactor Vessel Materials, Fabrication and Inspection", ACNP-62025, Allis-Chalmers Corporation December 1, 1962

2.9 "ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB

APPENDIX 2.10.6-A

Brittle Fracture Analysis

I OBJECTIVE: TO PERFORM BRITTLE FRACTURE EVALUATION

II METHOD OF APPROACH

Brittle fracture evaluation will be performed using the procedure described in NUREG/CR-1815 UCRL-53013, RT. "Recommendation for Protecting Against Failure by Brittle Fracture in Ferritic Steel shipping containers up to four inches Thick"

NOMENCLATURE

Ref. 2.5

A	Temperature relative to NDT; $A = LST - T_{NDT}$
AAR	Association of American Railroads
AWS	American Welding Society
B	Section thickness
β	A dimensionless parameter $= \frac{1}{B}\left(\frac{K_{ID}}{\sigma_{yd}}\right)^2$
COD	Crack Opening Displacement
CVN, C_V	Charpy V-notch test or the test results
DWTT	Drop Weight Tear Test
DT	Dynamic Tear test or the test results
HAZ	Heat affected zone of welds
K_I	Stress intensity factor
K_{IC}	Critical value of K_I for static loading rates. When K_{IC} is exceeded, fracture occurs.
K_{ID}	Critical value of K_I for dynamic loading rates
$K_{I(t)}$	Critical value of K_I for intermediate loading rates.
LST	Lowest service temperature (lowest metal temperature)
(L)	Limit of plane strain
NDT	Nil Ductility Transition
Q&T	Quenched and Tempered
σ	Nominal stress (see glossary)
σ_{ys}	Yield strength for a static loading rate. This is considered the ASTM minimum yield for a specific steel.
σ_{yd}	Yield strength for dynamic loading rate $= \sigma_{ys} + 30$ ksi for steels with $\sigma_{ys} \leq 60$ ksi $= \sigma_{ys} + 15$ ksi for steels with $\sigma_{ys} \geq 70$ ksi $= \sigma_{ys} + 20$ ksi for steels with 60 ksi $< \sigma_{ys} <$ 70 ksi
T_{NDT}	Nil Ductility Transition (NDT) temperature
(YC)	Yield Criterion; the level of toughness required to provide fracture arrest at a nominal stress equal to the yield strength.

.tlg ENGINEERING

BY I. Husain DATE 9/6/89 SECTION 2.3.4-2

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Reactor Vessel Analysis - Type A Shipping Container.

As per NUREG/CR-1815, the Pathfinder Reactor Vessel will be evaluated to meet the fracture toughness requirements & qualification procedures associated with Category III and Category II

Ref. 25

Category	Category I		Category II		Category III	
Required degree of safety (see Appendix C)	Very large margin of safety.		Large margin of safety.		Adequate margin of safety.	
Required amount of fracture toughness (see Sec. 5).	Sufficient to arrest large cracks under dynamic loading; general yielding will precede fracture.		Sufficient to prevent fracture initiation of pre-existing cracks under dynamic loading.		Sufficient to prevent fracture initiation at minor defects typical of good fabrication practice.	
	Thickness (B) (in.)	Criteria for meeting toughness requirements[a]	Thickness (B) (in.)	Criteria for meeting toughness requirements[a]	Thickness (B) (in.)	Criteria for meeting toughness requirements
	4.0 ↕ 0.625	*NDT temperature[b] must be less than a maximum value. See Fig. 3 and Secs. 5.1.1, 5.1.2. And, if $\sigma_{ys} \geq 70$ ksi, either: *5/8 in. thick DT[d] must be greater than 400 ft-lb at upper shelf temperatures. See Sec. 5.1.1. or *C_V[e] must be greater than 45 ft-lb at upper shelf temperatures. See Sec. 5.1.1.	4.0 ↕ 0.625	*With full dynamic loading, NDT temperature[c] must be less than a maximum value. See Fig. 6 and Sec. 5.2.1. Or *With reduced loading rates, NDT temperature can be determined from Fig. 7. See Sec. 5.2.2.	4.0 ↕ 0.4	*Without testing, use normalized steel made to "Fine Grain Practice" or better. Or show that: *NDT[c] ≤ 10°F (for B ≥ 0.625 in.) Or test to show that: *DT[d] ≥ 50 ft-lb at 10°F, with 0.625 in. test specimen. Or test to show that: *C_V[e] ≥ 15 ft-lb at 10°F. Or *Without testing, use as-rolled steel, provided welds have been stress relieved and inspected by nondestructive evaluation techniques. See Sec. 5.3.1.
	0.625 ↕ 0.19	*Use DT Test E-604-80. 80% or greater shear fracture required at LST. See Sec. 5.1.3. Or *Use DWTT Test E-436. 80% or greater shear fracture required at LST. See Sec. 5.1.3.	0.620 ↕ 0.19	*Use DT Test E-604-80. 50% or greater shear fracture required at LST. See Sec. 5.2.3. Or *Use DWTT Test E-436. 50% or greater shear fracture required at LST. See Sec. 5.2.3. Or *Use any normalized steel made to "Fine Grain Practice" or better. See Sec. 5.2.3.	0.4 ↕ 0.0	*No requirements when B is less than 0.4 in. thick. See Sec. 5.3.2.
	0.19 ↕ 0.025	*Use Notch Tensile Test E-338. $\frac{\text{Notch tensile strength}}{\text{yield strength}} \geq 1.0$ at LST.	0.19 ↕ 0.0	*No requirements when B is less than 0.19 in. See Sec. 5.2.3.		

[a]Full scale destructive testing on a case-by-case basis may be used as an alternate to requirements listed below.

[b]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604.

[c]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604, or the NDT temperature requirement can be met by selecting the maximum NDT temperature given in Fig. 1 or Table 3.

[d]DT measured according to ASTM E-604.

5.3 CATEGORY III

The level of safety required for Category III is less than that for Category II. For Category III systems, fracture toughness must be sufficient to prevent fracture initiation at minor defects typical of good fabrication practices. A summary of fracture toughness requirements for Category III steels is shown in Table 6.

Ref. 2.5

Good engineering practices and careful selection of the steel make it reasonable to expect that brittle fracture is unlikely to occur.

TABLE 6. Category III fracture toughness requirements and criteria for ferritic steels with yield strength no greater than 100 ksi.

Required degree of safety (see Appendix C)	Adequate margin of safety.
Required amount of fracture toughness (see Sec. 5)	Sufficient to prevent fracture initiation at minor defects typical of good fabrication practices.
Thickness (B) (in.)	**Criteria for meeting toughness requirements**
0.4 to 4.0	• Without testing, use any normalized steel made to "Fine Grain Practice" or better[a]. See Sec. 5.3.1. Or • Show that NDT[b] < 10°F (B > 0.625 in.). Or • Test to show that DT[c] > 50 ft-lb at 10°F, with test specimen 0.625 in. thick. Or • Test to show that C_V[d] > 15 ft-lb at 10°. Or • Without testing, use as-rolled steel, provided the welds have been stress relieved and inspected by nondestructive evaluation techniques.
Less than 0.4	• No requirements when B is less than 0.4 in. See Sec. 5.3.2.

[a]Steel with an NDT temperature lower than steels made to a fine grain practice.

[b]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604 or the NDT temperature requirement can be met by selecting the maximum NDT temperature given in Fig. 1 or Table 3.

[c]DT measured according to ASTM E-604, for specimen thickness of 0.625 in.

[d]C_V measured according to ASTM E-23.

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BY I Husain DATE 9/6/89 SECTION 2.3.4-4

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TITLE NSP- PATHFINDER DECOMISSIONING STUDY
Reactor Vessel Analysis - Type A Shipping Container.

From Pathfinder Atomic Power Plant Report No. ACNP-62025, "Reactor Vessel Materials, Fabrication and Inspection", by Allis-Chalmers Mfg. Co. Milwaukee, WI, December 1, 1962,

Ref. 2.8

TABLE II

Component	Fig. No.	Item No.	Material	N.P. Test No.	Yield Strength (PSI)	Tensile Strength (PSI)	% Elongation	Charpy V-Notch Impact Energy at 10 F (Ft-Lb)
Top Flange	2	2	ASTM A105-II	202	67,600 57,200	85,900 81,600	27.8 31.0	119 - 120 - 108 82 - 65 - 70
Upper Neck (4 seg.)	2	3	ASTM A212-B	200	42,900	71,180 71,400	34	17 - 16 - 15
Upper Neck (4 Seg.)	2	2	ASTM A212-B	200	46,500	73,500 72,500	31	31 - 29 - 30
Main Cylinder #1	2	4	ASTM A212-B	212	42,500	72,600 75,000	32	19 - 15 - 17
Main Cylinder #2	2	4	ASTM A212-B	214	41,000	74,200 71,600	34	21 - 20 - 16
Lower Head	2	5	ASTM A212-B	201	47,000	71,800 73,000	30	26 - 30 - 31
Flue Ring	2	6	ASTM A105-II	203	47,150 45,150	74,250 74,500	33.5 33	28 - 27 - 31 27 - 23 - 29
Lower Cylinder	2	7	ASTM A212-B	212	40,500	76,500 74,900	34	16 - 16 - 17
Bottom Head	2	8	ASTM A212-B	211	40,800	74,700 75,000	33	15 - 16 - 15
Closure Head	3	2	ASTM A212-B	248	44,900	78,100 78,600	32	19 - 23 - 18
Closure Flange	3	3	ASTM A105-II	247	46,700 45,300	70,000 71,500	40.5 38.5	110 - 140 - 126 138 - 115 - 88
Studs Lot #1	4		ASTM A437 Gr B4B	311-1	110,000 108,000	146,800 146,500	14 14	ı6 Ave (See Note 2)
Studs Lot #2	4		ASTM A437 Gr B4B	311-2	115,000 114,000	155,000 154,000	13 14	15 Ave (See Note 2)
Nuts Lot #1	5		ASTM A437 Gr C4C	333	103,750	125,000	20	32 - 28 - 30 (See Note 3)
Nuts Lot #2	5		ASTM A437 Gr C4C	968	101,250	126,500	20	35 - 34 - 32 (See Note 3)

NOTES:

1. Keyhole impact at -50 F.
2. Charpy V-Notch impacts at room temperature.
3. Izod [redacted] impacts at room temperature.
4. Approved deviation from specified 30 Ft-Lb. Ave. impact energy.
5. Approved deviation from specified tensile strength of 120,000 psi.

Minimum, CVP @ 10°F = 15 ft-lbs

CONCLUSION. The Vessel meets the Category III, fracture toughness requirements and Criteria.

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Reactor Vessel Analysis as Type 'A' Shipping Container

From Page 8, NUREG/CR-1815

5.2 CATEGORY II

A summary of fracture toughness requirements for Category II steels is shown in Table 5.

The level of performance with respect to fracture safety necessary for Category II is less than that required for Category I. For Category II systems, fracture toughness must be sufficient to prevent fracture initiation of pre-existing cracks under dynamic loading.

With Category II steels, fracture toughness (or the corresponding temperature relative to NDT) must be greater than that needed to exceed plane strain conditions ($\beta = 0.4$) under dynamic loading. We recommend that in defining the Category II toughness requirement a value of $\beta = 0.6$ be used in the equation:

$$\beta = \frac{1}{B}\left(\frac{K_{ID}}{\sigma_{yd}}\right)^2$$

where σ_{yd} is the dynamic yield stress (as defined in the Nomenclature list), K_{ID} is the critical dynamic stress intensity, and B is the section thickness.

Using $\beta = 0.6$ in the above equation raises A (the temperature relative to NDT temperature) to a reasonable value for 1.0 in. thick sections. For example, with $\beta = 0.6$ and a 1.0 in. section thickness, the critical flaw size would be larger than 0.15 in. at yield stress loading.

Recommended procedures for selecting and qualifying Category II steels are discussed in Sec. 5.2.1. The basic requirements are modified for special situations in which reduced loading rates are assumed (Sec. 5.2.2), the sections used are thin (Sec. 5.2.3) or full-scale destructive testing is performed (Sec. 5.2.4).

The following relationship[9] must be used if a K_{ID} curve is constructed from Charpy data:

$$K_{ID}^2 = 5(C_V)E$$

where

K_{ID} = dynamic fracture toughness in psi$\sqrt{in.}$
E = modulus of the steel in psi
C_V = Charpy V-notch measurement in ft-lb.

from Table II of Pathfinder Report No. ACNP-62025, (Page)

C_V = 15.0 ft-lbs (minimum value)
= 16.0 ft-lbs (Average value)

E = 28×10^6 psi ASME Code

$\therefore K_{ID} = \{5\times15.0\times28\times10^6\}^{1/2}$
$= 45.83\times10^3$ psi$\sqrt{in}$
$= 45.83$ ksi$\sqrt{in}$

$\sigma_{yd} = \sigma_{ys} + 30.0$

$\sigma_{ys} = 40.5$ ksi Table II Page

$\therefore \sigma_{yd} = 40.5 + 30.0$
$= 70.5$ ksi

$\therefore \frac{K_{ID}}{\sigma_{yd}} = \frac{45.83}{70.5} = 0.65$

TABLE 5. Category II fracture toughness requirements and criteria for ferritic steels with yield strength no greater than 100 ksi.

Required degree of safety (see Appendix C)	Large margin of safety.
Required amount of fracture toughness (see Sec. 5.2)	Sufficient to prevent fracture initiation of cracks under dynamic loading.

Thickness (B) (in.)	Criteria for meeting toughness requirements[a]
0.625 to 4.0	• With full dynamic loading rates, NDT temperature[b] must be less than a maximum value. See Fig. 6 and Sec. 5.2.1. • With reduced loading rates, NDT temperature can be determined from Fig. 7. See Sec. 5.2.2.
0.19 to 0.625	• Use DT Test E-604-80. 50% or greater shear fracture appearance required at LST. See Sec. 5.2.3. Or • Use DWTT Test E-436. 50% or greater shear fracture appearance required at LST. See Sec. 5.2.3. Or • Use any normalized steel made to "Fine Grain Practice" or better[c]. See Sec. 5.2.3.
Less than 0.19	• No requirements when B is less than 0.19 in. See Sec. 5.2.3.

[a]Full scale destructive testing on a case-by-case basis may be used as an alternate to requirements listed below. See Sec. 5.2.4.

[b]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604 or the NDT temperature requirement can be met by selecting the maximum NDT temperature given in Fig. 1 or Table 3.

[c]Steel with an NDT temperature lower than steels made to a fine grain practice.

5.2.2 Qualifying Procedures for Reduced Loading Rates (0.625 in. to 4.0 in. thick sections)

Effective impact limiters have three major characteristics:

1. They provide protection in all drop orientations.

2. They absorb all the kinetic energy from an impact.

3. They dissipate kinetic energy at low force levels (on the order of 50 to 100 times the weight of the container).

For Category II, a temperature shift in the K_{ID}/σ_{yd} reference curve can be introduced if impact limiters are used to reduce the loading rate and protect fracture critical components. These energy absorbers can reduce the loading rate to well below that of the full dynamic level used to establish the K_{ID} curve. For loading rates that produce strain rates on the order of 10^{-1} in./in./s (typical for energy absorbing systems), the appropriate $K_{I(t)}/\sigma_{yd}$ curve shown on Fig. 7 can be used instead of the K_{ID}/σ_{yd} curve to establish the maximum allowable NDT temperature. A temperature shift of 70°F can be used for low strength steels (σ_{ys} < 60 ksi); for higher strength steels (60 ksi ≤ σ_{ys} ≤ 100 ksi), a shift of 30°F can be used.

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From Figure 7, for $K^1/\sigma_{yd} = 0.65$

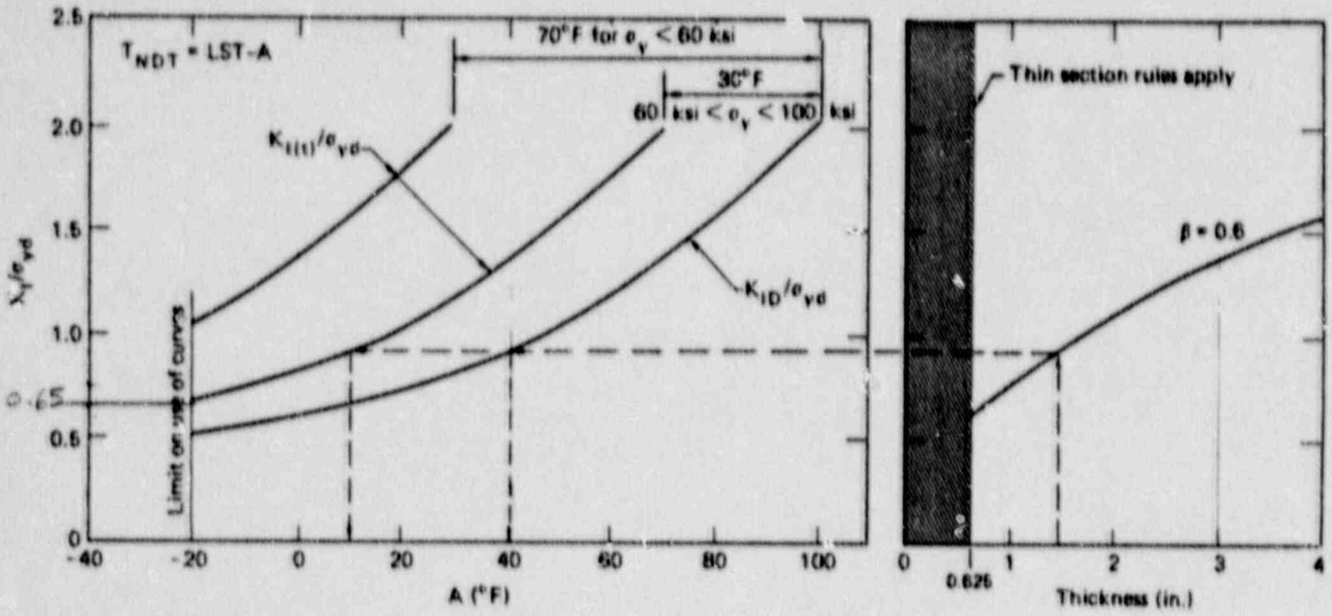

FIG. 7. Design chart for Category II fracture critical components.

For $K^1/\sigma_{yd} = 0.65$, $A = -20^\circ (F)$

$T_{NDT} = 10.0^\circ (F)$

Since T_{NDT} = LST-A

$10.0 = LST - (-20)$

$\therefore LST = -10^\circ F$

CONCLUSION: ALLOWABLE LOWEST SERVICE TEMPERATURE (Lowest metal Temperature) $LST = -10^\circ F$

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BY J. Hyssein DATE 9/6/89 SECTION 2.3.4-9
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For the outer vessel for HEXCEL Absorber containment, wall thickness = 3/8"

6.2.3 Qualifying Procedures for Thin Sections (up to 0.625 in. thick)

All sections between 0.19 in. and 0.625 in. thick have the same fracture toughness requirements. Any of the three following methods may be used to qualify Category II steels within this thickness range:

1. Application of full section thickness Dynamic Tear tests as specified in ASTM E-604-80. Steels will be qualified if 50% shear fracture appearance is achieved at the lowest service temperature.

2. Application of Battelle Drop Weight Tear Tests (ASTM E-436). If at least a 50% shear fracture appearance is observed at the lowest service temperature, then the fracture toughness of the steel is sufficient to qualify it.

3. Use of any normalized steel made to "Fine Grain Practice" or better.

Brittle fracture is not considered a problem for sections less than 0.19 in. thick in Category II, and there are no fracture toughness requirements for these sections.

APPENDIX 2.10.6-B

Penetration Evaluation

I OBJECTIVE : TO PERFORM PENETRATION ANALYSIS

II CRITERIA

The penetration analysis will assume a 13 pound steel cylinder having hemispherical ends with a 1-1/4 inch diameter will be dropped from a height of 40 inches on various critical locations of the vessel (critical location of smaller thicknesses such as a nozzle cap).

III METHOD OF APPROACH

vessel penetration calculation will be performed by hand calculations based on Ballistic Research Lab (BRL) and Stanford Research Lab (SRL) equations. These are described in Bechtel Topical Report 9A which has been reviewed and approved by NRC.

IV REFERENCE

1. BC-TOP-9A Revision 2 "Topical Report - Design of Structures for Missile Impact", Bechtel Power Corporation, San Francisco, CA. September 1974 (REF. 26)

BC-TOP-9-A Rev. 2

Table C-2

PERFORATION IN STEEL FORMULAS

Identification	Formula	Remarks	Equation No.
Ballistic Research Lab (Refs. 2, 3, 13)	$T^{3/2} = \frac{0.5\ MV_s^2}{17,400\ K^2 D^{3/2}}$		C-10
Stanford Research Institute (Ref. 20)	$\frac{E}{D} = \frac{S}{46,500}\left(16,000\ T^2 + 1,500 \frac{W}{W_s}\ T\right)$	See Limits page C-3	C-11

T = steel thickness to be just perforated (in.)

M = mass of the missile (lb-sec²/ft),

V_s = striking velocity of the missile normal to target surface (ft/sec),

K = constant depending on the grade of the steel, (K is usually = 1,)

D = diameter of the missile (in.)

E = critical kinetic energy required for perforation (ft-lb),

S = ultimate tensile strength of the target minus the tensile stress in the steel (psi)

W = length of a square side between rigid supports (in.),

W_s = length of a standard width (4 in.). (See Ref. 20)

PENETRATION (Cont'd.)

The BRL Formula is shown below, modified by setting a material constant K = 1 and solving directly for steel plate thickness, T, which will just be perforated by the missile.

$$T = \frac{\left(\frac{MV^2}{2}\right)^{2/3}}{672D}$$

Weight of Missile = 13.0 lbs

Mass of " = $\frac{13.0}{32.17}$ = 0.4041 $\frac{\text{lbs sec}^2}{\text{ft}}$ = M

Drop Height h = 40.0 in = 3.333 ft.

Impact Velocity $V_s = \sqrt{2gh}$

$= \sqrt{2 \times 32.17 \times 3.333}$

$= 14.645$ ft/sec.

Diameter of Missile = D = 1.25 in

Steel Thickness to be just perforated

$$T = \frac{\left\{\frac{0.4041(14.645)^2}{2}\right\}^{2/3}}{672 \times 1.25}$$

= 0.015 in.

Available Thickness of Vessel Wall = 3.0" >> 0.015"

" " " Nozzle Cap = 0.75" >> 0.015"

PENETRATION (Cont'd.)

ANALYSIS USING Stanford Research Institute Equation

External Kinetic Energy of Impact

$$E = \frac{1}{2} M V_s^2 = \frac{1}{2} \times 0.4041 (14.645)^2$$

$$= 43.33 \text{ ft lbs.} = 0.52 \text{ in K}$$

$$S = 70,000.0 - 0 = 70,000.0 \text{ psi.}$$

W = Conservatively Assume = 10.0 in

$$\therefore \frac{43.33}{1.25} = \frac{70,000.0}{46,500} \left(16000 T^2 + 1500 \times \frac{10.0}{4} T \right)$$

$$\text{or } T^2 + 0.3528T - 0.0014 = 0$$

$$\therefore T = \frac{-0.3528 \pm \sqrt{(0.3528)^2 + 4 \times 1 \times 0.0014}}{2 \times 1}$$

$$= 0.0039 \text{ in} \ll 3.0'' \text{ O.K}$$

$$\ll 0.75'' \text{ O.K}$$

CONCLUSION: As the vessel wall is considerably greater than calculated thickness of penetration, the effect of missile impact will be negligible on the vessel wall and nozzle cover plate

APPENDIX 2.10.6-C

Load Resistance Calculations

BY I. Hubans DATE 9-14-89 SECTION 2.6.11-1

CHKD [illegible] DATE 10/24/89 SUB-SECTION ____ OF ____

PROJECT NO. 4-22B TASK NO. PH1584 PAGE ____ OF ____

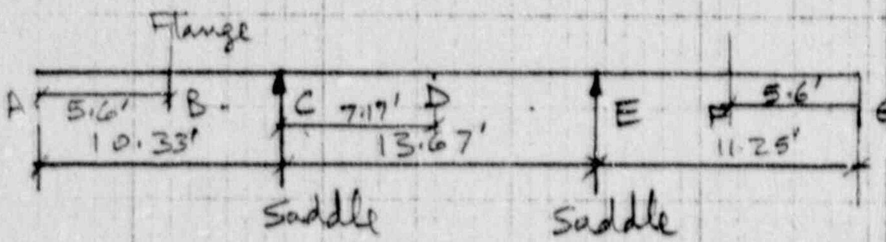
TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS

Reactor Vessel Analysis as Type 'A' Shipping Container

I OBJECTIVE - TO PERFORM LOAD RESISTANCE ANALYSIS.

II CRITERIA & METHOD OF APPROACH

10CFR Part 71 specifies a "Load Resistance" requirement for Type B packages. Specifically required is to regard the package as a simple beam supported at its ends with a loading equal to five times its fully loaded weight. The allowable stress for this condition is the material yield strength. To be consistent with the ASME Code limits applied elsewhere in this report, the more restrictive ASME Code primary membrane stress limit will be applied.



Max Moment at B (Flange connection)

$M_B = 2.676(5.1) + 5.389 \times 4.1 + 7.44 \times 3.1 + 11.2 \times 2.1 + 12.38 \times 1.1$

$+ \frac{13.73}{2} \times 0.1 = 96.63 \text{ Kft} = 1159.6 \text{ Kin}$ ✓

Max Moment at C.

$M_C = 2.676 \times 9.83 + 5.389 \times 8.83 + 7.44 \times 7.83 + 11.2 \times 6.83 + 12.38 \times 5.83$

$+ 13.73 \times 4.83 + 15.54 \times 3.83 + 17.07 \times 2.83 + 18.724 \times 1.83$

$+ 20.45 \times 0.83 + \frac{21.33}{1} \times \frac{(0.33)^2}{2}$

$= 507.35 \text{ Kft} = 6,088.2 \text{ Kin}$ ✓

Moment @ F $= 0.428 \times 5.1 + 1.096 \times 4.1 + 3.37 \times 3.1 + 4.13 \times 2.1$

$+ 4.28 \times 1.1 + 4.281 \frac{(0.6)^2}{2}$

$= 33.27 \text{ Kft} = 375.3 \text{ Kin}$ ✓

Load Resistance (Cont'd.)

Max. Moment at E

$M_E = 24.1 \times 0.5 + 26.55 \times 1.5 + 20.49 \times 2.5 + 18.38 \times 3.5$
$+ 9.89 \times 4.5 + 6.51 \times 5.5 + 4.28 \times 6.5 + 4.28 \times 7.5$
$+ 4.13 \times 8.5 + 3.37 \times 9.5 + 1.1 \times 10.5 + 0.45 \times 11.25$

$= 391.17$ Kft $= 4,694.0$ Kin.

Max Moment at A $= 9911.68 \times \frac{580.6}{582.2} = 9,887.84$ Kft

$9887.84 = R_C \times 10.33 + R_E \times 24.0$

$957.2 = R_C + 2.323 R_E$ --- (1)

$580.6 = R_C + R_E$ --- (2)

$\therefore 1.323 R_E = 957.2 - 580.6 = 376.6$

$\therefore R_E = 284.6$ K.

$R_C = 580.6 - 284.6 = 296.0$ K

Max. Shear is 0 @ $x = 6.5 + 0.67 = 7.17'$ from C

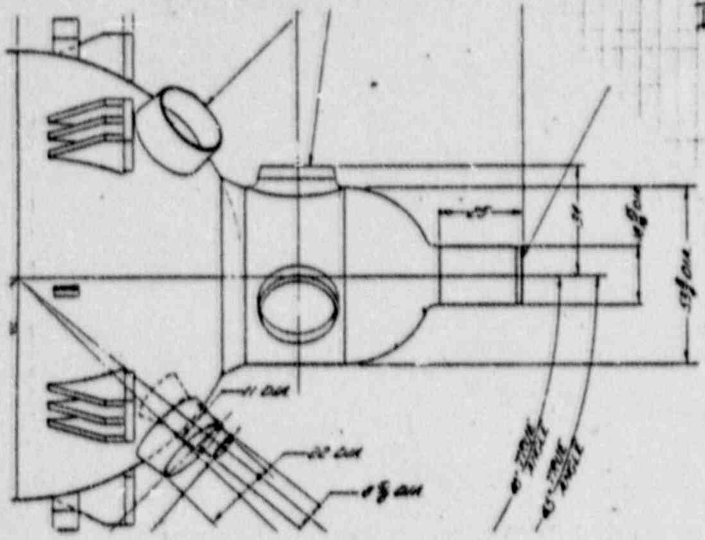
Max. Moment at D (17.5' from A) $= 2.68 \times 17.0 + 5.39 \times 16.0 + 7.44 \times 15.0 +$
$11.2 \times 14.0 + 12.38 \times 13.0 + 13.73 \times 12.0 + 15.54 \times 11.0$
$17.07 \times 10.0 + 18.72 \times 9.0 + 20.45 \times 8.0 + 21.33 \times 7.0$
$+ 20.95 \times 6.0 + 21.41 \times 5.0 + 22.49 \times 4.0 + 24.46 \times 3.0$
$+ 24.46 \times 2.0 + 24.46 \times 1.0 + \frac{24.46}{12} \frac{(6)^2}{2 \times 12}$
$- 296.0 \times 7.17$

$M_D = 100.86$ Kft $= 1,210.4$ Kin

Load Resistance (cont'd.)

Section Properties

AT Section F



$I = \frac{\pi}{64}(53.75^4 - 47.75^4)$

$= 154,526.9 \text{ in}^4$

Section Modulus

$S_{xx} = \frac{154,526.9}{53.75} \times 2$

$= 5,749.8 \text{ in}^3$

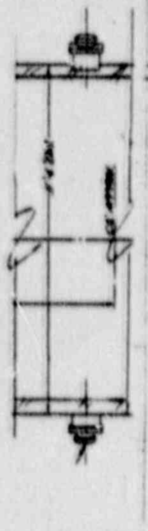
Max. Moment for 1 G Load

$= 375.3$ Kin

∴ Max Bending stress

$= \frac{375.3}{5,749.8} = 0.07$ Ksi

Section Modulus at C, D & E



$t = 3"$

$I = \frac{\pi}{64}(138^4 - 132^4) = 2,899,992.4 \text{ in}^4$

$S_{xx} = \frac{2,899,992.4}{138} \times 2 = 42,028.9 \text{ in}^3$

∴ Max Moment $M_C > M_D > M_E$

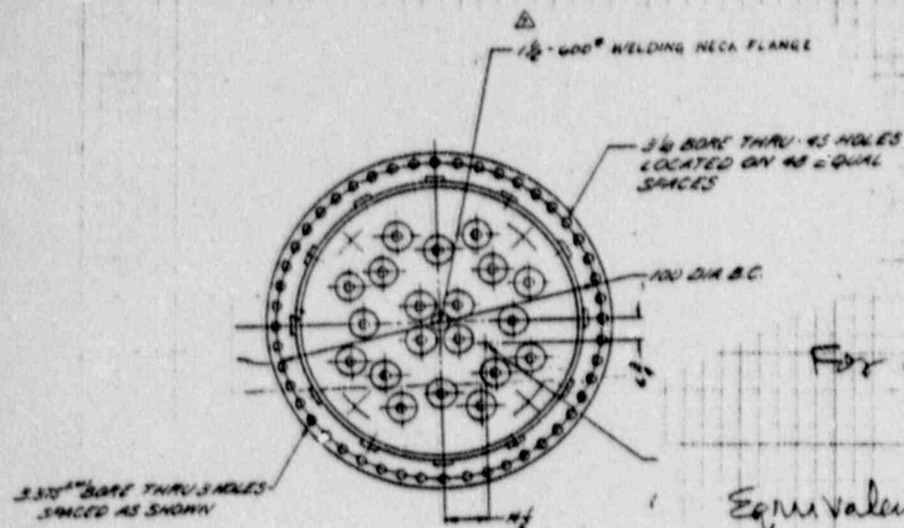
$M_C = 6,088.2$ K.in

∴ Max Bending stress $= \frac{6088.2}{42,028.9} = 0.145$ Ksi > 0.07

∴ For 5 g Load Max. Bending stress in the Vessel $= 5 \times 0.145 = 0.72$ Ksi.

Reactor Vessel Analysis as Type 'A' Shipping Container

AI Flange Section



For 3¼" ϕ Bolts,

Min. Root Area

$A = 6.72 \text{ in}^2$

For 48 Bolts

$A_B = 48 \times 6.72 = 322.56 \text{ in}^2$

Equivalent Thickness for Dia. of 100" $t = \dfrac{322.56}{\pi \times 100} = 1.03$ in

∴ Section Modulus $S_{xx} = \pi r^2 t = \pi \times 50.0^2 \times 1.03$

$= 8,064.0 \text{ in}^3$

∴ Max. Stress for 1g $= \dfrac{1159.6}{8,064} = 0.144$ Ksi

" " for 5g Load $= 5 \times 0.144 = 0.72$ Ksi

" " " 3.52g " $= 0.144 \times 3.52 = 0.51$ Ksi

Max. Shear Force in the bolt $= 2.68 + 5.39 + 7.44 + 11.2 + 12.38 = 39.09$ K

Max. shear stress in Bolt for 1G $= \dfrac{39.09}{322.56}$

$= 0.121$ Ksi

" " " " " for 5G $= 5 \times 0.121$

$= 0.61$ Ksi

" " " " for 3.52 G $= 3.52 \times 0.121$

$= 0.43$ Ksi

APPENDIX 2.10.7

References

References

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2.2 Technical Bulletin TSB120, "Mechanical Properties of Hexcel Honeycomb Materials", 1988, Hexcel, Dublin, CA

2.3 "ASME Boiler and Pressure Vessel Code", Section III, Division 1, 1983 Edition, and Addenda through 1985.

2.4 Welding Research Council Bulletin No. 107, August 1985, "Local Stresses in Spherical and Cylindrical Shells Due to External Loadings:, by K.R. Wichman, et.al.

2.5 NUREG/CR-1815 UCRL-53013, RT "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick".

2.6 Topical Report - "Design of Structures for Missile Impact", BC-TOP-9A Revision 2, Bechtel Power Corporation, San Francisco, CA, September 1974

2.7 Technical Bulletin TSB122, "Design Data for the Preliminary Selection of Honeycomb Energy Absorption systems", 1989, Hexcel, Dublin, CA

2.8 "Pathfinder Atomic Power Plant - Reactor Vessel Materials, Fabrication and Inspection", ACNP-62025, Allis-Chalmers Corporation December 1, 1962

2.9 Algor Interactive Systems, Inc., SUPERSAP Reference Manual Algor Finite Element Systems, Version 1.0, June, 1987.

2.10 "ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB

LIST OF FIGURES

FIGURE 2.1
MANUFACTURERS' DATA REPORT

FORM U-1A MANUFACTURERS' DATA REPORT FOR UNFIRED PRESSURE VESSELS

Alternate Form for Single Chamber Completely Shop-Fabricated Vessels Only

1. Manufactured by Allis-Chalmers Mfg. Co., West Allis, Wis. 2-4300-00[illegible]
2. Manufactured for Northern States Power Sioux Falls, So. Dakota Pathfinder (Name and address of Purchaser)
3. Type Vert. Vessel No. 379 Nat'l Bd. No. 204 Yr. Built 1961
4. SHELL: Mat'l SA-240 Type 304L Clad-Incl. 1/4" Clad. SA212 Gr.B T.S. 70000PS Nom. Thk. 5 In. Corr. Allow 0 In. Diam. 11 Ft. 0 In. Lgth. 36 Ft. 1 In.
5. SEAMS: Long Dbl. Buttweld Yes X.R. Compl. Sectioned No Efficiency 100 %
   Girth Dbl. Buttweld Yes X.R. Compl. Sectioned No No. of Courses 2
   (If stressed or brazed, describe under Remarks)
6. HEADS: SA-240 Type 304L SA 212 Gr.B T.S. 70000PS (b) Mat'l SA 240 Type 304L Clad. SA 212 Gr.B 70000PS

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical	Conical	Hemispherical	Flat Diameter	Side to Pressure (Convex or Concave)
(a) TOP	2-1/2" Incl. 1/4" Clad (Removable)					66-3/4"		Concave
(b) BOTTOM	3" Incl. 1/4" Clad.					66"		Concave

If removable, bolts used SA-437 Gr.B 48 TS 140,000 3" diam. 48 (Material, Spec. No., T.S., Size, Number) Other fastening (Describe or Attach Sketch)

7. Constructed for pressure of 700 psi Max Temp 500 °F Subzero °F Hydrostatic Test 1050 psi
8. SAFETY OR RELIEF VALVE OUTLETS: Number None Size Location See Remarks
9. NOZZLES:

Purpose (Inlet, Outlet, Drain)	Number	Size	Type	Material	Reinforcement Material	How Attached
Inlet	1	[illegible] Welding End	SA-[illegible]	SS Overlay	[illegible]	Welded
Inlet	1	[illegible] Welding End	SA [illegible]	SS Overlay	[illegible]	Welded
Outlet	1	[illegible] Welding End	SA [illegible]	SS Overlay	[illegible]	Welded

10. INSPECTION OPENINGS: Manholes, No. None Size Location Removable Top Head
    Handholes, No. Size Location
    Threaded, No. Size Location
11. SUPPORTS: Skirt No Lugs 8 Legs Other (Describe) Attached Welded (Where & How)
12. REMARKS: Code Case 1270N & 1273N
    Boiling Water Nuclear Reactor
    6 Safety Valves located on main steam line to turbine
    20 - 3.70" I.D. Control Rod Open. Top Head - Welded
    4 - 3.70" I.D. Lifting Pipes Top Head - Welded
    (Brief description of purpose of the vessel, as Air Tank, Water Tank, L.P.G., Etc.—State Contents.)

We certify that the statements made in this report are correct and that all details of material, construction, and workmanship of this vessel conform to the ASME Code for Unfired Pressure Vessels.

Date June 15 19 61 Signed Allis-Chalmers Mfg. Co. (Manufacturer) By Sam [illegible]

Certificate of Authorization Expires 12-31-61

CERTIFICATE OF SHOP INSPECTION

Inspection Agency's Serial No. 379

VESSEL MADE BY Allis-Chalmers Mfg. Co. at West Allis, Wis.

I, the undersigned, holding a Certificate of Competency as an Inspector of Boilers and Unfired Pressure Vessels in THE STATE OF ______ and employed by Hartford Steam Boiler Insp. & Ins. Co. of Hartford, inspected internally and externally, the vessel described in this report on June 15 19 61 and certify that the statements made in this report are correct corresponding with mill test reports of materials furnished by the builders, and measurements made of the vessel and that this vessel is constructed in accordance with the ASME Code for Unfired Pressure Vessels.

Date June 15 19 61 H. E. Merritt (Inspector's Signature) Commissions ND 1268 (State or Nat'l Bd. & Number)

Printed in U.S.A. Copies of this Form obtainable from Amer. Soc. Mech. Eng., 29 W. 39th St., New York 18, N.Y.

FIGURE 2.2
TYPICAL HEXCEL FORCE DEFORMATION CURVE

The load and deflection characteristics encountered in statically crushing honeycomb are graphically shown in the figure below. This curve indicates the value of the resistance to loading offered by the honeycomb as the compressive load is overcome and crushing starts and continues. Three items on this curve are of special interest:

A. COMPRESSIVE PEAK — Honeycomb systems which are not precrushed or in which the initial contact area has not been reduced exhibit this peak force level at impact. This undesirable peak can be easily eliminated by proper design.

B. MAXIMUM CRUSH LEVEL — A horizontal line has been drawn across this curve representing a maximum crush level. If this hypothetical line had been developed as a design maximum, then the actual honeycomb f_{cr} value must remain equal to or below this level for crushing to take place.

C. MINIMUM STOPPING DISTANCE — The vertical line drawn down this graph represents a hypothetical stopping distance minimum established in conjunction with the maximum crush level value. This value represents a minimum value for the maximum crush level line and any crush level selected below the maximum limit will require an increase in this minimum thickness.

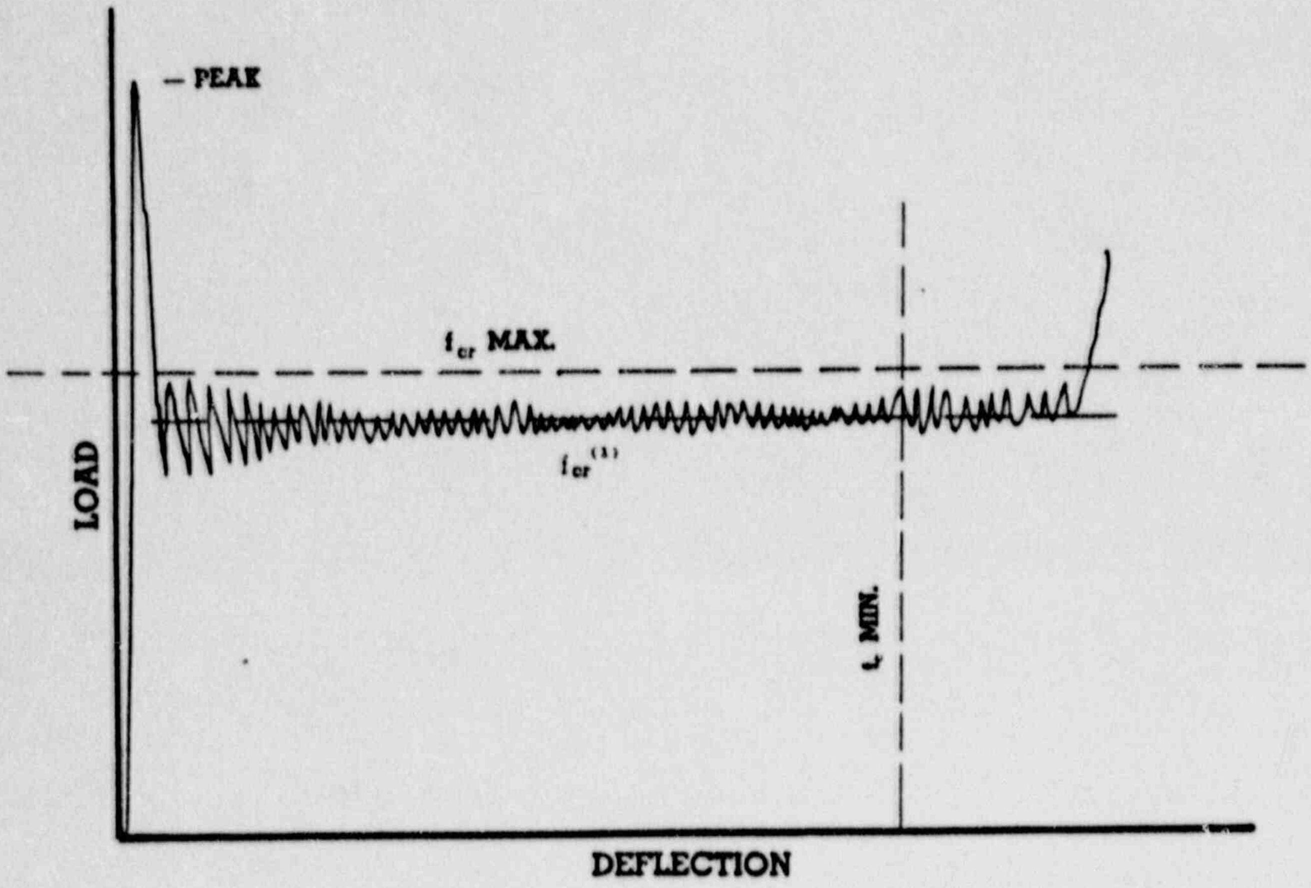
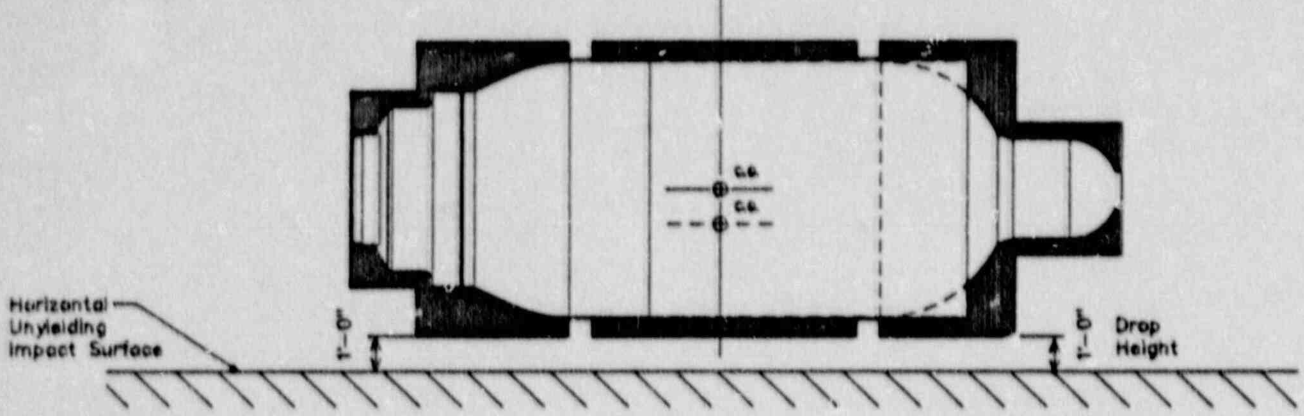
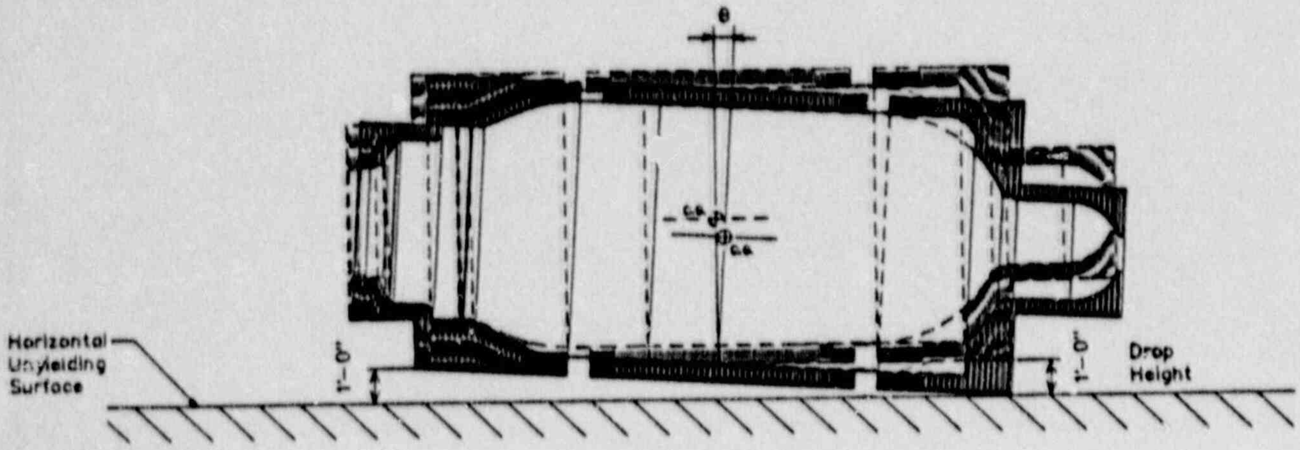


FIGURE 2.3
PACKAGE ORIENTATION
CASES 1 AND 2



Case 1 – Side Drop



Case 2 – Edge Drop

Orientation Angle

$$\theta = \tan^{-1} \frac{1}{13.67}$$

$$= 4.2°$$

FIGURE 2.4
HEXCEL PROPERTIES AND
WIDTH AND DEPTH OF CRUSHING

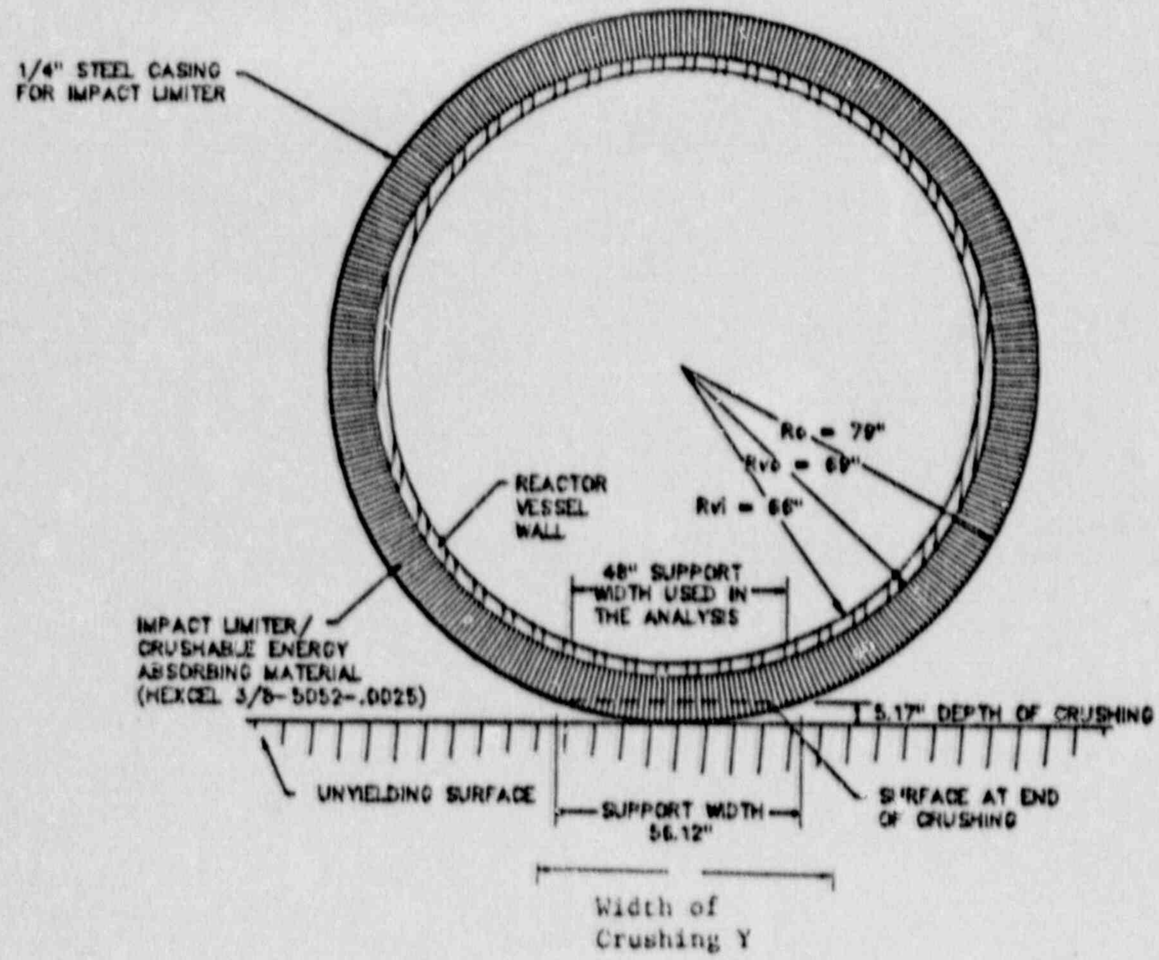


FIGURE 2.5
LOAD DEFORMATION CURVE
CASE 1 - SIDE DROP
(For Typical One foot Length of Package)

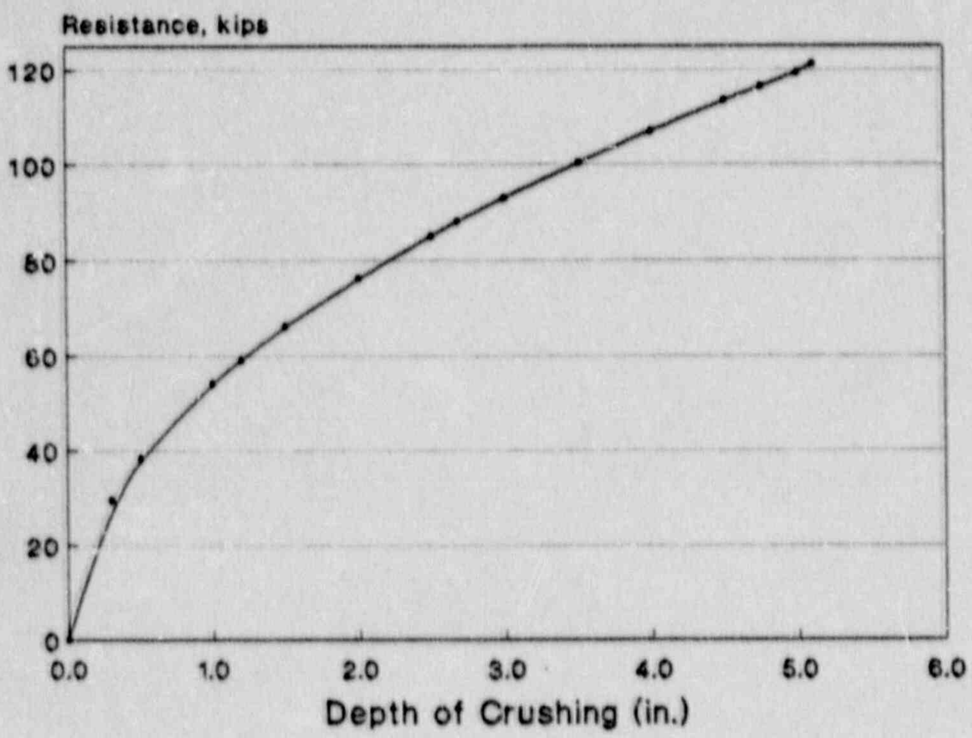


FIGURE 2.6
LOAD DEFORMATION CURVE
CASE 2 - EDGE DROP
(For Typical One foot Length of Package)

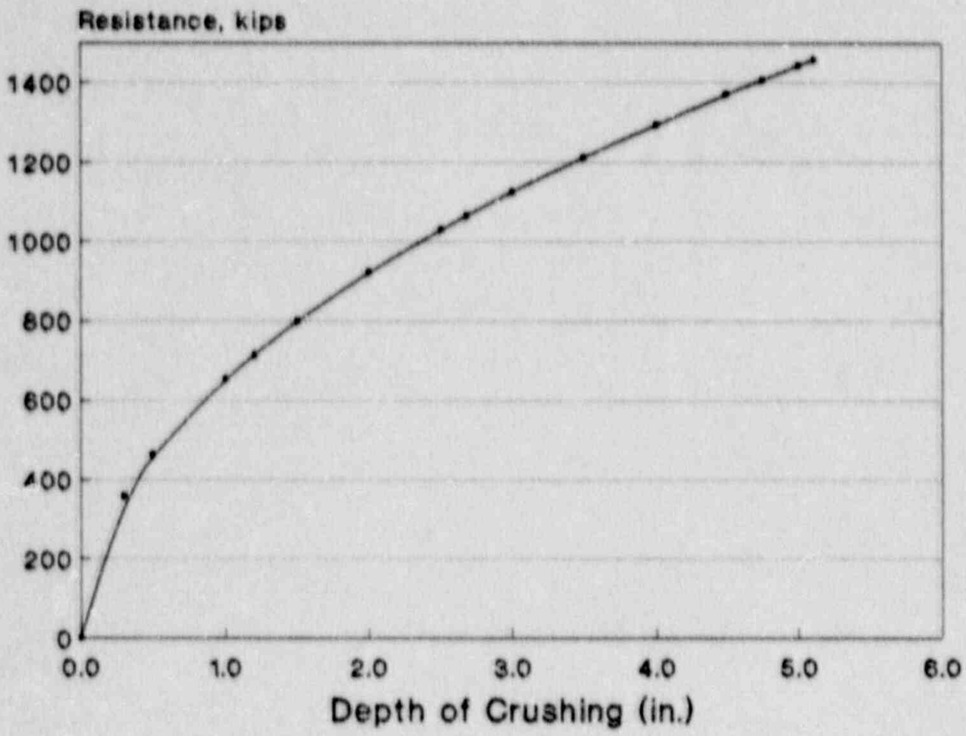


FIGURE 2.7
TYPICAL ANSYS 3-DIMENSIONAL
FINITE ELEMENT MODEL
CASE 1 - SIDE DROP

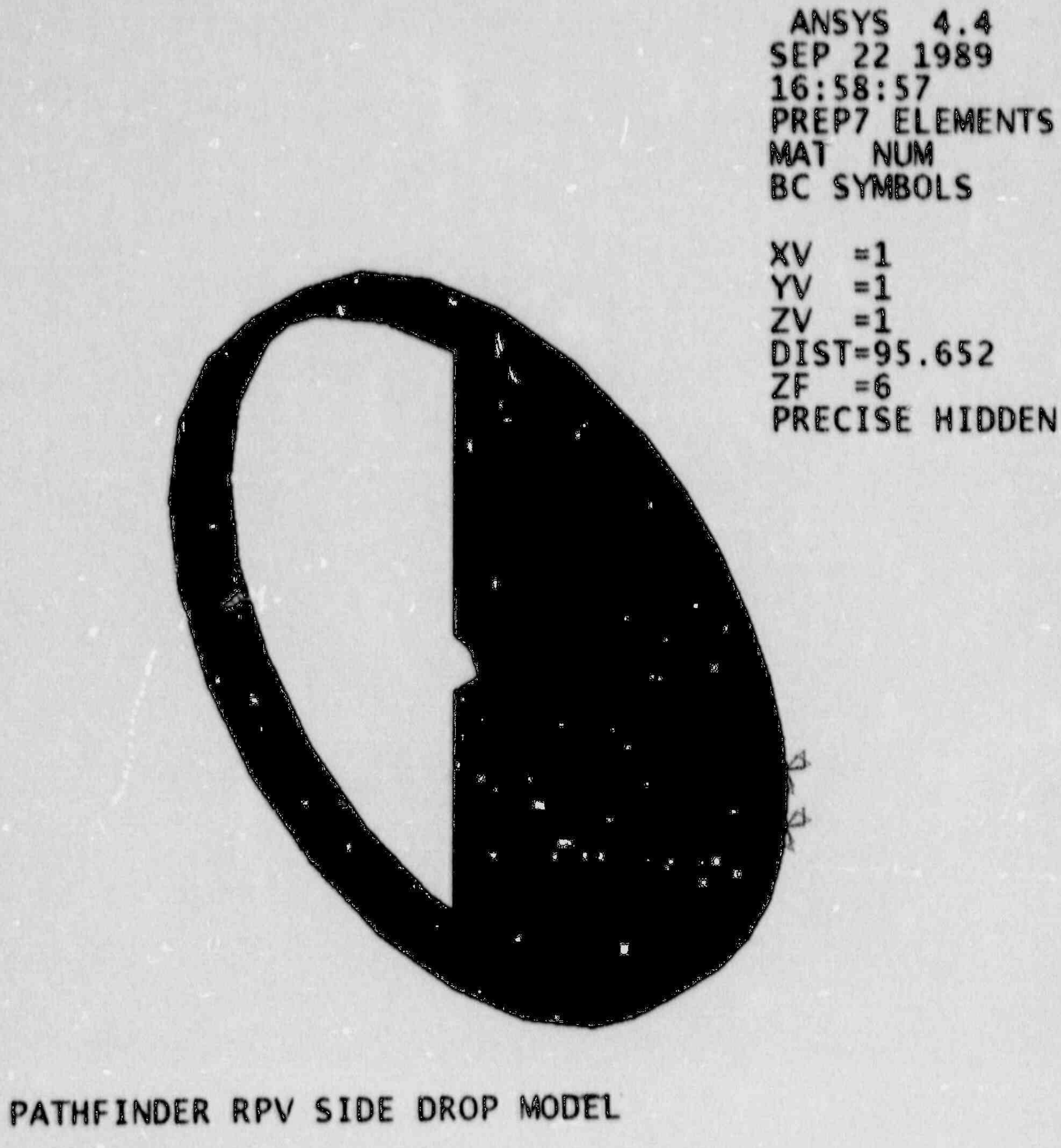
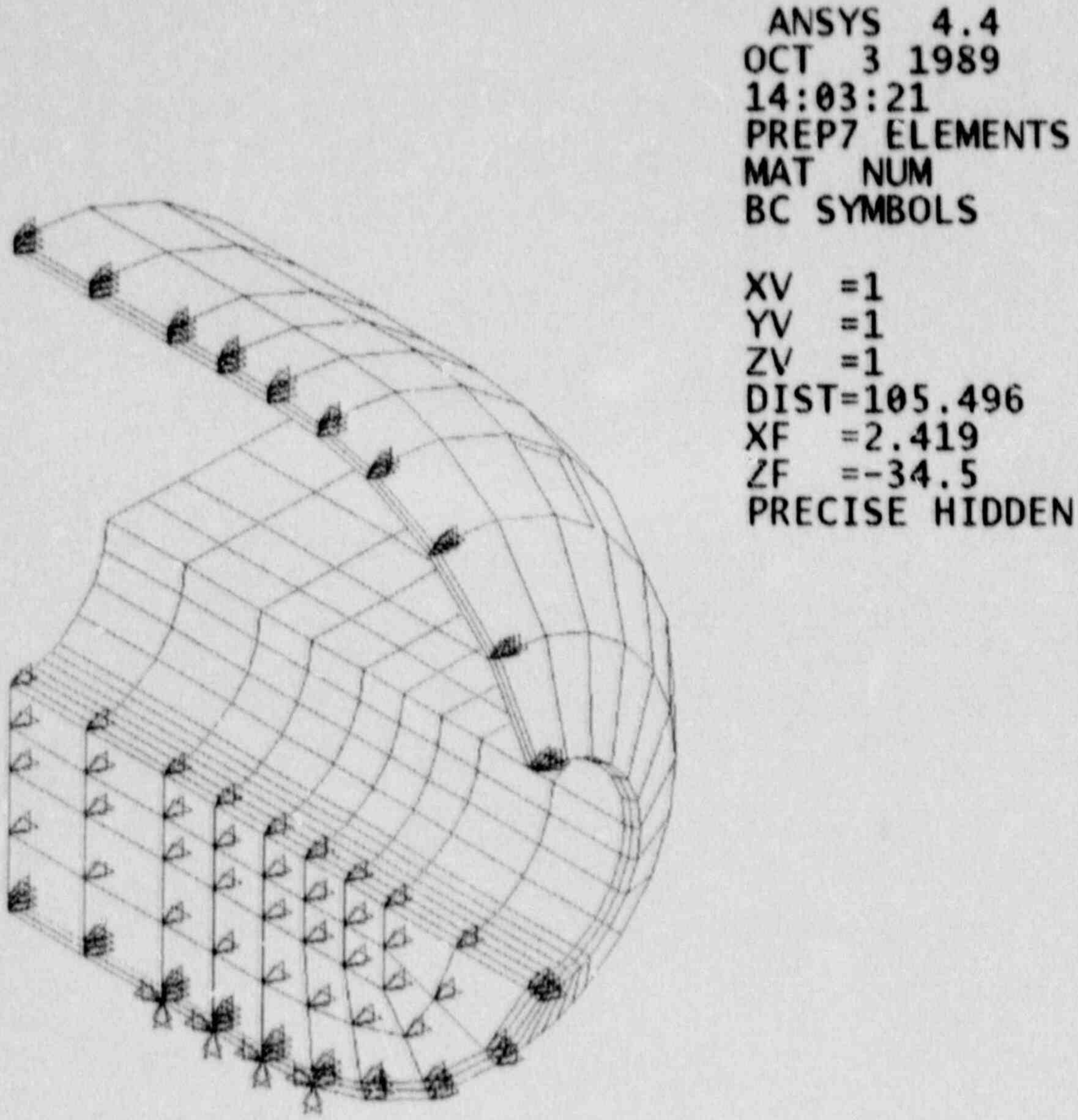


FIGURE 2.8
TYPICAL ANSYS 3-DIMENSIONAL
FINITE ELEMENT MODEL
CASE 2 - EDGE DROP



PATHFINDER RPV EDGE DROP SHELL/GROUT MODEL - THETA = 6

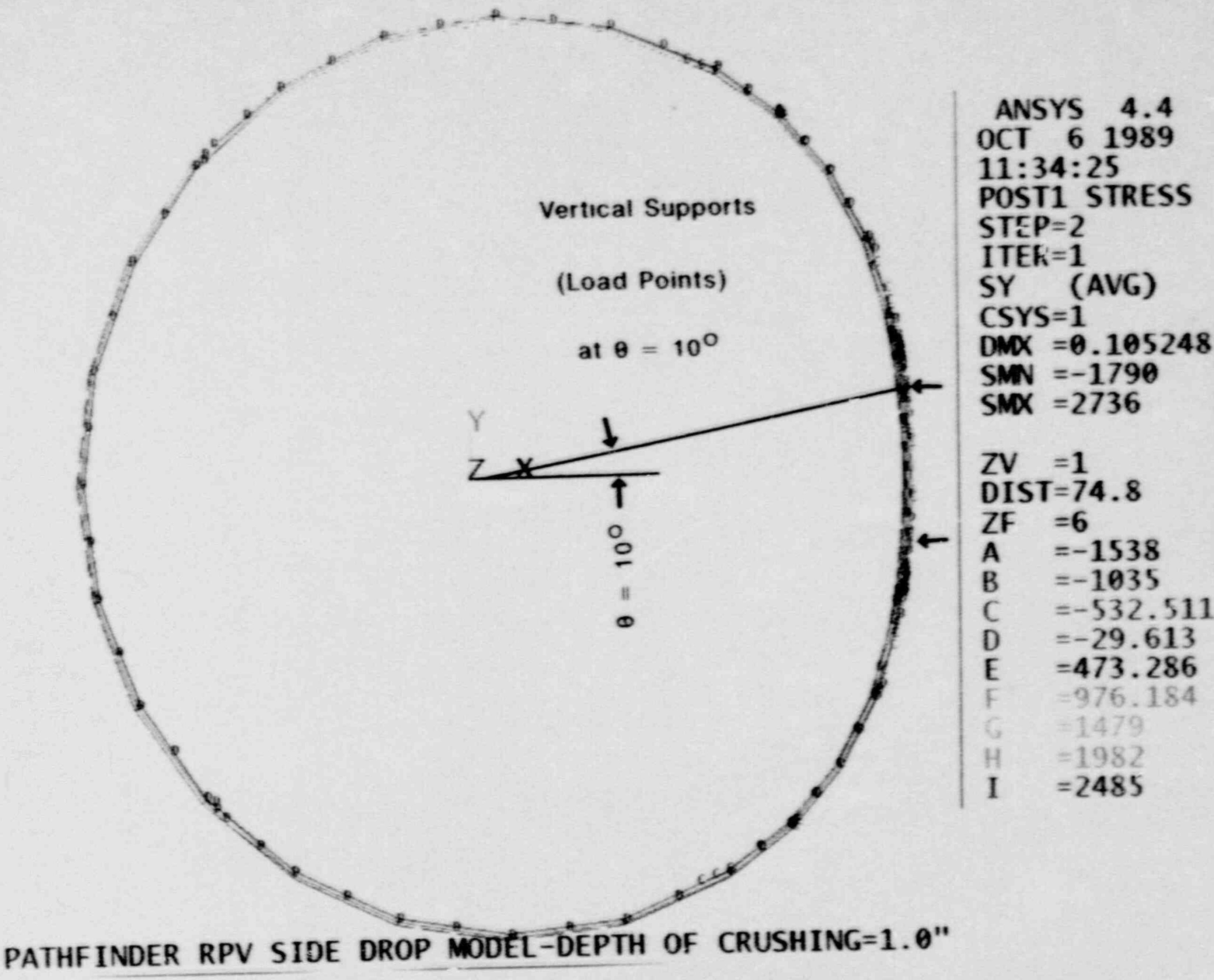
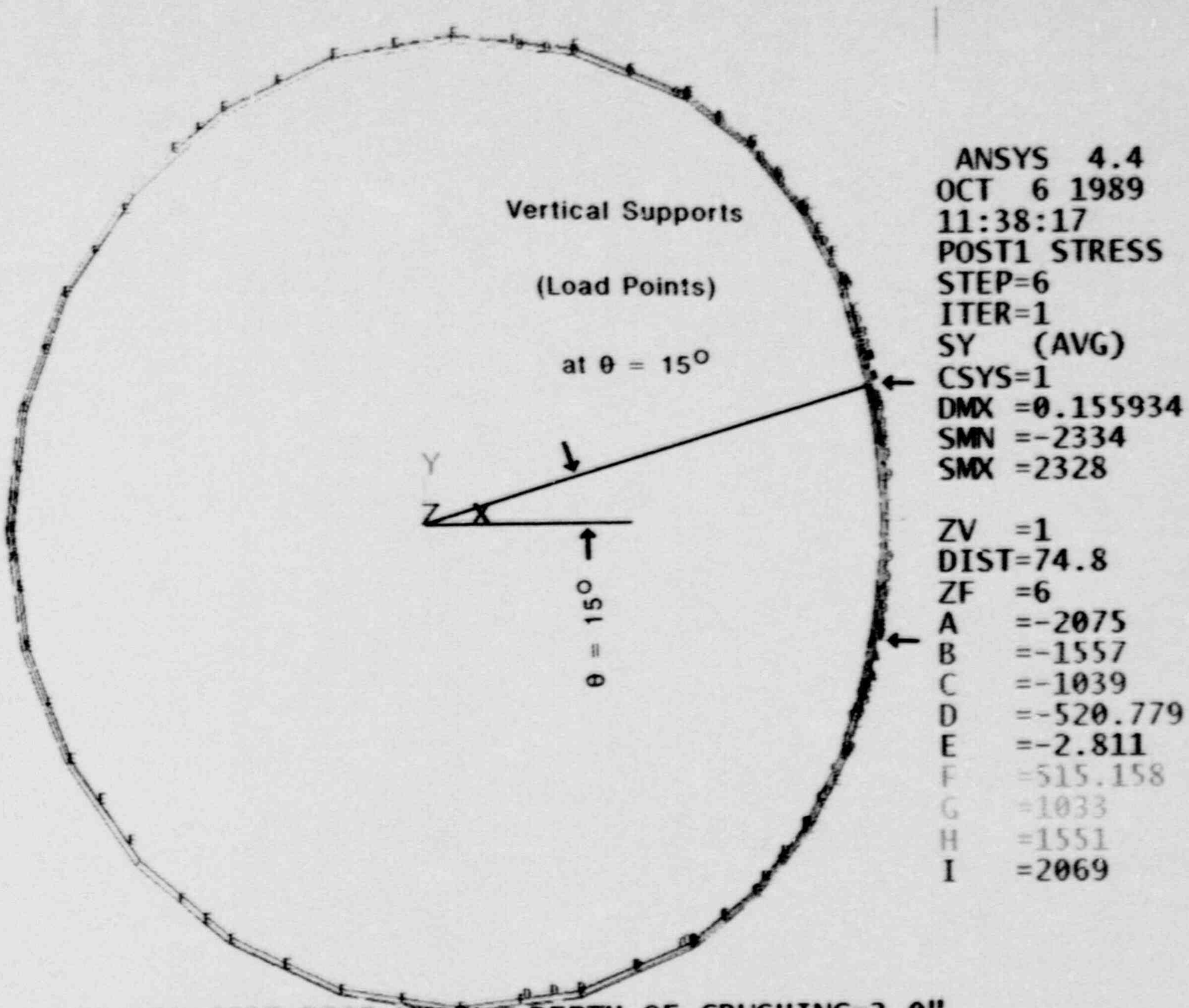


FIGURE 2.9
MAXIMUM MEMBRANE STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 1 INCH



PATHFINDER RPV SIDE DROP MODEL- DEPTH OF CRUSHING=3.0"

FIGURE 2.10
MAXIMUM MEMBRANE STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 3 INCHES

FIGURE 2.11
MAXIMUM MEMBRANE STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 5.11 INCHES

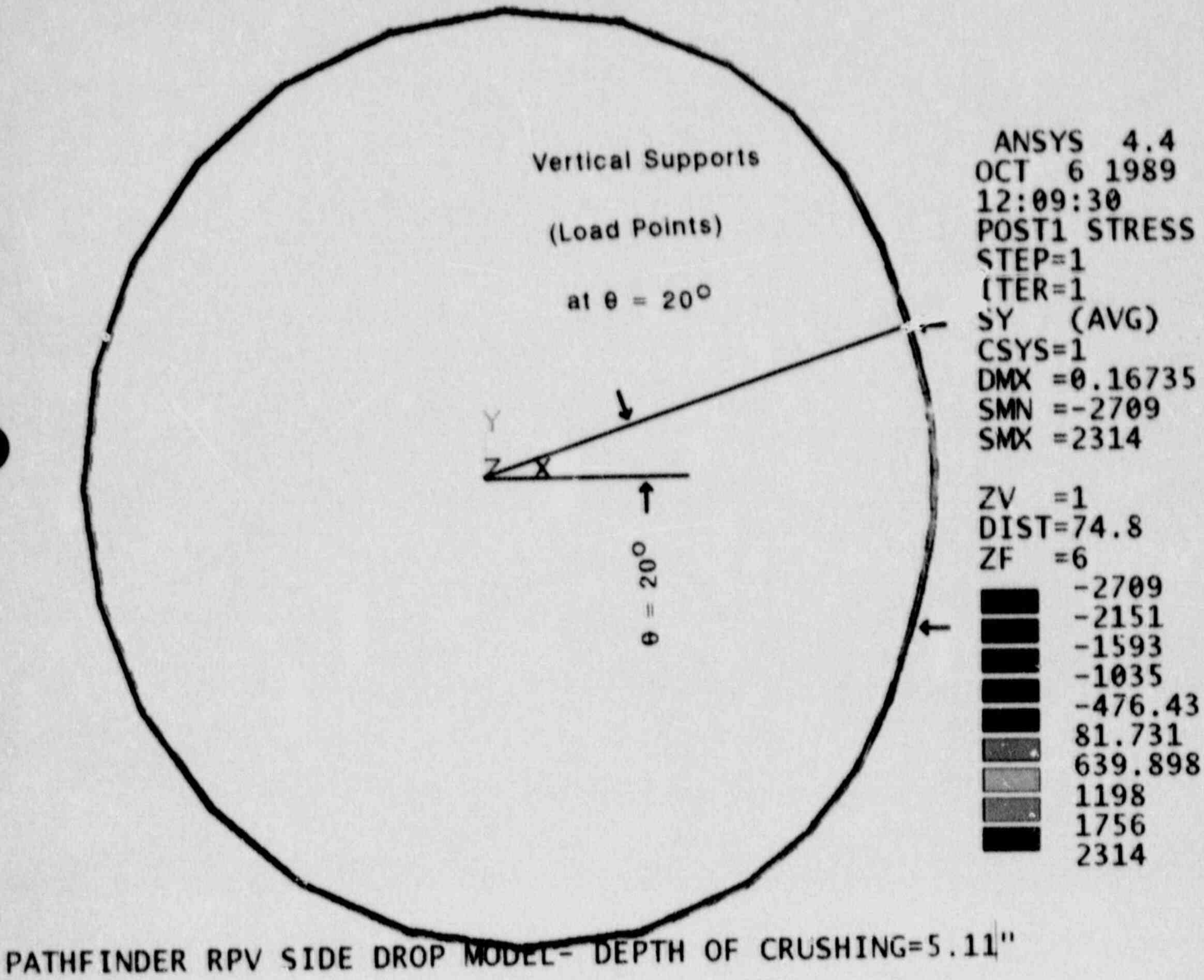


FIGURE 2.12
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 1 INCH

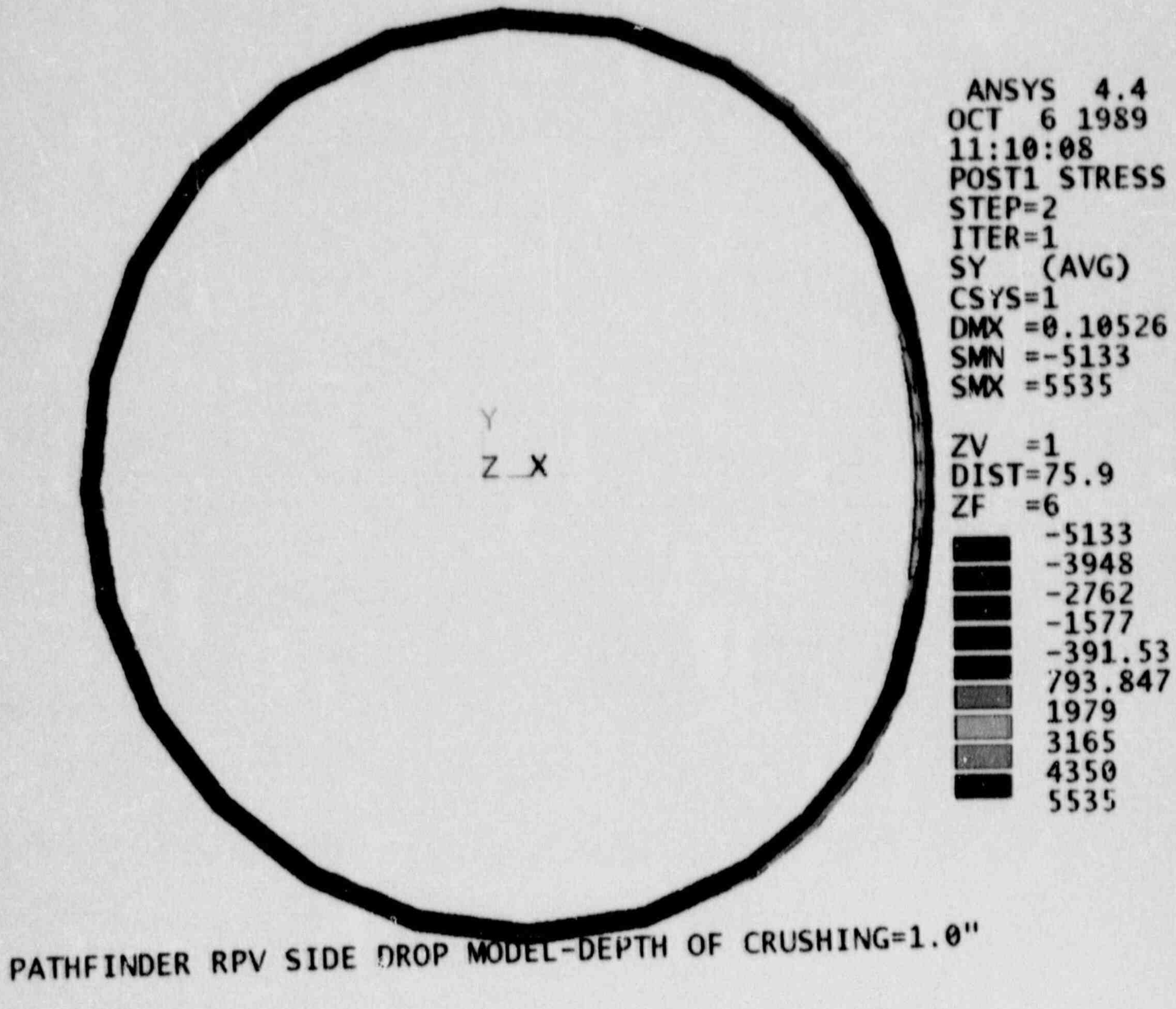


FIGURE 2.13
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 3 INCHES

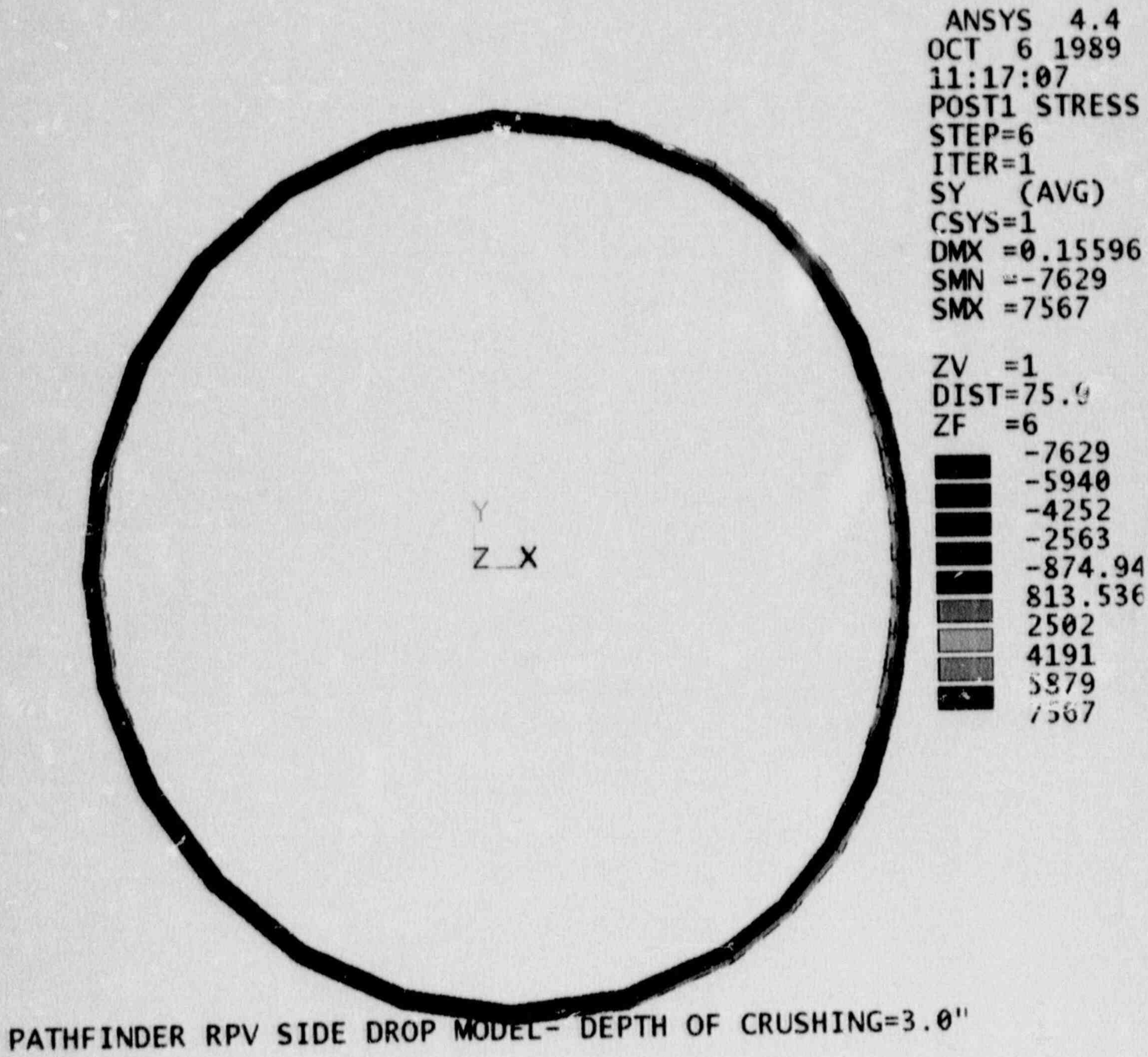


FIGURE 2.14
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 1 - SIDE DROP
CRUSH DEPTH = 5.11 INCHES

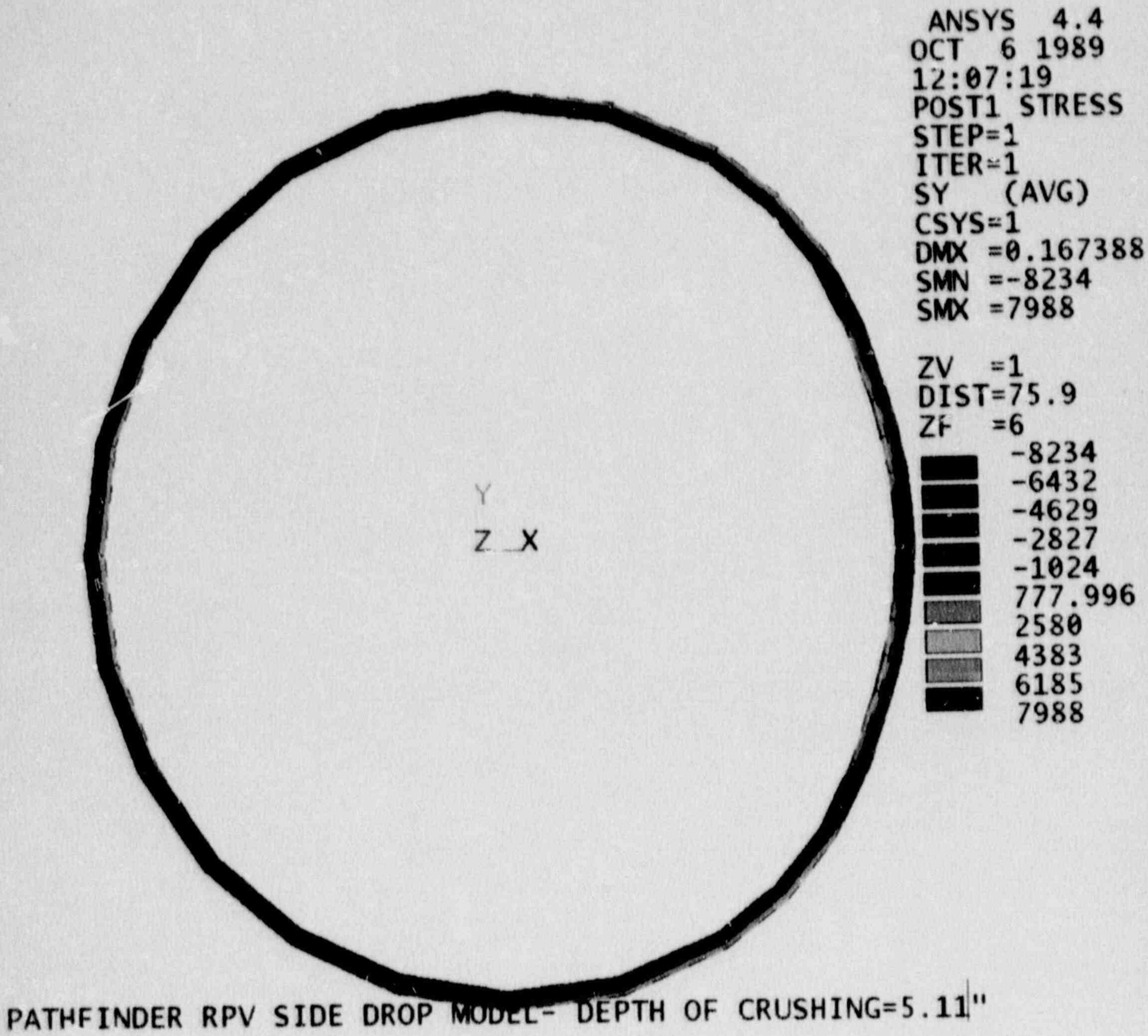
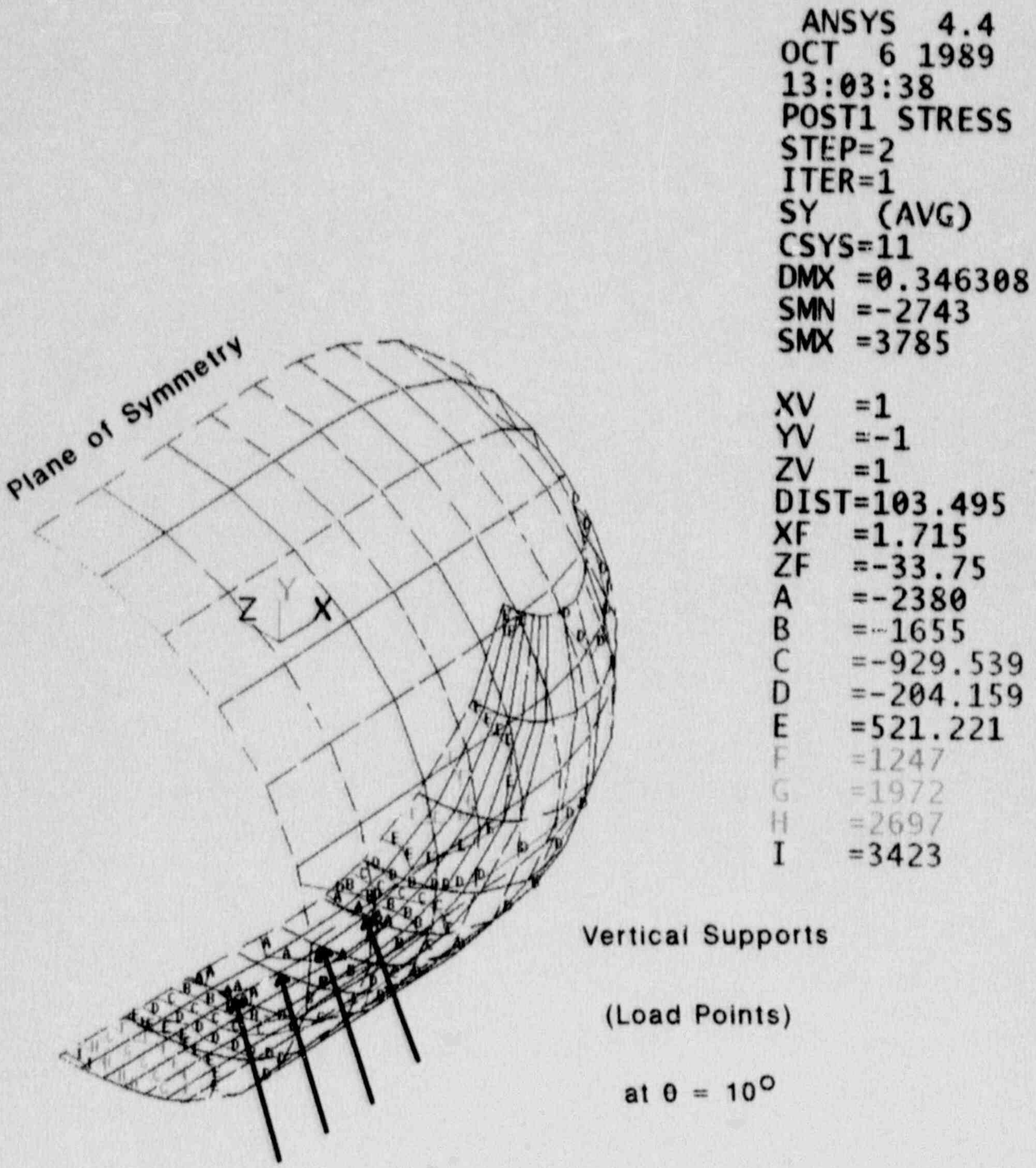
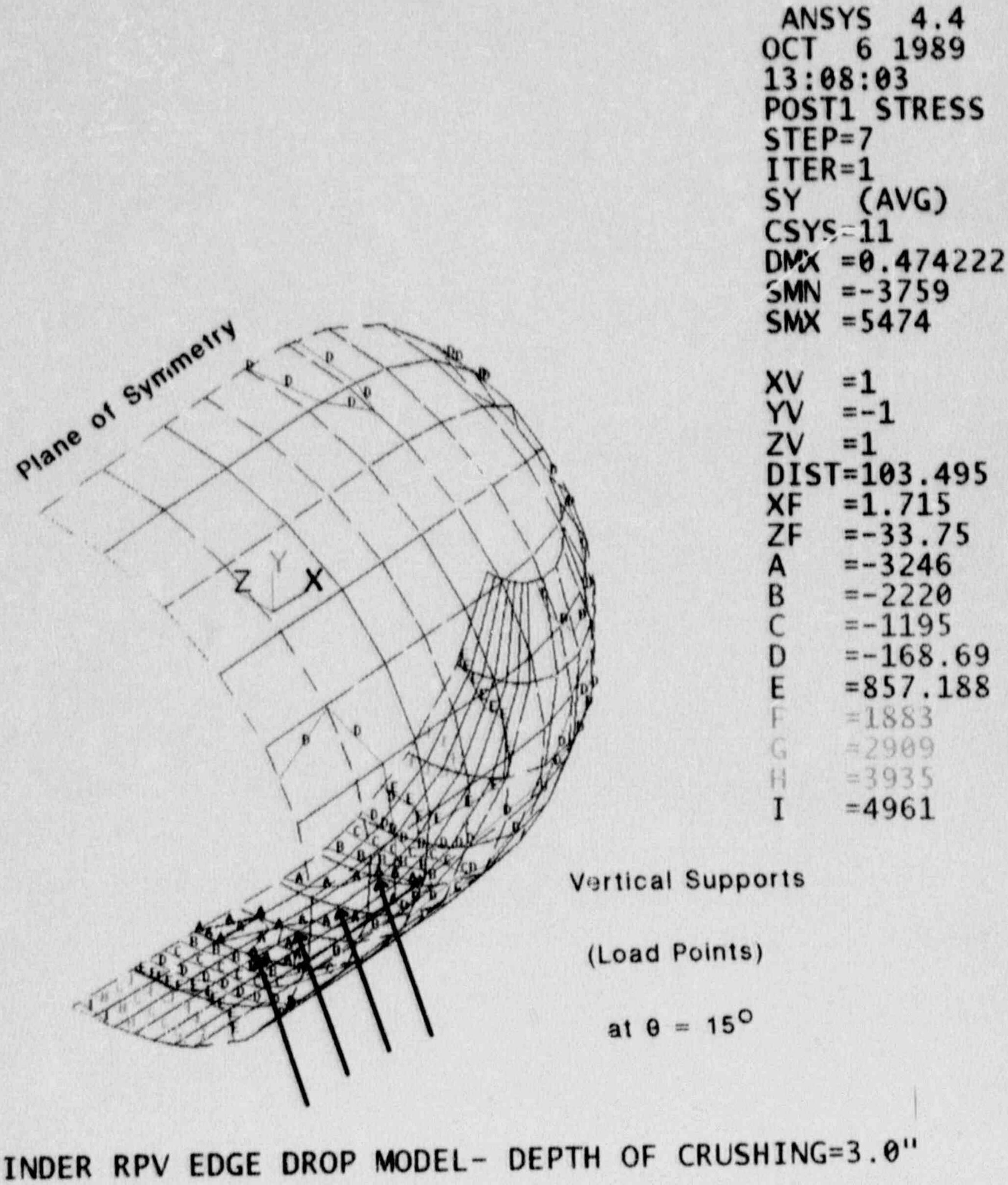


FIGURE 2.15
MAXIMUM MEMBRANE STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 1 INCH



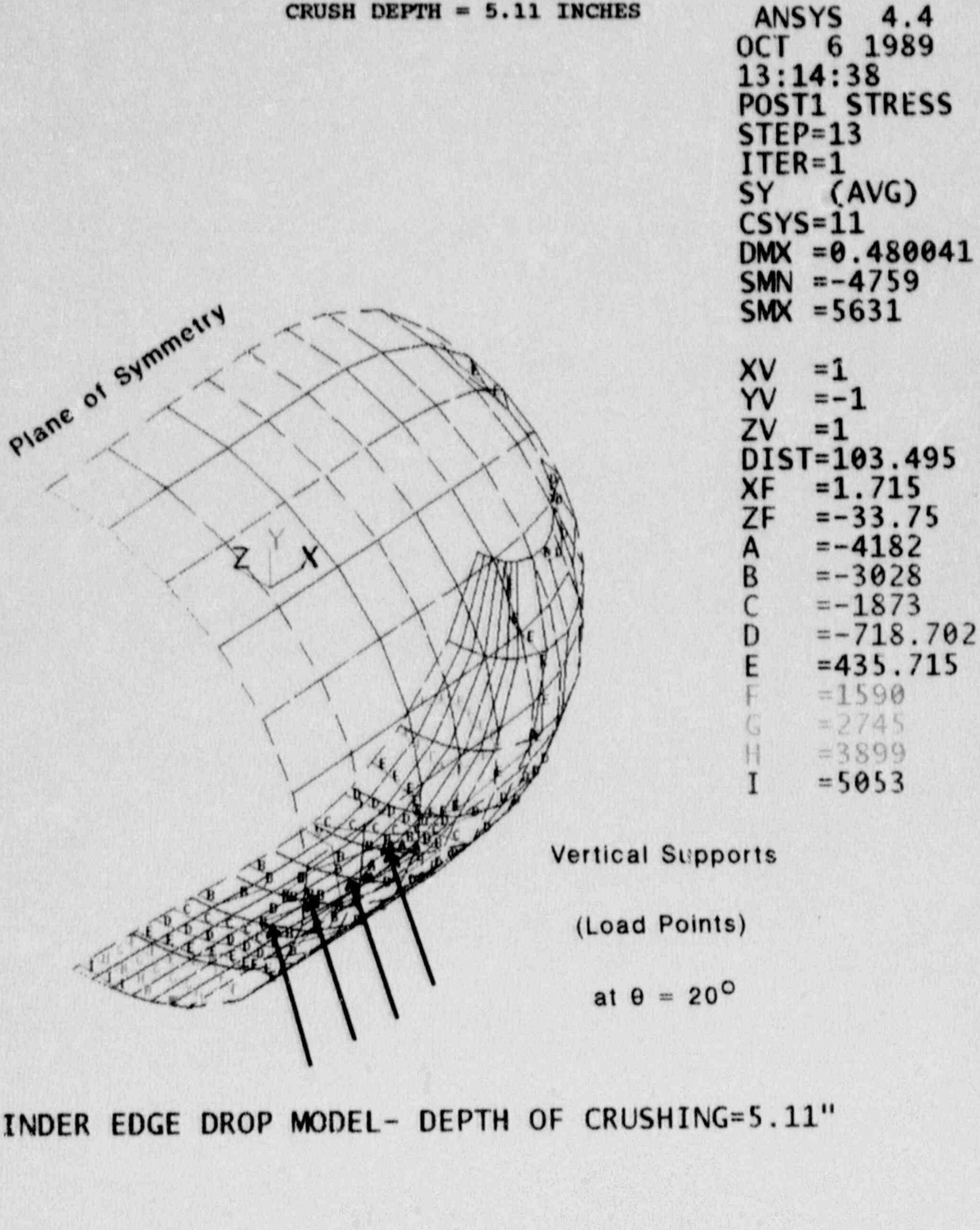
PATHFINDER RPV EDGE DROP MODEL DEPTH OF CRUSHING=1.0"

FIGURE 2.16
MAXIMUM MEMBRANE STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 3 INCHES



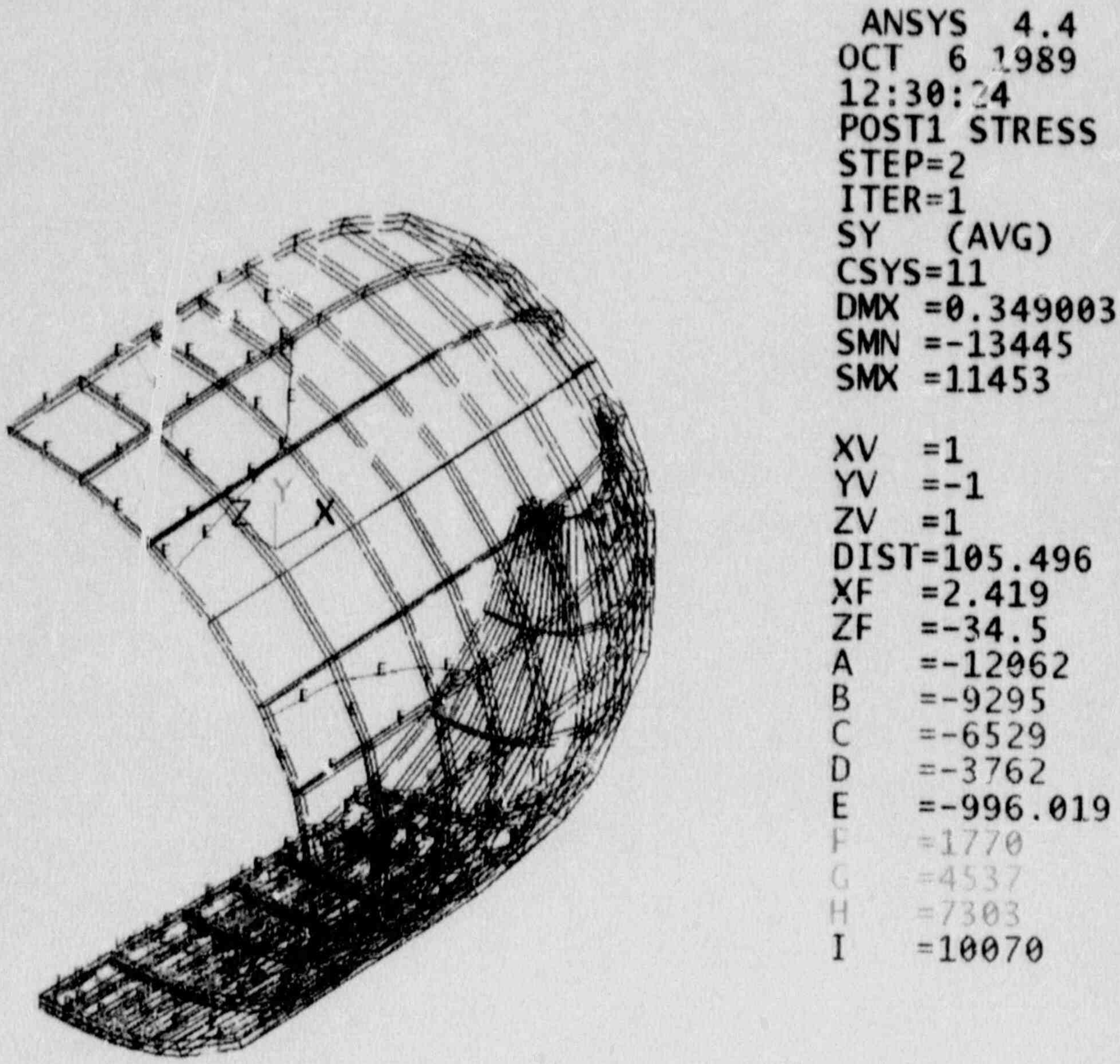
PATHFINDER RPV EDGE DROP MODEL- DEPTH OF CRUSHING=3.0"

FIGURE 2.17
MAXIMUM MEMBRANE STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 5.11 INCHES



PATHFINDER EDGE DROP MODEL- DEPTH OF CRUSHING=5.11"

FIGURE 2.18
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 1 INCH



PATHFINDER RPV EDGE DROP MODEL DEPTH OF CRUSHING=1.0"

FIGURE 2.19
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 3 INCHES

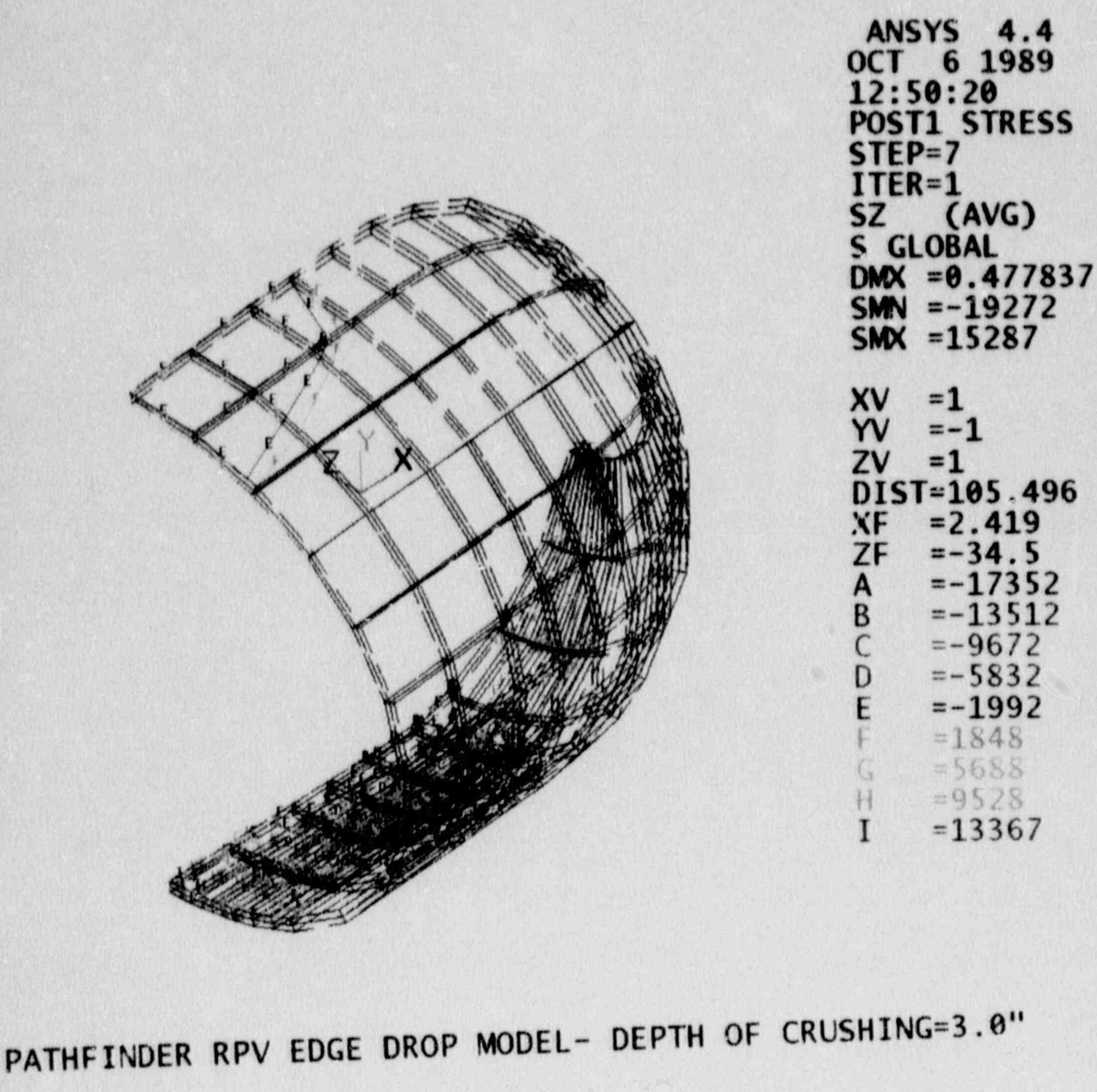
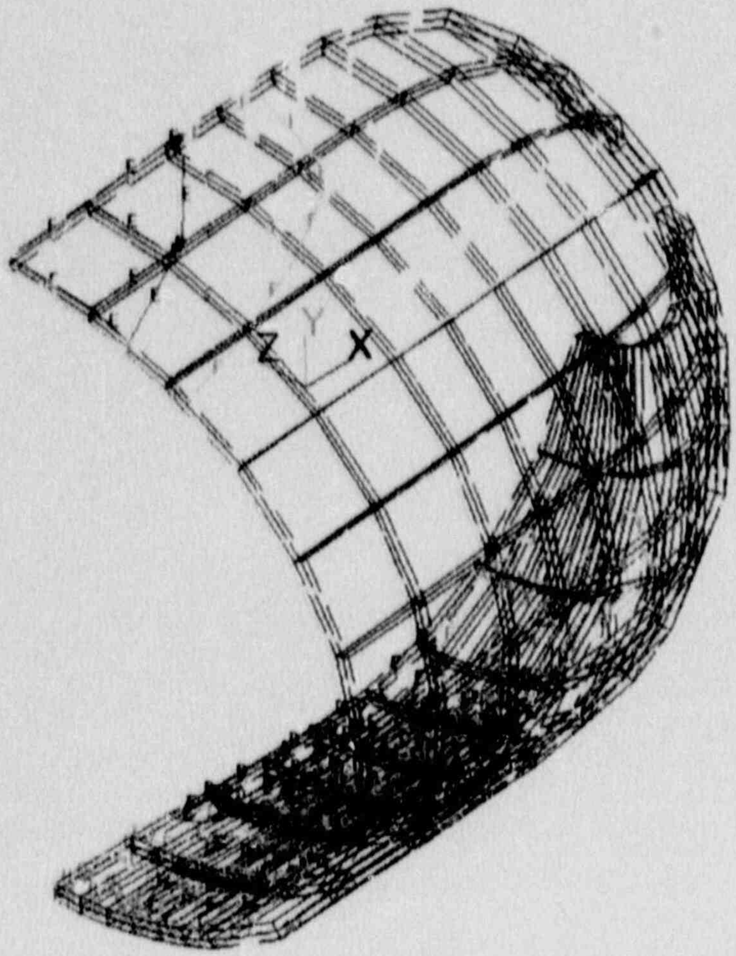


FIGURE 2.20
MAXIMUM MEMBRANE PLUS BENDING STRESS
CASE 2 - EDGE DROP
CRUSH DEPTH = 5.11 INCHES



PATHFINDER EDGE DROP MODEL- DEPTH OF CRUSHING=5.11"

LIST OF TABLES

TABLE 2.1
SUMMARY OF MARGINS OF SAFETY
FOR NORMAL CONDITIONS OF TRANSPORT

	Condition	Calculated Value	Allowable Value	Margin of Safety
2.6.1	Heat	Negligible	Sm = 17.88 1.5Sm = 26.81	High
2.6.2	Cold - Max. Stress (ksi)	Negligible	Sm = 17.88 1.5Sm = 26.81	High
2.6.3	Reduced External Pressure - Max. Stress (ksi)	0.25	Sm = 17.88	49.4
2.6.4	Increased External Pressure - Min. Allow. Press. (psi)	20.0	437	20.9
2.6.5	Vibration	0.72	1.5Sm = 26.81	36.2
2.6.6	Water Spray Max. Stress (ksi)	Negligible	Sm = 17.88	High
2.6.7	Free Drop Max. Membrane Stress (ksi)	6.24	Sm = 17.88	1.86
	Max. Membrane Plus Bending Stress (ksi)	21.14	1.5Sm = 26.81	0.27
2.6.8	Corner Drop	N/A	N/A	N/A
2.6.9	Compression	N/A	N/A	N/A
2.6.10	Penetration Max. Thickness of Penetration (in)	0.015	3.0	199.0
2.6.11	Load Resistance Max. Stress (ksi)	0.72	1.5Sm = 26.81	36.2

NOTE: The margin of safety is defined as:

Margin of Safety = MS = (Allowable/Calculated) - 1

A positive margin of safety indicates that the allowable has not been exceeded.

TABLE 2.2
MAJOR VESSEL COMPONENTS AND ASSEMBLIES
MATERIAL TYPES

TABLE .

Item or Assembly	Fig. No.	Items	Material	Manufacturing & Procurement Specs						
				Mat'l.	Mfg.	Weld	Weld Clad	Sonic	Mag Part	Fluid Pen.
Top Flange Assembly	2	2	ASTM A105-II +SS Weld Over	134*		203X	152X 307X 365	147*X		173X
Upper Neck	2	3	ASTM A212-B +304L Clad	131*	129*	130*	152X	132*X	165*	173*
Main Cylinder	2	4	ASTM A212-B +304L Clad	131*	129X	130X 319X	152X	132X	165X	173X
Lower Head	2	5	ASTM A212-B +304L Clad	131*	129*	130*	152X	132*X	165*	173*
Bottom Head	2	8	ASTM A212-B +304L Clad	131*	129*			132*X		173*
Lower Cylinder	2	7	ASTM A212-B +304L Clad	131*	129X	130X 319X	152X	132*X		173X
Flue Ring	2	6	ASTM A105-A +SS Weld Over	134*			152X 307X	147*X		173X
Feedwater Nozzle Assy.	2	12,26				207X 218X				133X
Feedwater Nozzle	2	12	ASTM A105-II +SS Weld Over	134*			152X	147*X		173X
Thermal Sleeve	2	26	ASTM A182 Type F 304L	217*				ACP 6-33*X		
Feedwater Pipe	2	67	ASTM A312 Type 304L SS Seamless	193*				ACP 6-32*X		
Suction Nozzle	2	13	ASTM A105-II +SS Weld Over	134*			152X	147*S		173X
Discharge Nozzle	2	14	ASTM A212-B +SS Weld Over	189*		203X	152X	132*X	165X	173X
Instrument Nozzle	2	11	ASTM A105-II + Inconel Overlay	134*			152X	147*X		173X
Liquid Level Nozzle	2	10	ASTM A105-II + Inconel Overlay	134*			152X	147*X		173X
Steam Outlet Nozzle	2	9,62,63				213X 214X			165X	173X
Outlet Nozzle	2	9	ASTM A105-II +SS Weld Over	134*			152X	147*X		173X
Internal Sleeve	2	62	304L SS	150*		207X		132*X		173X

TABLE 2.2 (Continued)
MAJOR VESSEL COMPONENTS AND ASSEMBLIES
MATERIAL TYPES

TABLE .

Item or Assembly	Fig. No.	Items	Material	Manufacturing & Procurement Specs: Mat'l.	Mfg.	Weld	Weld Clad	Sonic	Mag Part	Fluid Pen.
Thermal Sleeve	2	63	ASTM A335 Gr P22 + SS Weld Over.	192*			210X	ACP 6-32*X		173X
Lower Head Assembly	2	5,6,7,8, 9,12,13, 14,26,67		129X 216X	130X 196X 203X 319X		152X		165X	173X
Upper Head Assembly	2	2,3			129X	130X	152X		165X	173X
Major Vessel Assembly	2	All Items			129X	319X 130X	152X		165X	173X
Closure Head	3	2	ASTM A212-B +304L Clad	131*	129*			132*X		173X
Closure Flange	3	3	ASTM A105-II + SS Weld Over	134*			152X 307X 366X	147*X		173X
Control Rod Sleeve	3	4	ASTM B167 (Inconel Pipe)	169*				ACP 6-32*X		
Flanges	3	7,35	ASTM A182 Type F 304	217*				147*X		
Liquid Level Nozzle	3	9	ASTM B166 (Inconel Bar)					ACP 6-31*X		
Instrument Nozzle	3	14	ASTM B166 (Inconel Bar)					ACP 6-31*X		
Closure Assembly	3	All Items			129X	130X 319X 198X	152X		165X	173X 133X
Studs	4		ASTM A437 Gr B4B	ACM 143*	216X	218X 260X		ACP 6-31*X	165X	
Nuts	5		ASTM A437 Gr C4?	ACM 12*	216X 479X			ACP 6-31X	165X	
Vessel Support Columns	6		USS "TI"	322*	321X			132*X	165X	

NOTES:

* Indicates for material procurement or outside manufacture

X Indicates A-C shop procedure

All items were cleaned in accordance with A-C specification #43-201-661.

Identification of all items was maintained in accordance with A-C specification #43-101-282.

TABLE 2.3
PRESSURE CONTAINING PARTS AND SUPPORT STRUCTURES MATERIAL PROPERTIES

TABLE II

Component	Fig. No.	Item No.	Material	W.P. Test No.	Yield Strength (PSI)	Tensile Strength (PSI)	% Elongation	Charpy V-Notch Impact Energy at 10 F (FT-LB)
Top Flange	2	2	ASTM A105-II	202	67,600 57,200	85,900 81,600	27.8 31.0	119 - 120 - 108 82 - 65 - 70
Upper Neck (4 seg.)	2	3	ASTM A212-B	200	42,900	71,100 71,400	34	17 - 16 - 15
Upper Neck (4 Seg.)	2	3	ASTM A212-B	200	46,500	73,500 72,500	31	31 - 29 - 30
Main Cylinder #1	2	4	ASTM A212-B	213	42,500	72,600 75,000	32	19 - 15 - 17
Main Cylinder #2	2	4	ASTM A212-B	214	41,000	74,200 71,600	34	21 - 20 - 16
Lower Head	2	5	ASTM A212-B	201	47,000	71,800 73,000	30	26 - 30 - 31
Flue Ring	2	6	ASTM A105-II	203	47,150 45,150	74,250 74,500	33.5 33	28 - 27 - 31 27 - 23 - 29
Lower Cylinder	2	7	ASTM A212-B	212	40,500	76,500 74,900	34	16 - 16 - 17
Bottom Head	2	8	ASTM A212-B	211	40,800	74,700 75,000	33	15 - 16 - 15
Steam Outlet Nozzle	2	9	ASTM A105-II	209	45,000	73,000	34	21 - 18 - 18
Liquid Level Nozzle	2	10	ASTM A105-II	208	50,900	74,000	32	16 - 20 - 19
Instrument Nozzle	2	11	ASTM A105-II	210	51,500	74,000	25	18 - 17 - 15
Feedwater Nozzle	2	12	ASTM A105-II	209	51,500	74,000	25	18 - 17 - 15
Suction Nozzle #1	2	13	ASTM A105-II	205	42,500 40,300	72,500 71,500	34 32.5	17 - 18 - 22
Suction Nozzle #2	2		ASTM A105-II	206	44,800 40,400	72,000 71,750	33 30.5	22 - 16 - 15 15 - 22 - 15
Suction Nozzle #3	2		ASTM A105-II	207	43,700 41,200	71,750 72,000	35.5 34	18 - 19 - 19
Discharge Nozzles #1,2,3	2	14	ASTM A212-B	215 216 217	49,200	77,200 77,400 84,500	34	23 - 21 - 24
Foot Pad	2	25	ASTM A212-B	243	46,200	80,400	30	28 - 25 - 24 (See Note 1)
Support Lugs	2	25	ASTM A212-B	244 245	46,100	78,200 77,500	31.5	16 - 16 - 19
Thermal Sleeve	2	26	ASTM A182 Type F 304L	246	29,100	77,100	77	
Seal Ring	2	27	ASTM A212-B	251	51,500	79,800 78,400	27	20 - 20 - 18
Key	2	33	ASTM A212-B	234	49,100	80,900 78,400	33	18 - 22 - 19
Steam Outlet Sleeve	2	62	ASTM A240 Type 304L	231	32,950	78,927	64	

TABLE 2.3 (Continued)
PRESSURE CONTAINING PARTS AND SUPPORT STRUCTURES
MATERIAL PROPERTIES

TABLE II

Component	Fig. No.	Item No.	Material	N.P. Test No.	Yield Strength (PSI)	Tensile Strength (PSI)	% Elongation	Charpy V-Notch Impact Energy at 10 F (Ft-Lb)
Feedwater Pipe	2	67	ASTM A312 Type 304 Seamless	228	41,000	79,800	76	
Closure Head	3	2	ASTM A212-B	248	44,900	78,100 78,600	32	19 - 23 - 18
Closure Flange	3	3	ASTM A105-II	247	46,700 45,300	70,000 71,500	40.5 38.5	110 - 140 - 126 138 - 115 - 88
Control Rod Sleeve (17 pcs) Control Rod Sleeve (9 pcs)	3	3	ASTM B167	249	36,000 33,500	89,000 91,500	46 48	
Flange (21) Flange (1)	3 3	7 7	ASTM A182 Type F304	361 361	35,200 36,000	81,100 83,000	63 65	
Liquid Level Nozzle	3	9	ASTM B166	263	37,000	93,000	45	
Instrument Nozzle	3	14	ASTM B166	262	42,000	96,500	44	
Instrument Flange	3	35	ASTM A182 Type F304	362	35,750	81,350	67	
Studs Lot #1	4		ASTM A437 Gr B4B	311-1	110,000 108,000	146,800 146,500	14 14	16 Ave (See Note 2)
Studs Lot #2	4		ASTM A437 Gr B4B	311-2	115,000 114,000	155,000 154,000	13 14	15 Ave (See Note 2)
Nuts Lot #1	5		ASTM A437 Gr C4C	333	103,750	125,000	20	32 - 28 - 30 (See Note 3)
Nuts Lot #2	5		ASTM A437 Gr C4C	968	101,250	126,500	20	35 - 34 - 32 (See Note 3)
Support Columns 4" Top Plate	6	2	"T1"	302	122,400 126,300	132,700 133,900	18 20	30 - 18 - 19 (See Note 4)
1-1/8" WEB	6	5	"T1"	299	119,400 117,200	127,800 125,600	20 21	32 - 33 - 35
1-1/4" Flanges	6	5	"T 1"	300	106,000 108,000	116,100 117,100 (See Note 5)	19 18	30 - 30 - 31
1" Gussets	6	6,7,8	"T 1"					
3" Base Plate	6	18	"T 1"	303	122,400 126,300	132,700 133,900	18 20	30 - 18 - 19 (See Note 4)
1/2" Plates	6	20,22	"T 1"	304	116,200 114,800	123,900 121,000	24 26	33 - 30 - 35
3/4" Top Plate	6	21	"T 1"	305	108,600 108,200	117,600 117,800 (See Note 5)	24 23	34 - 34 - 34
1½" Bottom Plate	6	23	"T 1"	301	106,000 108,000	116,100 117,100 (See Note 5)	19 18	30 - 30 - 31

NOTES:

1. Keyhole impact at -50 F.
2. Charpy V-Notch impacts at room temperature.
3. Izod impacts at room temperature.
4. Approved deviation from specified 30 Ft-Lb. Ave. impact energy.
5. Approved deviation from specified tensile strength of 120,000 psi.

TABLE 2.4
SPECIFIED MINIMUM MECHANICAL PROPERTIES OF STEEL MATERIALS

Material Specification	Application	Youngs Modulus $E(10^3 ksi)$	Yield Strength $\sigma y(ksi)$	Tensile Strength $\sigma u(ksi)$
ASME SA-212, Grade B	Shell and Hemispherical Head	28	38	70

ASTM Tentative Specification (A212-61T)

TABLE 2.5
SUMMARY OF DESIGN STRESS INTENSITY VALUES, Sm

Stress Intensity, ksi (Multiply by 1000 to Obtain psi), For Metal Temperatures, deg F. Not to Exceed

Material	100	200	300	400	500	600	650	700
ASME SA-36	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
ASTM A-212 Grade B *	17.88	17.88	17.88	17.88	17.88	17.88	17.88	17.88

$$* \; Sm = \frac{\text{Min. Actual Tensile Strength (Table 2.3)}}{4}$$

$$= 71.5/4$$

$$= 17.88 \text{ ksi}$$

TABLE 2.6
HEXCEL STRUCTURAL PROPERTIES

5052 Alloy Hexagonal Aluminum Honeycomb — Specification Grade

Hexcel Honeycomb Designation Cell — Material — Gage	Nominal Density pcf	Compressive					Crush Strength psi	Plate Shear					
		Bare		Stabilized				"L" Direction			"W" Direction		
		Strength psi		Strength psi		Mod ksi		Strength psi		Mod ksi	Strength psi		Mod ksi
		typ	min	typ	min	typ	typ	typ	min	typ	typ	min	typ
3/8—5052—.0025	3.7	405	270	420	285	105	180	260	200	55.0	170	115	26.0
1/4—5052—.004	7.9	1420	970	1490	1050	340	725	700	650	130	440	390	52.8

Notes:
Test data obtained at 0.625 inch thickness.

TABLE 2.7
WEIGHT, VELOCITY AND KINETIC ENERGY
FREE DROP ANALYSIS

Condition	Max. Tributary Weight	Velocity of Impact, ft/sec	Kinetic Energy of Impact
Side Drop	24.5 k/ft	8.02	294.0 in.k/ft
Edge Drop	291.1 k	8.02	3,493.2 in.k

TABLE 2.8
LOAD DEFORMATION CHARACTERISTICS

Condition	Depth of Crush, in.	Percent of Available Crush Thkns.	Peak Deceleration Value, g	Maximum Resistance Load, k/ft
Side Drop	5.17	64.6	2.32	121
Edge Drop	5.11	63.9	2.35	1,457

TABLE 2.9
MAXIMUM STRESS SUMMARY

Depth of Crushing, in	Side Drop Max. Membrane Stress, ksi	Side Drop Max. Membrane + Bending, ksi	Edge Drop Max. Membrane Stress, ksi	Edge Drop Max. Membrane + Bending, ksi
0.5	2.56	5.33	3.03	13.06
1.0	2.74	5.54	3.79	13.45
1.5	3.35	6.77	4.63	16.44
2.0	1.91	6.25	4.49	17.11
2.5	2.13	6.97	5.01	19.10
3.0	2.33	7.63	5.47	19.27
3.5	2.52	8.23	5.90	20.78
4.0	2.39	7.27	5.00	20.26
4.5	2.54	7.77	5.30	21.47
5.11	2.71	8.23	5.63	22.83

TABLE 2.10
MEMBRANE AND MEMBRANE PLUS BENDING
MARGINS OF SAFETY

Maximum membrane stress	= 5.90 ksi
Allowable membrane stress = Sm	= 17.88 ksi
Margin of safety = (17.88/5.90) - 1	= **2.03**
Membrane plus bending stress	= 22.83 ksi
Allowable membrane plus bending = 1.5 Sm	= 26.81 ksi
Margin of safety = (26.81/22.83) - 1	= **0.17**
Maximum tensile stress in closure head bolts	= 0.51 ksi
Allowable tensile stress in bolts = Sm	= 17.88 ksi
Margin of safety = (17.88/0.51) -1	= **34.06**
Maximum shear stress in bolts	= 0.43 ksi
Allowable shear stress in the bolts = 0.6 X 38.0	= 22.80 ksi
Margin of safety = (22.8/0.43) -1	= **52.02**

3.0 THERMAL EVALUATION

Since the package does not contain spent fuel, the release of fission products from a fuel source due to excessive temperatures does not need to be considered. Furthermore, since the decay heat generation is conservatively calculated to be 4.67 watts, there are no significant internal thermal gradients that will lead to differential thermal expansion that will, in turn, result in stresses that must be considered in evaluating the structural integrity of the package. For a worst case analysis, a scenario was evaluated for the situation where the vessel and interior concrete are initially at a temperature of 100 deg F and the vessel instantaneously cools to -40 deg F (the maximum range of hot and cold environments specified in 10 CFR 71). In this case the vessel will shrink onto the interior concrete surface and stop further deformation. This is a self equilibrating phenomenon typical of thermal stress situations. For this worst case scenario, the calculated stress in the vessel wall is 23.9 ksi which is less than the 1.5 Sm allowable for membrane plus bending stress of 26.81 ksi. The self equilibrating effect of this phenomenon, coupled with the thermal conductivity effects of the concrete heating the steel and relieving the stress condition is evidence that there will be no significant vessel damage.

The detailed calculations of the decay heat generation are shown in Appendix 3.1.1. The decay heat contribution from the other unlisted isotopes is negligible and was not shown.

The calculations of the thermal stress calculations are shown in Appendix 3.1.2.

APPENDIX 3.1.1

Decay Heat Generation Calculations

Pathfinder Reactor Vessel and Internals
Decay Heat Calculation

Isotope	Curies	Decay Heat (Mev/decay)	Energy Released (Mev/sec)	Energy Released (Watts)
H-3	5.900E-01	5.683E-03	1.241E+08	1.987E-05
C-14	2.500E-01	4.947E-01	4.576E+09	7.331E-04
Fe-55	3.736E+01	5.700E-03	7.879E+09	1.262E-03
Co-60	2.567E+02	2.601E+00	2.470E+13	3.957E+00
Ni-59	1.490E+00	6.700E-03	3.694E+08	5.917E-05
Ni-63	1.787E+02	6.700E-01	4.429E+12	7.096E-01
Nb-94	1.000E-02	1.719E+00	6.360E+08	1.019E-04
Tc-99	1.000E-02	8.460E-02	3.130E+07	5.015E-06
Eu-152	1.300E-01	1.276E+00	6.138E+09	9.832E-04
Eu-154	1.000E-02	1.509E+00	5.583E+08	8.944E-05
	4.752E+02			4.670E+00

APPENDIX 3.1.2

Thermal Stress Calculations

tlg ENGINEERING

BY I Husain DATE 10/16/89 SECTION 3.0-1
CHKD JL DATE 10/22/89 SUB-SECTION ____ OF ____
PROJECT NO. 4-22B TASK NO. PH1584 PAGE ____ OF ____
TITLE NSP - PATHFINDER VESSEL SHIPPING ANALYSIS
Reactor Vessel Analysis as Type 'A' Shipping Container

OBJECTIVE: TO PERFORM STRESS ANALYSIS DUE TO THERMAL LOAD EFFECTS FOR NORMAL CONDITION OF TRANSPORT

II ASSUMPTIONS: ASSUMPTIONS ARE LISTED IN COMPUTATIONS WHERE THEY OCCUR

III REFERENCES:- GENERAL REFERENCES ARE GIVEN ON PAGE 2-23 OF APPENDIX 2.10.7
SPECIFIC REFERENCES ARE PROVIDED WHERE EVER THEY OCCUR

NORMAL CONDITIONS OF TRANSPORT

Initial Conditions for all load cases -
Initial conditions of ambient temperature at -20°F with no insolation and of ambient temperature at 100°F with maximum insolation

LOAD CASE 1 - Hot Environment *

The vessel will be structurally evaluated for an ambient temperature of 130°F in still air and with maximum insolation

LOAD CASE 2 - COLD Environment.*

The vessel will be structurally evaluated for cold ambient temperature of -40°F in still air and shade.

LOAD CASE-1 EVALUATION

As there is no internal heat generation and there are no constraints to thermal expansion, stresses in the vessel due to hot environment condition will be negligible.

LOAD CASE-2 - EVALUATION

In lieu of detail Thermal analysis and lack of temperature profile, it will be conservatively assumed that initially the vessel wall and internal grout gets heated to 100°F and then the temperature drops to -40°F at which point the vessel wall will try to contract and will be constrained to do so by the expanded concrete internals.

Conservatively Assuming Max Temperature Differential $\Delta T = 100 - (-40)$
$= 140°F$

Thermal Analysis (cont'd.)

From ASME Code Section III, Appendix I
Ref 2.3

TABLE I-5.0
COEFFICIENTS OF THERMAL EXPANSION

Materials	Coefficient[1]	70	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
		Temperature, F															
Carbon steel; Carbon-moly steel; low-chrome steels (through 3 Cr)	A	6.07	6.20	6.44	6.67	6.89	7.10	7.33	7.54	7.76	7.96	8.16	8.35	8.54	8.76	8.94	9.16
	B	6.07	6.13	6.25	6.38	6.49	6.60	6.71	6.82	6.92	7.02	7.12	7.23	7.33	7.44	7.54	7.65
	C	0	.0023	.0061	.0099	.0140	.0182	.0226	.0270	.0316	.0362	.0411	.0460	.0511	.0563	.0616	.0670

NOTES:
(1) Coefficient A is the instantaneous coefficient of thermal expansion × 10^{-6} (in./in./F). Coefficient B is the mean coefficient of thermal expansion × 10^{-6} (in./in./F) in going from 70 F to indicated temperature. Coefficient C is linear thermal expansion (in./ft) in going from 70 F to indicated temperature.
(2) For grades 1, 2, 3, and 7.

Table I-5.0

TABLE I-6.0
MODULI OF ELASTICITY OF MATERIALS FOR GIVEN TEMPERATURES — Ref 2.3

Material	−325	−200	−100	70	200	300	400	500	600	700	800
	Modulus of Elasticity, E, = Value Given × 10^6 (psi) for Temperature (F) of										
Ferrous Materials											
Carbon steels with carbon content 0.30 or less, 3½ Ni	30.0	29.5	29.0	27.9	27.7	27.4	27.0	26.4	25.7	24.8	...

Max. Stress in the Vessel Wall Due to ΔT of $140^\circ = E\alpha\Delta T$

where E = Modulus of Elasticity

$$E = \left\{\frac{29.0+27.9}{2} + \frac{27.9+27.7}{2}\right\}\frac{10^6}{2} = 28.13\times10^6 \text{ psi}$$

Coefficient of Thermal Expansion $\alpha = B = 6.07\times10^{-6}$ in/in/°F

Max. Stress in the vessel wall $= 28.13\times10^6 \times 6.07\times10^{-6} \times 140$

$= 23{,}900.6$ psi

$= 23.9$ ksi

4.0 CONTAINMENT

This chapter identifies the package containment for normal conditions of transport. Use of the term containment is predicated on the fact that the package source term consists of activated base metal and a thin internal corrosion film on the surfaces of the well confined internal structural components. In addition, the grout pumped into the vessel under pressure will also serve to bind the surface contamination within the interior of the reactor vessel. The package contains no free-standing pools of contaminated liquids, no explosive mixtures or potential aerosol particles that could be considered radiological hazard.

The exterior of the containment boundary is a steel structure which contains no valves or leak test ports. Leak test criteria or leak rate limits are not applicable to this package as a quantitative measure of containment integrity. Chapters 2.0 and 3.0 showed that there will be no rupture of the vessel due to normal conditions of transport from either structural or thermal stresses, and consequently there will be no release of activated or contaminated radioactive material.

4.1 Containment Boundary

The containment boundary consists of the reactor vessel, vessel head and the nozzle closure plates welded to the nozzle openings. The upper closure head contains 20 control rod drive nozzles, one liquid level and one instrumentation nozzle. The lower hemispherical head contains three pump suction nozzles and one feedwater nozzle. The lower cylinder assembly (part of the lower hemispherical head) contains three pump discharge nozzles and one steam outlet nozzle extending through the bottom of the cylinder assembly. There is a liquid level nozzle and an instrument nozzle connected to the shell of the vessel. Each of these nozzles will be seal welded closed with 3/4 in. thick plates.

4.1.1 Containment Vessel

The primary containment vessel is the reactor vessel itself and its closure head. The detailed description of the three inch thick vessel and closure head is presented in Section 2.1.1. The vessel and closure head were obviously designed to contain radioactivity as an operating power reactor vessel. The nozzles described in Section 4.1 will be seal welded closed to complete the containment boundary.

4.1.2 Containment Penetrations

There are no containment penetrations other than the seal welded closed nozzles as described above. There are no vents, valves or other openings in the containment boundary.

4.1.3 Seals and Welds

The containment does not contain any liquids, gases or materials that could leak out. Containment welds are described in Section 4.1.1.

4.1.4 Closure

The closure head is bolted closed with the original 48 closure studs and nuts designed to contain pressure and radioactivity during reactor power operation. The closure studs have been analyzed in Section 2.6.11 for stress loadings for normal conditions of transport, and shown not to exceed yield stresses for the one-foot drop case.

In addition, the Hexcel outer 1/4-inch thick shell is welded closed and cannot be inadvertently opened.

4.2 Requirements for Normal Conditions of Transport

The limit for radioactive material releases is defined in 10 CFR 71.51(a)(1) for normal conditions of transport. This regulation requires that there would be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^-6 A2 per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.

4.2.1 Containment of Radioactive Material

The radioactive material contents are activated metal components and radionuclides in the thin corrosion product layer. The layer is formed on the internal surface of the reactor vessel and internals. A listing of the radioactive material contents is shown in Section 1.2.4. Activities are referenced to January, 1990. The total source term for the Pathfinder package is 476 Curies of activated material and 95 millicuries of surface contamination.

4.2.1.1 Activated Materials

Nearly the entire source term is comprised of activated carbon steel, stainless steel and Zircaloy-2 components that make up the Pathfinder package. The radionuclides are dispersed in matrices of component alloys which are stable under the conditions of normal transport. Therefore, the activated radionuclides will be contained within the metallic alloys under these conditions.

4.2.1.2 Corrosion Product Layer

The corrosion product layer is a thin, tenacious surface deposit which occurs on components that were in contact with the primary coolant. To evaluate the potential for release of this material, the 95 millicuries was divided by the allowable A2 value for the principal radionuclides of Co-60, Ni-63, Ni-59 and Fe-55 to compare the potential release to the 10^{-6} A2 limit. Accordingly, for the mixture of radionuclides:

$$F1+F2+F3+...Fn \leq 1$$

$$F\ Co\text{-}60 = 5.17 \times 10^{-2}\ Ci\ /\ (7\ Co\text{-}60/A2)$$
$$= 7.39 \times 10^{-3}\ Ci$$

$$F\ Ni\text{-}63 = 4.23 \times 10^{-2}\ Ci\ /\ (100\ Ni\text{-}63/A2)$$
$$= 4.23 \times 10^{-4}\ Ci$$

$$F\ Ni\text{-}59 = 1.30 \times 10^{-4}\ Ci\ /\ (900\ Ni\text{-}59/A2)$$
$$= 1.44 \times 10^{-7}\ Ci$$

$$F\ Fe\text{-}55 = 9.45 \times 10^{-4}\ Ci\ /\ (1000\ Fe\text{-}55/A2)$$
$$= 9.45 \times 10^{-7}\ Ci$$

$$F\ avg = 7.81 \times 10^{-3}\ Ci$$

Therefore,

$$A2\ Quantity = 9.50 \times 10^{-3}\ Ci\ /\ 7.81 \times 10^{-3}/A2$$
$$= 1.22 \times 10^{-6}\ A2$$

The package is designed not to be breached. However, even in the most extreme case if all the surface contamination were instantaneously released from the package, the dispersal would be only slightly above the A2 limit. Obviously, this is a highly conservative case and actual dispersal would be much lower. As noted earlier, within the vessel, the interior of the vessel cavities will be filled with a grout to stabilize the pea gravel and to further bind the surface contamination to the vessel internals. The likelihood of all the surface contamination being released instantaneously is remote.

4.2.2 Pressurization of Containment Vessel

No gases or vapors are available to form an explosive gas in the reactor vessel. Therefore, containment pressurization is not possible. Containment internal pressure is evaluated in Chapter 2.0.

4.2.3 Coolant Contamination

The Pathfinder packa..e contains no coolant.

4.2.4 Coolant Loss

The Pathfinder package contains no coolant.

4.3 <u>Containment Requirements - Hypothetical Accident Conditions</u>

Not applicable.

5.0 SHIELDING EVALUATION

This chapter demonstrates that the shielding around the Pathfinder package meets the requirements set by 10 CFR 71 during normal conditions of transport. The controlling factor for shielding is to show that the exposure rate at two meters from the package will be less than 10 mRem/hr, and at the surface of the package will be less than 200 mRem/hr.

5.1 Shielding Design Features

5.1.1 Shield Description

The shielding used for the Pathfinder package consists of a 1-3/4 inch thick steel cylindrical shell welded to the vessel exterior shell, and a 1/4 inch thick steel shell welded around the exterior of the Hexcel impact limiter. The length of the 1-3/4 in. thick shield extends three feet below the bottom of the core elevation and five feet above the top of the core elevation. The overall length of the 1-3/4 in. shield is 14 feet. The extension above and below the core will shield the contribution from the core internals at the upper and lower regions of the core. There is a 1/8 inch thick shield covering the radial regions where the vessel support saddles and lifting sling points are located. The thinner shielding in these areas is to ensure impact loads will not be transmitted to the vessel shell. Figure 1.2 shows the general arrangement of the shielding materials around the reactor vessel.

In addition, the Pathfinder vessel was filled with 1/4 in. diameter pea gravel at the time of initial decommissioning. The pea gravel filled the vessel cavity with the apparent exception of one point at elevation 1289.5 ft on the northwest side of the vessel. Based on measurements made at the side of the vessel there appears to be a void of approximately six inches diameter, with an exposure rate reading of 600 mR/hr. All other exposure rates are approximately 150 mR/hr at the same elevation. The pea gravel void fraction is assumed to be 25 per cent based on a correlation between calculated and measured exposure rates. In addition, no credit is taken for the grout fill material to be added prior to shipment for its shielding effectiveness other than filling in the apparent void with grout.

5.1.2 Shield Effectiveness

The combination steel shield and gravel materials are sufficient to reduce the calculated core axial centerline exposure rate at two meters from the package surface to approximately 6.9 mR/hr. The contact exposure rate (at one centimeter from the surface) is 24.9

mRem/hr. These exposure rates are well below the 10 CFR 71.47(c) limit of 10 mR/hr at two meters. Table 5.1 summarizes the maximum exposure rates.

Northern States Power Company made dose rate measurements at the outer surface of the vessel in the reactor cavity. The measurements were taken from the basement of the reactor building recording dose rate and elevations vertically upward. The measurements were made on the outer surface of the five-inch thick asbestos insulation. The results of the measurements show that the contact readings were all within the 10 CFR 71 limits of 200 mR/hr, ranging from a few mR/hr to about 80 mR/hr except for a band at the core beltline region that read between 100 to 200 mR/hr. One hot spot, had a reading of 600 mR/hr as noted earlier was located on the northwest side of the vessel at an elevation of 1289.5 ft. This hot spot appears to be a void in the gravel fill, and the grout fill is expected to shield the area sufficiently to meet the 10 CFR 71 limits. If grout does not fill the void, an external shield patch will be welded to the shield cylinder.

5.2 Source Specification

The primary radiation source present within the package is the gamma ray source resulting from the neutron activation of the metal components during operation of the reactor. The dominant radiation source is from Co-60 as confirmed by a field survey spectral analysis. The contribution of other activation radionuclides are negligible.

5.2.1 Gamma Source

The gamma ray source is dominated by the presence of Co-60 which is derived from the Co-59 impurity through an n-gamma reaction. Co-60 has two high energy gamma rays at 1.17 MeV and 1.33 MeV. The gamma ray energy spectrum that is present at the surface of the package will be the result of the attenuation of gamma rays emitted at these two source energies.

5.2.2 Neutron Source

The Pathfinder package does not have any neutron activity since there is no fissile material in the package. The spent antimony-beryllium source was disposed of in the reactor vessel, but the neutron activity is now negligible since the antimony-125 has a half-life of only 2.73 years and the reactor has been shut down since 1967.

5.2.3 Quantity of Radioactive Materials - Activation Analysis

An activation analysis was performed to determine the number of Curies of radioactive material in the vessel and internals. ORIGEN2 (Ref. 5.1) was the point activation analysis code used for this activation analyses. The Pathfinder plant's operating history, neutron flux, materials in the vessel and internals, and location of the components with respect to the core centerline were used to develop input for the ORIGEN2 code. Where specific information was not available from Pathfinder, references from other similar reactors were used with adjustments to account for differences in plant design or configuration. The ORIGEN2 code outputs provided the Curie per gram contents for each major region of the vessel and internals. These Curie per gram quantities were then multiplied by the number of grams in each component to obtain the number of Curies in each component. The total number of curies estimated is 476 Curies, 99 per cent of which is from Co-60, Ni-63, Fe-55 and Ni-59. The activation analysis was documented in a report entitled, "Radionuclide Inventory and Package Dose Rate for the Pathfinder Atomic Power Plant", prepared by TLG Engineering, Inc., October, 1989. A copy of this report is included in Appendix 5.5.1. The estimated radionuclide inventory is reproduced in Table 1.2, herein.

An estimate was also prepared of the surface contamination source term contribution to the gamma dose rate. Samples from the feedwater system piping to the reactor vessel were collected by Battelle Pacific Northwest Laboratories in 1980 and analyzed for surface contamination levels. The major constituents were Co-60, Ni-63, Fe-55 and Ni-59 as expected. Applying these measured interior surface contamination levels to the surface areas of each component of the vessel and internals showed the total inventory of surface contamination to be 95 millicuries. The detailed description of these calculations are also shown in the TLG Engineering, Inc. report in Appendix 5.5.1. The contribution of this internal surface contamination to the overall package dose is negligible.

5.3 Model Specification

5.3.1 Description of the Shielding Configuration

The concentric geometry of the Pathfinder vessel and internals lends itself to the use of cylindrical geometry for modeling. Vessel internals were represented by homogenized cylinders of the component materials and activation curies, radiating to its outer neighboring cylinder. In turn, each cylinder represents self-shielding to its interior cylinder neighbor reducing the contribution to dose reaching the vessel exterior.

In addition, the 66 cubic yards of pea gravel added at the time of initial decommissioning provides internal shielding. However, the density of the gravel is affected by the void fraction assuming uniform void fraction distribution within the vessel. The gravel void fraction is estimated to be 23.4 percent, and is conservatively assumed to be 25 percent for this analysis.

An external steel shield was provided to reduce the external dose rates to meet 10 CFR 71 limits. The cylindrical shield extended from a point three feet below the bottom of the core to a point five feet above the top of the core. The extension above and below the core region was included to shield from the axial contribution at the top and bottom of the core region.

Two dose points were considered. The first was at the vessel outer wall core midplane region at a distance of one centimeter from the surface. This point was chosen to correlate the measured dose rates to the calculated dose rates to confirm the calculational assumptions of distribution and gravel void fraction. The second dose point was also at the core midplane, but at a distance of two meters from the package outer surface. This latter dose point was selected to evaluate the dose limits in accordance with Title 10 CFR Part 71. Figure 5.1 shows the shielding geometry used for this analysis and the dose points selected for evaluation.

5.3.2 Shield Regional Densities

The shield design was based on a shield density of 7.8 gm/cm^3 for iron. To keep the package weight to a minimum, the exterior shield was divided into two cylinders. The inner cylinder of 1-3/4 in. thickness welded to the vessel outer shell, and the outer shell of 1/4 in. thickness used as the Hexcel impact limiter container.

The shielding analysis was based on a 25% void fraction in the gravel grout mixture. Therefore, no credit was taken for the grout, except for shielding the hot spot.

5.4 Shielding Evaluation

The shielding evaluation was based on the ORIGEN2 activation analysis computer code results. These results were used as input to the Microshield (Ref. 5.2) computer code. All activation quantity results were decayed to January, 1990 to reflect the dose rates in the same year in which the vessel is expected to be shipped. Appendix 5.5 includes the report of the vessel shielding analysis and sample input for the Microshield code runs.

APPENDIX 5.5.1

Radionuclide Inventory and Dose Rate Report

RADIONUCLIDE INVENTORY AND DOSE RATE

for the

PATHFINDER ATOMIC POWER PLANT REACTOR PACKAGE

Prepared for

NORTHERN STATES POWER COMPANY

October 1989

Prepared by:

Francis W. Seymore PE

Approved by:

Thomas S. LaGuardia PE

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APPENDICES

REVISION LOG

Rev.	Date	Affected Pages	Description	Approval
0	18 Oct 89		Original Issue	TLG

EXECUTIVE SUMMARY

An activation analysis was performed for the Pathfinder Atomic Power Plant reactor vessel and internals in support of the Pathfinder Decommissioning Project. The results indicate that approximately 476 curies of neutron activation products, mainly Co60 and Ni63, are present within the reactor vessel and internals. The maximum curie density in any single reactor internal occurred in the boiler shroud, where the specific curie content was estimated to be 0.248 millicuries per gram.

The internal contamination ("crud") layer of the vessel and internals wetted surfaces contains approximately 95 millicuries, mainly Co60 and Ni63.

The external dose rate from the vessel package was calculated to be 6.8 mR per hour at two meters from the vessel at the reactor core midplane. This dose rate is based on 2 inches of carbon steel shielding on the vessel exterior, extending from five feet above the core upper elevation to three feet below the core lower elevation. This calculated dose rate also assumes an average packing density of the gravel present in the reactor vessel of 75% of the maximum.

The results of these analyses show that the Pathfinder reactor vessel and internals can be shipped intact as a single package without exceeding the LSA limits on specific curie content or US DOT external package dose rate.

1. PURPOSE

This report details the calculations performed to support and provide data for the Pathfinder Atomic Power Plant decommissioning plan. They consist of a neutron activation analysis of the reactor vessel and internals, estimation of internal surfaces contamination levels, and estimation of dose rates from the package as currently envisioned for shipping.

The neutron activation calculations have been performed using the ORIGEN2 [1] computer code, which was obtained through Oak Ridge National Laboratory's Radiation Shielding Information Center. The calculations determining the total curies based upon the ORIGEN2 specific curie values (curies per gram) were performed using the Lotus 1-2-3 version 2.01 [2].

The estimate of the primary system surface contamination was made using manual estimates of vessel and vessel internals surface areas, coupled with the Battelle estimates of specific surface contamination levels in the feedwater and main steam systems [3].

The calculation of the external exposure rates from the Pathfinder vessel package were performed using the Microshield code version 3.12 [4]. A variety of calculations were performed to bracket the possible amounts of gravel between the more highly activated portions of the reactor internals and the exterior of the package.

2. APPROACH

The activation analysis has been performed using ORIGEN2. Input to the code included material compositions, the Pathfinder operating history and neutron fluxes. Wherever possible, data obtained through NSP [5,6,7] has been employed. The balance of the input data was extracted from the available literature and is referenced as such. Conservative assumptions were made and justified wherever actual plant data was not available.

The estimate of the primary system surface contamination has been made using manual estimates of vessel and vessel internals surface areas, coupled with the Battelle estimates of specific surface contamination levels in the feedwater and main steam systems [3].

For the shielding analysis, cylindrical source geometry was used as the input model to the Microshield code. Multiple concentric cylindrical regions were used to model the vessel and internals. The activation analysis results from ORIGEN2 were used as a source term for the vessel and internals.

3. PATHFINDER OPERATING HISTORY

The Pathfinder Atomic Power Plant operating history has been extracted from data provided by Northern States Power. An available Pathfinder Six-Month Operating Report indicated that Pathfinder had its initial criticality on March 24, 1964. The plant's final shutdown occurred, due to a condenser tube failure, on September 16, 1967. The total core burnup was 16,635 megawatt(thermal)-days [5].

The Pathfinder Atomic Power Plant Safeguards Report [6] and subsequent correspondence [8] indicates the core design 100% power level to be 199.6 megawatts-thermal, at a core design average neutron flux of 3.5 E+13 neutrons/cm^2-second.

Since most of the power operation occurred towards the end of the plant's life, for the purposes of this analysis it was conservatively assumed that the plant operated at 100% power for 87.6 days, until September 16, 1967.

4. MATERIAL COMPOSITION

Three material compositions were used in this analysis - Type 304 stainless steel, carbon steel and Zircaloy-2. There are other materials used in the construction of the components in this analysis. However, from the research performed, there does not appear to be any component of significant mass manufactured from a material other than the three analyzed here, which would significantly affect the results of this study.

In some of the material composition tables included below it may be noticed that some rather conspicuous elements are missing. As an example, in 304 SS, carbon and oxygen are missing from the table. The source of some of this data [9] did not include certain elements because their activation would not contribute significantly to the long-lived isotopes of interest in a decommissioning study. Annotations have been made in the footnotes to the tables regarding the lack of certain isotopes, and their typical concentrations in the material have been provided.

4.1 Stainless Steel Type 304 [9]

With the exception of the boiler boxes, all reactor vessel internals and the reactor vessel cladding are assumed to be manufactured from Type 304 stainless steel. The composition of this steel for use as input to the ORIGEN2 activation code is listed below.

Element	ppm or %	Element	ppm or %
Li	0.13	Y	5
N	452	Zr	10
Na	9.7	Nb	89
Al	100	Mo	2.60%
Cl	70	Ag	2
K	3	Sb	12.3
Ca	19	Cs	0.3
Sc	0.03	Ba	500
Ti	600	La	0.2
V	456	Ce	371
Cr	18.4%	Sm	0.1
Mn	1.53%	Eu	0.02
Fe	70.6%	Tb	0.47
Co	1414	Dy	1
Ni	10.0%	Ho	1
Cu	3080	Yb	2
Zn	457	Lu	0.8
Ga	129	Hf	2
As	194	W	186
Se	35	Pb	67
Br	2	Th	1
Rb	10	U	2
Sr	0.2		

Notes: No material certifications are available for the Pathfinder vessel internals; the elemental composition of 304 stainless steel above was taken from NUREG/CR-3474 [9]

Carbon is not included in this composition, but normally exists in Type 304 stainless steel at a maximum level of approximately 800 ppm. The creation of C^{14} from the $N^{14}(n,p)C^{14}$ reaction dominates the $C^{12}(n,\gamma)(n,\gamma)C^{14}$ reaction by several orders of magnitude.

The reactor vessel cladding may contain up to 0.8% niobium (columbium) [10]

4.2 Carbon Steel [9]

The reactor vessel shell is manufactured from carbon steel. The composition of this steel for use as input to the ORIGEN2 activation code is listed below.

Element	ppm or %	Element	ppm or %
Li	0.30	Y	20
N	84	Zr	10
Na	23	Nb	18.8
Al	33	Mo	0.56%
Cl	40	Ag	2
K	12	Sb	11
Ca	14	Cs	0.2
Sc	0.26	Ba	273
Ti	2	La	0.1
V	80	Ce	1
Cr	0.17%	Sm	0.017
Mn	1.02%	Eu	0.031
Fe	98.0%	Tb	0.45
Co	122	Dy	-
Ni	0.66%	Ho	0.8
Cu	1274	Yb	1
Zn	100	Lu	0.2
Ga	80	Hf	0.21
As	532	Ta	0.13
Se	0.7	W	5.5
Br	0.85	Pb	820
Rb	48	Th	0.18
Sr	0.15	U	0.20

Notes: No material certifications are available for the Pathfinder vessel and internals; the elemental composition of carbon steel above was taken from NUREG/CR-3474 [9].

Carbon is not included in this composition, but normally exists in carbon steel at a maximum level of approximately 3000 ppm. The creation of C^{14} from the $N^{14}(n,p)C^{14}$ reaction dominates the $C^{12}(n,\gamma)(n,\gamma)C^{14}$ reaction by several orders of magnitude.

4.3 Zircaloy-2 [11]

The boiler boxes surrounding the boiler fuel in the reactor are manufactured from Zircaloy-2. The composition of this metal for use as input to the ORIGEN2 activation code is listed below.

Element	ppm or %	Element	ppm or %
H	13	Fe	0.15%
B	0.33	Co	10
C	120	Ni	500
N	80	Cu	20
O	950	Zr	98.0%
Al	24	Nb	120
S	35	Cd	0.25
Ti	20	Sn	1.6%
V	20	Hf	78
Cr	0.1%	W	20
Mn	20	U	0.2

Notes: The elemental composition of Zircaloy-2 above was taken from PNL-6046 [10].

5. DISCUSSION OF THE POINT ACTIVATION ANALYSIS CALCULATIONS

The point activation calculation of materials at the Pathfinder Atomic Power Plant was divided into two categories:

1. Materials located within the radius of the core boundary.

2. Materials located outside the radius of the core boundary.

For materials located within the core boundary, the ORIGEN2 BWR-U cross section library was chosen. This library contains one-group energy spectrum-averaged neutron cross sections, which best represent the neutron energy spectrum within the core. For materials located outside the core boundary, the ORIGEN2 thermal cross section library - which contains only thermal cross sections at 68 °F. - was used.

A review of the information available on the thermal and fast neutron fluxes as a function of radial distance from the core boundary at Pathfinder indicated a high degree of spectrum thermalization beyond the core boundary, through and beyond the pressure vessel. Typically, more recent light water reactor (LWR) designs have pressure vessels two to three times the thickness of the Pathfinder vessel. While the large LWR's and Pathfinder both see significant thermalization in the plenum region just beyond the core boundary, the thick pressure vessel of the new, large LWR's significantly hardens the neutron flux energy spectrum. At Pathfinder, the neutron spectrum remains relatively well-thermalized beyond the outer wall of the pressure vessel.

Generally, the region inside the core boundary of typical light water reactors has an average fast/thermal neutron flux ratio on the order of 8:1. Outside the core boundary at Pathfinder, the fast/thermal neutron flux ratio was usually less than 1:5. Using in-core cross sections (the ORIGEN2 BWR-U library) would not be representative of the neutron spectrum, and would underestimate the activation of materials beyond the core boundary.

Use of the thermal cross section libraries (the ORIGEN2 thermal library) for radial regions beyond the core boundary requires several factors to be taken into account:

1. The thermal cross section libraries contains cross section data for neutrons at room temperature (2200 m/second, or 68 °F). The curie content results calculated by ORIGEN2 must be temperature-corrected for regional temperatures outside the core boundary.

2. Certain radionuclides in an activation analysis of reactor materials are products of fast neutron reactions only. There is only one radionuclide produced which has a significant impact on curie content and radiation levels - Mn^{54}. Manganese-54 is the product of the $Fe^{54}(n,p)Mn^{54}$ reaction, which a has significant cross section only above 1 MeV.

Since all of the radionuclides of interest in an activation analysis of reactor materials (with the exception of Mn^{54}) have temperature-corrected thermal cross sections which are greater than or nearly equal to the epithermal cross sections, the use of the thermal cross section library in conjunction with the total neutron flux will produce conservative results. In the case of Mn^{54}

the short half-life of the radioisotope (312.5 days) and the long decay time since shutdown (more than 20 years) imply that neglecting this isotope will not seriously impact the final results.

5.1 Activation Within the Core Boundary

Using ORIGEN2 and the BWR-U cross section library, point activation analyses were performed for Type 304 stainless steel and Zircaloy-2. A neutron flux of 3.50 E+13 n/cm^2-second was used as input. The results were decayed to June 1, 1989 within the ORIGEN2 runs. Additional decay to January 1, 1990 was performed exterior to ORIGEN2 with Lotus 1-2-3 during the mass determination and total curie estimates.

5.2 Activation Radially Beyond the Core Boundary

The ORIGEN2 thermal cross section library was used in the point activation analyses of materials radially beyond the core boundary. Neutron fluxes for locations beyond the core boundary (at the core midplane) through the reactor vessel wall were taken from Reference 6. The fast and thermal fluxes from the reference figure were totaled, and the total used as input to ORIGEN2. The radial core midplane neutron fluxes are tabulated below.

Radial Location	Total flux (n/cm^2-sec)
Core boundary	3.50 E+13
Boiler baffle	1.16 E+13
Steam separators	1.07 E+12
Reactor vessel inner wall	3.30 E+10
Reactor vessel outer wall	2.50 E+09

See Figure 5.1 for depiction of assumed axial flux profile.

For components located between the radial locations at which point activation analyses were performed, a logarithmic average of the ORIGEN2-calculated specific curie content results was used. Two such averages were computed and used. The first was at the location of the boiler shroud at a radius of 100.33 cm. The second was at the radial midpoint of the region from the core edge to the inner wall of the reactor vessel, an average radius of 127.6 cm. Point activation analyses were performed for Type 304 stainless steel and carbon steel. The results were decayed to June 1, 1989 internal to the ORIGEN2 code; additional decay to January 1, 1990 was performed with Lotus 1-2-3 during the mass determination and total curie estimates.

5.3 Activation Axially Beyond the Core Boundary

In the absence of axial flux maps for Pathfinder in regions above and below the core axial boundaries, flux reduction scaling factors were employed. For each 30 centimeter segment above and below the core, the total flux was conservatively reduced only by a factor of 10. In addition, for the regions axially above and below the core, point activation calculations were made with the thermal cross section libraries. For above and below the active core region, specific curie content results were multiplied by the axial flux reduction factors to obtain corrected results.

See Figure 5.2 for depiction of assumed radial flux profile.

5.4 Neutron Activation Model

A model was developed for the radionuclide estimation of the Pathfinder vessel and internals; in general the features of the model matched the actual Pathfinder vessel and internals layout with the following exceptions:

- The reactor vessel lower head curvature was ignored; a straight, vertical wall was assumed to run the entire length of the model.

- Material more than 90 centimeters above the core or below the core was not included in the model.

- Neutron fluxes were identified for specific regions of the vessel and internals, i.e. the reactor core, the core boundary, the steam separator region, the vessel inner wall, and the vessel outer wall. Within each of these regions specific curie contents (curies per gram) were calculated using ORIGEN2 for each material present in the region. No effort was made to identify peaks or depressions in the local neutron flux levels and to incorporate these local flux disturbances into the activation model.

- For the purpose of this estimate, the concrete bioshield was not considered in the activation analysis.

Figures 5.3 and 5.4 detail the neutron activation model used for the Pathfinder activation analysis.

FIGURE 5.1

PATHFINDER ATOMIC POWER PLANT
ASSUMED AXIAL FLUX

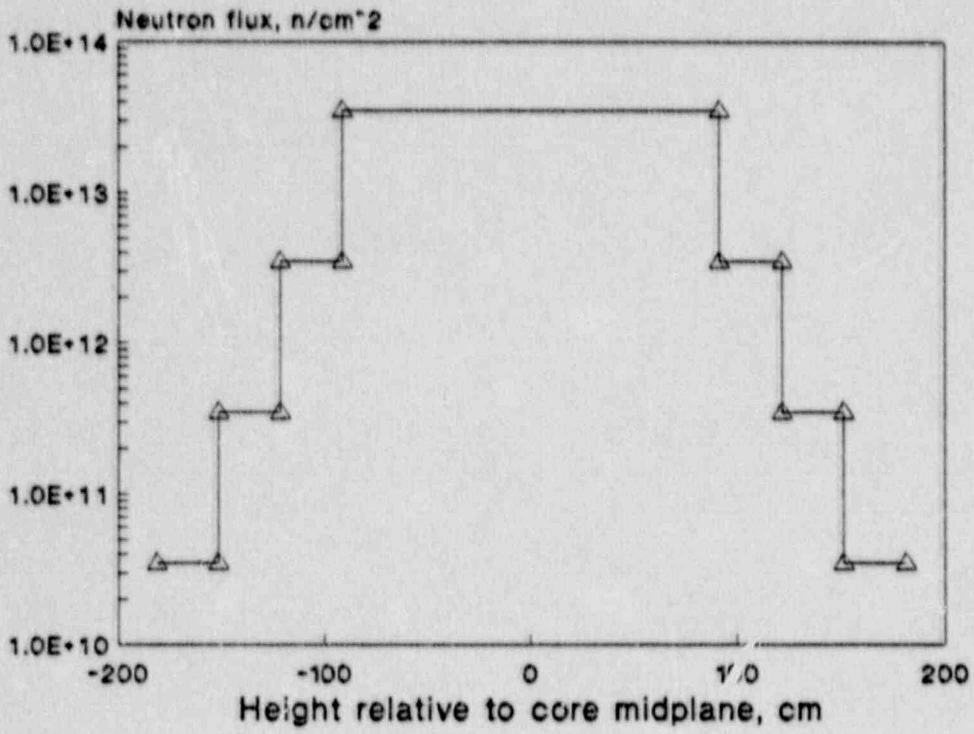


FIGURE 5.2

PATHFINDER ATOMIC POWER PLANT
ASSUMED RADIAL FLUX

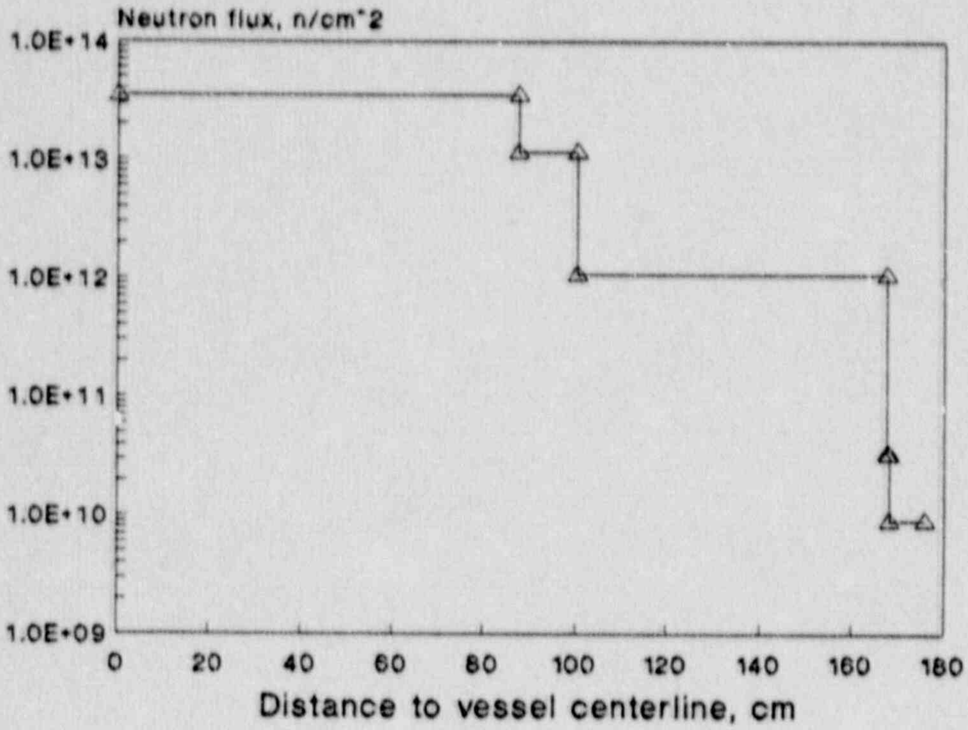


FIGURE 5.3

PATHFINDER ATOMIC POWER PLANT
NEUTRON ACTIVATION MODEL
AXIAL PROFILE

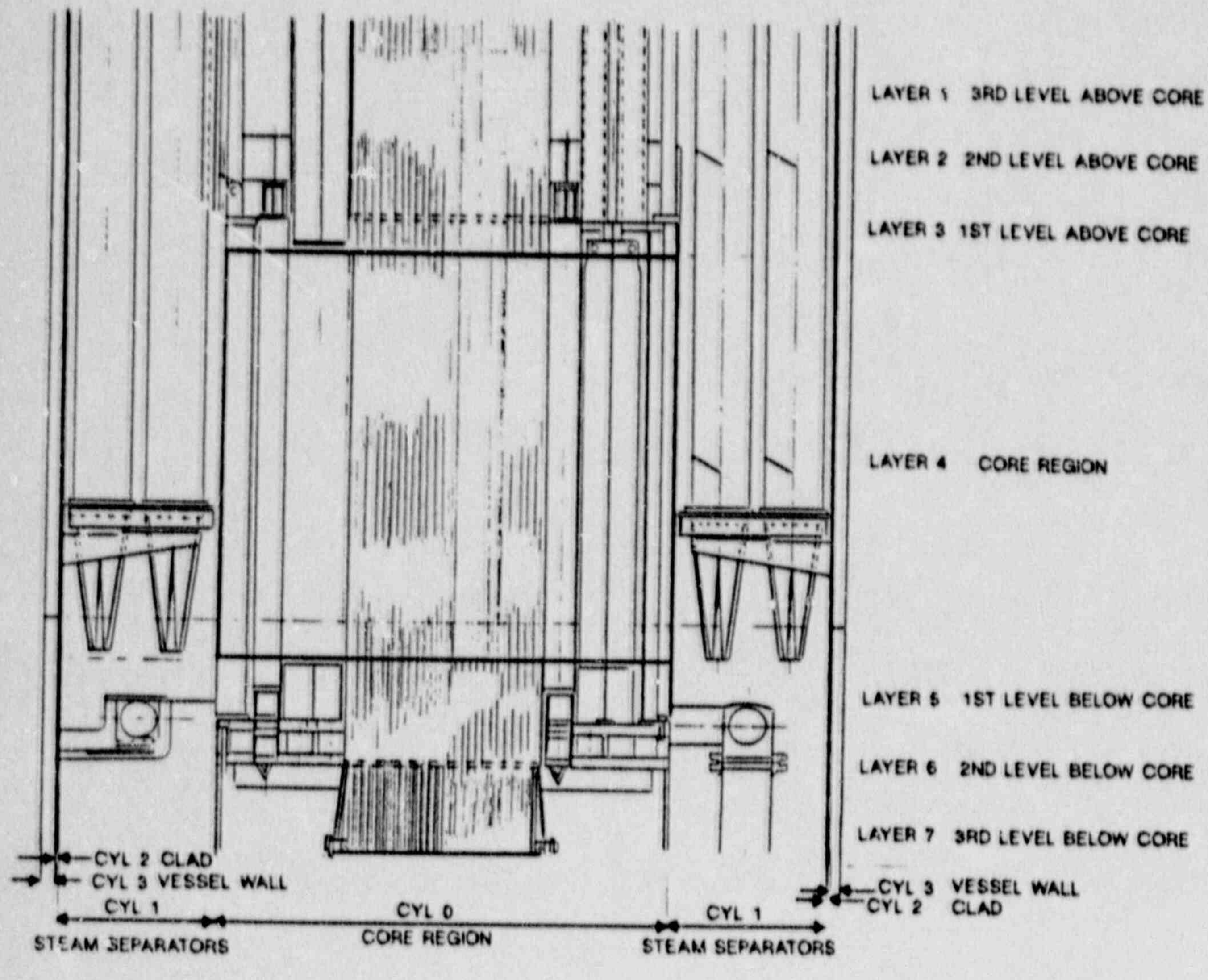
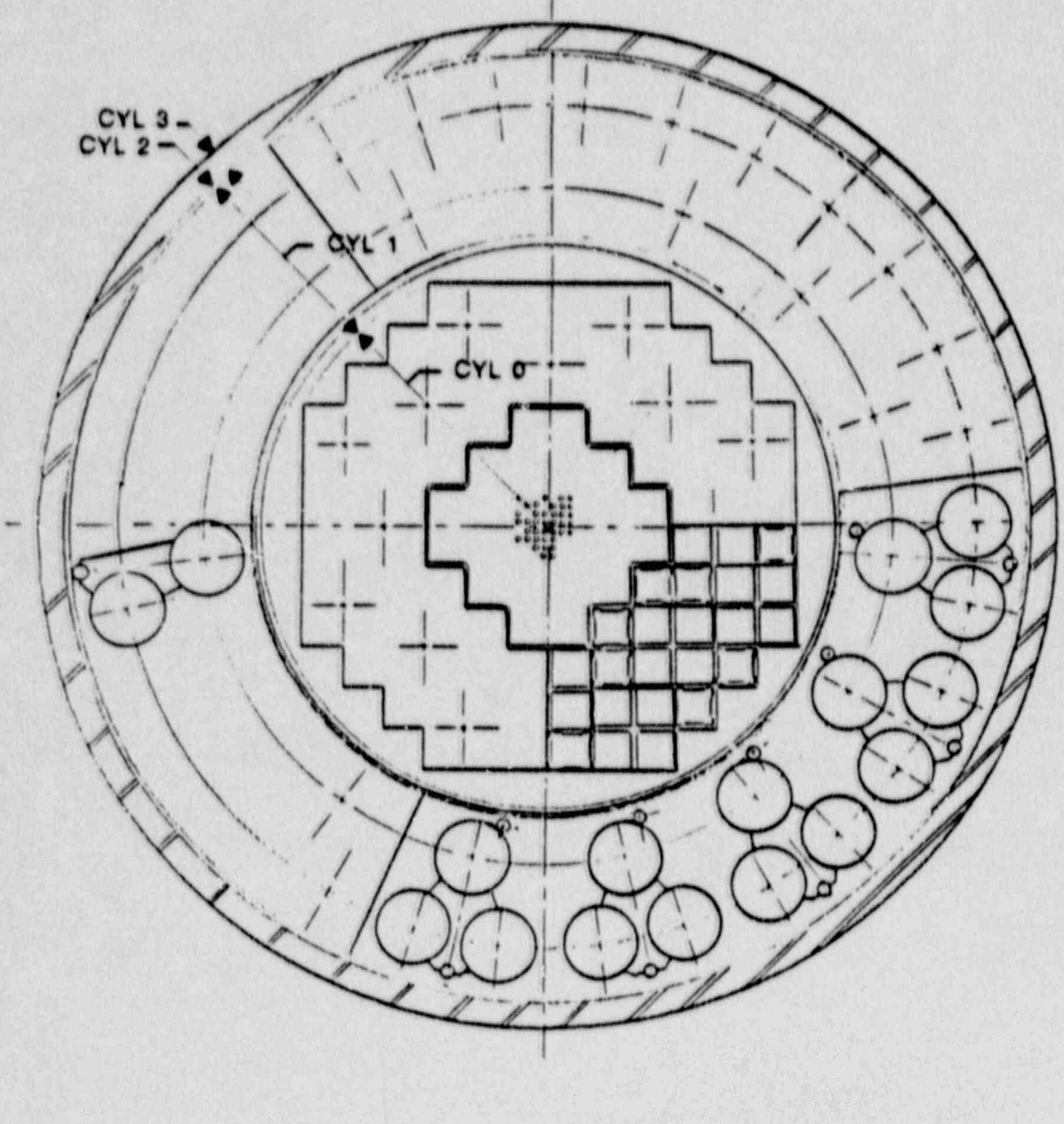


FIGURE 5.4

PATHFINDER ATOMIC POWER PLANT
NEUTRON ACTIVATION MODEL
RADIAL PROFILE



6. COMPONENT DIMENSIONS AND MATERIALS

The Pathfinder reactor was a unique concept in early nuclear design, incorporating nuclear superheating of steam at the center of the reactor core. To achieve this superheating the reactor core was more complicated than current LWR designs, necessitating some unusual components, or components different from those in standard LWR designs. This section describes each component within the vessel package at Pathfinder. Unless stated otherwise, all components are Type 304 stainless steel.

It is important to remember that many of these components fall within two or more regions of the neutron activation model, and as such no single curie per gram value can be allocated to each component. Also, portions of the vessel internals which lay outside the neutron activation model were not considered in the model.

6.1 Superheater fuel element insulating tubes

Each fuel element in the superheater region of the reactor core was contained within an inner and outer insulating tube. The superheater fuel elements themselves were tube shaped, with a central flow path for the superheated steam. The insulating tubes surrounded the fuel element tube, providing additional flow paths for the steam to travel from the top of the reactor vessel through the superheater region and exiting from the vessel bottom. Water for neutron moderation surrounded the outside of the insulating tubes. The tubes run the entire length of the activation model. There are 468 sets of inner and outer superheater fuel element insulating tubes in the Pathfinder vessel internals. Fifty-two of the 468 fuel element/insulating tube sets also contained a superheater control rod.

6.2 Superheater baffle

The superheater baffle is a structural support for the superheater fuel elements as well as a flow baffle separating the water in the boiler section of the reactor core from the water surrounding the superheater fuel elements. It is 0.25 thick inch stainless steel and runs the entire length of the activation model.

6.3 Superheater support plate

The superheater support plate lies at the bottom of the superheater fuel elements, providing support and alignment of the elements. It is stainless steel and curved such that portions of the curved plate would lie outside the activation model; however all portions of the support plate were assumed to lie within the activation model.

6.4 Superheater control rods

The superheater control rods are solid stainless steel of approximately 0.79 inches diameter. Four clusters of 13 control rods are within the superheater fuel element insulating tubes.

6.5 Boiler fuel boxes

Each boiler fuel element was individually contained within a Zircaloy-2 shroud to prevent cross-flow of water through the fuel assembly. The bottoms of the fuel boxes are manufactured from Type 304 stainless steel. There are 48 boiler fuel boxes, together containing 96 boiler fuel assemblies. There are 16 fuel boxes which contain 4 fuel assemblies apiece, and 32 fuel boxes which contain a single fuel assembly.

6.6 Boiler shroud

The boiler shroud is approximately 0.25 inch thick and surrounds the boiler fuel elements, separating the boiler reactor core section from the steam separator region of the vessel. It provides a flow baffle from the upflow through the boiler core region, and the down flow of the steam separator region.

6.7 Boiler fuel element holddown structure

The boiler fuel element holddown structure provides alignment of the boiler fuel assemblies, maintaining inter-assembly spacing for both fuel alignment and movement of the boiler control rods. The bottom of the holddown structure is an alignment grid to contain the fuel assemblies tops; the holddown structure also compresses the fuel assemblies lower nozzle springs, thereby providing both vertical and lateral alignment. The holddown structure also houses and provides alignment for the boiler control rod guide tubes.

6.8 Boiler CR guide tubes and remaining structure

This is basically the balance of the holddown structure above the lower fuel alignment grid; this section provides the rigidity necessary to compress the boiler fuel element lower nozzle springs and maintain the fuel alignment, both vertically and laterally. There are 16 boiler control rod guide tubes integral with the holddown structure.

6.9 Boiler element poison shims

Each boiler element boiler fuel box has indentations on each of it's four sides for the addition of a poison shim for use during initial core startup for control of excess fuel reactivity. It is estimated that 40 poison shims are present in the Pathfinder vessel at this time.

6.10 Boiler control blades

There are 16 cruciform-shaped control blades for the boiler fuel. Each blade is manufactured from borated steel; for the purpose of the activation analysis the boron present in the steel was ignored. The control blades entered from the top of the reactor core.

The six-month operation summaries for Pathfinder indicate several different rod bank heights for the boiler control blades were used during the core physics testing. For the activation analysis, a uniform rod bank height of 36 inches (one half out of core) was used. The 36 inches within the core was irradiated at full core flux, each 30 cm segment above the core was irradiated at 10% of the lower layers value, i.e. 10%, 1%, and 0.1% of full core flux.

6.11 Instrumentation tubing and sample holders

Three 0.75 inch outside diameter stainless steel instrument tubes run from the bottom to the top of the reactor core; in addition there are 12 small and 3 large sample holders at the elevation of the core. Without further information these items were combined into one item and assumed irradiated at the full core flux.

6.12 Boiler grid plate

The boiler grid plate provides lateral alignment for the boiler fuel elements as well as providing support for the fuel elements. The grid plate consists of two separate plates connected by bored-out pipes which surround the fuel element lower nozzles.

6.13 Steam separators and support shelves

The steam separators lie outside the core region at the same elevation as the core. There are 44 separators, grouped in sets of three; these are individually supported by three steam separator support shelves attached to the reactor vessel wall. Suction at the bottom of the reactor vessel draws water through the steam separator lower nozzle, which in turn draws water horizontally through the inlet nozzle in the side of the steam separator. The swirling action of the water separates the entrained steam which exits out the top of the separator.

Portions of the steam separator nozzles failed towards the end of operation of the Pathfinder reactor; these pieces were collected for examination, then returned to the vessel prior to final closure at the end of life.

6.14 Feedwater ring and supports

The feedwater ring is located at the bottom of the reactor vessel, beneath the steam separator support shelves. It is a ring header, oval in cross-section, which is perforated with holes to allow feedwater to be introduced into the lower plenum of the vessel. There the water mixes with water drawn through the steam separators prior to removal by the recirculation pumps and re-injection into the boiler section of the reactor core.

6.15 Reactor vessel cladding

The one quarter inch thick vessel cladding is made of SA 240 Type 304L stainless steel. As in the vessel shell, the cladding runs the entire vertical length of the activation model.

6.16 Reactor vessel base metal

The three inch thick outer wall of the reactor vessel is manufactured of SA212 Grade B carbon steel; it runs the entire vertical length of the activation model. The lower head of the vessel actually would lie within the model; but for simplicity the curvature of the lower head has been ignored, and the walls assumed to continue as a cylindrical shell to the bottom of the model.

6.17 Gravel

The plant records indicate that approximately 66 cubic yards of pea gravel, weighing 214,000 pounds, were placed in the vessel after unloading of the fuel took place; this was done at the recommendation of the Atomic Energy Commission. The estimated void in the vessel after subtracting the volume occupied by the internals is approximately 75.6 cubic yards. This indicates an average packing fraction of approximately 87.3%. There will no doubt be local variations on this packing fraction. In addition, the void of 75.6 cubic yards does not consider the volume of piping beneath the vessel, and some of the gravel probably went through the core region and fell into these pipes.

7. ACTIVATION ANALYSIS RESULTS

7.1 Specific curie contents

The ORIGEN2 outputs provided the following curie per gram contents for the following regions and materials:

Region	Material	Ci/gram
Core (full flux)	304 SS	2.01E-4
Core (full flux)	Zirc-2	1.74E-6
Core (thermal flux)	304 SS	2.94E-5
Boiler Shroud	304 SS	2.48E-4*
Steam Separators	304 SS	5.66E-6
Vessel cladding	304 SS	1.09E-6
Vessel wall (average)	SA212 CS	7.54E-8

* The increase in the curie per gram value for the boiler shroud relative to the in-core values is the result of the conservative assumption that the neutron flux is totally thermalized at this point.

The specific curie content of any individual portion of any component, except the boiler core shroud, within the activation analysis model meets the current definition of LSA waste, i.e. less than 0.3 millicuries per gram. The boiler core shroud, due to the conservative assumption of full thermalization of the flux, exceeds 0.3 millicuries per gram for the section of the shroud immediately adjacent to the reactor core. If the upper and lower sections of the shroud, which are irradiated at 10% of the flux level of the core region, are weight averaged with the central portion, the average millicurie per gram decreases to 0.248, which then meets the definition of LSA waste.

7.2 Curie contents by component

The results of the neutron activation analysis is presented in Table 7.1, and shows the radionuclides by component.

The reactor vessel cladding may contain up to 0.8% niobium [10]. At this level, the amount of Nb^{94} present in the vessel cladding will be approximately 190 μCi. At a weight of approximately 4,240 pounds of stainless steel cladding in the activation analysis model, this equals a concentration of 0.00078 μCi Nb^{94} per cubic centimeter. The limit for Class A waste is 0.02 μCi Nb^{94} per cubic centimeter; therefore the concentration in the vessel cladding in the activation analysis model region alone is only 3.9% of the limit and will not present a problem for disposal.

TABLE 7.1

ESTIMATED RADIONUCLIDE INVENTORY IN THE REACTOR VESSEL AND INTERNALS AS OF JANUARY 1990

Component	H3	C14	Fe55	Co60	Ni59	Ni63	Nb94	Tc99	Eu152	Eu154	Others	Total Curies
Superheater baffle	0.08	0.03	4.58	34.40	0.19	21.97	---	---	0.02	---	---	61.3
Superheater fuel insul. tubes	0.15	0.06	8.77	65.92	0.35	42.11	---	---	0.05	---	---	117.4
Superheater support plate	---	---	---	---	---	---	---	---	---	---	---	<0.01
Superheater control rods	---	---	0.04	0.32	---	0.21	---	---	---	---	---	0.6
Boiler fuel boxes	0.01	0.03	0.84	7.19	0.04	4.35	---	---	---	---	0.86	13.3
Boiler shroud	0.15	0.06	9.59	51.61	0.39	46.84	---	---	---	---	0.01	108.6
Boiler hold down structure	0.01	---	0.61	4.58	0.02	2.93	---	---	---	---	---	8.1
Boiler CR tubes/remain. struct.	---	---	0.49	3.69	0.02	2.36	---	---	---	---	0.01	6.6
Boiler element poison shims	0.03	0.01	1.88	14.14	0.08	9.03	---	---	0.01	---	---	25.2
Boiler control blades	0.11	0.04	6.39	48.03	0.26	30.68	---	---	0.03	---	---	85.5
Instrumentation/sample holders	---	---	0.48	3.58	0.02	2.29	---	---	---	---	0.01	6.4
Boiler grid plate	0.04	0.02	2.52	18.96	0.10	12.11	---	---	0.01	---	---	33.8
[illegible] separators & supports	---	---	0.54	2.93	0.02	2.66	---	---	---	---	0.01	6.2
[illegible]ater ring & supports	---	---	0.15	0.83	---	0.75	---	---	---	---	0.01	1.7
Vessel cladding	---	---	0.06	0.34	---	0.31	---	---	---	---	---	0.7
Vessel	---	---	0.41	0.14	---	0.09	---	---	---	---	---	0.6
Total by isotope (curies)	0.59	0.25	37.36	256.66	1.49	178.68	<0.01	<0.01	0.13	<0.01	0.93	476.1
Percent of total by isotope	0.12%	0.05%	7.85%	53.91%	0.31%	37.53%	<0.01%	<0.01%	0.03%	<0.01%	0.19%	

8. PRIMARY SYSTEM SURFACE CONTAMINATION

8.1 Methodology

An estimate was prepared to determine the total amount of radioactivity present in the surface contamination ("crud") layer on the wetted area of the reactor vessel interior and internals. A surface area for the vessel interior was calculated using dimensioned drawings. The surface area for the vessel internals proved impossible to accurately determine with the available drawings. An assumption was made as to the average thickness of the internals structural components; using this, and with the calculated and/or stated weight of each internals component, the total surface area can be estimated.

8.2 Surface areas

Calculations were performed to determine the wetted internal surface area of the reactor vessel and internals. The total estimated interior surface area of the reactor vessel is approximately 660 square feet. Using the weights stated on the drawings provided by NSP for all internal components, an effective surface area for the internals was calculated. For an average thickness of one-quarter inch, the 44,600 pounds of the internals equates to approximately 8,660 square feet. The total of both areas, converted to square centimeters, yields an affected surface area of 8.67E+6 square centimeters.

8.3 Source terms

In 1980, Battelle Pacific Northwest Laboratories took samples throughout the Pathfinder Plant. There were three samples taken in the feedwater system; these were used as being representative of the type of interior contamination within the reactor vessel [3]. PNL data, when decayed to January 1, 1990, yields the following surface contamination levels:

Radionuclide	pCi/cm^2
Na22	<0.0077
Fe55	109
Ni59	15
Co60	5965
Ni63	4882
Nb94	<0.25
Ag108m	<0.09
Sb125	<0.01
Sn126	<0.06
Cs134	<0.002
Cs137	<0.06
Eu152	<0.2
Eu154	<0.45
Eu155	<0.04
Ho166m	<9.55
Ra228	<0.3
Pu238	<0.00093
Pu239	<0.0039

8.4 Results

Using the total surface areas for the wetted portion of the reactor vessel and internals, and the areal curie density of each radionuclide measured by Battelle, total curies for each radionuclide was determined.

Radionuclide	Total curies	% of Total
Fe55	9.45E-4	1.0
Ni59	1.30E-4	0.14
Co60	5.17E-2	54.4
Ni63	4.23E-2	44.5

All radionuclides with a total activity of less than 0.1 millicurie (i.e. < 1.0E-4 curies) have been ignored. The total estimate of surface contamination radionuclides within the Pathfinder reactor vessel is 95 millicuries.

9. PATHFINDER VESSEL PACKAGE DOSE ESTIMATES

9.1 Method of Calculation

Using the total curies per component estimated with the Lotus 1-2-3 spreadsheet and the geometry of the internals, the dose rate was estimated for a point external to the vessel. Given the multiple layers of sources represented by the concentric nature of the internals arrangement in the Pathfinder vessel, many different runs were necessary, since each source is also a shield for other sources in the internals. All dose rate models used cylindrical sources with cylindrical shields.

In addition to the self-shielding and shielding provided by the internals components and vessel, the gravel added at shutdown serves as an effective shield. However, the density of the gravel undoubtedly varies throughout the region of the neutron activation model. With 66 cubic yards placed into a free void of 75.6 cubic yards, the average gravel packing factor is 87.3% of the theoretical maximum. The maximum density is estimated to be 120 pounds per cubic foot (1.92 grams per cubic centimeter), based upon 214,000 pounds weight of the 66 cubic yards. Since this is similar to the density and composition of concrete, the shielding parameters for concrete were used in the Microshield problems.

Two dose points were considered. The first was at 1 centimeter distance from the vessel outer wall at the core midplane. This determines the maximum contact dose rate and can be readily compared to the measured doses that NSP collected in May of 1989. The second dose point is on the same plane as the first, the core midplane, but is two meters from the edge of the shielded package. The package in this case includes the impact absorbing material and carbon steel shield which will surround the vessel for shipment. The impact absorbing material, together with any radiation shielding, will add approximately ten inches to the radius of the vessel package. This second dose point corresponds to the measuring point necessary to meet the U.S. Department of Transportation (US DOT) regulations.

In addition to the direct dose estimate from the core height region of the vessel internals and vessel wall, the regions above and below the core region are also neutron activated and must be considered in the dose rate. Calculations were performed which indicated, in the most conservative case (no shielding), that the total dose rate at two meters from the package side increased approximately 15% above the dose calculated for the core region. Rather than calculating a dose rate for each shield thickness for the regions above and below the core, the dose rate from the core midsection was increased by 15% to account for the contributions of the regions above and below the core.

See Table 9.1 for measured dose rates on the side of the Pathfinder vessel as of May 1989.

9.2 Results of Analysis

The unshielded dose rate at the core midplane on contact with reactor vessel, assuming a 75% gravel packing factor, is estimated by the activation analysis model to be approximately 254 mR per hour.

With the equivalent of two inches of steel shielding, and assuming a gravel packing factor of 75%, the external radiation exposure rate at the core midplane 2 meters from the exterior of the impact absorbing shell will be 6.8 mR per hour. The dose rate at 1 centimeter from the exterior of the impact absorbing shell (i.e. contact dose rate) at the core midplane will be 24.9 mR per hour. These dose estimates meet the US DOT requirements for external dose rates.

See Figure 9.1 for a depiction of vessel package radiation exposure rates versus the percentage of gravel in the interior void spaces at 1 centimeter from the vessel outer wall. Figure 9.2 shows a depiction of the vessel package radiation exposure rates versus the percentage of gravel in the interior void spaces for three shield thicknesses, as well as unshielded, at a distance of 2 meters from the package.

9.3 Discussion

Given the uncertainties present as to the actual configuration of the gravel within the vessel interior, the best that can be stated about the results shown in section 9.2 is that the measured dose rates alongside the vessel exterior are reasonably close to those estimated with the assumption of 75% gravel packing factor (without external shielding). Since the lowest core midplane dose rate is on the east side of the vessel package and is approximately 40% less than the dose rate estimate of 254 mR per hour, one approach might be to use this as a bench mark and adjust all dose rates accordingly. This would compensate for the built-in conservatism in the activation analysis model. For the purpose of the shield design, this was not done, the recommended shielding thickness is based solely upon the ORIGEN2 activation analysis and Microshield dose model.

The shield thickness of two inches obviously runs the full length of the core region. The shield should also run five feet above and three feet below the core region as well. The five feet above will encompass the 100 mR per hour peak on the west side of the vessel, which occurs approximately 2 feet above the top of the core. With the five additional feet of shielding above the core, all dose rates measured on the side of the vessel above this point meet US DOT limits. For the section below the core, the three foot length is based more upon mechanical considerations than dose limits, as the support feet for the vessel can serve as attachment points for the lower portion of the radiation shield. Based upon the dose readings in Table 9.1, a two foot length would be sufficient to meet US DOT radiation limits; but the three foot length will be easier to implement.

The hot spot shown on the northwest section of the vessel, as listed in Table 9.1 is probably a region of gravel with a packing factor lower than average. If this is the case, the grouting operation will almost certainly close this void region and lower the dose rates. Since the grouting will be performed prior to vessel lift, this will be determined prior to the loss of shielding around the vessel now presently provided by the bioshield. The grouting of the vessel will reduce the dose rate to that comparable for the remaining sections of the reactor vessel package at the same elevation.

The decommissioning crew should be prepared for the possibility that the dose rates will be greater than those estimated to be present with the recommended two inches of steel shielding. If this occurs it is likely to be on a limited basis, most probably one or two small areas. Additional steel shielding will then have to be used to further reduce the radiation levels to meet 10 mR/hour at 2 meters from the package.

9.4 Recommendations

The project should plan for the fabrication and use of a two inch thick steel shield surrounding the reactor vessel, starting at three feet below the bottom of the core, and ending five feet above the top of the core. The two inch thickness can include any additional steel to be placed around these regions, such as the impact absorbing material.

The vessel interior should be grouted to reduce the possibility of voids or "windows," which would allow excessive radiation leakage.

If the opportunity occurs, additional characterization would be invaluable in reducing the uncertainties with this hot-spot region on the northwest side of the vessel. Detailed geometry studies would help assess the extent of void assumed to be present.

TABLE 9.1

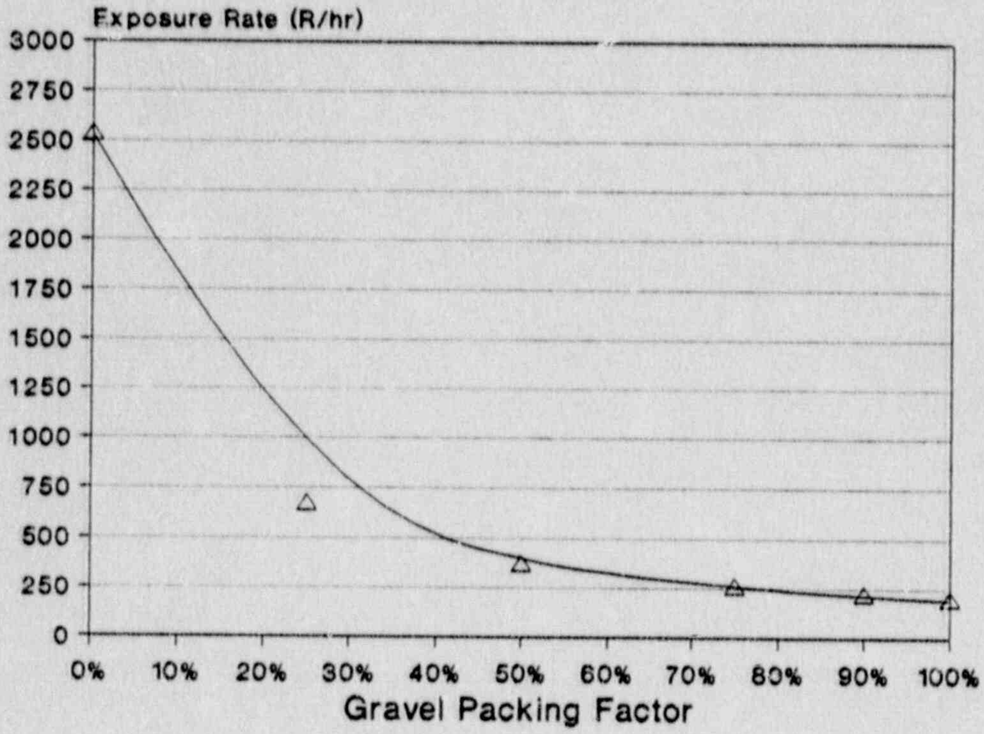
PATHFINDER MEASURED RADIATION LEVELS AS OF MAY 1989

Elevation (MSL)	South mR/hr	West mR/hr	North mR/hr	East mR/hr
1285	1.75	2	5	1.8
1286	3	8	5	2.2
1287	9	27	20	7
1288	33	80	225	30
1289	90	175	450	150
1290	45	75	140	80
1291	17	85	35	22
1292	15	90	18	15
1293	9	95	10	10
1294	6	100	7	5
1295	3	75	3.8	3.2
1296	1.8	35	2.8	2
1297	1.5	8	2.2	1.5
1298	1.7	2.2	1.5	1.6
1299	1.7	1.2	1.5	.9
1300	.5	.7	.8	.5
1301	.3	.7	.5	.4
1302	.3	1.5	.25	.25
1303	--	3	.3	1.8
1304	--	7	--	--
1305	--	.2	--	--

The highest observed dose rate was 600 mR/hour at elevation 1289.5 elevation, on the north-west side of the vessel.

FIGURE 9.1

PATHFINDER VESSEL PACKAGE
GRAVEL PACKING % vs EXPOSURE RATE
CONTACT DOSE

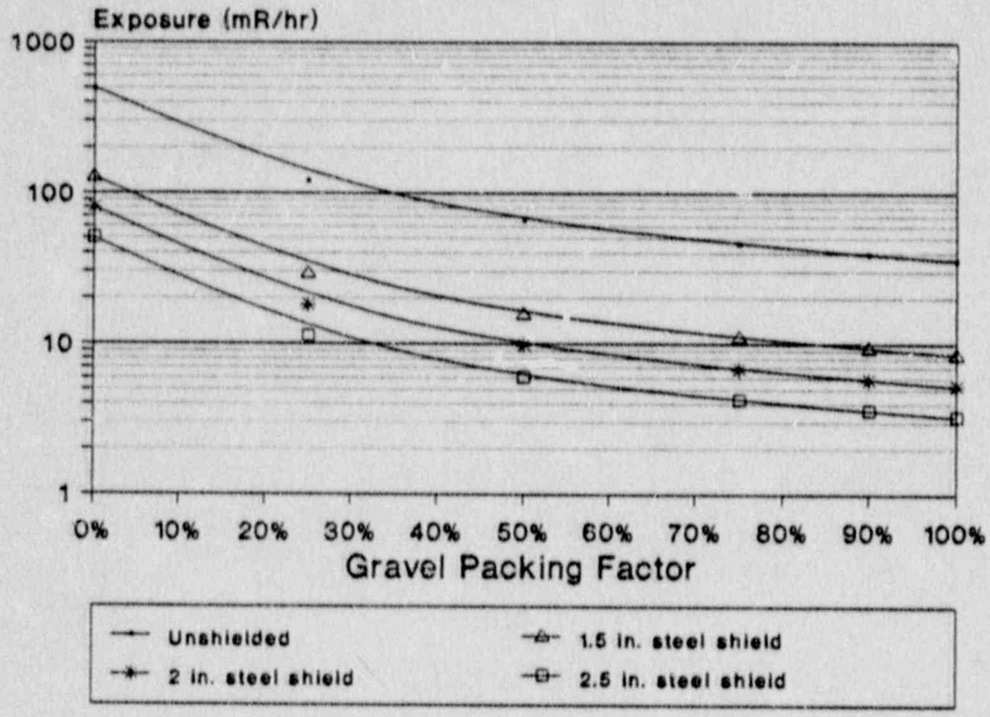


Shield Thickness	Gravel Packing Factor, % 0	25	50	75	90	100
Dose rate (mR/hr)	2529	665.6	364.4	253.5	214.3	194.3

Dose rate is measured at a point 1 centimeter from the vessel outer surface directly adjacent with the reactor core midplane.

FIGURE 9.2

PATHFINDER VESSEL PACKAGE
GRAVEL PACKING % vs EXPOSURE RATE
DOSE AT 2 METERS



Shield Thickness	Gravel Packing Factor, % 0	25	50	75	90	100
Dose rate (mR/hr)						
0.0 inch	498.2	120.2	65.49	45.98	39.08	35.56
1.5 inch	128.1	29.04	15.73	11.03	9.377	8.54
2.0 inch	80.18	18.04	9.768	6.845	5.825	5.303
2.5 inch	49.97	11.16	6.041	4.234	3.603	3.282

Dose rate is measured at a point 2 meters from the vessel package directly adjacent with the reactor core midplane. Values include an additional 15% for the portions of the activated reactor core above and below the active fuel section.

10. REFERENCES

1. ORNL/TM-7175, "A User's Manual For The ORIGEN2 Computer Code", Croff, A.G., Oak Ridge National Laboratory, July 1980.

2. Part Number 12020, "Reference Manual", Software Version 2.01, Lotus Development Corporation, Cambridge, MA 1985.

3. PNL-4326, "Residual Radionuclide Distribution and Inventory at the Pathfinder Generating Plant", Robertson, D.E., et. al., Table 3.2, Pacific Northwest Laboratory, June 1982.

4. Microshield 3 Reference Manual, Software Version 3.12, Grove Engineering, Inc. Rockville, MD 1988.

5. NSP 6801, "Pathfinder Atomic Power Plant - Six Month Operating Report No. 4 - Nov. 19, 1967 to May 19, 1968", Northern States Power Company, June 1968.

6. ACNP-5905, "Pathfinder Atomic Power Plant - Safeguards Report, Part II License Application." Northern States Power Company, October 1960.

7. Op. cit., ACNP-5905, Figure 4.4.

8. Letter NSLTG-89-110, Kuroyama to LaGuardia dated September 1, 1989, with attachment Page iii of ACNP-5905, "Pathfinder Atomic Power Plant - Safeguards Report, Part II License Application." Northern States Power Company, January 1962.

9. NUREG/CR-3474, "Long-Lived Activation Products in Reactor Materials", Evans, J.C., Pacific Northwest Laboratory, August 1984.

10. ACNP-62025, "Pathfinder Atomic Power Plant - Reactor Vessel Materials, Fabrication and Inspection", Patterson,J.F. and Potochnik, J.F., Page A-147, Allis-Chalmers Manufacturing Company, December 1, 1962.

11. PNL-6046, "Spent Fuel Disassembly Hardware and Other Non-Fuel Bearing Components: Characterization, Disposal Cost Estimates, and Proposed Repository Acceptance Requirements", Luksic, A.T., et. al., Pacific Northwest Laboratory, October 1986.

APPENDIX A

ORIGEN2 INPUT AND OUTPUT DESCRIPTION

APPENDIX A

ORIGEN2 INPUT AND OUTPUT DESCRIPTION

The calculation of neutron-induced activity in the Pathfinder pressure vessel and internals was performed using a PC version of the point neutron activation and depletion code ORIGEN2. This version of the code was originally obtained from the Oak Ridge National Laboratory (ORNL) as ORIGEN2-PC Version 1.00, and recompiled under Microsoft's FORTRAN 4.01 optimizing compiler. After recompilation, the code was verified using the sample problem given in the ORNL-provided manual.

Some of the problem-specific data required as input for ORIGEN2 include the following:

1. Material compositions.
2. Neutron flux exposure histogram.
3. Total neutron flux (or specific power level).
4. One-group neutron cross-section libraries, decay libraries and photon libraries.

Material compositions for the materials analyzed in this activation analysis were taken from the available literature. Material certifications for the Pathfinder reactor vessel and internals were unavailable and/or did not contain trace element data.

Based upon plant data, the Pathfinder plant operated for 16,635 MWd (thermal). Some discrepancies were encountered in the review of plant data regarding the plant's thermal output at 100% rated power. Early plant documents indicate a core design thermal output of 190 MWt, and a core design flux of 5.0 E+13 neutrons/cm^2-sec. However, subsequent correspondence stated a thermal output of 199.6 MWt, and a design flux of 3.5 E+13 neutrons/cm^2-sec over the life of the plant.

For input files used to analyze the activation of materials in the reactor core and at the reactor core boundary, a core average total flux of 5.0 E+13 was used. After verification of the actual average core flux from the Pathfinder staff, the results generated by ORIGEN2 were scaled linearly down to correspond to the 3.5 E+13 level, for the core and core boundary regions. This scaling was performed in the Lotus 1-2-3 spreadsheet, as given in Appendix B. All fluxes beyond the core boundary were used as given in the Pathfinder plant documents.

The total exposure (16,635 MWd) was used to provide the exposure time input necessary for ORIGEN2. To calculate the total effective full power days, the core design thermal output value of 190 MWt was used. This provided a conservative result of 87.6 effective full power days. Additionally, it was conservatively assumed that all of this exposure occurred immediately prior to plant shutdown.

The ORIGEN2 libraries were used as the source of neutron cross sections, photon information and decay data. For all calculations of neutron activation inside the reactor core, the ORIGEN2 BWR-U neutron cross section library was employed. For calculations of neutron activation outside the reactor core, the ORIGEN2 thermal library was used. The decay library used was the ORIGEN2-provided library. The H_2O bremsstrahlung photon library was used; however, the choice of photon libraries has no impact on the results of concern in this analysis.

Figure A-1 contains a sample input file, and Figure A-2 a portion of the output file for the activation of stainless steel at the core boundary. This problem required a material composition for stainless steel and the thermal neutron cross section library as input.

FIGURE A-1

ORIGEN2 SAMPLE INPUT

```
  -1
  -1
  -1
*
*    CALCULATION OF ACTIVATION AND DEPLETION IN THE PATHFINDER ATOMIC POWER
*    PLANT INTERNALS, VESSEL, AND BIOLOGICAL SHIELD.
*
*    THE PATHFINDER ATOMIC POWER PLANT HAD ITS INITIAL CRITICALITY ON
*    MARCH 24, 1964.  THE PLANT'S FINAL SHUTDOWN OCCURRED, DUE TO A CONDENSER
*    TUBE FAILURE, ON SEPTEMBER 16, 1967.  THE TOTAL CORE BURNUP AT THAT TIME
*    WAS 16635 MWD.  THE CORE DESIGN POWER IS 190 MWt.  SINCE MOST OF THE
*    POWER OPERATION OCCURRED AT THE END OF THE PLANT'S LIFE, WE WILL
*    CONSERVATIVELY ASSUME THE PLANT OPERATED AT 100% POWER FOR 87.553 DAYS,
*    UNTIL SEPTEMBER 16, 1964.
*
*    USE DEFAULT FRACTIONAL RECOVERY VALUES, AS GIVEN BY FIRST THREE
*    RECORDS OF THIS FILE.
*
*    PROVIDE A TITLE FOR THE PROBLEM.
*
 TIT    PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*
*    STORAGE VECTOR DEFINITIONS.
*
*        -1 = STAINLESS STEEL.
*
*    READ THERMAL CROSS SECTION LIBRARY AND PUT DATA ON UNIT 9.
*
 LIB    0  1  2  3  201  202  203  9  0  0  1  0
*
*    READ H2O-BREMSSTRAHLUNG PHOTON LIBRARY.  PUT DATA ON UNIT 10.
*
 PHO    101  102  103  10
*
*    READ STAINLESS STEEL COMPOSITION.
*
 INP    -1  1  4*0
*
*             $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
*             $                                                 $
*             $    ACTIVATION AND DEPLETION CALCULATION.        $
*             $                                                 $
*             $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

FIGURE A-1

ORIGEN2 SAMPLE INPUT
(CONTINUED)

```
*
*   PREPARE FOR ACTIVATION.
*
 BAS    THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.
*
*   MOVE MATERIAL COMPOSITION TO OUTPUT VECTOR 1.
*
 MOV    -1  1  0  1.0
*
*   FLUX EXPOSURE OF MATERIAL OF INTEREST.
*
 BUP
 IRF     87.553  5.00E13  1  2  4  2
 BUP
*
*             $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
*             $                                          $
*             $    DECAY OF THE IRRADIATED MATERIAL.     $
*             $                                          $
*             $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
*
*   PREPARE FOR THE DECAY CALCULATION.
*
*   DECAY THE ACTIVATED MATERIAL OF INTEREST OUT TO JUNE 1, 1989.
*
 DEC    7929.0  2  3  4  1
*
*   PROVIDE HEADINGS FOR THE COLUMNS.
*
 HED    1  *  STARTUP
 HED    2  * SHUTDOWN
 HED    3  *1-JUN-1989
*
*   PRINT THE NUCLIDE AND CURIE TABLES ONLY, IN GRAMS, FOR THE MATERIAL
*   OF INTEREST.
*
 OPTL    6*8  5  17*8
 OPTA   24*8
 OPTF   24*8
 OUT    3  1  0  0
 END
```

FIGURE A-1

ORIGEN2 SAMPLE INPUT
(CONTINUED)

```
*
*   MATERIAL COMPOSITION.
*
  4  030000  1.30E-7  070000  4.52E-4  110000  9.70E-6  130000  1.00E-4
  4  170000  7.00E-5  190000  3.00E-6  200000  1.90E-5  210000  3.00E-8
  4  220000  6.00E-4  230000  4.56E-4  240000  1.84E-1  250000  1.53E-2
  4  260000  7.06E-1  270000  1.41E-3  280000  1.00E-1  290000  3.08E-3
  4  300000  4.57E-4  310000  1.29E-4  330000  1.94E-4  340000  3.50E-5
  4  350000  2.00E-6  370000  1.00E-5  380000  2.00E-7  390000  5.00E-6
  4  400000  1.00E-5  410000  8.90E-5  420000  2.60E-2  470000  2.00E-6
  4  510000  1.23E-5  550000  3.00E-7  560000  5.00E-4  570000  2.00E-7
  4  580000  3.71E-4  620000  1.00E-7  630000  2.00E-8  650000  4.70E-7
  4  660000  1.00E-6  670000  1.00E-6  700000  2.00E-6  710000  8.00E-7
  4  720000  2.00E-6  740000  1.86E-4  820000  6.70E-5  900000  1.00E-6
  4  920000  2.00E-6  0        0.0
  0
```

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT

```
1                                                         OUTPUT UNIT = 8                       PAGE   13
   * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*                                                                              ACTIVATION PRODUCTS
   POWER= 0.00000E+00 MW.  BURNUP= 0.00000E+00 MWD.  FLUX= 5.00E+13 N/CM**2-SEC
0                 7 NUCLIDE TABLE:  RADIOACTIVITY.  CURIES
                              THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.
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	STARTUP	SHUTDOWN	1-JUN-1989
H 1	0.000E+00	0.000E+00	0.000E+00
H 2	0.000E+00	0.000E+00	0.000E+00
H 3	0.000E+00	1.215E-05	3.593E-06
H 4	0.000E+00	2.050E-12	0.000E+00
HE 3	0.000E+00	0.000E+00	0.000E+00
HE 4	0.000E+00	0.000E+00	0.000E+00
HE 6	0.000E+00	0.000E+00	0.000E+00
LI 6	0.000E+00	0.000E+00	0.000E+00
LI 7	0.000E+00	0.000E+00	0.000E+00
LI 8	0.000E+00	5.231E-07	0.000E+00
BE 8	0.000E+00	5.231E-07	0.000E+00
BE 9	0.000E+00	0.000E+00	0.000E+00
BE 10	0.000E+00	0.000E+00	0.000E+00
BE 11	0.000E+00	0.000E+00	0.000E+00
B 10	0.000E+00	0.000E+00	0.000E+00
B 11	0.000E+00	0.000E+00	0.000E+00
B 12	0.000E+00	0.000E+00	0.000E+00
C 12	0.000E+00	0.000E+00	0.000E+00
C 13	0.000E+00	0.000E+00	0.000E+00
C 14	0.000E+00	1.374E-06	1.370E-06
C 15	0.000E+00	1.792E-11	0.000E+00
N 13	0.000E+00	0.000E+00	0.000E+00
N 14	0.000E+00	0.000E+00	0.000E+00
N 15	0.000E+00	0.000E+00	0.000E+00
N 16	0.000E+00	2.326E-09	0.000E+00
O 16	0.000E+00	0.000E+00	0.000E+00
O 17	0.000E+00	0.000E+00	0.000E+00
O 18	0.000E+00	0.000E+00	0.000E+00
O 19	0.000E+00	0.000E+00	0.000E+00
F 19	0.000E+00	0.000E+00	0.000E+00
F 20	0.000E+00	0.000E+00	0.000E+00
NE 20	0.000E+00	0.000E+00	0.000E+00
NE 21	0.000E+00	0.000E+00	0.000E+00
NE 22	0.000E+00	0.000E+00	0.000E+00
NE 23	0.000E+00	0.000E+00	0.000E+00
NA 22	0.000E+00	0.000E+00	0.000E+00
NA 23	0.000E+00	0.000E+00	0.000E+00
NA 24	0.000E+00	1.819E-04	0.000E+00
NA 24M	0.000E+00	1.373E-04	0.000E+00
NA 25	0.000E+00	0.000E+00	0.000E+00
MG 24	0.000E+00	0.000E+00	0.000E+00
MG 25	0.000E+00	0.000E+00	0.000E+00
MG 26	0.000E+00	0.000E+00	0.000E+00
MG 27	0.000E+00	5.807E-19	0.000E+00
MG 28	0.000E+00	9.512E-24	0.000E+00
AL 27	0.000E+00	0.000E+00	0.000E+00
AL 28	0.000E+00	6.935E-04	0.000E+00
AL 29	0.000E+00	0.000E+00	0.000E+00
AL 30	0.000E+00	0.000E+00	0.000E+00
SI 28	0.000E+00	0.000E+00	0.000E+00
SI 29	0.000E+00	0.000E+00	0.000E+00
SI 30	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 8 PAGE 14

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.

	STARTUP	SHUTDOWN	1-JUN-1989
SI 31	0.000E+00	3.186E-17	0.000E+00
SI 32	0.000E+00	0.000E+00	0.000E+00
P 31	0.000E+00	0.000E+00	0.000E+00
P 32	0.000E+00	9.270E-08	0.000E+00
P 33	0.000E+00	2.186E-18	0.000E+00
P 34	0.000E+00	0.00CE+00	0.000E+00
S 32	0.000E+00	0.000E+00	0.000E+00
S 33	0.000E+00	0.000E+00	0.000E+00
S 34	0.000E+00	0.000E+00	0.000E+00
S 35	0.000E+00	2.952E-04	0.000E+00
S 36	0.000E+00	0.000E+00	0.000E+00
S 37	0.000E+00	3.076E-11	0.000E+00
CL 35	0.000E+00	0.000E+00	0.000E+00
CL 36	0.000E+00	2.859E-08	2.859E-08
CL 37	0.000E+00	0.000E+00	0.000E+00
CL 38	0.000E+00	1.665E-04	0.000E+00
CL 38M	0.000E+00	1.946E-06	0.000E+00
AR 36	0.000E+00	0.000E+00	0.000E+00
AR 37	0.000E+00	7.677E-07	0.000E+00
AR 38	0.000E+00	0.000E+00	0.000E+00
AR 39	0.000E+00	1.444E-11	1.365E-11
AR 40	0.000E+00	0.000E+00	0.000E+00
AR 41	0.000E+00	3.221E-11	0.000E+00
AR 42	0.000E+00	1.430E-20	9.267E-21
K 39	0.000E+00	0.000E+00	0.000E+00
K 40	2.571E-15	1.724E-14	1.724E-14
K 41	0.000E+00	0.000E+00	0.000E+00
K 42	0.000E+00	6.129E-06	9.267E-21
K 43	0.000E+00	0.000E+00	0.000E+00
K 44	0.000E+00	0.000E+00	0.000E+00
CA 40	0.000E+00	0.000E+00	0.000E+00
CA 41	0.000E+00	3.067E-10	3.066E-10
CA 42	0.000E+00	0.000E+00	0.000E+00
CA 43	0.000E+00	0.000E+00	0.000E+00
CA 44	0.000E+00	0.000E+00	0.000E+00
CA 45	0.000E+00	2.505E-06	5.652E-21
CA 46	0.000E+00	0.000E+00	0.000E+00
CA 47	0.000E+00	9.445E-09	0.000E+00
CA 48	0.000E+00	0.000E+00	0.000E+00
CA 49	0.000E+00	8.056E-07	0.000E+00
SC 45	0.000E+00	0.000E+00	0.000E+00
SC 46	0.000E+00	7.363E-06	0.000E+00
SC 46M	0.000E+00	5.164E-06	0.000E+00
SC 47	0.000E+00	4.021E-08	0.000E+00
SC 48	0.000E+00	0.000E+00	0.000E+00
SC 49	0.000E+00	8.056E-07	0.000E+00
SC 50	0.000E+00	0.000E+00	0.000E+00
TI 46	0.000E+00	0.000E+00	0.000E+00
TI 47	0.000E+00	0.000E+00	0.000E+00
TI 48	0.000E+00	0.000E+00	0.000E+00
TI 49	0.000E+00	0.000E+00	0.000E+00
TI 50	0.000E+00	0.00JE+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

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1                                                              OUTPUT UNIT = 6                    PAGE   15
    * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*                                                                                  ACTIVATION PRODUCTS
    POWER= 0.00000E+00 MW,  BURNUP= 0.00000E+00 MWD,  FLUX= 5.00E+13 N/CM**2-SEC
0                   7 NUCLIDE TABLE:  RADIOACTIVITY,  CURIES
                              THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.
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	STARTUP	SHUTDOWN	1-JUN-1989
TI 51	0.000E+00	9.496E-05	0.000E+00
V 49	0.000E+00	0.000E+00	0.000E+00
V 50	1.999E-19	1.946E-19	1.943E-19
V 51	0.000E+00	0.000E+00	0.000E+00
V 52	0.000E+00	3.755E-02	0.000E+00
V 53	0.000E+00	0.000E+00	0.000E+00
V 54	0.000E+00	0.000E+00	0.000E+00
CR 50	0.000E+00	0.000E+00	0.000E+00
CR 51	0.000E+00	1.760E+00	0.000E+00
CR 52	0.000E+00	0.000E+00	0.000E+00
CR 53	0.000E+00	0.000E+00	0.000E+00
CR 54	0.000E+00	0.000E+00	0.000E+00
CR 55	0.000E+00	2.512E-02	0.000E+00
MN 54	0.000E+00	0.000E+00	0.000E+00
MN 55	0.000E+00	0.000E+00	0.000E+00
MN 56	0.000E+00	2.997E+00	0.000E+00
MN 57	0.000E+00	0.000E+00	0.000E+00
MN 58	0.000E+00	0.000E+00	0.000E+00
FE 54	0.000E+00	0.000E+00	0.000E+00
FE 55	0.000E+00	8.320E-02	2.550E-04
FE 56	0.000E+00	0.000E+00	0.000E+00
FE 57	0.000E+00	0.000E+00	0.000E+00
FE 58	0.000E+00	0.000E+00	0.000E+00
FE 59	0.000E+00	2.549E-02	0.000E+00
CO 58M	0.000E+00	0.600E+00	0.000E+00
CO 58	0.000E+00	0.000E+00	0.000E+00
CO 59	0.000E+00	0.000E+00	0.000E+00
CO 60	0.000E+00	2.215E-02	1.274E-03
CO 60M	0.000E+00	3.638E-01	0.000E+00
CO 61	0.000E+00	5.324E-04	0.000E+00
CO 62	0.000E+00	0.000E+00	0.000E+00
NI 58	0.000E+00	0.000E+00	0.600E+00
NI 59	0.000E+00	8.855E-06	8.853E-06
NI 60	0.000E+00	0.000E+00	0.000E+00
NI 61	0.000E+00	0.000E+00	0.000E+00
NI 62	0.000E+00	0.000E+00	0.000E+00
NI 63	0.000E+00	1.266E-03	1.075E-03
NI 64	0.000E+00	0.000E+00	0.000E+00
NI 65	0.000E+00	1.882E-02	0.000E+00
NI 66	0.000E+00	2.993E-07	0.000E+00
CU 62	0.000E+00	0.000E+00	0.000E+00
CU 63	0.000E+00	0.000E+00	0.000E+00
CU 64	0.000E+00	1.225E-01	0.000E+00
CU 65	0.000E+00	0.000E+00	0.000E+00
CU 66	0.000E+00	2.634E-02	0.000E+00
CU 67	0.000E+00	7.649E-08	0.000E+00
ZN 63	0.000E+00	0.000E+00	0.000E+00
ZN 64	0.000E+00	0.000E+00	0.000E+00
ZN 65	0.060E+00	4.761E-04	7.763E-14
ZN 66	0.000E+00	0.000E+00	0.000E+00
ZN 67	0.000E+00	0.000E+00	0.000E+00
ZN 68	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 6 PAGE 16

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL

	STARTUP	SHUTDOWN	1-JUN-1939
ZN 69	0.000E+00	1.144E-03	0.000E+00
ZN 69M	0.000E+00	7.690E-05	0.000E+00
ZN 70	0.000E+00	0.000E+00	0.000E+00
ZN 71	0.000E+00	2.925E-06	0.000E+00
ZN 71M	0.000E+00	3.066E-07	0.000E+00
GA 69	0.000E+00	0.000E+00	0.000E+00
GA 70	0.000E+00	1.519E-03	0.000E+00
GA 71	0.000E+00	0.000E+00	0.000E+00
GA 72	0.000E+00	2.913E-03	0.000E+00
GA 72M	0.000E+00	9.001E-05	0.000E+00
GE 70	0.000E+00	0.000E+00	0.000E+00
GE 71	0.000E+00	1.589E-06	0.000E+00
GE 71M	0.000E+00	1.607E-07	0.000E+00
GE 72	0.000E+00	0.000E+00	0.000E+00
GE 73	0.000E+00	0.000E+00	0.000E+00
GE 74	0.000E+00	0.000E+00	0.000E+00
GE 75	0.000E+00	1.464E-15	0.000E+00
GE 75M	0.000E+00	5.467E-14	0.000E+00
GE 76	0.000E+00	0.000E+00	0.000E+00
GE 77	0.000E+00	0.000E+00	0.000E+00
GE 77M	0.000E+00	0.000E+00	0.000E+00
AS 75	0.000E+00	0.000E+00	0.000E+00
AS 76	0.000E+00	9.041E-03	0.000E+00
AS 77	0.000E+00	0.000E+00	0.000E+00
SE 74	0.000E+00	0.000E+00	0.000E+00
SE 75	0.000E+00	6.387E-05	7.588E-25
SE 76	0.000E+00	0.000E+00	0.000E+00
SE 77	0.000E+00	0.000E+00	0.000E+00
SE 77M	0.000E+00	7.312E-04	0.000E+00
SE 78	0.000E+00	0.000E+00	0.000E+00
SE 79	0.000E+00	8.679E-11	8.677E-11
SE 79M	0.000E+00	2.809E-05	0.000E+00
SE 80	0.000E+00	0.000E+00	0.000E+00
SE 81	0.000E+00	1.094E-04	0.000E+00
SE 81M	0.000E+00	1.435E-05	0.000E+00
SE 82	0.000E+00	0.000E+00	0.000E+00
SE 83	0.000E+00	1.293E-06	0.000E+00
SE 83M	0.000E+00	1.924E-07	0.000E+00
BR 79	0.000E+00	0.000E+00	0.000E+00
BR 80	0.000E+00	1.141E-04	0.000E+00
BR 80M	0.000E+00	2.672E-05	0.000E+00
BR 81	0.000E+00	0.000E+00	0.000E+00
BR 82	0.000E+00	2.650E-05	0.000E+00
BR 82M	0.000E+00	2.447E-05	0.000E+00
BR 83	0.000E+00	1.485E-06	0.000E+00
KR 78	0.000E+00	0.000E+00	0.000E+00
KR 79	0.000E+00	0.000E+00	0.000E+00
KR 79M	0.000E+00	0.000E+00	0.000E+00
KR 80	0.000E+00	0.000E+00	0.000E+00
KR 81	0.000E+00	2.194E-13	2.193E-13
KR 81M	0.000E+00	1.798E-07	0.000E+00
KR 82	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 6 PAGE 17

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.

	STARTUP	SHUTDOWN	1-JUN-1989
KR 83	0.000E+00	0.000E+00	0.000E+00
KR 83M	0.000E+00	1.683E-06	0.000E+00
KR 84	0.000E+00	0.000E+00	0.000E+00
KR 85	0.000E+00	7.012E-15	1.728E-15
KR 85M	0.000E+00	2.047E-12	0.000E+00
KR 86	0.000E+00	0.000E+00	0.00P:+00
KR 87	0.000E+00	1.597E-21	0.000E+00
KR 88	0.000E+00	3.164E-25	0.000E+00
RB 85	0.000E+00	0.000E+00	0.000E+00
RB 86	0.000E+00	3.037E-05	0.000E+00
RB 86M	0.000E+00	3.433E-06	0.000E+00
RB 87	2.477E-13	2.477E-13	2.477E-13
RB 88	0.000E+00	3.178E-06	0.000E+00
RB 89	0.000E+00	2.448E-13	0.000E+00
SR 84	0.000E+00	0.000E+00	0.000E+00
SR 85	0.000E+00	4.628E-09	0.000E+00
SR 85M	0.000E+00	5.716E-09	0.000E+00
SR 86	0.000E+00	0.000E+00	0.000E+00
SR 87	0.000E+00	0.000E+00	0.000E+00
SR 87M	0.000E+00	1.605E-07	0.000E+00
SR 88	0.000E+00	0.000E+00	0.000E+00
SR 89	0.000E+00	6.224E-09	0.000E+00
SR 90	0.000E+00	2.799E-15	1.670E-15
SR 91	0.000E+00	1.670E-16	0.000E+00
SR 93	0.000E+00	0.000E+00	0.000E+00
Y 89	0.000E+00	0.000E+00	0.000E+00
Y 89M	0.000E+00	0.000E+00	0.000E+00
Y 90	0.000E+00	5.851E-05	1.670E-15
Y 90M	0.000E+00	4.572E-08	0.000:+00
Y 91	0.000E+00	3.901E-09	0.000E+00
Y 92	0.000E+00	1.992E-'2	0.000E+00
Y 93	0.000E+00	0.000E+00	0.000E+00
Y 94	0.000E+00	0.000E+00	0.000E+00
Y 96	0.000E+00	0.000E+00	0.000E+00
ZR 89	0.000E+00	0.000E+00	0.000E+00
ZR 90	0.000E+00	0.000E+00	0.000E+00
ZR 91	0.000E+00	0.000E+00	0.000E+00
ZR 92	0.000E+00	0.000E+00	0.000E+00
ZR 93	0.000E+00	4.303E-13	4.303E-13
ZR 94	0.000E+00	0.000E+00	0.000E+00
ZR 95	0.000E+00	5.322E-07	0.000E+00
ZR 96	0.000E+00	0.000E+00	0.000E+00
ZR 97	0.000E+00	4.244E-08	0.000E+00
NB 91	0.000E+00	0.000E+00	0.000E 00
NB 92	0.000E+00	0.000E+00	0.000E+00
NB 93	0.000E+00	0.000E+00	0.000E+00
NB 93M	9.000E+00	2.487E-15	2.744E-13
NB 94	0.000E+00	7.312E-09	7.306E-09
NB 95	0.000E+00	2.717E-06	0.000E+00
NB 95M	0.000E+00	3.726E-09	0.000E+00
NB 96	0.000E+00	4.167E-09	0.000E+00
NB 97	0.000E+00	4.244E-08	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 8 PAGE 18

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL

	STARTUP	SHUTDOWN	1-JUN-1989
NB 97M	0.000E+00	4.016E-08	0.000E+00
NB 98	0.000E+00	0.000E+00	0.000E+00
NB100	0.000E+00	0.000E+00	0.000E+00
MO 92	0.000E+00	0.000E+00	0.000E+00
MO 93M	0.000E+00	1.957E-04	0.000E+00
MO 93	0.000E+00	7.898E-08	7.868E-08
MO 94	0.000E+00	0.000E+00	0.000E+00
MO 95	0.000E+00	0.000E+00	0.000E+00
MO 96	0.000E+00	0.000E+00	0.000E+00
MO 97	0.000E+00	0.000E+00	0.000E+00
MO 98	0.000E+00	0.000E+00	0.000E+00
MO 99	0.000E+00	6.908E-03	0.000E+00
MO100	0.000E+00	0.000E+00	0.000E+00
MO101	0.000E+00	4.211E-03	0.000E+00
TC 97	0.000E+00	0.000E+00	0.000E+00
TC 97M	0.000E+00	0.000E+00	0.000E+00
TC 98	0.000E+00	0.000E+00	0.000E+00
TC 99	0.000E+00	6.381E-10	6.685E-10
TC100	0.000E+00	5.879E-06	0.000E+00
TC101	0.000E+00	4.211E-03	0.000E+00
RU 96	0.000E+00	0.000E+00	0.000E+00
RU 97	0.000E+00	0.000E+00	0.000E+00
RU 98	0.000E+00	0.000E+00	0.000E+00
RU 99	0.000E+00	0.000E+00	0.000E+00
RU100	0.000E+00	0.000E+00	0.000E+00
RU101	0.000E+00	0.000E+00	0.000E+00
RU102	0.000E+00	0.000E+00	0.000E+00
RU103	0.000E+00	4.423E-10	0.000E+00
RU104	0.000E+00	0.000E+00	0.000E+00
RU105	0.000E+00	1.102E-19	0.000E+00
RU106	0.000E+00	0.000E+00	0.000E+00
RU107	0.000E+00	0.000E+00	0.000E+00
RH102	0.000E+00	0.000E+00	0.000E+00
RH103	0.000E+00	0.000E+00	0.000E+00
RH104	0.000E+00	6.578E-13	0.000E+00
RH104M	0.000E+00	4.820E-14	0.000E+00
RH105	0.000E+00	7.977E-19	0.000E+00
RH105M	0.000E+00	3.086E-20	0.000E+00
RH106	0.000E+00	8.277E-20	0.000E+00
RH106M	0.000E+00	3.443E-20	0.000E+00
RH107	0.000E+00	0.000E+00	0.000E+00
PD102	0.000E+00	0.000E+00	0.000E+00
PD103	0.000E+00	0.000E+00	0.000E+00
PD104	0.000E+00	0.000E+00	0.000E+00
PD105	0.000E+00	0.000E+00	0.000E+00
PD106	0.000E+00	0.000E+00	0.000E+00
PD107	0.000E+00	0.000E+00	0.000E+00
PD107M	0.000E+00	0.000E+00	0.000E+00
PD108	0.000E+00	0.000E+00	0.000E+00
PD109	0.000E+00	2.878E-08	0.000E+00
PD109M	0.000E+00	4.721E-10	0.000E+00
PD110	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

```
1                                                          OUTPUT UNIT =  8                    PAGE   19
    * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*                                                                           ACTIVATION PRODUCTS
    POWER= 0.00000E+00 MW,  BURNUP= 0.00000E+00 MWD,  FLUX= 5.00E+13 N/CM**2-SEC
0                   7 NUCLIDE TABLE:  RADIOACTIVITY,  CURIES
                              THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.
```

	STARTUP	SHUTDOWN	1-JUN-1989
PD111	0.000E+00	1.540E-10	0.000E+00
PD111M	0.000E+00	1.442E-11	0.000E+00
AG106	0.000E+00	0.000E+00	0.000E+00
AG107	0.000E+00	0.000E+00	0.900E+00
AG108	0.000E+00	2.636E-04	2.405E-09
AG108M	0.000E+00	3.042E-08	2.702E-05
AG109	0.000E+00	0.000E+00	0.000E+00
AG109M	0.000E+00	3.503E-08	4.491E-14
AG110	0.000E+00	6.242E-04	2.507E-17
AG110M	0.000E+00	6.718E-06	1.885E-15
AG111	0.000E+00	1.716E-06	0.000E+00
AG111M	0.000E+00	8.581E-07	0.000E+00
AG112	0.000E+00	2.390E-10	0.000E+00
CD106	0.000E+00	0.000E+00	0.000E+00
CD107	0.000E+00	0.000E+00	0.000E+00
CD108	0.000E+00	0.000E+00	0.000E+00
CD109	0.000E+00	6.258E-09	[illegible].491E-14
CD110	0.000E+00	0.000E+00	0.000E+00
CD111	0.000E+00	0.000E+00	0.000E+00
CD111M	0.000E+00	2.406E-08	0.000E+00
CD112	0.000E+00	0.000E+00	0.000E+00
CD113	0.000E+00	0.000E+00	0.000E+00
CD114	0.000E+00	0.000E+00	0.000E+00
CD115	0.000E+00	1.395E-16	0.000E+00
CD115M	0.000E+00	3.422E-18	0.000E+00
CD116	0.000E+00	0.000E+00	0.000E+00
CD117	0.000E+00	0.000E+00	0.000E+00
CD117M	0.000E+00	0.000E+00	0.000E+00
CD119	0.000E+00	0.000E+00	0.000E+00
CD121	0.000E+00	0.000E+00	0.000E+00
IN113	0.000E+00	0.000E+00	0.000E+00
IN113M	0.000E+00	0.000E+00	0.000E+00
IN114	0.000E+00	0.000E+00	0.000E+00
IN114M	0.000E+00	0.000E+00	0.000E+00
IN115	0.000E+00	2.542E-34	1.090E-33
IN116	0.000E+00	1.301E-20	0.000E+00
IN116M	0.000E+00	4.539E-20	0.000E+00
IN117	0.000E+00	0.000E+00	0.000E+00
IN117M	0.000E+00	0.000E+00	0.000E+00
IN118	0.000E+00	0.000E+00	0.000E+00
IN119	0.000E+00	0.000E+00	0.000E+00
IN119M	0.000E+00	0.000E+00	0.000E+00
IN120	0.000E+00	0.000E+00	0.000E+00
IN120M	0.000E+00	0.000E+00	0.000E+00
IN121	0.000E+00	0.000E+00	0.000E+00
SN112	0.000E+00	0.000E+00	0.000E+00
SN113	0.000E+00	0.000E+00	0.000E+00
SN113M	0.000E+00	0.000E+00	0.000E+00
SN114	0.000E+00	0.000E+00	0.000E+00
SN115	0.000E+00	0.000E+00	0.000E+00
SN116	0.000E+00	0.000E+00	0.000E+00
SN117	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

```
1                                                                 OUTPUT UNIT = 6                    PAGE   20
     * PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL
*                                                                             ACTIVATION PRODUCTS
     POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC
0                   7 NUCLIDE TABLE: RADIOACTIVITY, CURIES
                              THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL
```

	STARTUP	SHUTDOWN	1-JUN-1989
SN117M	0.000E+00	0.000E+00	0.000E+00
SN118	0.000E+00	0.000E+00	0.000E+00
SN119	0.000E+00	0.000E+00	0.000E+00
SN119M	0.000E+00	0.000E+00	0.000E+00
SN120	0.000E+00	0.000E+00	0.000E+00
SN121	0.000E+00	0.000E+00	0.000E+00
SN121M	0.000E+00	0.000E+00	0.000E+00
SN122	0.000E+00	0.000E+00	0.000E+00
SN123	0.000E+00	9.285E-11	3.082E-29
SN123M	0.000E+00	2.540E-12	0.000E+00
SN124	0.000E+00	0.000E+00	0.000E+00
SN125	0.000E+00	0.000E+00	0.000E+00
SN125M	0.000E+00	0.000E+00	0.000E+00
SB121	0.000E+00	0.000E+00	0.000E+00
SB122	0.000E+00	2.939E-04	0.000E+00
SB122M	0.000E+00	2.586E-06	0.000E+00
SB123	0.000E+00	0.000E+00	0.000E+00
SB124	0.000E+00	9.617E-05	0.090E+00
SB124M	0.000E+00	3.787E-07	0.000E+00
SB125	0.000E+00	8.026E-09	3.511E-11
SB126	0.000E+00	3.163E-11	0.000E+00
SB126M	0.000E+00	3.947E-11	0.000E+00
TE120	0.000E+00	0.000E+00	0.000E+00
TE121	0.000E+00	0.000E+00	0.000E+00
TE121M	0.000E+00	0.000E+00	0.000E+00
TE122	0.000E+00	0.000E+00	0.000E+00
TE123	0.000E+00	1.530E-21	2.336E-21
TE123M	0.000E+00	2.461E-08	2.797E-28
TE124	0.000E+00	0.000E+00	0.000E+00
TE125	0.000E+00	0.000E+00	0.000E+00
TE125M	0.000E+00	7.896E-10	8.566E-12
TE126	0.000E+00	0.000E+00	0.000E+00
TE127	0.000E+00	1.052E-14	0.000E+00
TE127M	0.000E+00	1.846E-16	0.000E+00
TE128	0.000E+00	0.000E+00	0.000E+00
TE129	0.000E+00	0.000E+00	0.000E+00
TE129M	0.000E+00	0.000E+00	0.000E+00
TE130	0.000E+00	0.000E+00	0.000E+00
TE131	0.000E+00	0.000E+00	0.000E+00
TE131M	0.000E+00	0.000E+00	0.000E+00
I125	0.000E+00	0.000E+00	0.000E+00
I126	0.000E+00	0.000E+00	0.000E+00
I127	0.000E+00	0.000E+00	0.000E+00
I128	0.000E+00	5.789E-18	0.000E+00
I129	0.000E+00	0.000E+00	0.000E+00
I130	0.000E+00	0.000E+00	0.000E+00
I130M	0.000E+00	0.000E+00	0.000E+00
I131	0.000E+00	0.000E+00	0.000E+00
I132	0.000E+00	0.000E+00	0.000E+00
XE124	0.000E+00	0.000E+00	0.000E+00
XE125	0.000E+00	0.000E+00	0.000E+00
XE125M	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 6 PAGE 21

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.

	STARTUP	SHUTDOWN	1-JUN-1989
XE126	0.000E+00	0.000E+00	0.000E+00
XE127	0.000E+00	0.000E+00	0.000E+00
XE127M	0.000E+00	0.000E+00	0.000E+00
XE128	0.000E+00	0.000E+00	0.000E+00
XE129	0.000E+00	0.000E+00	0.000E+00
XE129M	0.000E+00	1.582E-22	0.000E+00
XE130	0.000E+00	0.000E+00	0.000E+00
XE131	0.000E+00	0.000E+00	0.000E+00
XE131M	0.000E+00	0.000E+00	0.0'0E+00
XE132	0.000E+00	0.000E+00	0.000E+00
XE133	0.000E+00	5.129E-11	0.000E+00
XE133M	0.000E+00	3.350E-12	0.000E+00
XE134	0.000E+00	0.000E+00	0.000E+00
XE135	0.000E+00	9.793E-19	0.000E+00
XE135M	0.000E+00	8.525E-20	0.000E+00
XE136	0.000E+00	0.000E+00	0.000E+00
XE137	0.000E+00	8.183E-23	0.000E+00
CS131	0.000E+00	4.279E-05	0.000E+00
CS132	0.000E+00	0.000E+00	0.000E+00
CS133	0.000E+00	0.000E+00	0.000E+00
CS134	0.000E+00	3.945E-06	2.672E-09
CS134M	0.000E+00	4.541E-06	0.000E+00
CS135	0.000E+00	9.620E-14	9.620E-14
CS136	0.000E+00	2.916E-09	0.000E+00
CS137	0.000E+00	5.002E-16	3.029E-16
CS138	0.000E+00	3.758E-18	0.000E+00
BA130	0.000E+00	0.000E+00	0.000E+00
BA131	0.000E+00	4.355E-05	0.000E+00
BA131M	0.000E+00	6.105E-06	0.000E+00
BA132	0.000E+00	0.000E+00	0.000E+00
BA133	0.000E+00	4.159E-07	1.027E-07
BA133M	0.000E+00	2.008E-06	0.000E+00
BA134	0.000E+00	0.000E+00	0.000E+00
BA135	0.000E+00	0.000E+00	0.000E+00
BA135M	0.000E+00	1.122E-05	0.000E+00
BA136	0.000E+00	0.000E+00	0.000E+00
BA136M	0.000E+00	2.713E-06	0.000E+00
BA137	0.000E+00	0.000E+00	0.000E+00
BA137M	0.000E+00	2.344E-06	2.866E-16
BA138	0.000E+00	0.000E+00	0.000E+00
BA139	0.000E+00	7.435E-04	0.000E+00
BA140	0.000E+00	1.581E-09	0.000E+00
BA141	0.000E+00	2.016E-13	0.000E+00
LA137	0.000E+00	8.132E-11	8.206E-11
LA138	3.393E-18	3.179E-18	3.179E-18
LA139	0.000E+00	0.000E+00	0.000E+00
LA140	0.000E+00	1.303E-05	0.000E+00
LA141	0.000E+00	3.676E-10	0.000E+00
CE136	0.000E+00	0.000E+00	0.000E+00
CE137	0.000E+00	2.955E-05	0.000E+00
CE137M	0.000E+00	3.877E-06	0.000E+00
CE138	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 6 PAGE 22

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

* ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW, BURNUP= 0.00000E+00 MWD, FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.

	STARTUP	SHUTDOWN	1-JUN-1989
CE139	0.000E+00	2.141E-06	9.687E-24
CE139M	0.000E+00	8.102E-08	0.000E+00
CE140	0.000E+00	0.000E+00	0.000E+00
CE141	0.000E+00	9.151E-04	0.000E+00
CE142	9.994E-13	9.990E-13	9.990E-13
CE143	0.000E+00	2.267E-04	0.000E+00
CE144	0.000E+00	2.190E-09	8.782E-18
CE145	0.000E+00	3.879E-12	0.000E+00
PR141	0.000E+00	0.000E+00	0.000E+00
PR142	0.000E+00	2.573E-06	0.000E+00
PR142M	0.000E+00	8.728E-07	0.000E+00
PR143	0.000E+00	2.175E-04	0.000E+00
PR144	0.000E+00	1.638E-06	8.677E-18
PR145	0.000E+00	3.879E-12	0.000E+00
ND142	0.000E+00	0.000E+00	0.000E+00
ND143	0.000E+00	0.000E+00	0.000E+00
ND144	0.000E+00	7.822E-22	7.831E-22
ND145	0.000E+00	0.000E+00	0.000E+00
ND146	0.000E+00	0.000E+00	0.000E+00
ND147	0.000E+00	1.168E-13	0.000E+00
ND148	0.000E+00	0.000E+00	0.000E+00
ND149	0.000E+00	0.000E+00	0.000E+00
ND150	0.000E+00	0.000E+00	0.000E+00
ND151	0.000E+00	0.000E+00	0.000E+00
PM145	0.000E+00	9.123E-12	4.853E-11
PM147	0.000E+00	5.579E-15	2.243E-17
PM148	0.000E+00	2.216E-14	0.000E+00
PM148M	0.000E+00	4.251E-16	0.000E+00
PM149	0.000E+00	3.817E-15	0.000E+00
PM150	0.000E+00	7.366E-17	0.000E+00
PM151	0.000E+00	0.000E+00	0.000E+00
PM152	0.000E+00	0.000E+00	0.000E+00
SM144	0.000E+00	0.000E+00	0.000E+00
SM145	0.000E+00	1.881E-09	1.800E-16
SM146	0.000E+00	5.395E-19	5.395E-19
SM147	3.355E-16	3.274E-16	3.274E-16
SM148	3.358E-21	3.461E-21	3.461E-21
SM149	3.307E-21	1.832E-25	1.832E-25
SM150	0.000E+00	0.000E+00	0.000E+00
SM151	0.000E+00	3.700E-09	3.130E-09
SM152	0.000E+00	0.000E+00	0.000E+00
SM153	0.000E+00	2.922E-05	0.000E+00
SM154	0.000E+00	0.000E+00	0.000E+00
SM155	0.000E+00	6.713E-07	0.000E+00
EU151	0.000E+00	0.000E+00	0.000E+00
EU152	0.000E+00	5.451E-07	1.803E-07
EU152M	0.000E+00	5.335E-06	0.000E+00
EU153	0.000E+00	0.000E+00	0.000E+00
EU154	0.000E+00	3.670E-07	6.380E-08
EU155	0.000E+00	1.287E-07	6.192E-09
EU156	0.000E+00	4.026E-06	0.000E+00
GD152	0.000E+00	3.869E-20	5.153E-20

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

1 OUTPUT UNIT = 6 PAGE 23

* PATHFINDER ACTIVATION ANALYSIS. CURIES PER GRAM OF MATERIAL.

\+ ACTIVATION PRODUCTS

POWER= 0.00000E+00 MW. BURNUP= 0.00000E+00 MWD. FLUX= 5.00E+13 N/CM**2-SEC

0 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES

THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.

	STARTUP	SHUTDOWN	1-JUN-1989
GD153	0.000E+00	2.023E-06	2.776E-16
GD154	0.000E+00	0.000E+00	0.000E+00
GD155M	0.000E+00	3.506E-12	0.000E+00
GD155	0.000E+00	0.000E+00	0.000E+00
GD156	0.000E+00	0.000E+00	0.000E+00
GD157	0.000E+00	0.000E+00	0.000E+00
GD158	0.000E+00	0.000E+00	0.000E+00
GD159	0.000E+00	4.768E-05	0.000E+00
GD160	0.000E+00	0.000E+00	0.000E+00
GD161	0.000E+00	7.156E-15	0.000E+00
GD162	0.000E+00	3.552E-18	0.000E+00
TB157	0.000E+00	1.031E-10	9.374E-11
TB159	0.000E+00	0.000E+00	0.000E+00
TB160	0.000E+00	3.187E-05	0.000E+00
TB161	0.000E+00	7.539E-06	0.000E+00
TB162	0.000E+00	1.144E-10	0.000E+00
DY156	0.000E+00	0.000E+00	0.000E+00
DY157	0.000E+00	9.304E-08	0.000E+00
DY158	0.000E+00	0.000E+00	0.000E+00
DY159	0.000E+00	7.562E-08	2.010E-24
DY160	0.000E+06	0.000E+00	0.000E+00
DY161	0.000E+00	0.000E+00	0.000E+00
DY162	0.000E+00	0.000E+00	0.000E+00
DY163	0.000E+00	0.000E+00	0.000E+00
DY164	0.000E+00	0.000E+00	0.000E+00
DY165	0.000E+00	1.547E-03	0.000E+00
DY165M	0.000E+00	9.278E-04	0.000E+00
DY166	0.000E+00	3.681E-06	0.000E+00
HO163	0.000E+00	0.000E+00	0.000E+00
HO165	0.000E+00	0.000E+00	0.000E+00
HO166	0.000E+00	3.641E-04	0.000E+00
HO166M	0.000E+00	2.617E-09	2.584E-09
ER162	0.000E+00	0.000E+00	0.000E+00
ER163	0.000E+00	0.000E+00	0.000E+00
ER164	0.000E+00	0.000E+00	0.000E+00
ER165	0.000E+00	1.366E-11	0.000E+00
ER166	0.000E+00	0.000E+00	0.000E+00
ER167	0.000E+00	0.000E+00	0.000E+00
ER167M	0.000E+00	1.915E-06	0.000E+00
ER168	0.000E+00	0.000E+00	0.000E+00
ER169	0.000E+00	1.458E-10	0.000E+00
ER170	0.000E+00	0.000E+00	0.000E+00
ER171	0.000E+00	5.875E-11	0.000E+00
ER172	0.000E+00	3.212E-14	0.000E+00
TM169	0.000E+00	0.000E+00	0.000E+00
TM170	0.000E+00	1.093E-07	2.995E-26
TM170M	0.000E+00	4.861E-08	0.000E+00
TM171	0.000E+00	2.098E-10	8.284E-14
TM172	0.000E+00	2.269E-10	0.000E+00
TM173	0.000E+00	1.009E-10	0.000E+00
YB168	0.000E+00	0.000E+00	0.000E+00
YB169	0.000E+00	1.767E-05	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

```
1                                                          OUTPUT UNIT = 6                    PAGE  24
    * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*                                                                              ACTIVATION PRODUCTS
    POWER= 0.00000E+00 MW,  BURNUP= 0.00000E+00 MWD,  FLUX= 5.00E+13 N/CM**2-SEC
0                   7 NUCLIDE TABLE:  RADIOACTIVITY,  CURIES
                                THERMAL XSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL
```

	STARTUP	SHUTDOWN	1-JUN-1989
YB170	0.000E+00	0.000E+00	0.000E+00
YB171	0.000E+00	0.000E+00	0.000E+00
YB172	0.000E+00	0.000E+00	0.000E+00
YB173	0.000E+00	0.000E+00	0.000E+00
YB174	0.000E+00	0.000E+00	0.000E+00
YB175	0.000E+00	1.894E-04	0.000E+00
YB175M	0.000E+00	1.339E-04	0.000E+00
YB176	0.000E+00	0.000E+00	0.000E+00
YB177	0.000E+00	2.843E-06	0.000E+00
LU175	0.000E+00	0.000E+00	0.000E+00
LU176	1.417E-15	7.378E-16	7.378E-16
LU176M	0.000E+00	6.003E-05	0.000E+00
LU177	0.000E+00	1.171E-04	1.422E-23
LU177M	0.000E+00	1.550E-07	6.183E-23
HF174	0.000E+00	0.000E+00	0.000E+00
HF175	0.000E+00	3.035E-06	0.000E+00
HF176	0.000E+00	0.000E+00	0.000E+00
HF177	0.000E+00	0.000E+00	0.000E+00
HF178	0.000E+00	0.000E+00	0.000E+00
HF178M	0.000E+00	1.678E-06	0.000E+00
HF179	0.000E+00	0.000E+00	0.000E+00
HF179M	0.000E+00	1.384E-04	0.000E+00
HF180	0.000E+00	0.000E+00	0.000E+00
HF180M	0.000E+00	4.494E-07	0.000E+00
HF181	0.000E+00	3.064E-05	0.000E+00
HF182	0.000E+00	3.684E-15	3.684E-15
TA180	0.000E+00	0.000E+00	0.000E+00
TA181	0.000E+00	0.000E+00	0.000E+00
TA182	0.000E+00	1.436E-08	3.684E-15
TA182M	0.000E+00	7.645E-11	0.000E+00
TA183	0.000E+00	8.440E-08	0.000E+00
W180	0.000E+00	0.000E+00	0.000E+00
W181	0.000E+00	1.475E-06	2.965E-26
W182	0.000E+00	0.000E+00	0.000E+00
W183M	0.000E+00	1.067E-04	0.000E+00
W183	0.000E+00	0.000E+00	0.000E+00
W184	0.000E+00	0.000E+00	0.000E+00
W185	0.000E+00	2.524E-04	0.000E+00
W185M	0.000E+00	5.011E-07	0.000E+00
W186	0.000E+00	0.000E+00	0.000E+00
W187	0.000E+00	8.774E-03	0.000E+00
W188	0.000E+00	2.010E-06	0.000E+00
W189	0.000E+00	5.066E-26	0.000E+00
RE185	0.000E+00	0.000E+00	0.000E+00
RE186	0.000E+00	5.967E-06	0.000E+00
RE187	0.000E+00	2.848E-14	2.896E-14
RE188	0.000E+00	2.419E-04	0.000E+00
RE188M	0.000E+00	2.348E-04	0.000E+00
RE189	0.000E+00	2.133E-09	0.000E+00
OS184	0.000E+00	0.000E+00	0.000E+00
OS185	0.000E+00	0.000E+00	0.000E+00
OS186	0.000E+00	0.000E+00	0.000E+00

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

```
1                                                          OUTPUT UNIT =  6                          PAGE   25
    * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL.
*                                                                                    ACTIVATION PRODUCTS
    POWER= 0.00000E+00 MW,  BURNUP= 0.00000E+00 MWD,  FLUX= 5.00E+13 N/CM**2-SEC
0                    7 NUCLIDE TABLE:  RADIOACTIVITY,  CURIES
                              THERMAL KSTC - FLUX AT CORE BOUNDARY - STAINLESS STEEL.
```

	STARTUP	SHUTDOWN	1-JUN-1989
OS187	0.000E+00	0.000E+00	0.000E+00
OS188	0.000E+00	0.000E+00	0.000E+00
OS189	0.000E+00	0.000E+00	0.000E+00
OS190	0.000E+00	0.000E+00	0.000E+00
OS190M	0.000E+00	6.362E-15	0.000E+00
OS191	0.000E+00	3.267E-13	0.000E+00
OS191M	0.000E+00	4.948E-13	0.000E+00
OS192	0.000E+00	0.000E+00	0.000E+00
OS193	0.000E+00	9.[illegible]9E-21	0.000E+00
OS194	0.000E+00	0.000E+00	0.000E+00
IR191	0.000E+00	0.000E+00	0.000E+00
IR192	0.000E+00	2.084E-15	8.779E-22
IR192M	0.000E+00	8.772E-22	8.772E-22
IR193	0.000E+00	0.000E+00	0.000E+00
IR194	0.000E+00	5.873E-18	0.000E+00
IR194M	0.000E+00	3.096E-19	0.000E+00
PT190	0.000E+00	0.000E+00	0.000E+00
PT191	0.000E+00	0.000E+00	0.000E+00
PT192	0.000E+00	0.000E+00	0.000E+00
PT193	0.000E+00	8.361E-23	8.881E-23
PT193M	0.000E+00	2.210E-19	0.000E+00
PT194	0.000E+00	0.000E+00	0.000E+00
PT195	0.000E+00	0.000E+00	0.000E+00
PT195M	0.000E+00	2.476E-23	0.000E+00
PT196	0.000E+00	0.000E+00	0.000E+00
PT197	0.000E+00	0.000E+00	0.000E+00
PT197M	0.000E+00	0.000E+00	0.000E+00
PT198	0.000E+00	0.000E+00	0.000E+00
PT199	0.000E+00	0.000E+00	0.000E+00
PT199M	0.000E+00	0.000E+00	0.000E+00
AU197	0.000E+00	0.000E+00	0.000E+00
AU198	0.000E+00	0.000E+00	0.000E+00
AU199	0.000E+00	0.000E+00	0.000E+00
AU200	0.000E+00	0.000E+00	0.000E+00
HG196	0.000E+00	0.000E+00	0.000E+00
HG197	0.000E+00	0.000E+00	0.000E+00
HG197M	0.000E+00	0.000E+00	0.000E+00
HG198	0.000E+00	0.000E+00	0.000E+00
HG199	0.000E+00	0.000E+00	0.000E+00
HG199M	0.000E+00	0.000E+00	0.000E+00
HG200	0.000E+00	0.000E+00	0.000E+00
HG201	0.000E+00	0.000E+00	0.000E+00
HG202	0.000E+00	0.000E+00	0.000E+00
HG203	0.000E+00	0.000E+00	0.000E+00
HG204	0.000E+00	0.000E+00	0.000E+00
HG205	0.000E+00	0.000E+00	0.000E+00
TL203	0.000E+00	0.000E+00	0.000E+00
TL204	0.000E+00	0.000E+00	0.000E+00
TL205	0.000E+00	0.000E+00	0.000E+00
TL206	0.000E+00	2.649E-19	9.810E-21
PB204	1.156E-20	1.156E-20	1.156E-20
PB205	0.000E+00	1.349E-14	1.349E-14

FIGURE A-2

PARTIAL ORIGEN2 SAMPLE OUTPUT
(CONTINUED)

```
1                                                    OUTPUT UNIT =  6                    PAGE   26
    * PATHFINDER ACTIVATION ANALYSIS.  CURIES PER GRAM OF MATERIAL
*                                                                        ACTIVATION PRODUCTS
    POWER= 0.00000E+00 MW,  BURNUP= 0.00000E+00 MWD,  FLUX= 5.00E+13 N/CM**2-SEC
0                  7 NUCLIDE TABLE:  RADIOACTIVITY,  CURIES
                            THERMAL KSEC - FLUX AT CORE BOUNDARY - STAINLESS STEEL
```

	STARTUP	SHUTDOWN	1-JUN-1989
PB206	0.000E+00	0.000E+00	0.000E+00
PB207	0.000E+00	0.000E+00	0.000E+00
PB208	0.000E+00	0.000E+00	0.000E+00
PB209	0.000E+00	6.718E-08	0.000E+00
BI208	0.000E+00	0.000E+00	0.000E+00
BI209	0.000E+00	0.000E+00	0.000E+00
BI210	0.000E+00	4.827E-13	0.000E+00
BI210M	0.000E+00	9.850E-21	9.849E-21
BI211	0.000E+00	8.142E-19	0.000E+00
PO210	0.000E+00	8.430E-14	3.940E-23
PO211	0.000E+00	2.184E-18	0.000E+00
PO211M	0.000E+00	3.038E-20	0.000E+00
TOTAL	1.251E-12	5.555E+00	2.619E-03

```
0                                   CUMULATIVE TABLE TOTALS
```

AP+FP	1.251E-12	5.555E+00	2.619E-03
ACT+FP	0.000E+00	0.000E+00	0.000E+00
AP+ACT+FP	1.251E-12	5.555E+00	2.619E-03

APPENDIX B

PATHFINDER CURIE ESTIMATE SPREADSHEET

APPENDIX B

PATHFINDER CURIE ESTIMATE SPREADSHEET

Using the curie per gram source terms for 1 June 1989 calculated for the various materials as typically shown in Appendix A, a Lotus 1-2-3 spreadsheet was constructed to perform the disparate tasks necessary to determine the total curie contents of the vessel package and individual components as of 1 January 1990. These tasks are:

- Further decay of the curie/gram source terms to 1 January 1990 (the spreadsheet shown has already decayed these values from 1 June 1989 to 1 January 1990; therefore the decay factor for all radionuclides is shown as 1.00
- Calculation of logarithmic averages for various regions and constructing a set of radionuclides appropriate for this average
- Determination of individual weights of materials in each region of the neutron activation model
- Calculation of curie contents by isotope in each component in each region of the activation model
- Summation of curie contents by isotope of each component
- Summation of curie contents by isotope for entire vessel package
- Summation of curie contents for entire package and determination of relative contribution by isotope

The regions referred to in the spreadsheet are those shown in the neutron activation model as described in Section 5 and depicted in Figures 5.3 and 5.4. Region numbering begins with the central cylinder, uppermost layer. Region numbers increase with decreasing elevation until the bottom of the central cylinder (region 7), then begins again with region 8 at the top of the first concentric ring around the core.

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
UPPER LEFT SECTION

NOTES: 1) All dimensions are CGS units unless otherwise noted
2) Top and bottom boundaries are relative to core midplane
3) Radii are based upon reactor vessel/core centerline
4) Material within the core region (region 4 only) are modeled on a standard ORIGEN2 BWR neutron flux spectrum.
5) Material outside the core region (regions 1-3 & 5-28) are modeled on thermal neutron spectrum only.
Standard thermal cross-sections assume 0.025 eV neutron energies; for reactor operating temperatures a correction factor to the average neutron velocity's absorption cross-section must be applied to the ORIGEN2 results.
Materials external to the reactor vessel are assumed to be at room temperature of 68 deg. F

MATERIAL DENSITIES (GM/CM^3):

Stainless steel 304L	7.90
Zircaloy-2	6.57
Carbon steel A212	7.09

GEOMETRY/MATERIAL AXIAL FLUX REDUCTION FACTORS:

From core avg to third layer above core	1.000E-03
second layer above core	1.000E-02
first layer above core	1.000E-01
first layer below core	1.000E-01
second layer below core	1.000E-02
third layer below core	1.000E-03

THERMAL NEUTRON CROSS-SECTION CORRECTION FACTORS:

0.025 eV neutron temperature:	68.00 deg. F =	293.00 K
Core operating temperature:	489.00 deg. F =	526.89 K
Cross-section compared to 293 K =		66.09%
Vessel wall avg temperature:	400.00 deg. F =	477.44 K
Cross-section compared to 293 K =		69.43%

Input isotopic decay date: 01-Jan-90
Proposed shipping date: 01-Jan-90

Cyl. No.	Cylinder n/cm^2	ORIGEN2/IBG MICRO VERSION * RADIONUCLIDE SOURCE TERMS (CI/GM):	H3	C14	K40	Ca41	Fe55	Co60	Ni59	Ni63	Zn65	Sr90	Zr93	Nb93m	Nb94	Tc99
0	3.50E+13	Core region stainless steel 304L	2.58E-07	9.83E-08	3.16E-15	1.27E-11	1.50E-05	1.13E-04	6.08E-07	7.22E-05	3.82E-15	5.30E-17	0.00	0.00	1.96E-09	4.06E-09
0	3.50E+13	Core region Zircaloy-2	2.19E-13	1.74E-08	0.00E+00	0.00E+00	3.23E-08	8.50E-07	3.01E-09	3.61E-07	8.90E-21	8.96E-13	0.00	0.00	2.59E-09	6.18E-17
	3.50E+13	Core bndry SS 304L (boiler shroud)	3.48E-07	1.37E-07	1.72E-15	1.86E-11	2.19E-05	1.18E-04	8.85E-07	1.07E-04	4.23E-15	1.65E-16	0.00	0.00	7.30E-10	7.00E-11
	3.50E+13	Core bndry SS 304L (except shroud)	4.12E-08	1.62E-08	2.04E-16	2.21E-12	2.60E-06	1.40E-05	1.05E-07	1.27E-05	5.01E-16	1.95E-17	0.00	0.00	8.65E-11	8.29E-12
1	1.07E+12	- Log average for region	8.60E-09	3.11E-09	5.90E-16	4.29E-13	4.98E-07	2.69E-06	2.03E-08	2.44E-06	9.59E-17	0.00E+00	9.78E-16	6.24E-16	1.66E-11	1.59E-12
2	3.30E+10	Vessel clad stainless steel 304L	1.80E-09	5.58E-10	1.71E-15	8.32E-14	9.57E-08	5.18E-07	3.94E-09	4.70E-07	1.84E-17	1.14E-21	0.00	0.00	3.20E-12	3.06E-13
	3.30E+10	Inner vessel wall carbon steel A212	2.15E-09	[illegible]	6.82E-15	6.13E-14	1.33E-07	4.49E-08	2.60E-10	3.10E-08	4.02E-18	8.58E-22	0.00	0.00	6.75E-13	6.59E-14
3	9.08E+09	- Log average for region	1.24E-10	3.76E-11	8.37E-15	2.63E-14	4.85E-08	1.58E-08	5.81E-11	1.05E-08	1.85E-18	0.00E+00	6.36E-17	4.05E-17	2.29E-13	2.23E-14
	2.50E+09	Outer vessel wall carbon steel A212	3.71E-12	1.27E-11	1.03E-14	1.13E-14	1.77E-08	5.55E-09	2.98E-11	3.57E-09	8.47E-19	0.00E+00	2.15E-17	1.37E-17	7.74E-14	7.55E-15
		Isotope half-life, years	12.35	5730.00	1.28E+09	0.8548	2.685	5.272	15130	100.10	0.6681	28.82	1,530,000	13.6	20320	214500
		Additional decay factor against Ci/gm values listed below	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00 (secular equilibrium)	1.00	1.00

* Note that the input Ci/gm values have been adjusted in another spreadsheet for decay, thermal, radial and component averaging corrections.

Region No.	Cylinder	Cylinder description	Outer Radius	Inner Radius	Layer	Layer Description	Boundary @Top	Boundary @Bottom	Region Volume	Region Material	Axial factor	Region contents
1	0	Core region	87.63	0.00	1	3rd layer above core	181.44	151.44	723,730	SS 304	1.00E-03	Superheater baffle
												Boiler control blades
												Control rod guide tubes
												Superheater control rods
												Superheater fuel element tubes
2					2	2nd layer above core	151.44	121.44	723,730	SS 304	1.00E-02	Superheater baffle
												Boiler control blades
												Control rod guide tubes
												Superheater control rods
												Superheater fuel element tubes
3					3	1st layer above core	121.44	91.44	723,730	Zircaloy	1.00E-01	4 element boiler boxes
										-		Single element boiler boxes
										SS 304		Superheater baffle
										-		Boiler control blades
										-		Control rod guide tubes
										-		Boiler element hold down structure
												Superheater control rods
										-		Superheater fuel element tubes
4					4	Reactor Core	91.44	-91.44	4,411,860	Zircaloy	1.00E+00	4 element boiler boxes
										-		Single element boiler boxes
										SS 304		Superheater baffle
										-		Instrumentation & sample holders
										-		Superheater fuel element tubes
										-		Boiler control blades
										-		Boiler element poison shims

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
LOWER LEFT SECTION

Region No.	Cylinder	Cylinder description	Outer Radius	Inner Radius	Layer	Layer Description	Boundary @Top	Boundary @Bottom	Region Volume	Region Material	Axial factor	Region contents
5					5	1st layer below core	-91.44	-121.44	723.730	Zircaloy	1.00E-01	4 element boiler box
										-		Single element boiler box
										SS 304		4 element boiler box bottom
										-		Single element boiler box bottom
										-		Superheater baffle
										-		Superheater fuel element tubes
										-		Boiler grid plate
6					6	2nd layer below core	-121.44	-151.44	723.730	SS 304	1.00E-02	Superheater baffle
												Superheater fuel element tubes
7					7	3rd layer below core	-151.44	-181.44	723.730	SS 304	1.00E-03	Superheater baffle
												Superheater support plate
												Superheater fuel element tubes
8	1	Steam separator region	167.64	87.63	1	3rd layer above core	181.44	151.44	1,924.931	SS 304	1.00E-03	Boiler baffle
												Steam separators
9					2	2nd layer above core	151.44	121.44	1,924.931	SS 304	1.00E-02	Boiler baffle
												Steam separators
10					3	1st layer above core	121.44	91.44	1,924.931	SS 304	1.00E+00	Boiler baffle **
												Steam separators
11					4	Reactor Core Level	91.44	-91.44	11,734.380	SS 304	1.00E+00	Boiler baffle
												Steam separators
												Steam separator nozzles
												Steam separators shelf
12					5	1st layer below core	-91.44	-121.44	1,924.931	SS 304	1.00E+00	Boiler baffle **
												Feedwater ring w/supports
13					6	2nd layer below core	-121.44	-151.44	1,924.931	SS 304	1.00E-02	(empty region)
14					7	3rd layer below core	-151.44	-181.44	1,924.931	SS 304	1.00E-03	(empty region)
15	2	Vessel cladding region	168.28	167.64	1	3rd layer above core	181.44	151.44	20.104	SS 304	1.00E-03	Vessel cladding
16					2	2nd layer above core	151.44	121.44	20.104	SS 304	1.00E-02	Vessel cladding
17					3	1st layer above core	121.44	91.44	20.104	SS 304	1.00E-01	Vessel cladding
18					4	Reactor Core Level	91.44	-91.44	122.552	SS 304	1.00E+00	Vessel cladding
19					5	1st layer below core	-91.44	-121.44	20.104	SS 304	1.00E-01	Vessel cladding
20					6	2nd layer below core	-121.44	-151.44	20.104	SS 304	1.00E-02	Vessel cladding
21					7	3rd layer below core	-151.44	-181.44	20.104	SS 304	1.00E-03	Vessel cladding
22	3	Vessel wall region	175.90	168.28	1	3rd layer above core	181.44	151.44	247.172	CS A212	1.00E-03	Vessel wall
23					2	2nd layer above core	151.44	121.44	247.172	CS A212	1.00E-02	Vessel wall
24					3	1st layer above core	121.44	91.44	247.172	CS A212	1.00E-01	Vessel wall
25					4	Reactor Core Level	91.44	-91.44	1,506.760	CS A212	1.00E+00	Vessel wall
26					5	1st layer below core	-91.44	-121.44	247.172	CS A212	1.00E-01	Vessel wall
27					6	2nd layer below core	-121.44	-151.44	247.172	CS A212	1.00E-02	Vessel wall
28					7	3rd layer below core	-151.44	-181.44	247.172	CS A212	1.00E-03	Vessel wall

TOTAL FOR VESSEL PACKAGE
Isotopic percentage of total

** Boiler baffle above and below core does not have a flux reduction factor due to the use of homogenized Ci/gm source term

SUMMARY OF CURIES BY COMPONENT:	Tot model Weight, lb	Model vs Total Wt.	H3	C14	K40	Ca41	Fe55	Co60	Ni59	Ni63	Zn65	Sr90	Zr93	Nb93m
Superheater baffle	1,300.72	11	7.87E-02	2.99E-02	9.61E-10	3.06E-06	4.58E+00	3.44E+01	1.85E-01	2.7[illegible]E+01	[illegible].16E-09	1.64E-11	8.36E-08	5.34E-08
Superheater fuel insul. tubes (inner & outer)	2,492.71	11	1.51E-01	5.74E-02	1.84E-09	7.39E-06	8.77E+00	6.59E+01	3.55E-01	4.21E+01	2.23E-09	3.14E-11	1.61E-07	1.02E-07
Superheater support plate	45.98	79.99%	3.56E-06	1.36E-06	4.35E-14	1.75E-10	2.07E-04	1.56E-03	8.38E-06	9.95E-04	5.26E-14	7.41E-16	3.79E-12	2.42E-12
Superheater control rods	275.52	25.63%	7.41E-04	2.82E-04	9.06E-12	3.43E-08	4.31E-02	3.24E-01	1.74E-03	2.07E-01	1.1[illegible]E-11	1.54E-13	7.89E-10	5.03E-10
Boiler fuel boxes	7,662.14	100.00%	1.35E-02	3.37E-02	1.64E-10	6.60E-07	8.35E-01	7.19E+00	3.86E-02	4.35E+00	1.99E-10	1.47E-06	1.14E-02	7.23E-03
Boiler shroud	1,460.00	100.00%	1.52E-01	5.99E-02	7.54E-10	8.16E-06	9.59E+00	5.16E+01	3.87E-01	4.68E+01	1.85E-09	7.20E-11	1.80E-08	1.20E-08
Boiler element hold down structure	1,352.39	11	1.05E-02	3.99E-03	1.28E-10	5.14E-07	6.09E-01	4.58E+00	2.46E-02	2.93E+00	1.55E-10	2.18E-12	1.12E-08	7.11E-09
Boiler CR guide tubes & remaining structure	2,942.83	61.36%	8.43E-03	3.21E-03	1.03E-10	4.14E-07	4.91E-01	3.69E+00	1.98E-02	2.36E+00	1.25E-10	1.76E-12	8.98E-09	5.73E-09
Boiler element poison shims	376.00	100.00%	3.24E-02	1.23E-02	3.95E-10	1.59E-06	1.88E+00	1.41E+01	7.61E-02	9.03E+00	4.78E-10	6.73E-12	3.45E-08	2.20E-08
Boiler control blades	1,816.18	69.21%	1.10E-01	4.18E-02	1.34E-09	5.39E-06	6.39E+00	4.80E+01	2.58E-01	3.07E+01	1.62E-09	2.29E-11	1.17E-07	7.46E-08
Instrumentation tubing & sample holders	69.05	103.47%	8.19E-03	3.12E-03	1.00E-10	4.01E-07	4.76E-01	3.58E+00	1.93E-02	2.29E+00	1.21E-10	1.70E-12	8.72E-09	5.56E-09
Boiler grid plate	5,600.00	100.00%	4.34E-02	1.65E-02	5.30E-10	2.13E-06	2.52E+00	1.90E+01	1.02E-01	1.21E+01	6.41E-10	9.03E-12	4.12E-08	2.95E-08
Steam separators & supports	4,636.00	61.94%	9.38E-03	3.40E-03	6.43E-10	4.67E-07	5.43E-01	2.93E+00	2.22E-02	2.66E+00	1.05E-10	0.00E+00	1.07E-09	6.80E-10
Feedwater ring & supports	1,027.00	100.00%	2.65E-03	9.59E-04	1.82E-10	1.32E-07	1.53E-01	8.28E-01	6.26E-03	7.52E-01	2.95E-11	0.00E+00	3.01E-10	1.92E-10
Vessel cladding	4,235.23	11	1.19E-03	3.96E-04	1.13E-09	5.52E-08	6.34E-02	3.44E-01	2.61E-03	3.12E-01	1.22E-11	7.59E-16	1.25E-10	7.96E-11
Vessel	52,005.84	38.93%	1.06E-03	3.22E-04	7.16E-08	2.25E-07	4.15E-01	1.35E-01	7.53E-04	9.01E-02	1.58E-11	0.00E+00	5.[illegible]E-10	3.47E-10
Totals	87,200.47	46.65%	0.42	0.27	0.00	0.00	37.36	296.66	1.50	178.68	0.00	0.00	0.01	0.01
Percent of total by isotope	n/a	n/a	0.13%	0.05%	0.00%	0.00%	7.85%	53.90%	0.31%	37.53%	0.00%	0.00%	0.00%	0.00%

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
UPPER CENTER SECTION

Component	Weight (lbs)
Superheater baffle	4,800.00
Superheater fuel insul. tubes (inner & outer)	!!
Superheater support plate	!!
Superheater control rods	1,075.40
Boiler fuel boxes	7,664.00
Boiler shroud	1,460.00
Boiler element hold down structure & guide tub	7,700.00
Boiler element poison shims	276.00
Boiler control blades	2,424.00
Instrumentation tubing & sample holders	67.50
Boiler grid plate	5,600.00
Steam separators & supports	7,485.00
Feedwater ring & supports	1,027.00
Steam dryer assembly	3,400.00
Vessel & cladding	144,450.00
	==========
Total weight of internals & vessel	186,130.50

Cyl. No.	Cylinder n/cm^2	ORIGEN2/IBM MICRO VERSION RADIONUCLIDE SOURCE TERMS (CI/GM):	Sn121m	Sb125	Te125m	Cs137	Eu152	Eu154	Total Ci/gm
0	3.50E+13	Core region stainless steel 304L	0.00	0.00	0.00	3.17E-18	8.18E-08	9.21E-09	2.01E-04
0	3.50E+13	Core region Zircaloy-2	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	1.74E-06
	3.50E+13	Core bndry SS 304L (boiler shroud)	0.00	0.00	0.00	2.99E-17	1.75E-08	6.08E-09	2.48E-04
	3.50E+13	Core bndry SS 304L (except shroud)	0.00	0.00	0.00	3.54E-18	2.07E-09	7.21E-10	2.94E-05
1	1.07E+12	- Log average for region	0.00E+00	1.77E-15	4.36E-16	0.00E+00	1.03E-09	1.47E-10	5.66E-06
2	3.30E+10	Vessel clad stainless steel 304L	0.00	0.00	0.00	0.00E+00	5.13E-10	3.01E-11	1.09E-06
	3.30E+10	Inner vessel wall carbon steel A212	0.00	0.00	0.00	0.00E+00	7.96E-10	4.67E-11	2.14E-07
3	9.08E+09	- Log average for region	0.00E+00	7.68E-19	1.92E-19	0.00E+00	2.74E-10	1.62E-11	7.54E-08
	2.50E+09	Outer vessel wall carbon steel A212	0.00E+00	7.56E-20	1.92E-20	0.00E+00	9.42E-11	5.61E-12	2.70E-08
		Isotope half-life, years	55	2.71	0.15	30.17	13.23	8.55	
		Additional decay factor against Ci/gm values listed below	1.00	1.00	1.00 (secular equilibrium)	1.00	1.00	1.00	

Region No.	Cylinder	Cylinder description	Outer Radius	Unit Volume	Quantity	Mat'l vol in region	Ci H3	Ci C14	K40	Ci Ca41	Ci Fe55	Ci Co60	Ci Ni59	Ci Ni63	Ci Zn65	Ci Sr90	Ci Zr93
1	0	Core region	87.63	6.17E+03	1	6174.10	8.33E-06	3.17E-06	1.02E-1.	4.08E-10	4.85E-04	3.64E-03	1.96E-05	2.33E-03	1.23E-13	1.73E-15	8.87E-12
				1.08E+03	16	17241.93	2.33E-05	8.85E-06	2.84E-13	1.14E-09	1.35E-03	1.02E-02	5.47E-05	6.50E-03	3.44E-13	4.84E-15	2.48E-11
				3.52E+03	16	56322.56	7.60E-05	2.89E-05	9.28E-13	3.73E-09	4.42E-03	3.32E-02	1.79E-04	2.12E-02	1.12E-12	1.58E-14	8.09E-11
				9.14E+01	65	5938.53	8.01E-06	3.05E-06	9.79E-14	3.93E-10	4.66E-04	3.50E-03	1.88E-05	2.24E-03	1.18E-13	1.67E-15	8.53E-12
				2.53E+01	468	11832.29	1.60E-05	6.08E-06	1.95E-13	7.83E-10	9.29E-04	6.98E-03	3.76E-05	4.46E-03	2.36E-13	3.32E-15	1.70E-11
2				6.17E+03	1	6174.10	8.33E-05	3.17E-05	1.02E-12	4.08E-09	4.85E-03	3.64E-02	1.96E-04	2.33E-02	1.23E-12	1.73E-14	8.87E-11
				1.08E+03	16	17241.93	2.33E-04	8.85E-05	2.84E-12	1.14E-08	1.35E-02	1.02E-01	5.47E-04	6.50E-02	3.44E-12	4.84E-14	2.48E-10
				3.52E+03	16	56322.56	7.60E-04	2.89E-04	9.28E-12	3.73E-08	4.42E-02	3.32E-01	1.79E-03	2.12E-01	1.12E-11	1.58E-13	8.09E-10
				7.60E+01	65	4940.40	6.67E-05	2.54E-05	8.14E-13	3.27E-09	3.88E-03	2.91E-02	1.57E-04	1.86E-02	9.85E-13	1.39E-14	7.10E-11
				2.53E+01	468	11832.29	1.60E-04	6.08E-05	1.95E-12	7.83E-09	9.29E-03	6.98E-02	3.76E-04	4.46E-02	2.36E-12	3.32E-14	1.70E-10
3				1.86E+03	16	29777.06	3.34E-03	1.27E-03	4.08E-11	1.64E-07	1.94E-01	1.46E+00	7.86E-03	9.33E-01	4.94E-11	6.95E-13	3.56E-09
				4.62E+02	32	14774.50	1.66E-03	6.31E-04	2.03E-11	8.13E-08	9.64E-02	7.25E-01	3.90E-03	4.63E-01	2.45E-11	3.45E-13	1.77E-09
				6.17E+03	1	6174.10	8.33E-04	3.17E-04	1.02E-11	4.08E-08	4.85E-02	3.64E-01	1.96E-03	2.33E-01	1.23E-11	1.73E-13	8.87E-10
				1.08E+03	16	17241.93	2.33E-03	8.85E-04	2.84E-11	1.14E-07	1.35E-01	1.02E+00	5.47E-03	6.50E-01	3.44E-11	4.84E-13	2.48E-09
				3.52E+03	16	56322.56	7.60E-03	2.89E-03	9.28E-11	3.73E-07	4.42E-01	3.32E+00	1.79E-02	2.12E+00	1.12E-10	1.58E-12	8.09E-09
				7.76E+04	1	77649.94	1.05E-02	3.99E-03	1.28E-10	5.14E-07	6.09E-01	4.58E+00	2.46E-02	2.93E+00	1.55E-10	2.18E-12	1.12E-08
				7.60E+01	65	4940.40	6.67E-04	2.54E-04	8.14E-12	3.27E-08	3.88E-02	2.91E-01	1.57E-03	1.86E-01	9.85E-12	1.39E-13	7.10E-10
				2.53E+01	468	11832.29	1.60E-03	6.08E-04	1.95E-11	7.83E-08	9.29E-02	6.98E-01	3.76E-03	4.46E-01	2.36E-11	3.32E-13	1.70E-09
4				1.59E+04	16	257729.25	2.40E-07	1.91E-02	0.00E+00	0.00E+00	3.53E-02	8.77E-01	3.30E-03	3.95E-01	4.75E-15	9.81E-07	7.99E-03
				3.91E+03	32	125140.68	1.19E-07	9.47E-03	0.00E+00	0.00E+00	1.75E-02	4.35E-01	1.64E-03	1.96E-01	4.84E-15	4.87E-07	3.77E-03
				3.76E+04	1	37637.80	7.68E-02	2.92E-02	9.39E-10	3.77E-06	4.47E+00	3.36E+01	1.81E-01	2.15E+01	1.14E-09	1.60E-11	8.18E-08
				4.01E+03	1	4010.29	8.19E-03	3.12E-03	1.00E-10	4.01E-07	4.76E-01	3.58E+00	1.93E-02	2.29E+00	1.21E-10	1.70E-12	8.72E-09
				1.54E+02	468	72129.66	1.47E-01	5.60E-02	1.80E-09	7.22E-06	8.57E+00	6.44E+01	3.46E-01	4.11E+01	2.18E-09	3.06E-11	1.57E-07
				3.28E+03	16	52553.41	1.07E-01	4.08E-02	1.31E-09	5.26E-06	6.24E+00	4.69E+01	2.52E-01	3.00E+01	1.59E-09	2.23E-11	1.14E-07
				3.96E+02	40	15847.02	3.24E-02	1.23E-02	3.95E-10	1.59E-06	1.88E+00	1.41E+01	7.61E-02	9.03E+00	4.78E-10	6.73E-12	3.45E-08

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
LOWER CENTER SECTION

Region No.	Cylinder	Cylinder description	Outer Radius	Unit Volume	Quantity	Mat'l vol in region	Ci H3	Ci C14	K40	Ci Ca41	Ci Fe55	Ci Co60	Ci Ni59	Ci Ni63	Ci Zn65	Ci Sr90	Ci Zr93
5				1.86E-03	16	29777.06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
				4.62E-02	32	14774.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
				2.73E+03	16	43671.74	5.89E-03	2.24E-03	7.20E-11	2.89E-07	3.43E-01	2.58E+00	1.39E-02	1.65E+00	8.71E-11	1.23E-12	6.28E-09
				5.93E+02	32	10970.82	2.56E-03	9.74E-04	3.13E-11	1.26E-07	1.49E-01	1.12E+00	6.02E-03	7.15E-01	3.78E-11	5.33E-13	2.73E-09
				6.17E+03	1	6174.18	8.33E-04	3.17E-04	1.02E-11	4.08E-08	4.85E-02	3.64E-01	1.96E-03	2.33E-01	1.23E-11	1.73E-13	8.87E-10
				2.53E+01	468	11832.29	1.60E-03	6.08E-04	1.95E-11	7.83E-08	9.29E-02	6.98E-01	3.76E-03	4.46E-01	2.36E-11	3.32E-13	1.70E-09
				3.22E+05	1	321533.83	4.34E-02	1.65E-02	5.30E-10	2.13E-06	2.52E+00	1.90E+01	1.02E-01	1.21E+01	6.41E-10	9.03E-12	4.62E-08
6				6.17E+03	1	6174.18	8.33E-05	3.17E-05	1.02E-12	4.08E-09	4.85E-03	3.64E-02	1.96E-04	2.33E-02	1.23E-12	1.73E-14	8.87E-11
				2.53E+01	468	11832.29	1.60E-04	6.08E-05	1.95E-12	7.83E-09	9.29E-03	6.98E-02	3.76E-04	4.46E-02	2.36E-12	3.32E-14	1.70E-10
7				6.17E+03	1	6174.18	8.33E-06	3.17E-06	1.02E-13	4.08E-10	4.85E-04	3.64E-03	1.96E-03	2.33E-03	1.23E-13	1.73E-15	8.87E-12
				2.64E+03	1	2640.18	3.56E-06	1.36E-06	4.35E-14	1.75E-10	2.07E-04	1.56E-03	8.38E-06	9.95E-04	5.26E-14	7.41E-16	3.79E-12
				2.53E+01	468	11832.29	1.60E-05	6.08E-06	1.95E-13	7.83E-10	9.29E-04	6.98E-03	3.76E-05	4.46E-03	2.36E-13	3.32E-15	1.70E-11
8	1	Steam separator region	167.64	none	0	0.00											
				6.56E-02	44	28844.16	1.30E-06	4.69E-07	8.89E-14	6.46E-11	7.50E-05	4.05E-04	3.06E-06	3.68E-04	1.44E-14	0.00E+00	1.47E-13
9				none	0	0.00											
				6.56E-02	44	28844.16	1.30E-05	4.69E-06	8.89E-13	6.46E-10	7.50E-04	4.05E-03	3.06E-05	3.68E-03	1.44E-13	0.00E+00	1.47E-12
10				1.77E+04	1	17684.36	3.21E-02	1.26E-02	1.59E-10	1.72E-06	2.02E+00	1.09E+01	8.17E-02	9.88E+00	3.90E-10	1.52E-11	3.97E-09
				6.56E+02	44	28844.16	1.30E-03	4.69E-04	8.89E-11	6.46E-08	7.50E-02	4.05E-01	3.06E-03	3.68E-01	1.44E-11	0.00E+00	1.47E-10
11				5.15E+04	1	51502.83	9.35E-02	3.68E-02	4.63E-10	5.01E-06	5.89E+00	3.17E+01	2.38E-01	2.88E+01	1.14E-09	4.43E-11	1.16E-08
				2.66E+03	44	117222.68	5.26E-03	1.91E-03	3.61E-10	2.62E-07	3.05E-01	1.65E+00	1.24E-02	1.49E+00	5.87E-11	0.00E+00	5.99E-10
				8.04E+02	44	35372.30	1.59E-03	5.75E-04	1.09E-10	7.92E-08	9.20E-02	4.97E-01	3.75E-03	4.51E-01	1.77E-11	0.00E+00	1.81E-10
				2.71E+04	1	27060.97	1.22E-03	4.40E-04	8.34E-11	6.06E-08	7.04E-02	3.80E-01	2.87E-03	3.45E-01	1.36E-11	0.00E+00	1.38E-10
12				1.46E+04	1	14641.27	2.66E-02	1.05E-02	1.32E-10	1.43E-06	1.68E+00	9.01E+00	6.76E-02	8.18E+00	3.23E-10	1.26E-11	3.29E-09
				5.90E+04	1	58967.01	2.65E-03	9.59E-04	1.82E-10	1.32E-07	1.53E-01	8.28E-01	6.26E-03	7.52E-01	2.95E-11	0.00E+00	3.01E-10
13				none	0	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14				none	0	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	2	Vessel cladding region	168.28	20.104	1	20.104	1.89E-07	6.27E-08	1.79E-13	8.73E-12	1.00E-05	5.44E-05	4.14E-07	4.94E-05	1.93E-15	1.20E-19	1.97E-14
16				20.104	1	20.104	1.89E-06	6.27E-07	1.79E-12	8.73E-11	1.00E-04	5.44E-04	4.14E-06	4.94E-04	1.93E-14	1.20E-18	1.97E-13
17				20.104	1	20.104	1.89E-05	6.27E-06	1.79E-11	8.73E-10	1.00E-03	5.44E-03	4.14E-05	4.94E-03	1.93E-13	1.20E-17	1.97E-12
18				122.552	1	122.552	1.15E-03	3.83E-04	1.09E-09	5.32E-08	6.12E-02	3.32E-01	2.52E-03	3.01E-01	1.18E-11	7.32E-16	1.20E-10
19				20.104	1	20.104	1.89E-05	6.27E-06	1.79E-11	8.73E-10	1.00E-03	5.44E-03	4.14E-05	4.94E-03	1.93E-13	1.20E-17	1.97E-12
20				20.104	1	20.104	1.89E-06	6.27E-07	1.79E-12	8.73E-11	1.00E-04	5.44E-04	4.14E-06	4.94E-04	1.93E-14	1.20E-18	1.97E-13
21				20.104	1	20.104	1.89E-07	6.27E-08	1.79E-13	8.73E-12	1.00E-05	5.44E-05	4.14E-07	4.94E-05	1.93E-15	1.20E-19	1.97E-14
22	3	Vessel wall region	175.90	247.172	1	247.172	1.68E-07	5.09E-08	1.13E-11	3.56E-11	6.57E-05	2.14E-05	1.19E-07	1.43E-05	2.50E-15	0.00E+00	8.61E-14
23				247.172	1	247.172	1.68E-06	5.09E-07	1.13E-10	3.56E-10	6.57E-04	2.14E-04	1.19E-06	1.43E-04	2.50E-14	0.00E+00	8.61E-13
24				247.172	1	247.172	1.68E-05	5.09E-06	1.13E-09	3.56E-09	6.57E-03	2.14E-03	1.19E-05	1.43E-03	2.50E-13	0.00E+00	8.61E-12
25				1,506.760	1	1,506.760	1.02E-03	3.10E-04	6.91E-08	2.17E-07	4.00E-01	1.30E-01	7.27E-04	8.69E-02	1.52E-11	0.00E+00	5.25E-10
26				247.172	1	247.172	1.68E-05	5.09E-06	1.13E-09	3.56E-09	6.57E-03	2.14E-03	1.19E-05	1.43E-03	2.50E-13	0.00E+00	8.61E-12
27				247.172	1	247.172	1.68E-06	5.09E-07	1.13E-10	3.56E-10	6.57E-04	2.14E-04	1.19E-06	1.43E-04	2.50E-14	0.00E+00	8.61E-13
28				247.172	1	247.172	1.68E-07	5.09E-08	1.13E-11	3.56E-11	6.57E-05	2.14E-05	1.19E-07	1.43E-05	2.50E-15	0.00E+00	8.61E-14
		TOTAL FOR VESSEL PACKAGE					6.23E-01	2.67E-01	7.99E-08	3.14E-05	3.74E+01	2.57E+02	1.50E+00	1.79E+02	8.76E-09	1.47E-06	1.14E-02
		Isotopic percentage of total					0.13%	0.06%	0.00%	0.00%	7.85%	53.90%	0.31%	37.53%	0.00%	0.00%	0.00%

SUMMARY OF CURIES BY COMPONENT:	Nb94	Tc99	Sn121m	Sb125	Te125m	Cs137	Eu152	Eu154	Total Curies
Superheater baffle	5.97E-04	1.24E-03	0.00E+00	1.11E-06	2.74E-07	9.66E-13	2.49E-02	2.80E-03	61.27
Superheater fuel insul. tubes (inner & outer)	1.14E-03	2.37E-03	0.00E+00	2.12E-06	5.25E-07	1.85E-12	4.77E-02	5.38E-03	117.42
Superheater support plate	2.70E-08	5.60E-08	0.00E+00	5.02E-11	1.24E-11	4.37E-17	1.13E-06	1.27E-07	0.00
Superheater control rods	5.62E-06	1.16E-05	0.00E+00	1.04E-08	2.58E-09	9.10E-15	2.35E-04	2.64E-05	0.58
Boiler fuel boxes	4.35E-03	2.11E-04	3.54E-02	6.40E-01	1.58E-01	1.65E-13	4.26E-03	4.80E-04	13.37
Boiler shroud	3.19E-04	3.06E-05	0.00E+00	1.32E-06	3.27E-07	1.31E-11	7.65E-03	2.66E-03	108.65
Boiler element hold down structure	7.95E-05	1.65E-04	0.00E+00	1.48E-07	3.65E-08	1.29E-13	3.32E-03	3.73E-04	8.16
Boiler CR guide tubes & remaining structure	6.40E-05	1.33E-04	0.00E+00	1.19E-07	2.94E-08	1.04E-13	2.67E-03	3.01E-04	6.57
Boiler element poison shims	2.45E-04	5.08E-04	0.00E+00	4.56E-07	1.13E-07	3.97E-13	1.02E-02	1.15E-03	25.19
Boiler control blades	8.33E-04	1.73E-03	0.00E+00	1.55E-06	3.82E-07	1.35E-12	3.48E-02	3.92E-03	85.55
Instrumentation tubing & sample holders	6.21E-05	1.29E-04	0.00E+00	1.15E-07	2.85E-08	1.00E-13	2.59E-03	2.92E-04	6.37
Boiler grid plate	3.29E-04	6.82E-04	0.00E+00	6.11E-07	1.51E-07	5.33E-13	1.37E-02	1.55E-03	33.78
Steam separators & supports	1.81E-05	1.74E-06	0.00E+00	1.93E-09	4.76E-10	0.00E+00	1.12E-03	1.61E-04	6.18
Feedwater ring & supports	5.12E-06	4.90E-07	0.00E+00	5.44E-10	1.34E-10	0.00E+00	3.17E-04	4.53E-05	1.74
Vessel cladding	2.12E-06	2.03E-07	0.00E+00	5.78E-12	1.43E-12	0.00E+00	3.40E-04	2.00E-05	0.72
Vessel	1.96E-06	1.91E-07	0.00E+00	6.57E-12	1.64E-12	0.00E+00	2.34E-03	1.38E-04	0.64
Totals	0.01	0.01	0.04	0.64	0.16	0.00	0.16	0.02	476.14
Percent of total by isotope	0.00%	0.00%	0.01%	0.13%	0.03%	0.00%	0.03%	0.00%	%

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
UPPER RIGHT SECTION

Region No.	Cylinder	Cylinder description	Outer Radius	Ci Nb93m	Ci Nb94	Ci Tc99	Ci Sn121m	Ci Sb125	Ci Te125m	Ci Cs137	Ci Eu152	Ci Eu154	Total Ci in region	Total % by region
1	0	Core region	87.63	5.66E-12	6.32E-08	1.31E-07	0.00E+00	1.17E-10	2.90E-11	1.02E-16	2.64E-06	2.97E-07	6.49E-03	0.00%
				1.58E-11	1.76E-07	3.65E-07	0.00E+00	3.28E-10	8.10E-11	2.86E-16	7.36E-06	8.29E-07	1.81E-02	0.00%
				5.16E-11	5.76E-07	1.19E-06	0.00E+00	1.07E-09	2.64E-10	9.33E-16	2.41E-05	2.71E-06	5.92E-02	0.01%
				5.44E-12	6.08E-08	1.26E-07	0.00E+00	1.13E-10	2.79E-11	9.83E-17	2.54E-06	2.86E-07	6.24E-03	0.00%
				1.08E-11	1.21E-07	2.51E-07	0.00E+00	2.25E-10	5.56E-11	1.96E-16	5.05E-06	5.69E-07	1.24E-02	0.00%
2				5.66E-11	6.32E-07	1.31E-06	0.00E+00	1.17E-09	2.90E-10	1.02E-15	2.64E-05	2.97E-06	6.49E-02	0.01%
				1.58E-10	1.76E-06	3.65E-06	0.00E+00	3.28E-09	8.10E-10	2.86E-15	7.36E-05	8.29E-06	1.81E-01	0.04%
				5.16E-10	5.76E-06	1.19E-05	0.00E+00	1.07E-08	2.64E-09	9.33E-15	2.41E-04	2.71E-05	5.92E-01	0.12%
				4.53E-11	5.06E-07	1.05E-06	0.00E+00	9.39E-10	2.32E-10	8.18E-16	2.11E-05	2.38E-06	5.19E-02	0.01%
				1.08E-10	1.21E-06	2.51E-06	0.00E+00	2.25E-09	5.56E-10	1.96E-15	5.05E-05	5.69E-06	1.24E-01	0.03%
3				2.27E-09	2.53E-05	5.25E-05	0.00E+00	4.71E-08	1.16E-08	4.10E-14	1.06E-03	1.19E-04	2.60E+00	0.55%
				1.13E-09	1.26E-05	2.60E-05	0.00E+00	2.34E-08	5.77E-09	2.03E-14	5.25E-04	5.91E-05	1.29E+00	0.27%
				5.66E-10	6.32E-06	1.31E-05	0.00E+00	1.17E-08	2.90E-09	1.02E-14	2.64E-04	2.97E-05	6.49E-01	0.14%
				1.58E-09	1.76E-05	3.65E-05	0.00E+00	3.28E-08	8.10E-09	2.86E-14	7.36E-04	8.29E-05	1.81E+00	0.38%
				5.16E-09	5.76E-05	1.19E-04	0.00E+00	1.07E-07	2.64E-08	9.33E-14	2.41E-03	2.71E-04	5.92E+00	1.24%
				7.11E-09	7.95E-05	1.65E-04	0.00E+00	1.48E-07	3.65E-08	1.29E-13	3.32E-03	3.73E-04	8.16E+00	1.71%
				4.53E-10	5.06E-06	1.05E-05	0.00E+00	9.39E-09	2.32E-09	8.18E-15	2.11E-04	2.38E-05	5.19E-01	0.11%
				1.08E-09	1.21E-05	2.51E-05	0.00E+00	2.25E-08	5.56E-09	1.96E-14	5.05E-04	5.69E-05	1.24E+00	0.26%
4				4.83E-03	2.84E-03	6.77E-11	2.37E-02	4.28E-01	1.06E-01	0.00E+00	0.00E+00	0.00E+00	1.90E+00	0.40%
				2.40E-03	1.41E-03	3.36E-11	1.17E-02	2.12E-01	5.24E-02	0.00E+00	0.00E+00	0.00E+00	9.44E-01	0.20%
				5.22E-08	5.83E-04	1.21E-03	0.00E+00	1.08E-06	2.67E-07	9.43E-13	2.43E-02	2.74E-03	5.98E+01	12.57%
				5.56E-09	6.21E-05	1.29E-04	0.00E+00	1.15E-07	2.85E-08	1.00E-13	2.59E-03	2.92E-04	6.37E+00	1.34%
				1.00E-07	1.12E-03	2.31E-03	0.00E+00	2.07E-06	5.12E-07	1.81E-12	4.66E-02	5.25E-03	1.15E+02	24.00%
				7.29E-08	8.14E-04	1.69E-03	0.00E+00	1.51E-06	3.73E-07	1.32E-12	3.40E-02	3.82E-03	8.35E+01	17.55%
				2.20E-08	2.45E-04	5.08E-04	0.00E+00	4.56E-07	1.13E-07	3.97E-13	1.02E-02	1.15E-03	2.52E+01	5.29%

FIGURE B-1
PATHFINDER CURIE ESTIMATE SPREADSHEET
LOWER RIGHT SECTION

Region No.	Cylinder	Cylinder description	Outer Radius	Ci Nb93m	Ci Nb94	Ci Tc99	Ci Sn121m	Ci Sb125	Ci Te125m	Ci Cs137	Ci Eu152	Ci Eu154	Total Ci in region	Total % by region
5				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%
				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%
				4.00E-09	4.47E-05	9.26E-05	0.00E+00	8.30E-08	2.05E-08	7.23E-14	1.87E-03	2.10E-04	4.59E+00	0.96%
				1.74E-09	1.94E-05	4.02E-05	0.00E+00	3.61E-08	8.91E-09	3.14E-14	8.11E-04	9.13E-05	1.99E+00	0.42%
				5.66E-10	6.32E-06	1.31E-05	0.00E+00	1.17E-08	2.90E-09	1.02E-14	2.64E-04	2.97E-05	6.49E-01	0.14%
				1.08E-09	1.21E-05	2.51E-05	0.00E+00	2.25E-08	5.56E-09	1.96E-14	5.05E-04	5.69E-05	1.24E+00	0.26%
6				2.95E-08	3.29E-04	6.82E-04	0.00E+00	6.11E-07	1.51E-07	5.33E-13	1.37E-02	1.55E-03	3.38E+01	7.09%
				5.66E-11	6.32E-07	1.31E-06	0.00E+00	1.17E-09	2.90E-10	1.02E-15	2.64E-05	2.97E-06	6.49E-02	0.01%
7				1.08E-10	1.21E-06	2.51E-06	0.00E+00	2.25E-09	5.56E-10	1.96E-15	5.05E-05	5.69E-06	1.24E-01	0.03%
				5.66E-12	6.32E-08	1.31E-07	0.00E+00	1.17E-10	2.90E-11	1.02E-15	2.64E-06	2.97E-07	6.49E-03	0.00%
				2.42E-12	2.70E-08	5.60E-08	0.00E+00	5.02E-11	1.24E-11	4.37E-17	1.13E-06	1.27E-07	2.77E-03	0.00%
				1.08E-11	1.21E-07	2.51E-07	0.00E+00	2.25E-10	5.56E-11	1.96E-16	5.05E-06	5.69E-07	1.24E-02	0.00%
8	1	Steam Separator region	167.64											
													0.00E+00	0.00%
9				5.39E-14	2.50E-09	2.40E-10	0.00E+00	2.66E-13	6.57E-14	0.00E+00	1.55E-07	2.22E-08	8.53E-04	0.00%
													0.00E+00	0.00%
10				9.39E-13	2.50E-08	2.40E-09	0.00E+00	2.66E-12	6.57E-13	0.00E+00	1.55E-06	2.22E-07	8.53E-03	0.00%
				2.53E-09	6.74E-05	6.46E-06	0.00E+00	2.79E-07	6.89E-08	2.76E-12	1.61E-03	5.62E-04	2.29E+01	4.81%
11				9.39E-11	2.50E-06	2.40E-07	0.00E+00	2.66E-10	6.57E-11	0.00E+00	1.55E-04	2.22E-05	8.53E-01	0.18%
				7.38E-09	1.96E-04	1.88E-05	0.00E+00	8.12E-07	2.01E-07	8.03E-12	4.70E-03	1.64E-03	6.68E+01	14.02%
				3.82E-10	1.02E-05	9.74E-07	0.00E+00	1.08E-09	2.67E-10	0.00E+00	6.31E-04	9.01E-05	3.47E+00	0.73%
				1.15E-10	3.07E-06	2.94E-07	0.00E+00	3.26E-10	8.06E-11	0.00E+00	1.90E-04	2.72E-05	1.05E+00	0.22%
				8.81E-11	2.35E-06	2.25E-07	0.00E+00	2.50E-10	6.16E-11	0.00E+00	1.46E-04	2.08E-05	8.00E-01	0.17%
12				2.10E-09	5.58E-05	5.35E-06	0.00E+00	2.31E-07	5.71E-08	2.28E-12	1.34E-03	4.65E-04	1.90E+01	3.99%
13				1.92E-10	5.12E-06	4.90E-07	0.00E+00	5.44E-10	1.34E-10	0.00E+00	3.17E-04	4.53E-05	1.74E+00	0.37%
14				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%
				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%
15	2	Vessel cladding region	168.28	1.26E-14	3.36E-10	3.21E-11	0.00E+00	9.15E-16	2.26E-16	0.00E+00	5.39E-08	3.16E-09	1.15E-04	0.00%
16				1.26E-13	3.36E-09	3.21E-10	0.00E+00	9.15E-15	2.26E-15	0.00E+00	5.39E-07	3.16E-08	1.15E-03	0.00%
17				1.26E-12	3.36E-08	3.21E-09	0.00E+00	9.15E-14	2.26E-14	0.00E+00	5.39E-06	3.16E-07	1.15E-02	0.00%
18				7.66E-11	2.05E-06	1.96E-07	0.00E+00	5.58E-12	1.38E-12	0.00E+00	3.29E-04	1.93E-05	6.98E-01	0.15%
19				1.26E-12	3.36E-08	3.21E-09	0.00E+00	9.15E-14	2.26E-14	0.00E+00	5.39E-06	3.16E-07	1.15E-02	0.00%
20				1.26E-13	3.36E-09	3.21E-10	0.00E+00	9.15E-15	2.26E-15	0.00E+00	5.39E-07	3.16E-08	1.15E-03	0.00%
21				1.26E-14	3.36E-10	3.21E-11	0.00E+00	9.15E-16	2.26E-16	0.00E+00	5.39E-08	3.16E-09	1.15E-04	0.00%
22	3	Vessel wall region	175.90	5.49E-14	3.10E-10	3.02E-11	0.00E+00	1.04E-15	2.60E-16	0.00E+00	3.71E-07	2.19E-08	1.02E-04	0.00%
23				5.49E-13	3.10E-09	3.02E-10	0.00E+00	1.04E-14	2.60E-15	0.00E+00	3.71E-06	2.19E-07	1.02E-03	0.00%
24				5.49E-12	3.10E-08	3.02E-09	0.00E+00	1.04E-13	2.60E-14	0.00E+00	3.71E-05	2.19E-06	1.02E-02	0.00%
25				3.35E-10	1.89E-06	1.84E-07	0.00E+00	6.34E-12	1.59E-12	0.00E+00	2.26E-03	1.34E-04	6.22E-01	0.13%
26				5.49E-12	3.10E-08	3.02E-09	0.00E+00	1.04E-13	2.60E-14	0.00E+00	3.71E-05	2.19E-06	1.02E-02	0.00%
27				5.49E-13	3.10E-09	3.02E-10	0.00E+00	1.04E-14	2.60E-15	0.00E+00	3.71E-06	2.19E-07	1.02E-03	0.00%
28				5.49E-14	3.10E-10	3.02E-11	0.00E+00	1.04E-15	2.60E-16	0.00E+00	3.71E-07	2.19E-08	1.02E-04	0.00%
				********	********	********	********	********	********	********	********	********	********	
		TOTAL FOR VESSEL PACKAGE		7.23E-03	8.05E-03	7.20E-03	3.54E-02	6.40E-01	1.58E-01	1.87E-11	1.56E-01	1.93E-02	4.76E+02	
		Isotopic percentage of total		0.00%	0.00%	0.00%	0.01%	0.13%	0.03%	0.00%	0.03%	0.00%		

APPENDIX C

MICROSHIELD INPUT AND OUTPUT DESCRIPTION

APPENDIX C

MICROSHIELD INPUT AND OUTPUT DESCRIPTION

MICROSHIELD Version 3.12 was used by TLG Engineering to perform the calculations required to estimate the shielding thickness for packaging the Pathfinder reactor vessel and internals. The computer code was verified and validated in-house using benchmark problems from ANSI 6.6.1 "Calculation and Measurement of Direct and Scattered Gamma Radiation from LWR Nuclear Power Plants".

An extensive number of calculations were made to determine the exposure rate two meters from the surface of the shipping package. For the purposes of this analysis, the vessel and its internals (the source region) were divided into four concentric regions and three axial regions as follows:

A. Concentric Regions
   1. Core region.
   2. Steam separator region.
   3. Vessel clad region.
   4. Vessel wall region.

B. Axial Regions
   1. Core height.
   2. One foot segment above the core.
   3. One foot segment below the core.

Exposure rate contributions were calculated for each of the twelve regions for various package shielding thicknesses and packing densities of gravel (concrete) in the vessel. Additionally, a calculation was made for various packing densities of gravel at the core centerline, one centimeter from the reactor vessel outer wall. This calculation was made in order to benchmark the shielding calculations to exposure rate measurements made at Pathfinder by the plant staff.

Figure C-1 is a MICROSHIELD calculation (input and output) for the exposure rate at two meters from the package surface due to the core region internals, for the height of the core, with twenty-five void percent gravel and a two inch thick carbon steel shield. The source term for the region, as for all regions, was taken from the curie spreadsheet as shown in Appendix B.

FIGURE C-1
MICROSHIELD SAMPLE PROBLEM

Microshield 3.12
================
(TLG Engineering - #141)

Page : 1 File Ref: ________
File : RXSHD1D1.MSH Date: __/__/__
Run date: October 3, 1989 By: ________
Run time: 9:07 a.m. Checked: ________

CASE: Core Region - Core Height - 25 v/O concrete - 2.0 in. shld.

GEOMETRY 7: Cylinder source from side - cylindrical shields

Distance to detector........................	X	403.2	cm.
Source length...............................	L	182.880	"
Dose point height from base.................	Y	91.440	"
Source cylinder radium......................	T1	87.630	"
Thickness of second shield..................	T2	79.375	"
Thickness of third shield...................	T3	0.640	"
Thickness of fourth shield..................	T4	7.620	"
Thickness of fifth shield...................	T5	5.080	"
Microshield inserted air gap................	air	222.855	"

Source Volume: 4.41186e+6 cubic centimeters

MATERIAL DENSITIES (g/cc):

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5	Air gap
Air						.001220
Aluminum						
Carbon						
Concrete	1.5390	1.7280				
Hydrogen						
Iron	.32620	.15560	7.90	7.890	7.90	
Lead						
Lithium						
Nickel						
Tin						
Titanium						
Tungsten						
Urania						
Uranium						
Water						
Zirconium	.5620					

FIGURE C-1
MICROSHIELD SAMPLE PROBLEM
(continued)

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CASE: Core Region - Core Height - 25 v/0 concrete - 2.0 in. shld

BUILDUP FACTOR: based on GP method
Using the characteristics of the materials in shield 5.

INTEGRATION PARAMETERS:

Number of lateral angle segments (Ntheta)..... 15
Number of azimuthal angle segments (Npsi)..... 15
Number of radial segments (Nradius)........... 15

SOURCE NUCLIDES:

Co-60: 1.6390e+02 curies

RESULTS:

Group #	Energy (MeV)	Activity (photons/sec)	Dose point flux MeV/(sq cm)/sec	Dose rate (mr/hr)
1	1.3359	6.064e+12	2.407e+00	4.344e-03
2	1.1797	6.064e+12	9.331e-01	1.734e-03
3	.6953	9.892e+08	1.815e-06	3.737e-09
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
TOTALS:		1.213e+13	3.341e+00	6.078e-03

APPENDIX 5.5.2

References

5.1 ORNL/TM-7175, "A user's Manual for the ORIGEN2 computer Code", Croff, A.G., Oak Ridge National Laboratory, July 1980

5.2 Microshield 3 Reference Manual, Software Version 3.12, Grove Engineering, Inc. Rockville, MD, 1988

FIGURE 5.1
SHIELDING MODEL GEOMETRY AND DOSE RATE LOCATIONS

PATHFINDER ATOMIC POWER PLANT
NEUTRON ACTIVATION MODEL
RADIAL PROFILE

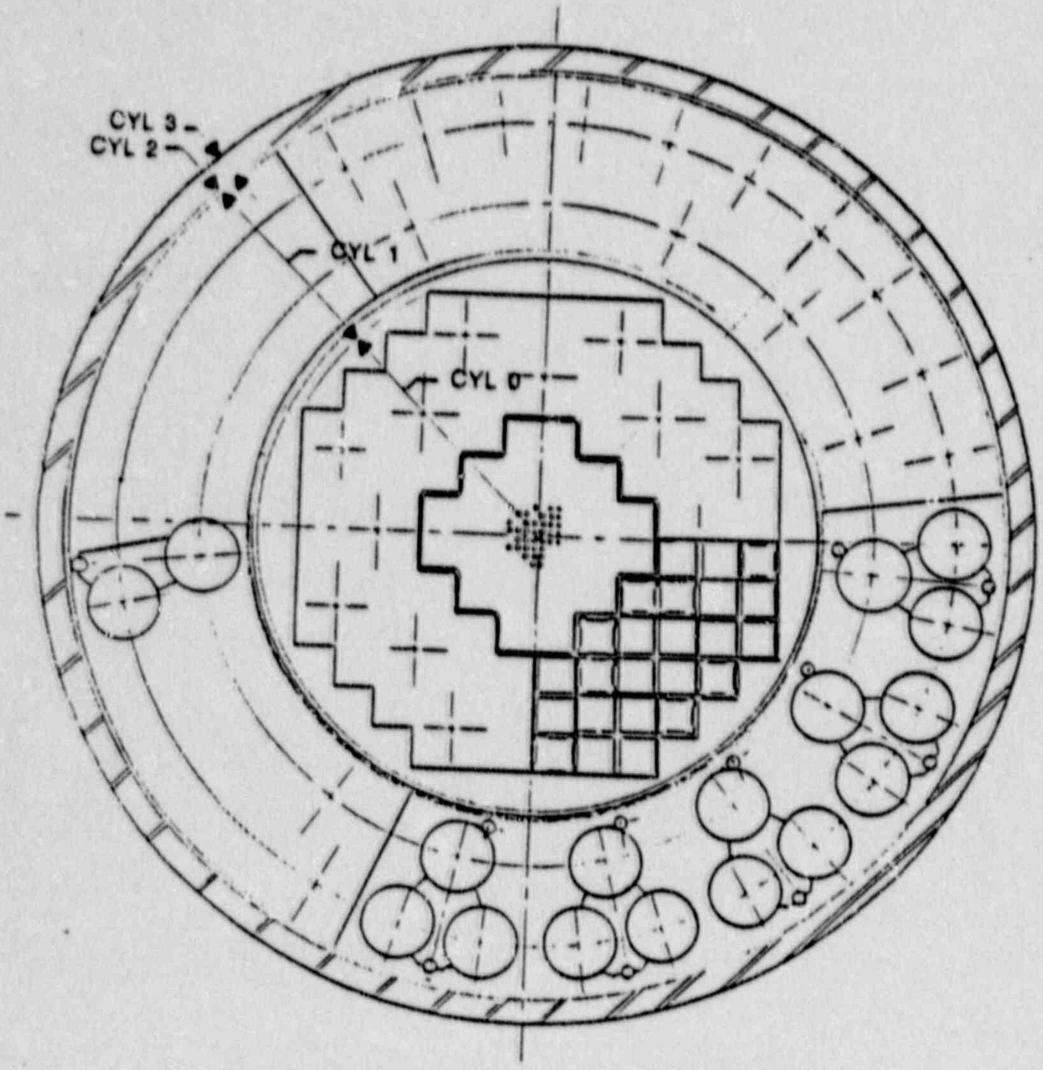

TABLE 5.1
SUMMARY OF MAXIMUM EXPOSURE RATES
(mR/hr)

NORMAL CONDITIONS OF TRANSPORT: EXCLUSIVE USE VEHICLE

	Package Surface*			2 Meters From Surface of Package		
	Side	Top	Bottom	Side	Top	Bottom
Gamma	38	Negl.	Negl.	6.9	Negl.	Negl.
Neutron	N/A	N/A	N/A	N/A	N/A	N/A
Total	38	Negl.	Negl.	6.9	Negl.	Negl.
10 CFR 71 Limit	200	200	200	10	10	10

* Package surface top refers to the forward end on the railcar, and package surface bottom refers to the aft end.

6.0 CRITICALITY EVALUATION

Not applicable.

7.0 OPERATING PROCEDURES

Not applicable.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The Pathfinder package is designed to be a one time use package for the disposal of the reactor vessel and internals. This chapter describes the acceptance tests required to place the package on a railcar for transport. No long term maintenance program is required since this is a one time shipment.

8.1 Acceptance Tests

Acceptance tests for the Pathfinder package will include tests for shielding and containment integrity, and a visual inspection of each stage of the package preparation. Pressure tests and leak tests are not required.

8.1.1 Visual Inspection

Prior to the attachment of the Hexcel impact limiter material, the vessel exterior surface will be visually checked for nozzle cover plate weld integrity, cylindrical shield weld integrity, head closure bolt damage. After attachment of the Hexcel material but before cover shell welding, a visual inspection of the Hexcel condition will be performed. Any damage to the Hexcel material will be evaluated as to its importance to the impact limiter performance. If deemed unacceptable, that portion of the Hexcel will be repaired or replaced as necessary. Upon application of the Hexcel cover shell and final welding, a visual inspection will be made of the cover condition.

If the inspection reveals any defects they will be evaluated as to their significance to the shipping package. Any modifications to the package design will be reviewed before proceeding, if required. All inspections and repairs will be appropriately documented with Quality Control inspection reports.

Prior to leaving the Pathfinder site, an inspection of the package will be made to verify that it was prepared in accordance with all requirements. The overall package will be visually inspected for any defect or unusual condition.

8.1.2 Structural and Pressure Tests

The package contains no removable closures, and no pressure tests are required.

Structural tests will include nondestructive tests of new welds and closure integrity including the shield to vessel weld. Nondestructive tests will include liquid penetrant or magnetic particle examination weld integrity inspections. These inspections will be made in accordance with the NSP QA program. NDE inspections of welds will be made in accordance with AWS D1.1 (Ref.8.1), and will include a 10% magnetic particle (MT) or liquid penetrant (PT) test.

8.1.3 Leak Tests

The package contains no liquids or contained gases and leak tests are not required.

8.1.4 Component Tests

The package is of passive design and contains no ancillary components which would require testing.

8.1.5 Tests for Shielding Integrity

Radiation and contamination surveys will be performed prior to shipment of the package to ensure the external dose rate and contamination levels are in accordance with 10 CFR 71. The acceptance limits are:

1) 200 mRem/hr at any point on the vertical planes projected from the outer edges of the package surface, on the upper surface of the load.

2) 10 mRem/hr at any point 2 meters from the vertical planes projected from the main edges of the package.

8.1.6 Thermal Acceptance Tests

The package will not be affected by the small thermal load produced by the contents (4.67 watts) and there are no thermal acceptance tests.

8.2 Maintenance Program

This is a one time use container and no maintenance program is required.

APPENDIX 8.3

References

8.1 American Welding Society Test Procedure for Nondestructive Weld Test Methods.