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Your ref: Project Number 740
Our ref: DCP/NRC1988

September 5, 2007

Subject: AP1000 COL Standard Technical Report Submittal of APP-GW-GLR-005, Revision 1 (TR 9)

In support of Combined License application pre-application activities, Westinghouse is submitting Revision 1 of AP1000 Standard Combined License Technical Report Number 9. The purpose of Technical Report 9 is to summarize the design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations) in compliance of COL Information Item 3.8-1. Revision 0 of the report addressed the equipment hatches and the airlocks. In a December 2006 meeting in Pittsburgh, the NRC asked that the report also address the main steam and feedwater penetrations and a round of Requests for Additional Information (RAIs) was received. This revision to Technical Report 9 describes the final design of penetration reinforcement for the main steam and feedwater penetrations, and addresses the responses to the RAIs. It also addresses the effect of extending the applicability of the AP1000 containment vessel design to soil sites.

This report is submitted as part of the NuStart Bellefonte COL Project (NRC Project Number 740). The information included in this report is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification.

The purpose for submittal of this report was explained in a March 8, 2006 letter from NuStart to the NRC.

Pursuant to 10 CFR 50.30(b), APP-GW-GLR-005, Revision 1, "Containment Vessel Design Adjacent to Large Penetrations," Technical Report Number 9, is submitted as Enclosure 1 under the attached Oath of Affirmation.

It is expected that when the NRC review of Technical Report Number 9 is complete, the changes to the AP1000 DCD identified in Technical Report 9 will be considered approved generically for COL applicants referencing the AP1000 Design Certification and that COL Information Item 3.8-1 will be closed.

Questions or requests for additional information related to content and preparation of this report should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

D079
D063
NRO

Westinghouse requests the NRC to provide a schedule for review of the technical report within two weeks of its submittal.

Very truly yours,

Mond D Bentley FOR

A. Sterdis, Manager
Licensing and Customer Interface
Regulatory Affairs and Standardization

/Attachment

1. "Oath of Affirmation," dated September 5, 2007

/Enclosure

1. APP-GW-GLR-005, Revision 1, "Containment Vessel Design Adjacent to Large Penetrations," Technical Report Number 9

cc:	D. Jaffe	-	U.S. NRC	1E	1A
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ATTACHMENT 1

"Oath of Affirmation"

ATTACHMENT 1

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the Matter of:)

NuStart Bellefonte COL Project)

NRC Project Number 740)

APPLICATION FOR REVIEW OF
"AP1000 GENERAL COMBINED LICENSE INFORMATION"
FOR COL APPLICATION PRE-APPLICATION REVIEW

W. E. Cummins, being duly sworn, states that he is Vice President, Regulatory Affairs & Standardization, for Westinghouse Electric Company; that he is authorized on the part of said company to sign and file with the Nuclear Regulatory Commission this document; that all statements made and matters set forth therein are true and correct to the best of his knowledge, information and belief.

W. E. Cummins
Vice President
Regulatory Affairs & Standardization

Subscribed and sworn to
before me this 5th day
of September 2007.

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Patricia S. Aston, Notary Public
Murrysville Boro, Westmoreland County
My Commission Expires July 11, 2011
Member, Pennsylvania Association of Notaries

Notary

ENCLOSURE 1

APP-GW-GLR-005, Revision 1

"Containment Vessel Design Adjacent to Large Penetrations"

Technical Report 9

AP1000 DOCUMENT COVER SHEET

TDC: ______ Permanent File: ______ APY: ______
RFS#: ______ RFS ITEM #: ______

AP1000 DOCUMENT NO.	REVISION NO.		ASSIGNED TO
APP-GW-GLR-005	1	Page 1 of ~~65~~ 61	L. Tunon-Sanjur

ALTERNATE DOCUMENT NUMBER: TR 09 — NP 8/29 — WORK BREAKDOWN #:

ORIGINATING ORGANIZATION: Westinghouse

TITLE: **Containment Vessel Design Adjacent to Large Penetrations**

ATTACHMENTS:	DCP #/REV. INCORPORATED IN THIS DOCUMENT REVISION:
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CALCULATION/ANALYSIS REFERENCE: See Table 2-10	

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APP-GW-GLR-005 **Westinghouse Non Proprietary Class 3** **August 2007**
Revision 1

AP1000 Standard Combined License Technical Report

Containment Vessel Design Adjacent to Large Penetrations

Revision 1

Westinghouse Electric Company LLC
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1.0 INTRODUCTION

This report summarizes the final design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations). The requirements for these analyses are identified in the AP1000 Design Control Document (DCD, Reference 1) Subsection 3.8.2.4.1.2. The completion of these analyses is identified as COL Information Item 3.8-1 (FSER {Reference 2} Action Item 3.8.2.4.1.2-1) in DCD Subsection 3.8.6.1 to be completed by the Combined License applicant and documented in the ASME Code design report.

> COL Information Item 3.8-1: "The final design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations) is completed by the Combined License applicant and documented in the ASME Code design report in accordance with the criteria described in subsection 3.8.2.4.1.2."

This report also describes the final design of penetration reinforcement for the main steam and feedwater penetrations.

This report also addresses the effect of extending the applicability of the AP1000 containment vessel design to soil sites. The global effects of soil sites are addressed in Reference 3. Comparisons of containment vessel response are provided in this report and demonstrate that the design for the hard rock site is also applicable at soil sites.

This report and the associated design calculations available for NRC audit will permit this Combined License information item to be closed.

The containment vessel and the penetrations are described in subsection 3.8.2 of the DCD. Pertinent portions from Rev 16 are provided in Appendix A.

2.0 TECHNICAL BACKGROUND

Westinghouse design calculations for the general portions of the containment vessel were reviewed by the NRC as part of the AP1000 design certification review. Methodology was described in the DCD (Reference 1) for more detailed analyses in the vicinity of the two equipment hatches and the two personnel airlocks. These more detailed analyses were identified to be completed by the Combined License applicant. These detailed analyses have now been completed and are summarized in this technical report. A design summary report has been prepared summarizing the design and analyses of the containment vessel.

The penetrations and penetration reinforcements are designed in accordance with the rules of ASME III, Subsection NE. The design of the large penetrations for the two equipment hatches and the two airlocks use the results of finite element analyses which consider the effect of the penetration and its dynamic response. These analyses and evaluations are described in the following sections.

2.1 3D model of containment vessel

A 3-D shell, finite element model of the containment vessel (Figure 2-1) was developed in ANSYS in order to consider the effect of the penetrations and their dynamic response. The large masses and local stiffness of the personnel locks and equipment hatches are discretely modeled. The polar crane is represented by a beam model (Figure 2-2). The bottom of the model is fixed at elevation 100' where the containment vessel is embedded in concrete.

The frequencies and mode shapes were calculated both with and without the polar crane included. The modal data without the polar crane was favorably compared to those of the axisymmetric model described in the DCD with the masses of the large penetrations smeared around the circumference, but without the mass of the polar crane.

The 3-D model was also used to solve one static load case representing the dead weight of the polar crane. The static results were favorably compared to results from the axisymmetric model for the same loading.

2.2 Dynamic analyses of 3D model

Time history seismic analyses were run to obtain the local responses of the large penetrations by applying the AP1000 ground motion time histories at the base of the containment vessel model (elevation 100'). This motion is applicable for a hard rock site as shown by the comparison in Figures 2-3 to 2-5 between the response at elevation 100' and the ground motion. This motion is also reasonable for soil sites as discussed in section 2.5.

Table 2-1 shows the maximum absolute accelerations on the axis of the four penetrations. These are given in polar coordinates along and normal to the axis of each penetration. Table 2-2 shows the equivalent static accelerations specified in the containment vessel design specification which are those obtained from the seismic analyses of the nuclear island stick models given in Table 3.7.2-6 of the DCD. As shown in Tables 2-1 and 2-2, the maximum accelerations from the time history analyses are similar to or lower than those specified in the design specification for the tangential and vertical directions. Note that the penetrations are generally on the east side so the tangential response can be compared to the north-south (X) equivalent static acceleration. In the radial direction accelerations are about 50% higher due to the shell flexibility. For the upper penetrations there is significant radial response and rotation of the airlock in the frequency range of 5 to 6 hertz. This is less noticeable for the lower penetrations due to the restraint at elevation 100'.

The equivalent static accelerations from the design specification impose an east-west global acceleration of 0.37g at elevation 112.5 and 0.54g at elevation 141.5. This is close to the radial direction since the azimuths of the centers of the penetrations range from -67 degrees to – 126 degrees (-23 to 36 degrees from east-west). The additional acceleration to be applied due to shell flexibility is the radial acceleration from Table 2-2 minus these global values as shown in Table 2-3. There is also a rotational acceleration to be considered, particularly for the airlocks which cantilever from the shell. Since the global accelerations of Table 2-2 do not cause rotational response, the full magnitudes shown in Table 2-1 are applied.

2.3 Static analyses of 3D model

Static analyses were performed on a finite element model having greater detail around the penetrations than that described in section 2.1 and used for the time history dynamic analyses in section 2.2. The mesh in the panels around the personnel locks and equipment hatches was refined **using elements with a size less than 0.25 √(Rt)**. Three sub-models were generated, one for the upper personnel lock, one for the upper equipment hatch, and one combined sub-model for the lower personnel lock and equipment hatch. The coarsely meshed panels around the openings in the dynamic model were replaced by the refined mesh panels. The refined model used in static analyses to evaluate the large penetrations is shown in Figure 2-6(a). The refined submodel for the upper equipment hatch is shown in Figure 2-6(b).

Individual Load Cases

Static analysis runs were made for internal pressure, dead load (including the polar crane in the parked position), thermal loads and seismic loads. The seismic cases consider both global accelerations and local axial and rotational accelerations about the horizontal and vertical at the large penetrations. **Each containment load is calculated individually in the analysis. The following loads are considered:**

- **Dead load**
- **Unit internal pressure load (1 psi internal pressure)**
- **Thermal load**
    - **Normal operation in cold weather**
    - **Design basis accident in hot weather**
- **Vessel global seismic load**
    - **Acceleration in N-S direction (x-axis in the model)**
    - **Acceleration in E-W direction (y-axis in the model)**
    - **Acceleration in Vertical direction (z-axis in the model)**
- **Local penetration seismic load**
    - **Acceleration in radial direction (axial direction of the penetrations)**
    - **Rotational acceleration about horizontal axis**
    - **Rotational acceleration about vertical axis**

Global seismic loads were applied in three load cases using the accelerations from the nuclear island stick model given in DCD Table 3.7.2-6 (X, Y, Z parallel to the three global axes of the containment vessel model). These equivalent static accelerations vary as a function of elevation. They are applied to the model using nodal forces. The forces are calculated for each node in the model using the product of acceleration times mass at a node. The acceleration is linearly interpolated based on the elevation of the node. The mass is the total contributing mass from all the elements at the node. Seismic loads from the polar crane were also applied as equivalent static forces.

The global loads described in the previous paragraph do not include the local amplified response of the large penetrations. These amplified local responses are included separately. Three individual seismic cases consider local axial and local rotational accelerations about both horizontal and vertical axes for each of the four penetrations, making a total of twelve cases, as shown in Table 2-3. The local accelerations were applied to the mass of each large penetration and its reinforcement and a band of shell

plate surrounding the reinforcement. The linear acceleration is applied parallel to the axis of the penetration. This linear acceleration is additive to the acceleration already applied to the penetration as part of the global accelerations. The rotational accelerations are applied about the horizontal and vertical axes orientated perpendicular to the axis of the penetration (tangential to the shell and vertical). The three axes, radial, tangential and vertical have their origins at the intersection of the axis of the penetration and the mid-surface of the vessel shell.

The local accelerations were applied to the model using forces acting at the penetration neck/reinforcement junction. The linear/rotational mass of the penetration, neck, reinforcement and surrounding shell was multiplied by the linear/rotational acceleration, respectively. The total force due to a local acceleration was distributed around the neck/reinforcement junction using forces acting parallel to the axis of the penetration. The distribution was uniform for the linear acceleration; and varied by the cosine and sine functions (local polar coordinates along axis of penetration) for the two rotational accelerations, respectively.

Combination of SSE loads

The twelve local analysis cases are based on the maximum radial and rotational accelerations from the time history analyses. These cases then represent the local shell response in individual modes. Global and local acceleration loads are assumed in-phase and stress results are added algebraically.

- The North-South (X) global results are combined with the local "rotation about the vertical axis" acceleration results.
- The East-West (Y) global results are combined with the "radial" local results.
- The Vertical (Z) global results are combined with the local "rotation about the horizontal axis" acceleration results.

The combined global and local seismic load cases are then combined for the three directions of input using either the square root sum of the squares method or the 100%, 40%, 40% method (as described in DCD subsection 3.7.2.6) and then added with dead weight, pressure and thermal stress results in accordance with the load combinations given in DCD Table 3.8.2-1. External pressure is scaled from the internal pressure load case. **The load combinations are shown in Table 2-4. Each load combination is uniquely identified in this table and results are shown in subsequent tables using these designations.**

2.4 Stress and buckling evaluation adjacent to large penetrations

2.4.1 External pressure and thermal loads

Design conditions for the containment vessel are specified as:

- Design Pressure — 59 PSIG at design temperature of 280°F
- External Pressure — 2.9 PSIG at design temperature of 70°F

Both the maximum external pressure and the temperature conditions are affected by the ambient temperature. Combinations of normal temperature and external pressure are evaluated as service conditions as follows:

Service Level A

- Dead load, uniform temperature of 70F, design external pressure of 2.9 psid
- Dead load, cold weather temperature distribution one hour after loss of all AC power, reduced pressure of 0.9 psid one hour after loss of all AC power in cold weather. This conservatively includes the low probability loss of all AC event as a normal operating condition.

Service Level D

- Dead load, uniform temperature of 70F, SSE, design external pressure of 2.9 psid
- Dead load, cold weather temperature distribution one hour after loss of all AC power, SSE, reduced pressure of 0.9 psid one hour after loss of all AC power in cold weather

Two temperature conditions are considered corresponding to plant operation during cold weather with the outside air temperature at the minimum value of -40F and during hot weather with the outside air temperature at 115F. The cold weather operation results in a significant temperature differential in the vicinity of the horizontal stiffener at elevation 131' 9". The vessel above the stiffener is exposed to the outside air in the upper annulus. This cold weather condition is assumed concurrent with the pressure reduction resulting from loss of all AC and is conservatively assumed as a normal operating condition. It is evaluated during normal operation as a Service level A event. It is also evaluated under Service level D in combination with the Safe Shutdown Earthquake.

The design external pressure of 2.9 psid is based on conservative analyses as described in DCD subsection 6.2.1.1.4. The evaluations are performed with the assumption of a -40°F ambient temperature with a steady 48 mph wind blowing to maximize cooling of the containment vessel. The initial internal containment temperature is conservatively assumed to be 120°F, creating the largest possible temperature differential to maximize the heat removal rate through the containment vessel wall. A negative 0.2 psig initial containment pressure is used for this evaluation. A conservative maximum initial containment relative humidity of 100 percent is used to produce the greatest reduction in containment pressure due to the loss of steam partial pressure by condensation. It is also conservatively assumed that no air leakage occurs into the containment during the transient. Results of these evaluations demonstrate that at one hour after the event the net external pressure is within the 2.9 psid design external pressure.

The extreme conservatism in the above analyses was reduced and an estimate of the external pressure was provided in the response to DSER Open Item 3.8.2.1-1.

With the postulated low outside temperatures, it is physically very unlikely, if not impossible (due to air cooling on the surface of the containment vessel) that the initial containment temperature will ever be 120 degrees F. A WGOTHIC calculation was performed to determine the containment pressure response with the containment initial temperature at as high a value as possible, and with the environment temperature as low as possible. An analysis was performed that determined that the highest containment atmosphere

temperature that could occur would be 75F while the reactor is operating and the environment temperature is -40F.

To determine the reduced pressure, the following assumptions were made:

1. Initial containment conditions from steady-state analysis; 75F, 100% relative humidity
2. Internal heat sinks inside containment are assumed to be 75F.
3. Fan coolers remove operating reactor heat so that no net heat load to containment is assumed.
4. Environment temperature assumed to be -40F.
5. Heat transfer coefficients to heat sinks and containment shell are nominal.

Without an internal heat load, the containment atmosphere will cool and the pressure will decrease. The pressure falls from 14.5 psia to 13.6 psia (0.9 psid) at 3600 seconds after the heat input to the containment atmosphere is terminated. This is sufficient time for operator action to prevent further pressure reduction, as discussed in AP1000 DCD Section 6.2.1.1.4. Thus the design value of 2.9 psid external pressure is very conservative.

Note that the 0.9 psid considered in this second case is also conservative since it assumes no net heat load into the containment. Immediately after reactor trip the reactor coolant loop stays hot and heat loads to the containment remain close to those during normal operation. The fan coolers cannot operate with the assumption of loss of all AC; nor would they be expected to be providing cooling when the exterior temperatures are so low.

2.4.2 Stress and buckling evaluation

2.4.2.1 Stress evaluation

Stresses are evaluated against the stress intensity criteria of ASME Section III, Subsection NE. **Hand calculations are used to check Primary General Membrane stresses (P_m). ANSYS output is used directly to make the other ASME Code stress checks. The results of these evaluations are shown in summary tables as follows:**

- **Primary General Membrane stresses (P_m) – see Table 2-5.**
- **Primary stresses - Local Membrane (P_L) – see Table 2-6**
- **Primary and Secondary Stresses ($P_b + P_L + Q$) – see Tables 2-7 and 2-8**

The ranges of the primary plus secondary stress intensity in the bottom head in Table 2-7 are larger than the $3S_{ml}$ limit for all cycles. These results are due to the restraint of thermal growth by the concrete at elevation 100' as shown by the stress summary in Table 2-8. These primary plus secondary stresses are evaluated using the simplified elastic-plastic analysis method in ASME Code, paragraph NE-3228.3. This evaluation showed 400 cycles of service level A with design basis accident and cold weather normal operation thermal loads are allowed. The range of primary plus secondary stress intensity limits are satisfied using simplified elastic-plastic analysis.

2.4.2.2 Buckling evaluation

Stability is evaluated against ASME Code Case N-284-1. Local stresses in the regions adjacent to the major penetrations are evaluated in accordance with paragraph 1711 of the code case. Stability is not evaluated in the reinforced penetration neck and insert plate which are substantially stiffer than the adjacent shell.

The ASME Code Case provides criteria for evaluation of shell stresses based on fairly large zones of the shell with uniform stress. ANSYS stress results were screened by applying the buckling criteria to every element in the shell within the local panels of the fine mesh around the large penetrations. Most elements satisfy the buckling criteria except for some local elements adjacent to the insert plates of the penetrations and/or the external stiffener at elevation 131′-9″. Elements that did not satisfy the criteria were then reviewed to better understand the local nature of the calculated stresses.

All cases where the evaluation of individual elements did not initially satisfy the buckling criteria are found to occur in very localized areas adjacent to the insert plates. The high stress area below the upper personnel lock also extends above and below the external stiffener. Due to the local nature of the stress in these areas, it is recognized that the buckling evaluation is very conservative when using allowable stresses for large zones of uniform stress from Code Case N-284-1. The high stresses are localized over a small sector of the circumference and a narrow band along the meridian.

Evaluations of these locations were made using two approaches. First, average stress components were used in accordance with paragraph 1711 of the Code Case. Second, theoretical buckling allowable stresses were calculated based on local buckling behavior.

- **The junctions of the insert plates with the shell are discontinuity locations. Stress components are averaged over a distance of** $0.5\sqrt{Rt}$ **on each side of the discontinuity. The junction of the external stiffener with the shell is also a discontinuity location. The stiffener is large enough to be considered a bulkhead stiffener and as such, is assumed to provide a line of fixity. Stress components are averaged over a distance of** $1.0\sqrt{Rt}$ **from this stiffener.**

- **The size of an area of high compressive stress is considered for the theoretical buckling allowable stress calculations, i.e., the length of the shell around the circumference and the height of the shell along the meridian where the compressive stresses are high (but are also significantly reduced beyond the boundary of the area). Knowing the size of a potential buckle based on the size of this area, theoretical buckling stresses are calculated using classical shell equations. These critical stress values are reduced by capacity reduction factors and factors of safety as defined in the Code Case.**

High local compression stresses also occur near the bottom tangent line of the vessel. The calculated hoop compression at this location, however, is not real because the inward deflection is prevented by the constraint of the concrete inside the containment shell up through elevation 107′-2″. For simplicity, this one directional constraint was not applied on the model.

Initial evaluations showed acceptability for all mechanical loads. Small overstresses existed when thermal stresses were combined with the stresses due to mechanical loads. **Insulation was added** in the vicinity of the equipment hatch and the airlock, at the operating deck level, to **reduce thermal stresses**. With these modifications, stresses and buckling safety factors have been shown to be within the allowable limits.

2.5 Application of AP1000 at soil sites

The containment vessel design for a hard rock site is described in DCD subsection 3.8.2. This uses seismic input from the nuclear island seismic analyses using the stick models as described in DCD subsection 3.7.2. The nuclear island seismic analyses have been updated and extended to soil sites in Reference 3. These analyses use a fixed base model in ANSYS for hard rock and SASSI for firm rock (FR), **soft rock (SR),** upper bound soft-to-medium soil (UB **or** UBSM), soft-to-medium (SM) **and soft soil (SS)**. The models are 3D shell models for the concrete buildings and a stick model for the containment vessel.

Table 2-**9** summarizes the maximum absolute acceleration at key elevations of the containment vessel. Figures 2-**7** to 2-**9** show floor response spectra at elevation 100' at the base of the containment vessel stick.

The second part of Table 2-**9** compares the envelope of all soil cases against the design values imposed as equivalent static global accelerations. The acceleration from the controlling soil cases is shown in bold in the upper part of the table. These design values are the maximum accelerations from the nuclear island analyses of the stick model on hard rock described in the DCD. These design values exceed those from all soil cases except for the locations discussed further below which are shown in italics in the lower portion of the table.

Figure 2-10 compares the maximum member forces in the containment vessel stick model from each of the time history soil cases. The figure also shows the member forces in the stick subject to the equivalent static accelerations given in the second part of Table 2-9. The maximum member forces are enveloped by the equivalent static analysis.

<u>Containment vessel global seismic loads</u>

The containment vessel is designed for seismic loads by applying equivalent static accelerations at each elevation based on the maximum acceleration from the nuclear island stick models. The vessel has been evaluated for the equivalent static accelerations tabulated in DCD Table 3.7.2-6 and specified in the containment vessel design specification. These accelerations from the stick models are shown as the design values in Table 2-**9**.

In **both horizontal** directions the maximum envelope **is less than the design values**. In the **vertical** direction the **hard rock results in the latest seismic analyses exceed the design values which were based on the previous hard rock analyses by about 5%. In addition at** elevation 100' **the soft to medium soil case is 31**% higher than the stick model design values. This is due to the fundamental

vertical mode of the nuclear island on the soil column. This is not significant to the design of the containment vessel since **these accelerations** are a relatively small contributor to the **global member forces.**

The global member forces from the equivalent static case exceed those from the soil cases as shown in Figure 2-10. Based on these comparisons the design acceleration values used for the global analyses are appropriate for **both** the hard rock and the soil sites.

<u>Local response of large penetrations</u>

The design in the vicinity of the large penetrations described in the previous paragraphs applies the free field ground motion at the base of the containment vessel. The comparisons shown in Figures 2-3 to 2-5 show this input motion is reasonable for the hard rock sites. Figures 2-**7** to 2-**9** show floor response spectra at the base of the containment vessel from the seismic analyses on shell models for hard rock and **five** soil sites. The comparisons show that the free field horizontal ground motion which is similar to the hard rock response is also a reasonable assumption for all soil conditions **for frequencies above 4 Hz**. However, there is significant vertical amplification particularly in the 4 to 10 hertz range due to the nuclear island mass on the soil spring. Figure 2-**9** shows peaks at 3.5 hertz for the **soft soil**, 4.5 hertz for the **soft-to-medium soil** and **5**.5 hertz for **upper bound soft-to-medium soil**. These are the fundamental vertical frequencies of the nuclear island on the soil column.

The vertical amplification has only a small effect on the equipment hatches but results in significantly higher response for the airlocks which are cantilevered from the vessel shell. The fundamental frequency of the airlock is in the frequency range of 5 to 6 hertz. The floor response spectrum at elevation 100' in Figure 2-**9** shows a response of about 1.**8**g for the broadened envelope of the soil cases and **1.1** g for the unbroadened hard rock. This increased response was evaluated by increasing the rotational acceleration about the horizontal axis by 60%. The evaluation showed that the vessel met the stress intensity and buckling criteria with this increased response.

2.6 Main Steam and Feedwater

The main steam penetration assembly is described in DCD subsection 3.8.2.1.5 and is in DCD Figure 3.8.2-4 (Sheet 1 of 6). This penetration has an inside sleeve diameter of 57". The penetration assembly is attached to the containment vessel by a flexible bellows. The feedwater penetration assembly is similar with a sleeve diameter of 38". The penetrations are combined into a common 3 ¾" thick insert plate as shown in Figure 2-11 of this report. The insert plate also includes the penetration for the 6" diameter startup feedwater pipe. This penetration assembly is shown in DCD Figure 3.8.2-4 (Sheet 2 of 6).

The insert plate is designed in accordance with NE-3330, "Openings and Reinforcement" of the ASME Code. There are no significant loads from the main steam and feedwater piping on this insert plate since the only connection is the expansion bellows.

2.7 ASME Code Design Specification and Design Report

Design documents for the AP1000 containment vessel are listed in Table 2-**10**. These documents are available for audit.

The ASME Design Specification is prepared by Westinghouse and specifies design requirements to the containment vessel supplier. This includes equivalent static seismic accelerations based on the seismic time history analyses described in section 3.7 of the DCD and extended to soil sites as described in Reference 3. It also includes additional equivalent static accelerations to be applied to each of the large penetrations based on time history dynamic analyses of the 3D model of the containment vessel.

The summary report plus the detailed calculations and drawings referenced therein is a major portion of the ASME Code Design Report. The ASME Code Design Report for each unit is completed and certified after construction deviations and site related detail design calculations, if any, are addressed. It will eventually include as-built information and will fulfill the ITAAC commitment for the as-built ASME Code Design Report.

The summary report and detail design calculations are available for audit. They include documents already reviewed by NRC as part of the AP1000 Design Certification. They include the analyses and evaluation of the regions adjacent to the large penetrations. They also include detail design documents prepared subsequent to the design certification review.

Table 2-1 Maximum Absolute Accelerations on Axis of Penetrations

				Maximum absolute accelerations (g and radians/sec^2)					
NODE	Elev.	Azimuth	Location	Radial	Tang.	Vert.	Rotx*	Roty*	Rotz*
Upper equipment hatch									
20001	141.50	-67.00	axis	0.750	0.382	0.447	0.104	0.535	0.452
Upper airlock									
20003	138.58	-107.00	axis	0.788	0.381	0.406	0.098	2.540	1.458
Lower equipment hatch									
20002	112.50	-126.00	axis	0.486	0.403	0.321	0.094	0.443	0.388
Lower airlock									
20004	110.50	-107.00	axis	0.568	0.331	0.323	0.083	1.493	1.865

Rotx, roty, and rotz are rotations about local x, y, and z axes, respectively, for each penetration.
The local coordinate system has x along the center line of the penetration, y horizontal and z vertical.

Table 2-2 Equivalent Static Accelerations Specified In Containment Vessel Design Specification (DCD Table 3.7.2-6)

Elevation	**N-S Direction**		**E-W Direction**		**Vertical Direction**	
	Mass center	Edge	Mass center	Edge	Mass center	Edge
			Accelerations (g)			
141.50	0.49	0.50	0.54	0.54	0.45	0.47
131.68	0.43	0.44	0.47	0.48	0.41	0.44
112.50	0.40	0.41	0.37	0.38	0.35	0.40
104.12	0.38	0.40	0.38	0.40	0.32	0.38

Table 2-3 Equivalent static accelerations to account for local shell flexibility

	Radial acceleration (g)	Rotational acceleration about horizontal axis (radians/sec^2)	Rotational acceleration about vertical axis (radians/sec^2)
Upper equipment hatch	0.21	0.54*	0.45
Upper airlock	0.27	2.54*	1.46
Lower equipment hatch	0.12	0.44*	0.39
Lower airlock	0.20	1.49*	1.87

*** The rotational accelerations were increased by a factor of 1.60 for the large penetration design analyses to envelope the response at soil sites as described in Section 2.5.**

Table 2-4 – Load Combinations for the Large Penetrations

Load			Design		Level A Service Limit			Level C Service Limit		Level D Service Limit		
	Con	Test	Des1	Des2	A1	A2	A3	C1	C2	D1	D2	D3
D	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
E_s								1.0		1.0	1.0	1.0
P_t		1.0										
T_t		1.0										
P_o									1.0			
P_i			1.0			1.0		1.0				1.0
P_e (2.9psid)				1.0			1.0			1.0		
P_e (0.9psid)					1.0						1.0	
T_o				(4)	(5)		(4)		(4)	(4)	(5)	
T_a			1.0			1.0		1.0				1.0

Notes:
1. Service limit levels are per ASME-NE.
2. Where any load reduces the effects of other loads, that load is to be taken as zero, unless it can be demonstrated that the load is always present or occurs simultaneously with the other loads.
3. Reduced pressure of 0.9 psid at one hour in loss of all AC transient in cold weather.
4. Temperature of vessel is 70F.
5. Temperature distribution for loss of all AC in cold weather.

Table 2-5 – General Membrane Stress Intensity and Limit

Load Case	Pressure (psi)	General Membrane Stress Intensity (ksi)		Stress Intensity Limit (ksi)
		Shell	Bottom head	
Test	66	29.45	27.28	$0.75\sigma_y = 45$
Constructio n	0.0	0.96	4.15	$1.0S_{mc} = 26.73$
Design1	59	26.33	23.95	26.73
Design2	-2.9	1.61	5.51	26.73
A1	-0.9	1.16	4.57	26.73
A2	59	26.33	23.95	26.73
A3	-2.9	1.61	5.51	26.73
C1	59	26.33	41.46	$1.0S_y = 52.3$ (300°F)
C2	1.0	1.19	3.69	$1.0S_y = 60$ (70°F)
D1	-2.9	5.54	23.13	$1.0S_f = 50.58$
D2	-0.9	5.09	22.20	50.58
D3	59	26.33	41.46	50.58

Table 2-6 – Local Membrane Stress Intensity and Limit

Load Case	Maximum Local Membrane Stress Intensity (ksi)				Stress Intensity Limit (ksi)
	Shell	Bottom head	Insert Plate	Neck	
Test	39.56	22.69	35.22	37.03	$1.15\sigma_y = 69$
Construction	2.73	2.81	1.42	1.51	$1.5S_{mc} = 40.1$
Design1	35.52	20.22	31.59	33.18	40.1
Design2	2.71	2.99	2.11	2.25	40.1
A1	2.62	2.85	1.59	1.73	40.1
A2	35.52	20.22	31.59	33.18	40.1
A3	2.71	2.99	2.11	2.25	40.1
C1	37.99	23.42	33.33	35.30	$1.5S_y = 78.45$
C2	3.16	2.80	1.59	1.71	$1.5S_y = 90$

D1	12.65	13.71	6.60	7.25	$1.5S_f = 75.86$
D2	12.77	13.60	6.65	6.72	75.86
D3	37.99	23.42	33.33	35.30	75.86

Table 2-7 – Primary plus Secondary Stress Intensity and Limit

Load Range	Maximum Primary plus Secondary Stress Intensity (ksi)				Stress Intensity Limit (ksi)
	Shell	Bot. head	Insert Plate	Neck	
A2 to zero	69.8	110.0	64.4	56.3	$3.0S_{m1} = 84.9$
A2 to A3	77.4	108.3	63.8	56.5	84.9
A2 to A1	78.7	117.1	66.6	55.4	84.9

Table 2-8 – Maximum Stress Intensity in the Bottom Head for Different Load Cases

Load Range	$P_l + P_b + Q$ with thermal stress (ksi)	$P_l + P_b + Q$ without thermal stress (ksi)	Q thermal stress (ksi)	P_m pressure stress (ksi)
A2 to zero	110.0	41.2	89.6	28.1
A2 to A3	108.3	45.2	89.6	29.5
A2 to A1	117.1	43.7	99.5	28.5

Table 2-9 Maximum absolute acceleration of SCV stick for soil cases

Elev	HR	FR	SR	UB	SM	SS
			X-acceleration (g)			
100.00	**0.328**	0.312	0.306	0.327	0.299	0.228
131.68	**0.387**	0.362	0.358	0.373	0.347	0.239
169.93	**0.587**	0.483	0.470	0.430	0.412	0.270
224.00	**0.928**	0.811	0.800	0.612	0.513	0.322
281.90	**1.209**	1.089	1.083	0.829	0.627	0.360
			Y-acceleration (g)			
100.00	**0.343**	0.317	0.321	0.327	0.321	0.238
131.68	**0.471**	0.433	0.441	0.397	0.342	0.253
169.93	0.599	**0.604**	0.592	0.501	0.396	0.290
224.00	1.008	**1.064**	0.883	0.701	0.498	0.424
281.90	1.353	**1.464**	1.209	0.916	0.617	0.562
			Z-acceleration (g)			
100.00	0.311	0.323	0.347	0.373	**0.407**	0.320
131.68	**0.440**	0.394	0.364	0.394	0.427	0.328
169.93	**0.557**	0.441	0.393	0.414	0.442	0.333
224.00	**0.684**	0.489	0.464	0.441	0.458	0.339
281.90	**1.270**	0.751	0.774	0.565	0.498	0.351

The acceleration from the controlling soil cases is shown in bold above

Elev	Envelope of soil cases			Maximum acceleration from stick model in DCD Table 3.7.2-6		
	X	Y	Z	X	Y	Z
100.00	**0.328**	**0.343**	***0.407***	0.38	0.39	0.31
131.68	**0.387**	**0.471**	***0.440***	0.43	0.47	0.41
169.93	**0.587**	**0.604**	***0.557***	0.69	0.72	0.53
224.00	**0.928**	**1.064**	***0.684***	1.09	1.11	0.66
281.90	**1.209**	**1.464**	***1.270***	1.48	1.56	1.25

See the text for a discussion of the values shown in italics

HR = Hard Rock
FR = Firm Rock
SR = Soft Rock
UB = Upper bound soft-to-medium
SM = Soft-to-medium
SS = Soft Soil

Table 2-10 Containment Vessel Design Documents

Document number	Title	Notes
APP-MV50-Z0-001, Rev 3	Containment Vessel Design Specification	(1)
APP-MV50-Z0C-001, Rev 0	Miscellaneous Calculations for Containment Vessel Design Specification (update of AP600 calculation MV50-S2C-001, Rev 1)	(2)
APP-MV50-S2C-009, Rev 0	Time history analyses of 3D Model of Containment	(2)
APP-MV50-S2C-003, Rev 0	Containment Vessel Pressure Capacity Capabilities	(4)
APP-MV50-S3R-003, Rev 0	Containment Vessel ASME Design Summary Report	(3)
APP-MV50-S2C-001, Rev 0	Containment Vessel Seismic Model (axisymmetric and stick models)	(4)
APP-MV50-S2C-002, Rev 0	Design of Containment Vessel for Internal and External Pressure	(4)
APP-MV50-S2C-004, Rev 0	Containment Vessel Design, Polar Crane Loads on Shell Analysis	(4)
APP-MV50-S2C-005, Rev 0	Containment Vessel Design, Seismic Analysis With Polar Crane	(4)
APP-MV50-S2C-006, Rev 1	Stress Evaluation Calculations	(4)
APP-MV50-S2C-007, Rev 0	Containment Vessel Displacements and Stresses due to Axisymmetric Temperatures	
APP-MV50-S2C-008, Rev 0	3D Model - Modal Analysis of Containment	
APP-MV50-S2C-010, Rev 0	3D Model - Analysis of Large Penetrations	
APP-MV50-S2C-012, Rev **2**	**Design Of Containment Vessel Penetration Reinforcement**	
APP-MV50-S2C-013, Rev 1	**Reconciliation of Containment Vessel Seismic Design for Soil Sites**	

Notes:

1. Rev 1 was basis for hard rock design certification
2. These documents provide inputs to the design specification
3. Summary report covers design in accordance with the ASME design specification. It references and summarizes design documents listed subsequently in this table.
4. These calculations were reviewed by NRC as part of AP1000 hard rock design certification

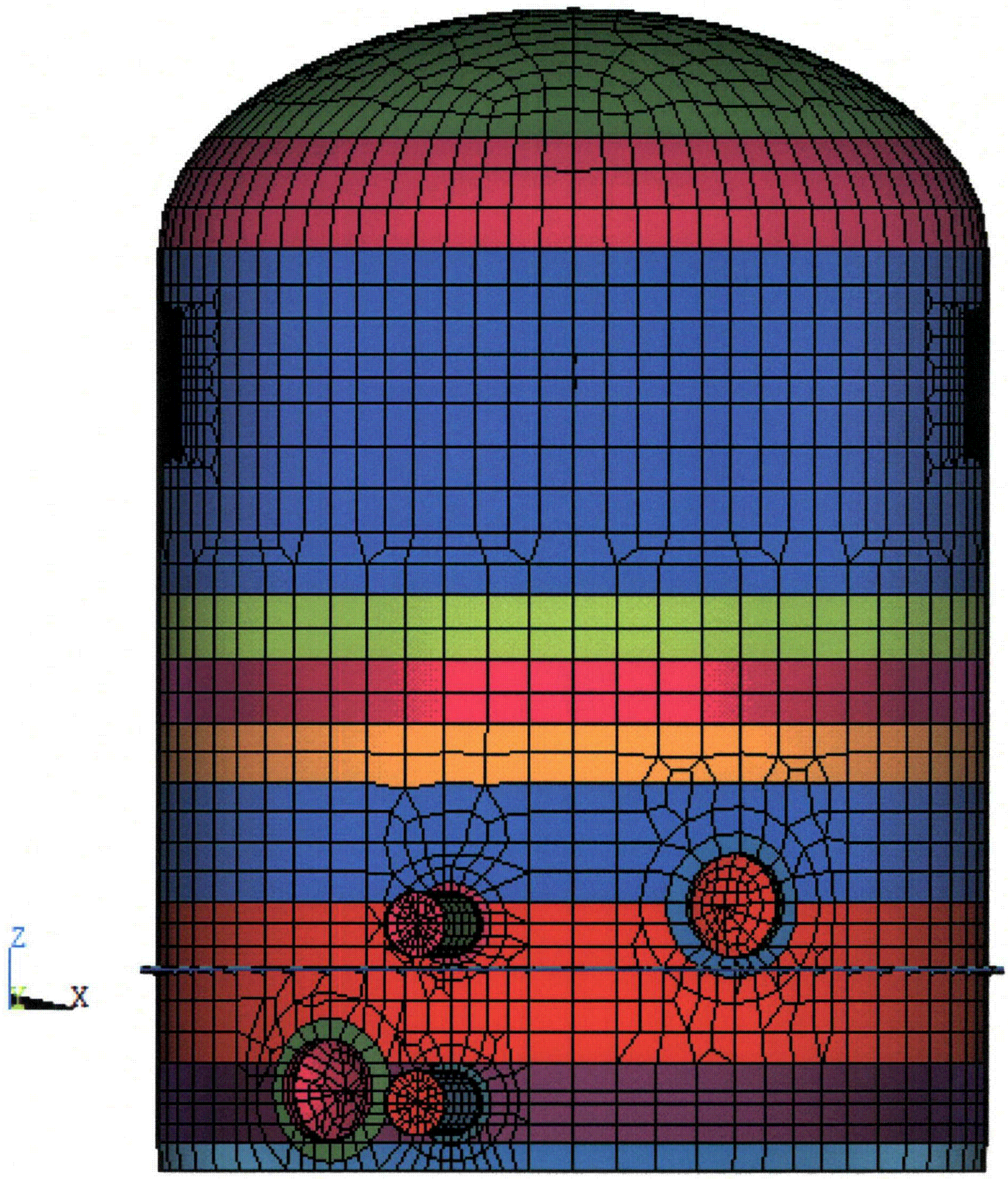

Figure 2-1 3D dynamic model of containment vessel

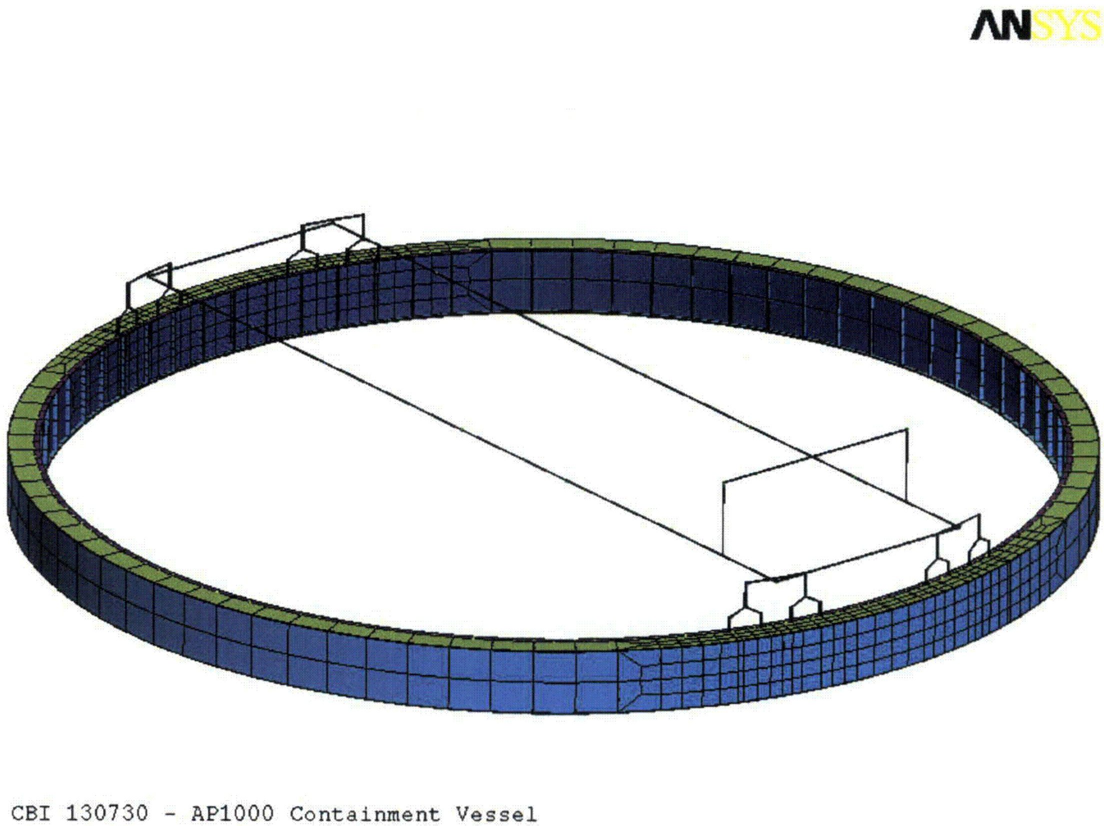

Figure 2-2 Polar crane and crane girder

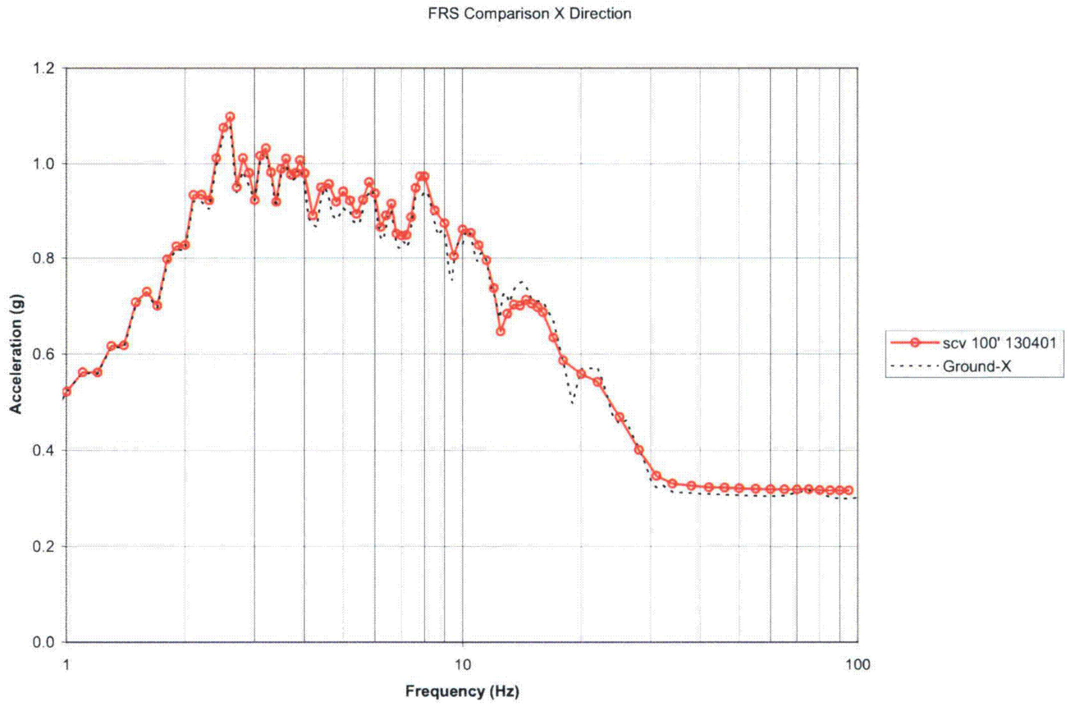

Figure 2-3 FRS (X) at base of NI10 containment vessel for hard rock versus ground input

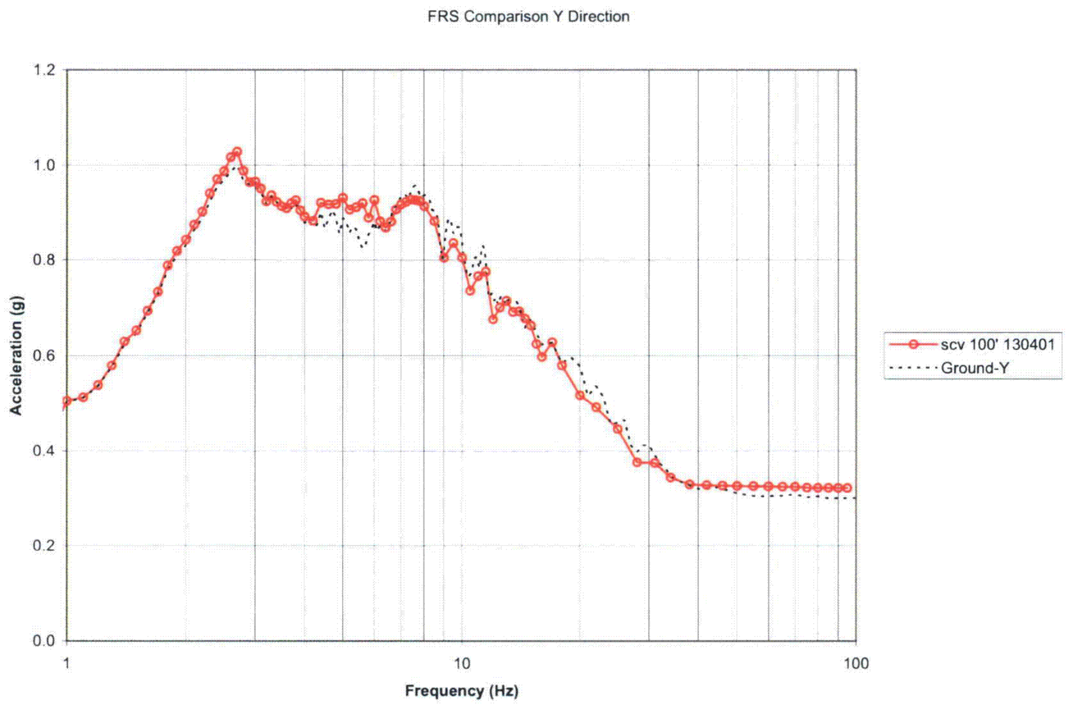

Figure 2-4 FRS (Y) at base of NI10 containment vessel for hard rock versus ground input

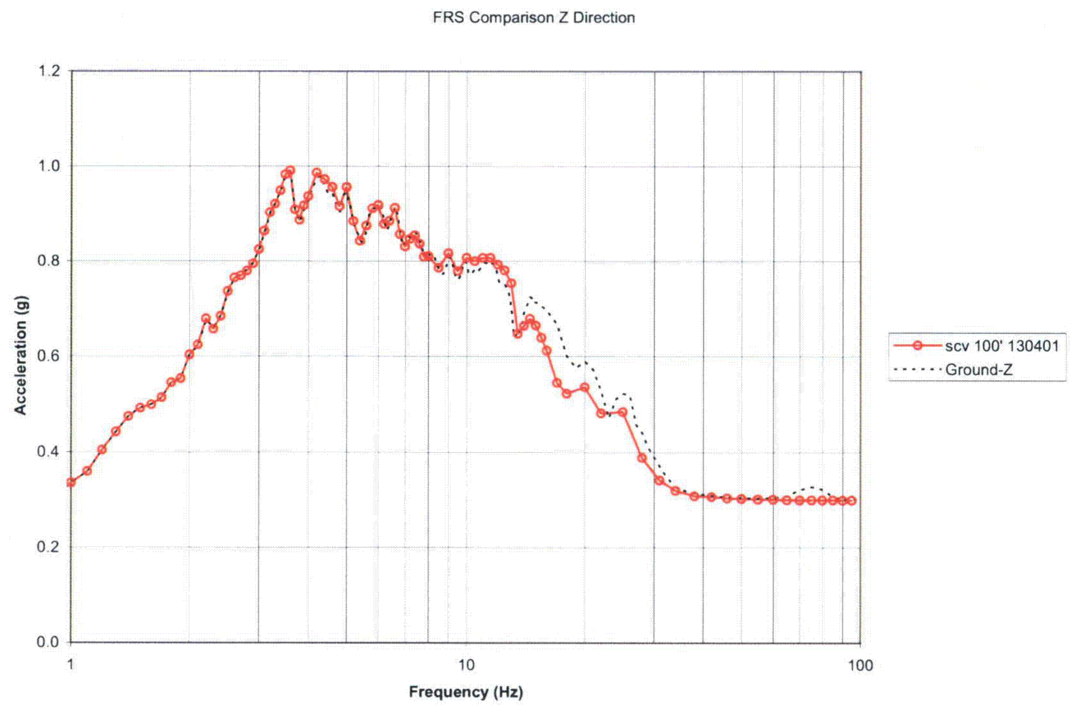

Figure 2-5 FRS (Z) at base of NI containment vessel for hard rock versus ground input

Figure 2-6(a) 3D static model of containment vessel

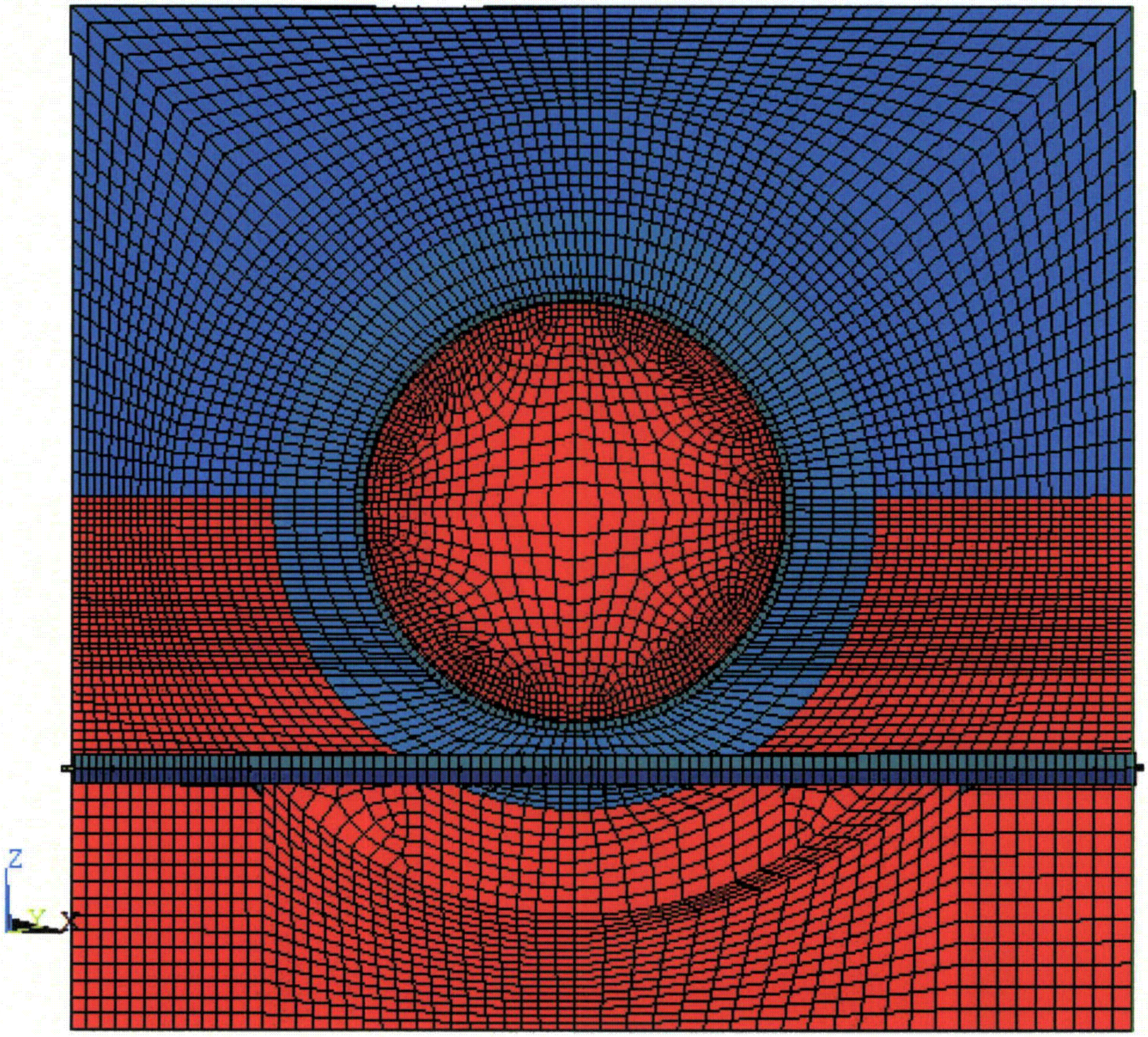

Figure 2-6(b) – Equipment Hatch (El. 141′-6″) Panel (Viewed from 67° azimuth)

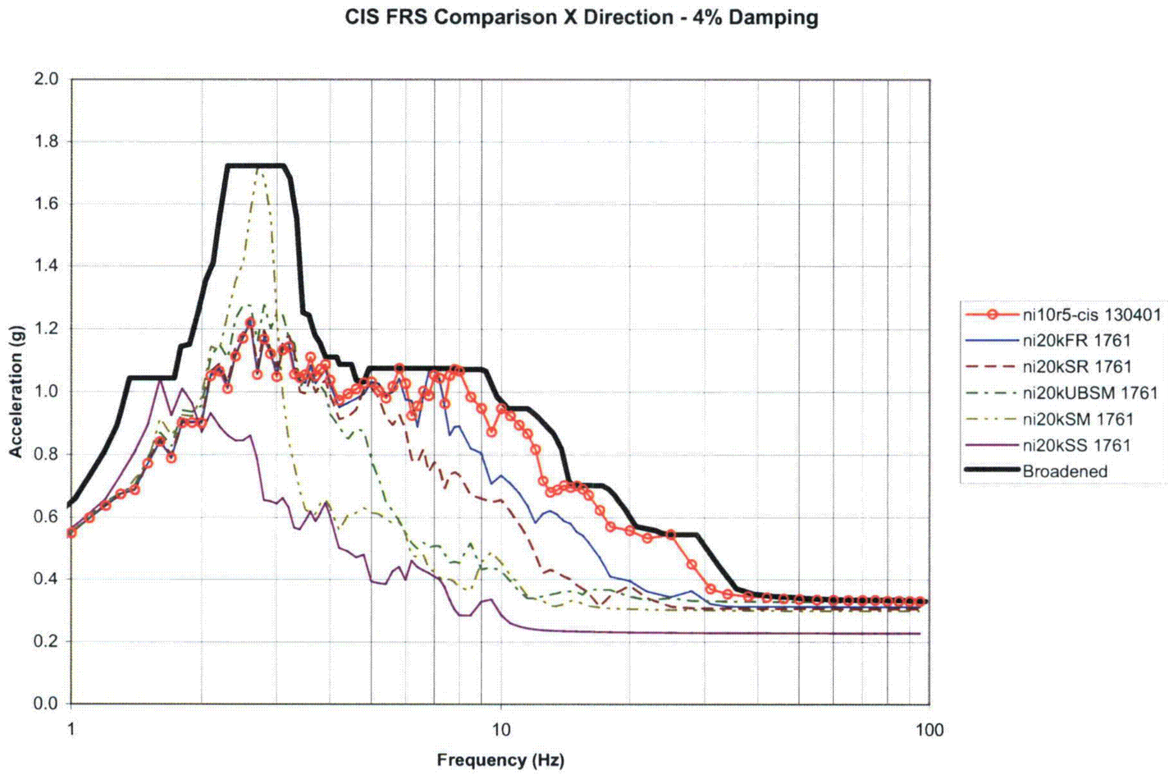

Figure 2-7 Floor Response Spectra (X) at Elevation 100' for Soil Cases

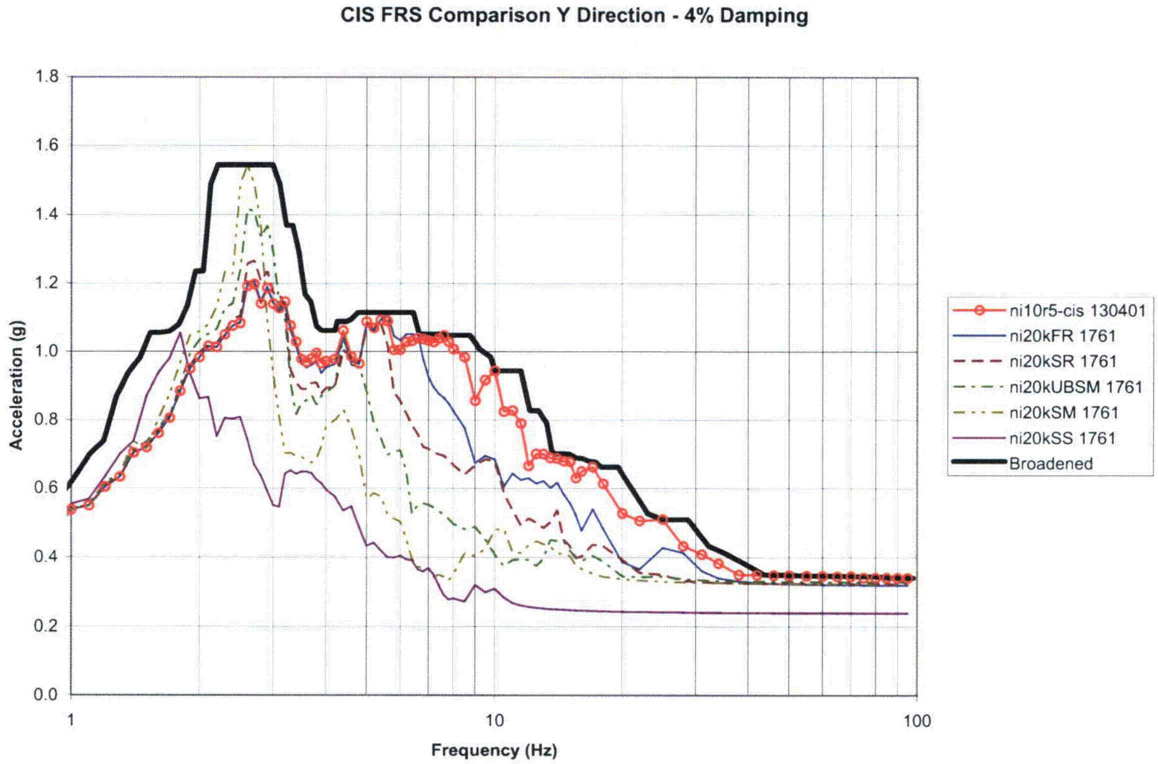

Figure 2-8 Floor Response Spectra (Y) at Elevation 100' for Soil Cases

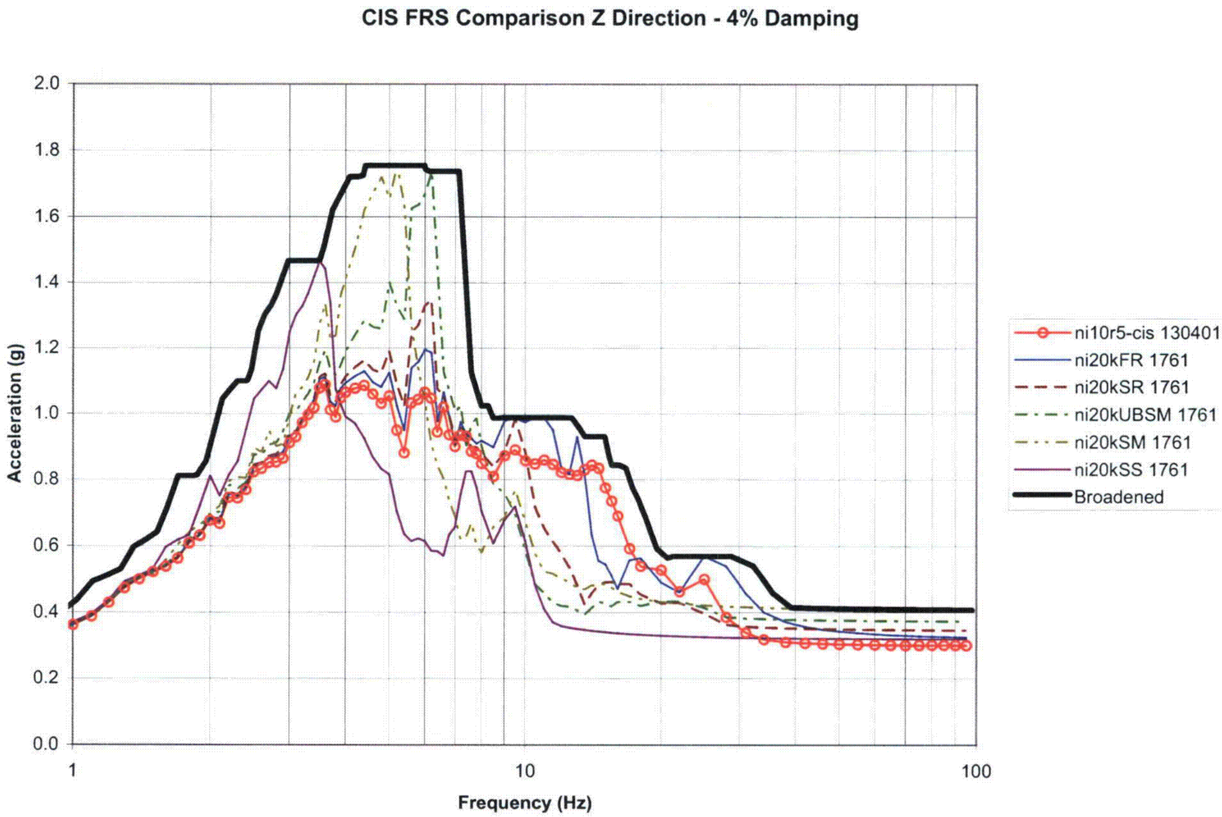

Figure 2-9 Floor Response Spectra (Z) at Elevation 100' for Soil Cases

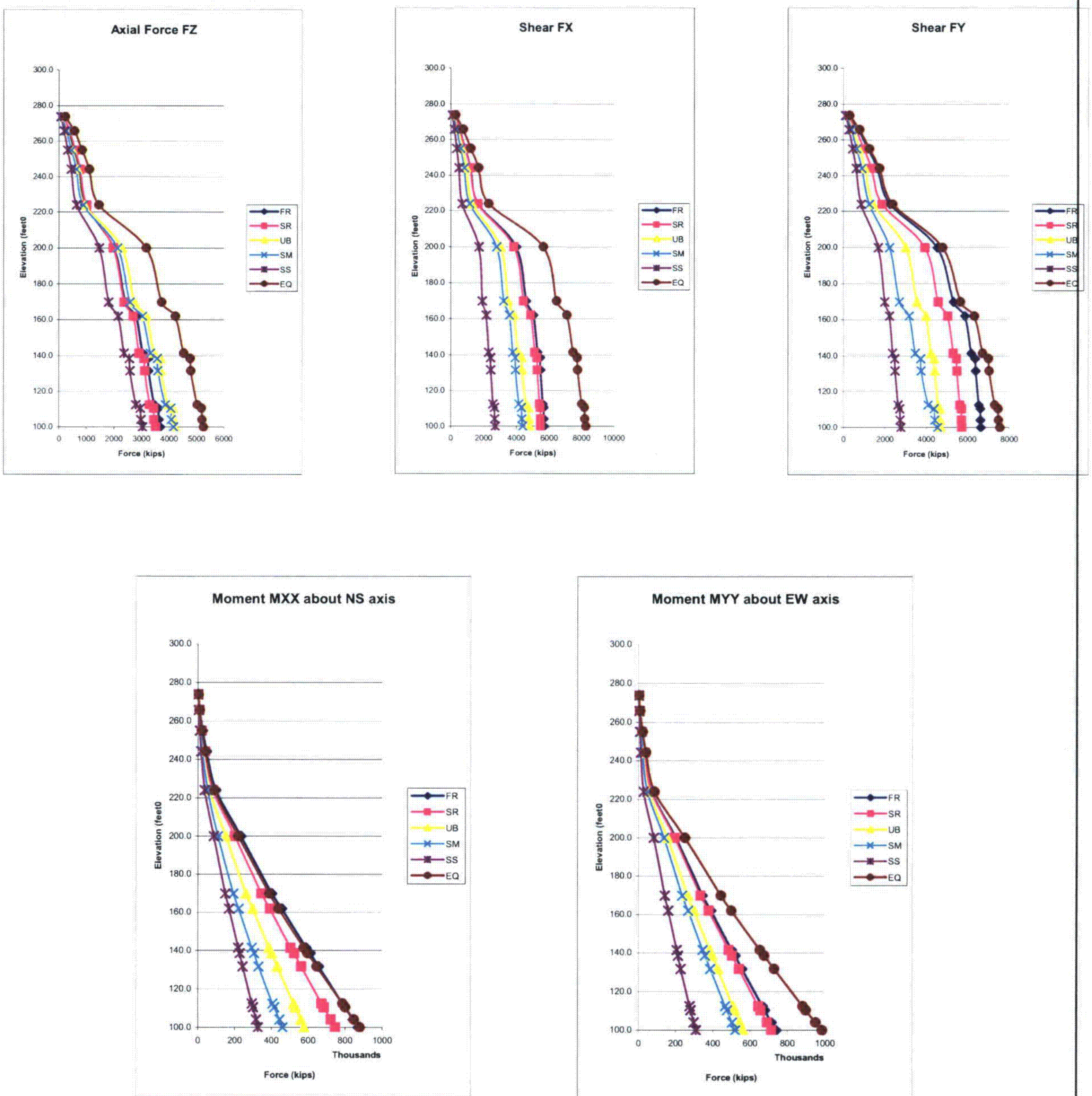

Figure 2-10 Member Forces in SCV Stick

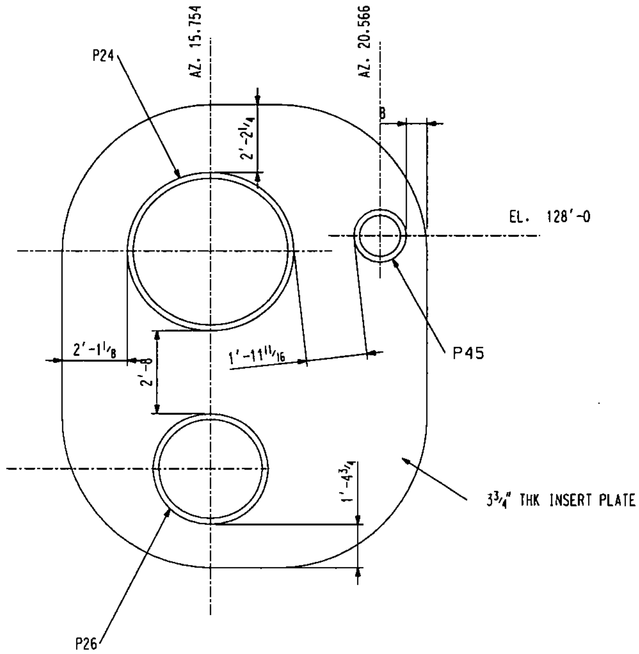

Figure 2-11 Combined Insert Plate for MS (P24), FW (P26) and SUFW (P45)

Note: This figure shows an elevation view of the insert plate assembly looking north from the inside of the containment. The axis of the sleeves is north-south. The openings in the shell are elliptical. Spacing dimensions shown are measured along the mid-surface of the insert plate.

3. REGULATORY IMPACT

The design of the containment vessel adjacent to the large penetrations is addressed in subsection 3.8.2.4.1.2 “Local Analyses” of the NRC Final Safety Analysis Report (FSER, Reference 2) write-ups. The completion of the analysis for the large penetrations is identified in the FSER as COL Action Item 3.8.2.4.1.2-1. Completion of the design of the large penetrations will impact these write-ups. The conclusions in the FSER about the local analyses are not altered.

The changes to the DCD presented in this report do not represent an adverse change to the design functions, including the pressure boundary integrity functions and the access function, or to how design functions are performed or controlled. The analysis of the large penetrations is consistent with the description of the analysis in 3.8.2.4.1.2 of the DCD. Therefore, the changes to the DCD do not involve revising or replacing a DCD-described evaluation methodology. The changes to the DCD do not involve a test or experiment not described in the DCD. The DCD change does not require a license amendment per the criteria of VIII. B. 5.b. of Appendix D to 10 CFR Part 52.

Since completion of the local analyses does not change the design or design functions of the containment or penetrations, the DCD change does not affect resolution of a severe accident issue and does not require a license amendment based on the criteria of VIII. B. 5.c of Appendix D to 10 CFR Part 52.

The closure of the COL Information Item will not alter barriers or alarms that control access to protected areas of the plant. The closure of the COL Information Item will not alter requirements for security personnel. Therefore, the closure of the COL Information Item does not have an adverse impact on the security assessment of the AP1000.

4. REFERENCES

1. APP-GW-GL-700, AP1000 Design Control Document, Revision 16.
2. Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design, September 2004.
3. APP-GW-**S2R-010**, Revision **1**, Extension of Nuclear Island Seismic Analyses to Soil Sites

5. DCD MARK UP

5.1 DCD Changes from Rev 15 to Rev 16

The following DCD markup identifies **the changes in DCD Rev 16.**

Revise Subsection 3.8.2.4.1.2 as follows:

3.8.2.4.1.2 Local Analyses

The penetrations and penetration reinforcements are designed in accordance with the rules of ASME III, Subsection NE. The design of the large penetrations for the two equipment

hatches and the two airlocks use the results of finite element analyses which consider the effect of the penetration and its dynamic response.
The **personnel** airlocks and equipment hatches are modeled in **a 3-D shell** finite element model **of the containment. The bottom of the model is fixed at elevation 100' where the containment vessel is embedded in concrete.**

Static analyses are performed using the finite element model shown in Figure 3.8.2-7 for internal pressure, dead load (including the polar crane in the parked position), thermal loads and seismic loads. The global seismic loads are applied as equivalent static accelerations using the maximum accelerations from the nuclear island stick model given in DCD Table 3.7.2-6. The amplified local responses are included separately for each of the four penetrations. Local seismic axial and rotational accelerations about both horizontal and vertical axes are applied based on the maximum amplified response determined from a time history analysis on a less refined dynamic model with seismic time histories at elevation 100'.

Stresses are evaluated against the stress intensity criteria of ASME Section III, Subsection NE **for the load combinations described in Table 3.8.2-1**. Stability is evaluated against ASME Code Case N-284-**1**. Local stresses in the regions adjacent to the major penetrations are evaluated in accordance with paragraph 1711 of the code case. Stability is not evaluated in the reinforced penetration neck and insert plate which are substantially stiffer than the adjacent shell.

Replace the last paragraph of Subsection 3.8.6.1 as follows:

3.8.6.1 Containment Vessel Design Adjacent to Large Penetrations

Completed. The design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations) is described in subsection 3.8.2.4.1.2.

Revise Table 3.8.2-1 as follows:

Table 3.8.2-1

LOAD COMBINATIONS AND SERVICE LIMITS FOR CONTAINMENT VESSEL

Load Description		Load Combination and Service Limit											
		Con	**Test**	**Des.**	**Des.**	**A**	**A**	**A**	**C**	**D**	**C**	**D**	**D**
Dead	D	x	x	x	x	x	x	x	x	x	x	x	x
Live	L	x	x	x	x	x	x	x	x	x	x	x	x
Wind	W	x				x							
Safe shutdown earthquake	E_s								x	x		x	x
Tornado	W_t										x		
Test pressure	P_t		x										
Test temperature	T_t		x										
Operating pressure	P_o										x		
Design pressure	P_d			x			x		x			x	
External pressure (2.9 psid)	P_e				x			x		x			
External pressure (0.9 psid)(3)						x							x
Normal reaction	R_o				x	x		x		x	x		
Normal thermal	T_o				(4)	(5)		(4)		(4)	(4)		(5)
Accident thermal reactions	R_a			x			x		x			x	
Accident thermal	T_a			x			x		x			x	
Accident pipe reactions	Y_r											x	
Jet impingement	Y_j											x	
Pipe impact	Y_m											x	

Notes:

1. Service limit levels are per ASME-NE.
2. Where any load reduces the effects of other loads, that load is to be taken as zero, unless it can be demonstrated that the load is always present or occurs simultaneously with the other loads.
3. **Reduced pressure of 0.9 psid at one hour in loss of all AC transient in cold weather**
4. **Temperature of vessel is 70F**
5. **Temperature distribution for loss of all AC in cold weather**

Replace Figure 3.8.2-7 by the figure below

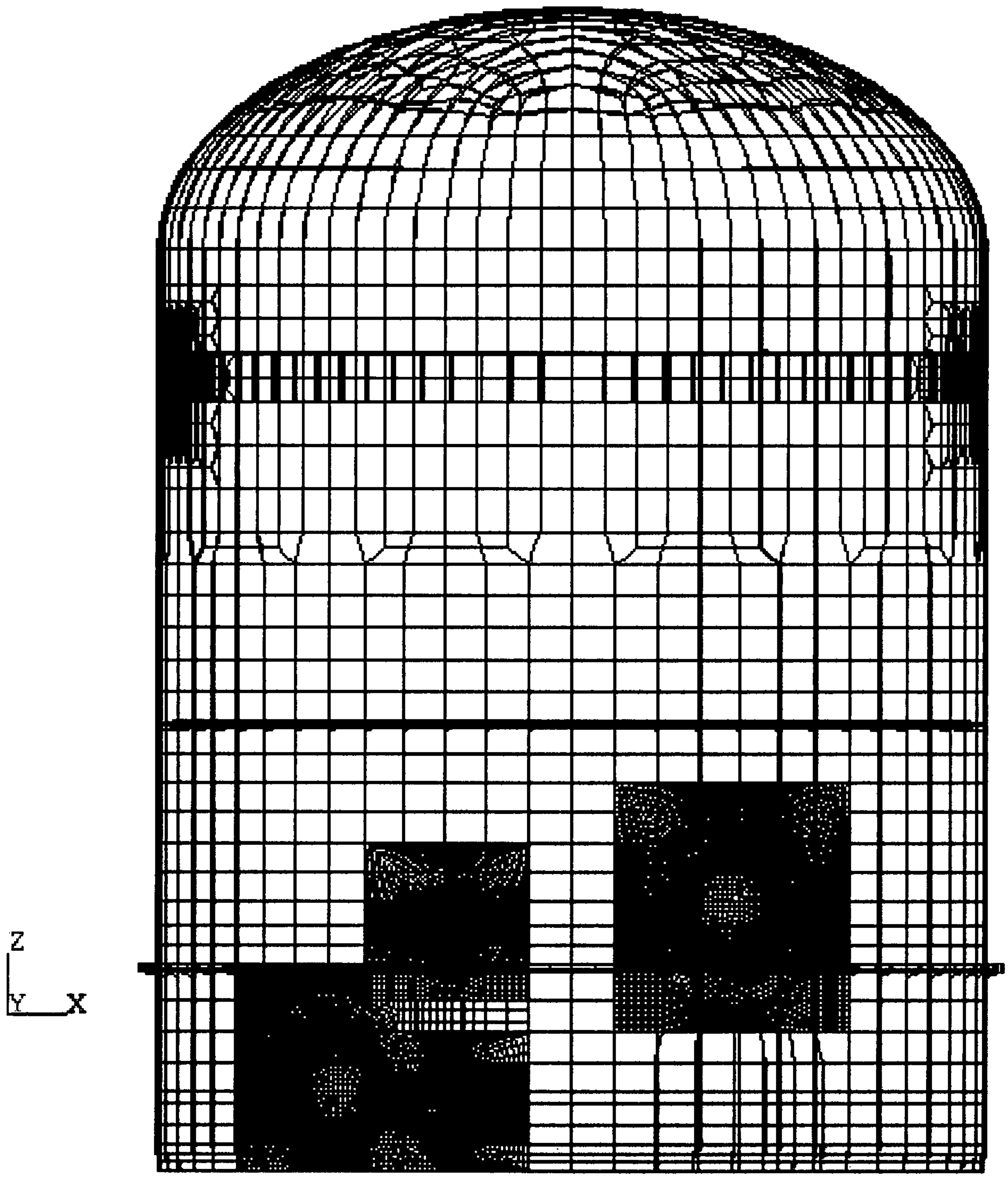

Figure 3.8.2-7
Finite Element Model for Large Penetration Local Analyses

5.2 DCD Changes to Rev 16

The following revisions are to DCD Rev 16.

Revise classification in Table 3.2.3 as shown below from MC to Class 2 for penetrations where the process pipe penetrates directly the containment vessel without the use of a flued head (see typical detail on lower half of Figure 3.8.2-4, sheet 4 of 6). In this case the sleeve is a boundary of the process fluid and is required by the ASME Code to be Class 2.

Revise sheets 2, 3, 4 and 6 of Figure 3.8.2-4 as shown on the following pages to reflect detail design of the penetration reinforcement.

DCD TABLE 3.2-3: AP1000 CLASSIFICATION OF MECHANICAL AND FLUID SYSTEMS, COMPONENTS, AND EQUIPMENT

Tag Number	Description	AP1000 Class	Seismic Category	Principal Con-struction Code	Comments
CAS-PY-C02	Containment Instrument Air Inlet Penetration	B	I	ASME III, ~~MC~~ 2	
CAS-PY-C03	Containment Service Air Inlet Penetration	B	I	ASME III, ~~MC~~ 2	
CCS-PY-C01	Containment Supply Header Penetration	B	I	ASME III, ~~MC~~ 2	
CCS-PY-C02	Containment Return Header Penetration	B	I	ASME III, ~~MC~~ 2	
FPS-PY-C01	**Fire Protection Containment Penetration**	B	I	ASME III, ~~MC~~ 2	
CVS-PY-C02	Letdown Line Containment Penetration	B	I	ASME III, ~~MC~~ 2	
CVS-PY-C04	Hydrogen Add Line Containment Penetration	B	I	ASME III, ~~MC~~ 2	
DWS-PY-C01	Containment Demineralized Water Supply Penetration	B	I	ASME III, ~~MC~~ 2	
PSS-PY-C03	Containment Atmosphere Sample Line Penetration	B	I	ASME III, ~~MC~~ 2	
PXS-PY-C01	Nitrogen Makeup Containment Penetration	B	I	ASME III, ~~MC~~ 2	
VFS-PY-C01	Containment Supply Duct Penetration	B	I	ASME III, ~~MC~~ 2	
VFS-PY-C02	Containment Exhaust Duct Penetration	B	I	ASME III, ~~MC~~ 2	
VWS-PY-C01	Containment Chilled Water Supply Penetration	B	I	ASME III, ~~MC~~ 2	
VWS-PY-C02	Containment Chilled Water Return Penetration	B	I	ASME III, ~~MC~~ 2	
WLS-PY-C02	Reactor Coolant Drain Tank WLS Connection Penetration	B	I	ASME III, ~~MC~~ 2	
WLS-PY-C03	Containment Sump Pumps Combined Discharge Penetration	B	I	ASME III, ~~MC~~ 2	

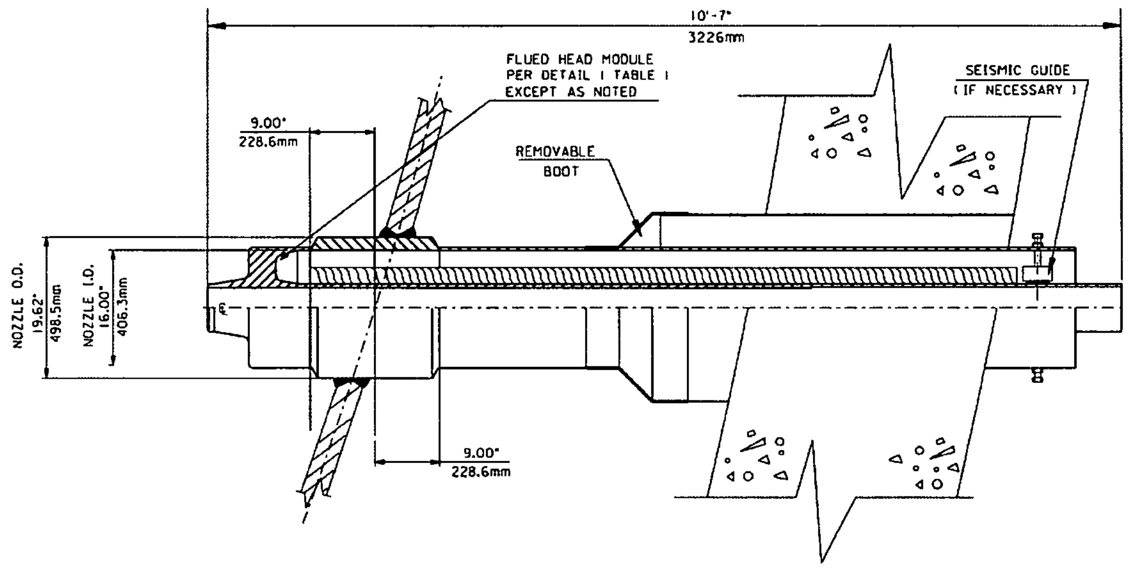

Figure 3.8.2-4 (Sheet 2 of 6)
Containment Penetrations Startup Feedwater

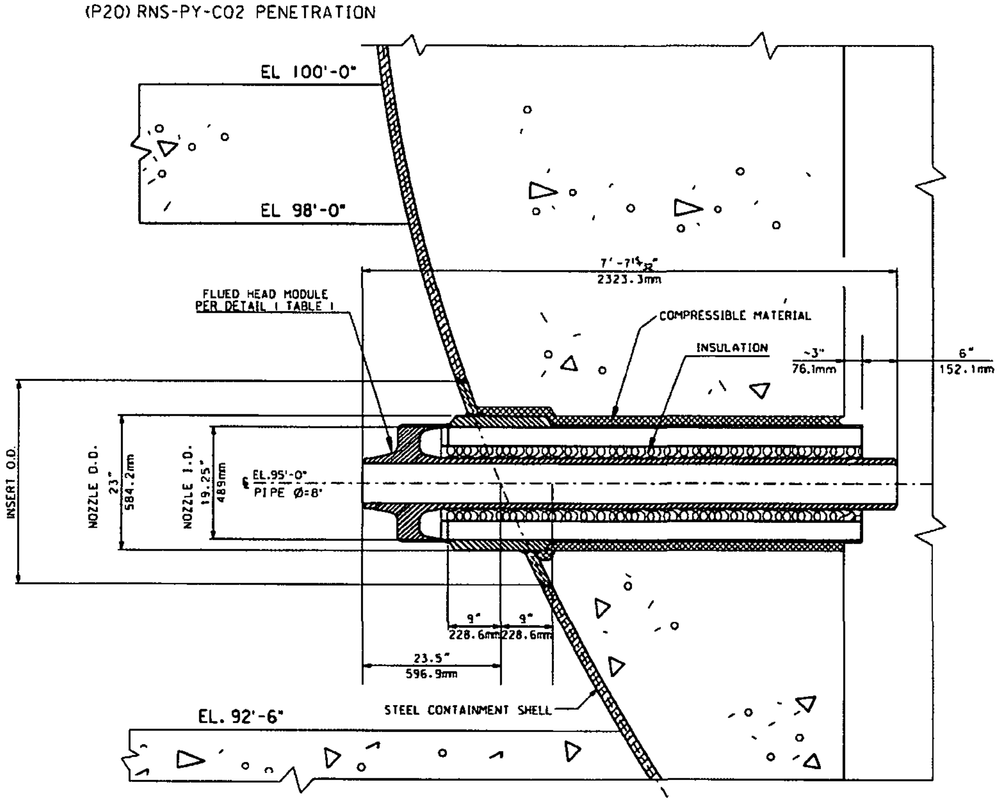

Figure 3.8.2-4 (Sheet 3 of 6)
Containment Penetrations Normal RHR Piping

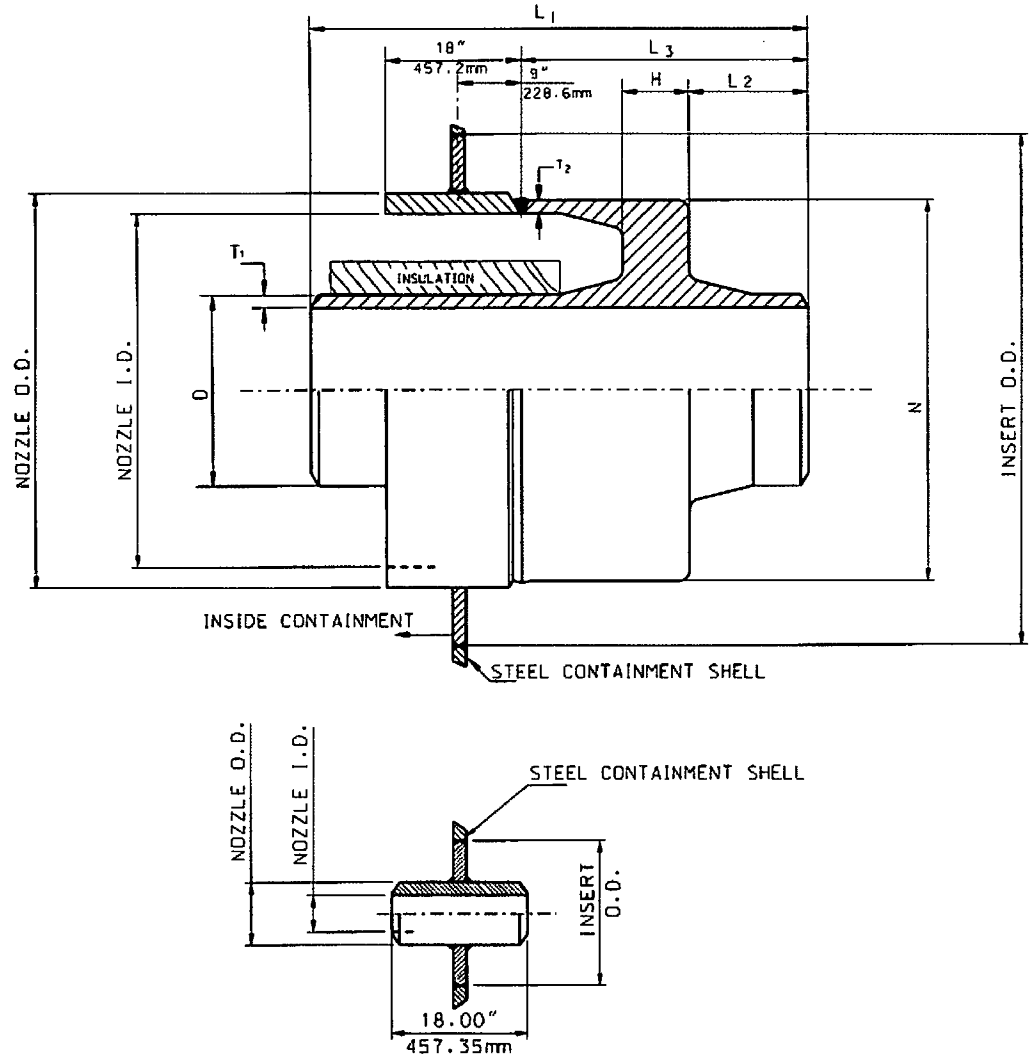

Figure 3.8.2-4 (Sheet 4 of 6)
Containment Penetrations

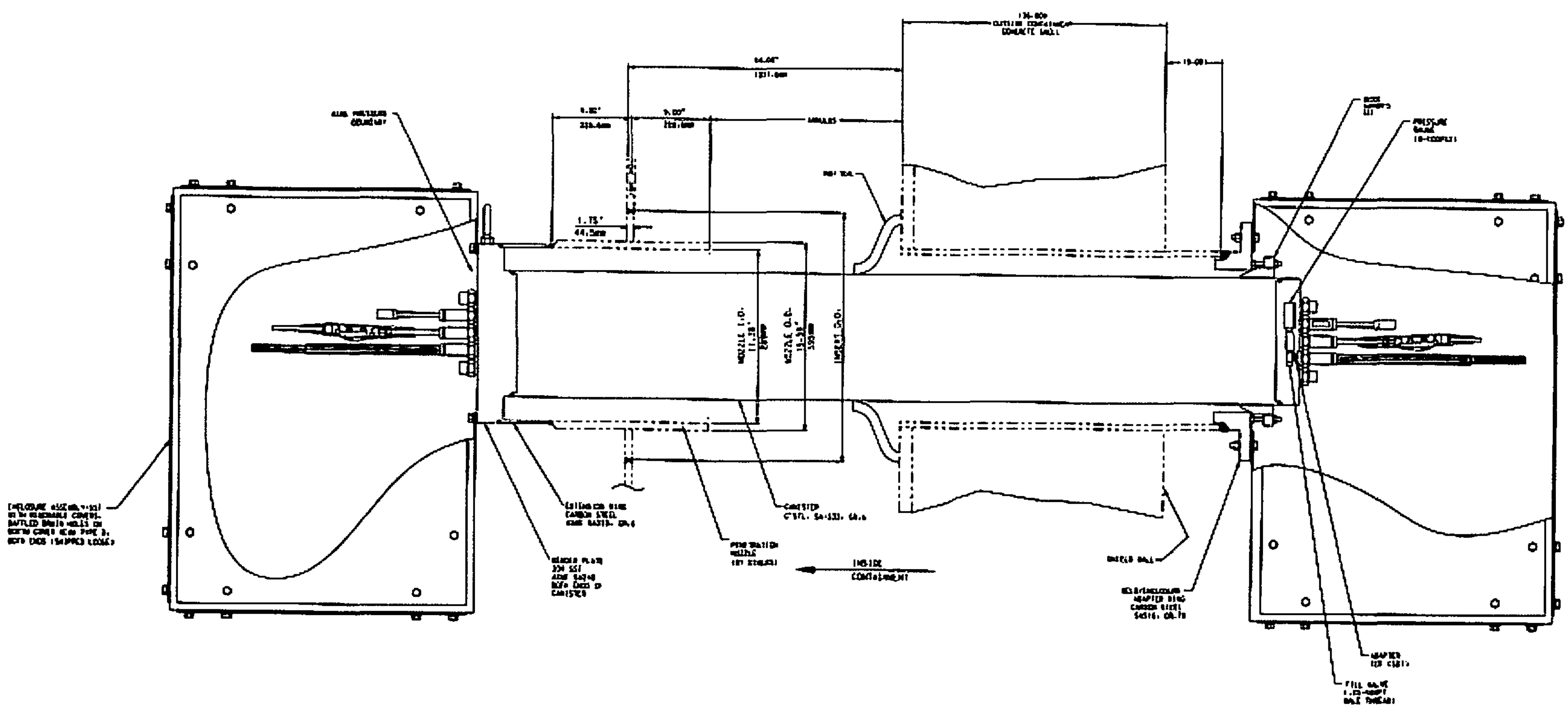

Figure 3.8.2-4 (Sheet 4 of 6)
Containment Penetration Typical Electrical Penetration

Appendix A- DCD Sections

This appendix provides sections of DCD, Rev 16. It includes the changes described in Section 5 of this report. Side bars in the margin show changes from Rev 15.

3.8.2 Steel Containment

3.8.2.1 Description of the Containment

3.8.2.1.1 General

This subsection describes the structural design of the steel containment vessel and its parts and appurtenances. The steel containment vessel is an integral part of the containment system whose function is described in Section 6.2. It serves both to limit releases in the event of an accident and to provide the safety-related ultimate heat sink.

The containment vessel is an ASME metal containment. The information contained in this subsection is based on the design specification and preliminary design and analyses of the vessel. Final detailed analyses will be documented in the ASME Design Report.

The containment arrangement is indicated in the general arrangement figures in Section 1.2. The portion of the vessel above elevation 132′-3″ is surrounded by the shield building but is exposed to ambient conditions as part of the passive cooling flow path. A flexible watertight and airtight seal is provided at elevation 132′-3″ between the containment vessel and the shield building. The portion of the vessel below elevation 132′-3″ is fully enclosed within the shield building.

Figure 3.8.2-1 shows the containment vessel outline, including the plate configuration and crane girder. It is a free-standing, cylindrical steel vessel with ellipsoidal upper and lower heads. [*The containment vessel has the following design characteristics:*

Diameter: 130 feet
Height: 215 feet 4 inches
Design Code: ASME III, Div. 1
Material: SA738, Grade B
Design Pressure: 59 psig
Design Temperature: 300°F
Design External Pressure: 2.9 psid

The wall thickness in most of the cylinder is 1.75 inches. The wall thickness of the lowest course of the cylindrical shell is increased to 1.875 inches to provide margin in the event of corrosion in the embedment transition region. The thickness of the heads is 1.625 inches.]* The heads are ellipsoidal with a major diameter of 130 feet and a height of 37 feet, 7.5 inches.

The containment vessel includes the shell, hoop stiffeners and crane girder, equipment hatches, personnel airlocks, penetration assemblies, and miscellaneous appurtenances and attachments. The design for external pressure is dependent on the spacing of the hoop stiffeners and crane

girder, which are shown on Figure 3.8.2-1. [*The spacing between each pair of ring supports (the bottom flange of the crane girder, the hoop stiffeners, and the concrete floor at elevation 100'-0") is less than 50 feet, 6 inches.*]*

The polar crane is designed for handling the reactor vessel head during normal refueling. The crane girder and wheel assemblies are designed to support a special trolley to be installed in the event of steam generator replacement.

The containment vessel supports most of the containment air baffle as described in subsection 3.8.4. The air baffle is arranged to permit inspection of the exterior surface of the containment vessel. Steel plates are welded to the dome as part of the water distribution system, described in subsection 6.2.2. The polar crane system is described in subsection 9.1.5.

3.8.2.1.2 Containment Vessel Support

The bottom head is embedded in concrete, with concrete up to elevation 100′ on the outside and to the maintenance floor at elevation 107′-2″ on the inside. The containment vessel is assumed as an independent, free-standing structure above elevation 100′. The thickness of the lower head is the same as that of the upper head. There is no reduction in shell thickness even though credit could be taken for the concrete encasement of the lower head.

Vertical and lateral loads on the containment vessel and internal structures are transferred to the basemat below the vessel by shear studs, friction, and bearing. The shear studs are not required for design basis loads. They provide additional margin for earthquakes beyond the safe shutdown earthquake.

Seals are provided at the top of the concrete on the inside and outside of the vessel to prevent moisture between the vessel and concrete. A typical cross section design of the seal is presented in Figure 3.8.2-8, sheets 1 and 2.

3.8.2.1.3 Equipment Hatches

Two equipment hatches are provided. One is at the operating floor (elevation 135′-3″) with an inside diameter of 16 feet. The other is at floor elevation 107′-2″ to permit grade-level access into the containment, with an inside diameter of 16 feet. The hatches, shown in Figure 3.8.2-2, consist of a cylindrical sleeve with a pressure seated dished head bolted on the inside of the vessel. The containment internal pressure acts on the convex face of the dished head and the head is in compression. The flanged joint has double O-ring or gum-drop seals with an annular space that may be pressurized for leak testing the seals. Each of the two equipment hatches is provided with an electrically powered hoist and with a set of hardware, tools, equipment and a self-contained power source for moving the hatch from its storage location and installing it in the opening.

3.8.2.1.4 Personnel Airlocks

Two personnel airlocks are provided, one located adjacent to each of the equipment hatches. Figure 3.8.2-3 shows the typical arrangement. Each personnel airlock has about a 10-foot external diameter to accommodate a door opening of width 3 feet 6 inches and height 6 feet 8 inches. The airlocks are long enough to provide a clear distance of 8 feet, which is not impaired by the swing of the doors within the lock. The airlocks extend radially out from the containment vessel through the shield building. They are supported by the containment vessel.

Each airlock has two double-gasketed, pressure-seated doors in series. The doors are mechanically interlocked to prevent simultaneous opening of both doors and to allow one door to be completely closed before the second door can be opened. The interlock can be bypassed by using special tools and procedures.

3.8.2.1.5 Mechanical Penetrations

The mechanical penetrations consist of the fuel transfer penetration and mechanical piping penetrations and are listed in Table 6.2.3-4.

Figure 3.8.2-4, sheet 1, shows typical details for the main steam penetration. This includes bellows to minimize piping loads applied to the containment vessel and a guardpipe to protect the bellows and to prevent overpressurization of the containment annulus in a postulated pipe rupture event. Similar details are used for the feedwater penetration.

Figure 3.8.2-4, sheet 2, shows typical details for the startup feedwater penetration. This includes a guardpipe to prevent overpressurization of the containment annulus in a postulated pipe rupture event. Similar details are used for the steam generator blowdown penetration.

Figure 3.8.2-4, sheet 3, shows typical details for the normal residual heat removal penetration. Similar details are used for other penetrations below elevation 107′-2″ where there is concrete inside the containment vessel. The flued head is integral with the process piping and is welded to the containment sleeve. The welds are accessible for in-service inspection. The containment sleeve is separated from the concrete by compressible material.

Figure 3.8.2-4, sheet 4 shows typical details for the other mechanical penetrations. These consist of a sleeve welded to containment with either a flued head welded to the sleeve (detail A), or with the process piping welded directly to the sleeve (detail B). Flued heads are used for stainless piping greater than 2 inches in nominal diameter and for piping with high operating temperatures.

Design requirements for the mechanical penetrations are as follows:

- Design and construction of the process piping follow ASME, Section III, Subsection NC. Design and construction of the remaining portions follow ASME Code, Section III, Subsection NE. The boundary of jurisdiction is according to ASME Code, Section III, Subsection NE.

- Penetrations are designed to maintain containment integrity under design basis accident conditions, including pressure, temperature, and radiation.

- Guard pipes are designed for pipe ruptures as described in subsection 3.6.2.1.1.4.

- Bellows are stainless steel or nickel alloy and are designed to accommodate axial and lateral displacements between the piping and the containment vessel. These displacements include thermal growth of the main steam and feedwater piping during plant operation, relative seismic movements, and containment accident and testing conditions. Cover plates are provided to protect the bellows from foreign objects during construction and operation. These cover plates are removable to permit in-service inspection.

The fuel transfer penetration, shown in Figure 3.8.2-4, sheet 5, is provided to transfer fuel between the containment and the fuel handling area of the auxiliary building. The fuel transfer tube is welded to the penetration sleeve. The containment boundary is a double-gasketed blind flange at the refueling canal end. The expansion bellows are not a part of the containment boundary. Rather, they are water seals during refueling operations and accommodate differential movement between the containment vessel, containment internal structures, and the auxiliary building.

3.8.2.1.6 Electrical Penetrations

Figure 3.8.2-4, sheet 6, shows a typical 12-inch-diameter electrical penetration. The penetration assemblies consist of three modules (or six modules in a similar 18-inch-diameter penetration) passing through a bulkhead attached to the containment nozzle. Electrical design of these penetrations is described in subsection 8.3.1.1.5.

Electrical penetrations are designed to maintain containment integrity under design basis accident conditions, including pressure, temperature, and radiation. Double barriers permit testing of each assembly to verify that containment integrity is maintained. Design and testing is according to IEEE Standard 317-83 and IEEE Standard 323-74.

3.8.2.2 Applicable Codes, Standards, and Specifications

[*The containment vessel is designed and constructed according to the 2001 edition of the ASME Code, Section III, Subsection NE, Metal Containment, including the 2002 Addenda. Stability of the containment vessel and appurtenances is evaluated using ASME Code, Case N-284-1, Metal Containment Shell Buckling Design Methods, Class MC, Section III, Division 1, as published in the 2001 Code Cases, 2001 Edition, July 1, 2001.*]*
Structural steel nonpressure parts, such as ladders, walkways, and handrails are designed to the requirements for steel structures defined in subsection 3.8.4.

Section 1.9 discusses compliance with the Regulatory Guides and the Standard Review Plans.

3.8.2.3 Loads and Load Combinations

Table 3.8.2-1 summarizes the design loads, load combinations and ASME Service Levels. They meet the requirements of the ASME Code, Section III, Subsection NE. The containment vessel is

designed for the following loads specified during construction, test, normal plant operation and shutdown, and during accident conditions:

- D Dead loads or their related internal moments and forces, including any permanent piping and equipment loads
- L Live loads or their related internal moments and forces, including crane loads
- P_o Operating pressure loads during normal operating conditions resulting from pressure variations either inside or outside containment
- T_o Thermal effects and loads during normal operating conditions, based on the most critical transient or steady-state condition
- R_o Piping and equipment reactions during normal operating conditions, based on the most critical transient or steady-state condition
- W Loads generated by the design wind on the portion of the containment vessel above elevation 132′, as described in subsection 3.3.1.1
- E_s Loads generated by the safe shutdown earthquake (SSE) as described in Section 3.7
- W_t Loads generated by the design tornado on the portion of the containment vessel above elevation 132′, as described in subsection 3.3.2
- P_t Test pressure
- P_d Containment vessel design pressure that exceeds the pressure load generated by the postulated pipebreak accidents and passive cooling function
- P_e Containment vessel external pressure
- T_a Thermal loads under thermal conditions generated by the postulated break or passive cooling function and including T_o. This includes variations around the shell due to the surrounding buildings and maldistribution of the passive containment cooling system water.
- R_a Piping and equipment reactions under thermal conditions generated by the postulated break, as described in Section 3.6, and including R_o
- Y_r Loads generated by the reaction on the broken high-energy pipe during the postulated break, as described in Section 3.6
- Y_j Jet impingement load on a structure generated by the postulated break, as described in Section 3.6
- Y_m Missile impact load on a structure generated by or during the postulated break, as from pipe whipping, as described in Section 3.6

Note that loads associated with flooding of the containment below elevation 107′ are resisted by the concrete structures and not by the containment vessel.

3.8.2.4 Design and Analysis Procedures

The design and analysis procedures for the containment vessel are according to the requirements of the ASME Code, Section III, Subsection NE.

The analyses are summarized in Table 3.8.2-4. The detailed analyses will use a series of general-purpose finite element, axisymmetric shell and special purpose computer codes to conduct such analyses. Code development, verification, validation, configuration control, and error reporting and resolution are according to the Quality Assurance requirements of Chapter 17.

3.8.2.4.1 Analyses for Design Conditions

3.8.2.4.1.1 Axisymmetric Shell Analyses

The containment vessel is modelled as an axisymmetric shell and analyzed using the ANSYS computer program. A model used for static analyses is shown in Figure 3.8.2-6.
Dynamic analyses of the axisymmetric model, which is similar to that shown in Figure 3.8.2-6, are performed to obtain frequencies and mode shapes. These are used to confirm the adequacy of the containment vessel stick model as described in subsection 3.7.2.3.2. Stress analyses are performed for each of the following loads:

- Dead load
- Internal pressure
- Seismic
- Polar crane wheel loads
- Wind loads
- Thermal loads

The seismic analysis **performed envelope all soil conditions. The seismic analysis is discussed in Section 3.7.** The torsional moments, which include the effects of the eccentric masses, are increased to account for accidental torsion and are evaluated in a separate calculation.
The results of these load cases are factored and combined in accordance with the load combinations identified in Table 3.8.2-1. These results are used to evaluate the general shell away from local penetrations and attachments, that is, for areas of the shell represented by the axisymmetric geometry. The results for the polar crane wheel loads are also used to establish local shell stiffnesses for inclusion in the containment vessel stick model described in subsection 3.7.2.3. The results of the analyses and evaluations are included in the containment vessel design report.

Design of the containment shell is primarily controlled by the internal pressure of 59 psig. The meridional and circumferential stresses for the internal pressure case are shown in Figure 3.8.2-5. The most highly stressed regions for this load case are the portions of the shell away from the hoop stiffeners and the knuckle region of the top head. In these regions the stress intensity is close to the allowable for the design condition.

Major loads that induce compressive stresses in the containment vessel are internal and external pressure and crane and seismic loads. Each of these loads and the evaluation of the compressive stresses are discussed below.

- Internal pressure causes compressive stresses in the knuckle region of the top head and in the equipment hatch covers. The evaluation methods are similar to those discussed in subsection 3.8.2.4.2 for the ultimate capacity.
- Evaluation of external pressure loads is performed in accordance with ASME Code, Section III, Subsection NE, Paragraph NE-3133.
- Crane wheel loads due to crane dead load, live load, and seismic loads result in local compressive stresses in the vicinity of the crane girder. These are evaluated in accordance with ASME Code, Case N-284.
- Overall seismic loads result in axial compression and tangential shear stresses at the base of the cylindrical portion. These are evaluated in accordance with ASME Code, Case N-284.

The bottom head is embedded in the concrete base at elevation 100 feet. This leads to circumferential compressive stresses at the discontinuity under thermal loading associated with the design basis accident. The containment vessel design includes a Service Level A combination in which the vessel above elevation 107′-2″ is specified at the design temperature of 300°F and the portion of the embedded vessel (and concrete) below elevation 100 feet is specified at a temperature of 70°F. The temperature profile for the vessel is linear between these elevations. Containment shell buckling close to the base is evaluated against the criteria of ASME Code, Case N-284.

Revision 1 of Code Case N-284 is used for the evaluation of the containment shell and equipment hatches.

3.8.2.4.1.2 Local Analyses

The penetrations and penetration reinforcements are designed in accordance with the rules of ASME III, Subsection NE. The design of the large penetrations for the two equipment hatches and the two airlocks use the results of finite element analyses which consider the effect of the penetration and its dynamic response.

The **personnel** airlocks and equipment hatches are modeled in **a 3-D shell** finite element model **of the containment.** The **bottom of the model is fixed at elevation 100′ where the containment vessel is embedded in concrete.**

Static analyses are performed using the finite element model shown in Figure 3.7.2-7 for internal pressure, dead load (including the polar crane in the parked position), thermal loads and seismic loads. The global seismic loads are applied as equivalent static accelerations using the maximum accelerations from the nuclear island stick model given in DCD Table 3.7.2-6. The amplified local responses are included separately for each of the four penetrations. Local seismic axial and rotational accelerations about both horizontal

and vertical axes are applied based on the maximum amplified response determined from a time history analysis on a less refined dynamic model with seismic time histories at elevation 100′.

Stresses are evaluated against the stress intensity criteria of ASME Section III, Subsection NE **for the load combinations described in Table 3.8.2-1**. Stability is evaluated against ASME Code Case N-284. Local stresses in the regions adjacent to the major penetrations are evaluated in accordance with paragraph 1711 of the code case. Stability is not evaluated in the reinforced penetration neck and insert plate which are substantially stiffer than the adjacent shell.

Table 3.8.2-1

LOAD COMBINATIONS AND SERVICE LIMITS FOR CONTAINMENT VESSEL

Load Description		**Load Combination and Service Limit**											
		Con	**Test**	**Des.**	**Des.**	**A**	**A**	**A**	**C**	**D**	**C**	**D**	**D**
Dead	D	x	x	x	x	x	x	x	x	x	x	x	x
Live	L	x	x	x	x	x	x	x	x	x	x	x	x
Wind	W	x				x							
Safe shutdown earthquake	E_s								x	x		x	x
Tornado	W_t										x		
Test pressure	P_t		x										
Test temperature	T_t		x										
Operating pressure	P_o										x		
Design pressure	P_d			x			x		x			x	
External pressure (2.9 psid)	P_e				x			x		x			
External pressure (0.9 psid)(3)						x							x
Normal reaction	R_o				x	x		x		x	x		
Normal thermal	T_o				**(4)**	**(5)**		**(4)**		**(4)**	**(4)**		**(5)**
Accident thermal reactions	R_a			x			x		x			x	
Accident thermal	T_a			x			x		x			x	
Accident pipe reactions	Y_r											x	
Jet impingement	Y_j											x	
Pipe impact	Y_m											x	

Notes:

1. Service limit levels are per ASME-NE.
2. Where any load reduces the effects of other loads, that load is to be taken as zero, unless it can be demonstrated that the load is always present or occurs simultaneously with the other loads.
3. **Reduced pressure of 0.9 psid at one hour in loss of all ac transient in cold weather.**
4. **Temperature of vessel is 70°F.**
5. **Temperature distribution for loss of all AC in cold weather.**

Table 3.8.2-4

SUMMARY OF CONTAINMENT VESSEL MODELS AND ANALYSIS METHODS

Model	Analysis Method	Program	Purpose
Axisymmetric shell	Modal analysis	ANSYS	To calculate frequencies and mode shapes for comparison against stick model
Lumped mass stick model	Modal analysis	ANSYS	To create equivalent stick model for use in nuclear island seismic analyses
Axisymmetric shell	Static analyses using Fourier harmonic loads	ANSYS	To calculate containment vessel shell stresses
Axisymmetric shell	Nonlinear bifurcation	BOSOR5	To calculate buckling capacity close to base under thermal loads To calculate pressure capacity of top head
Finite element shell	Linear bifurcation	ANSYS	To study local effect of large penetrations and embedment on buckling capacity for axial and external pressure loads
Finite element shell	Modal analysis	ANSYS	To calculate frequencies and mode shapes for local effects of equipment hatches and personnel airlocks
Finite element shell	Static analyses	ANSYS	To calculate local shell stress in vicinity of the equipment hatches and personnel airlocks

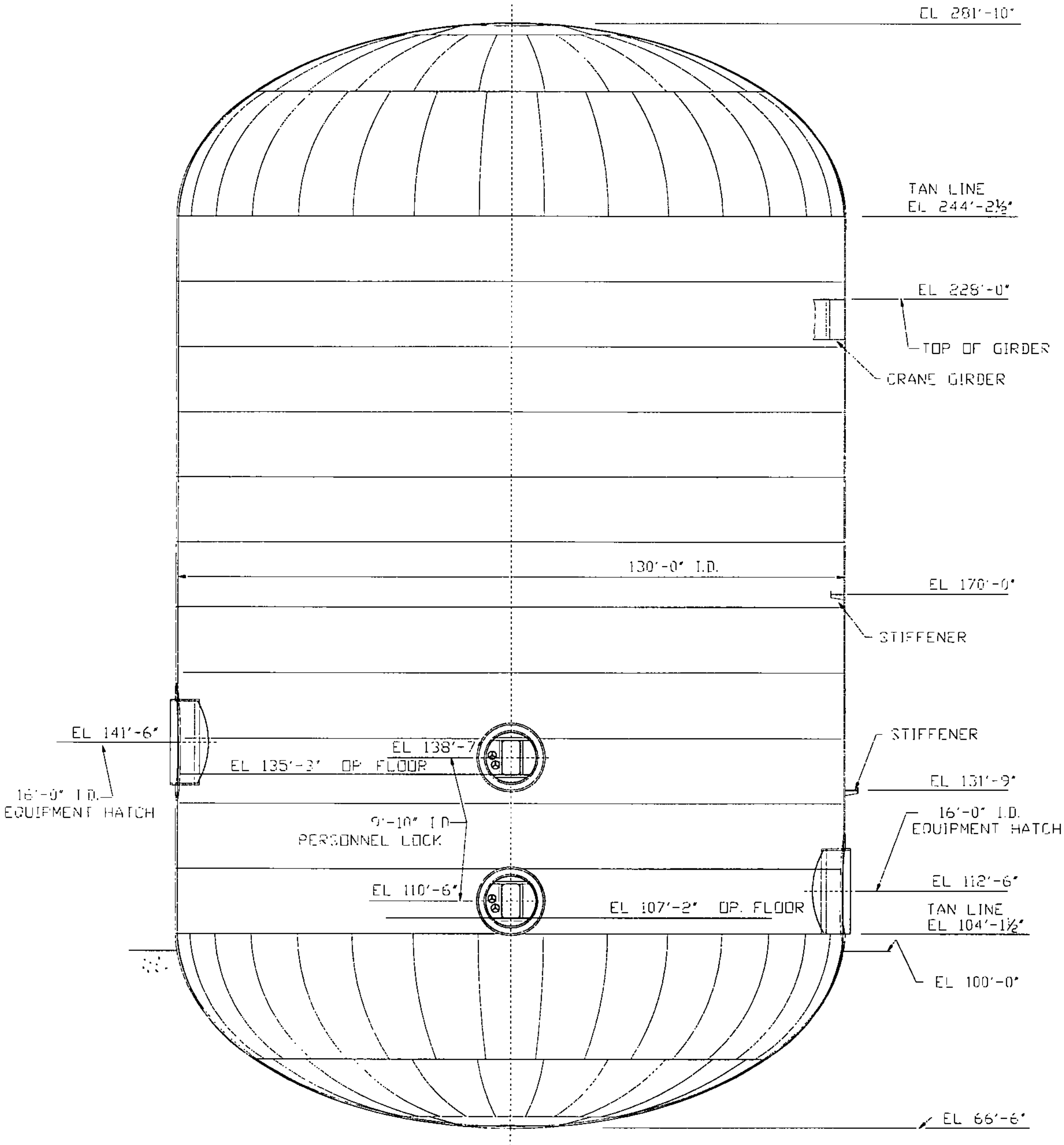

Figure 3.8.2-1 (Sheet 1 of 3)

Containment Vessel General Outline

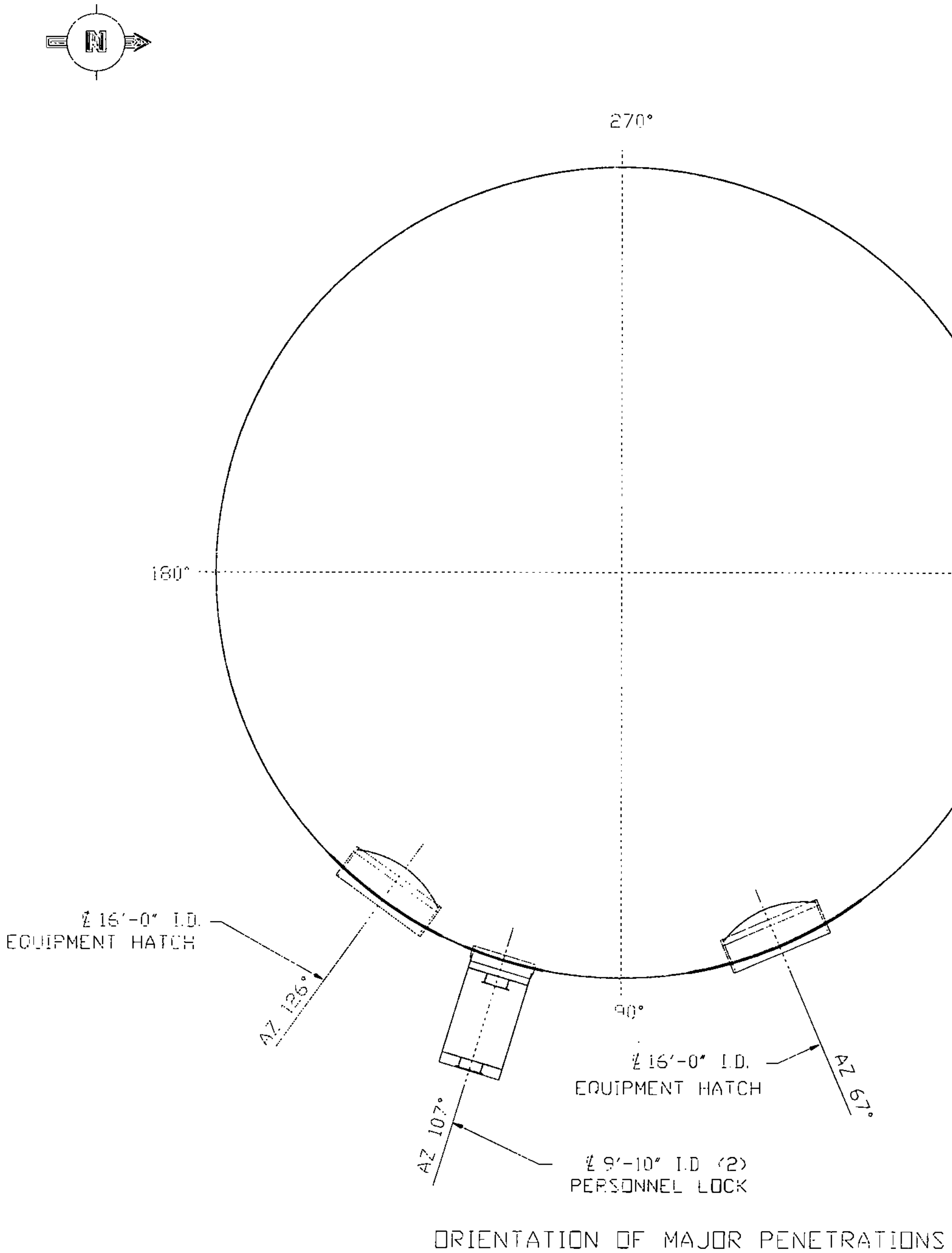

Figure 3.8.2-1 (Sheet 2 of 3)

Containment Vessel General Outline

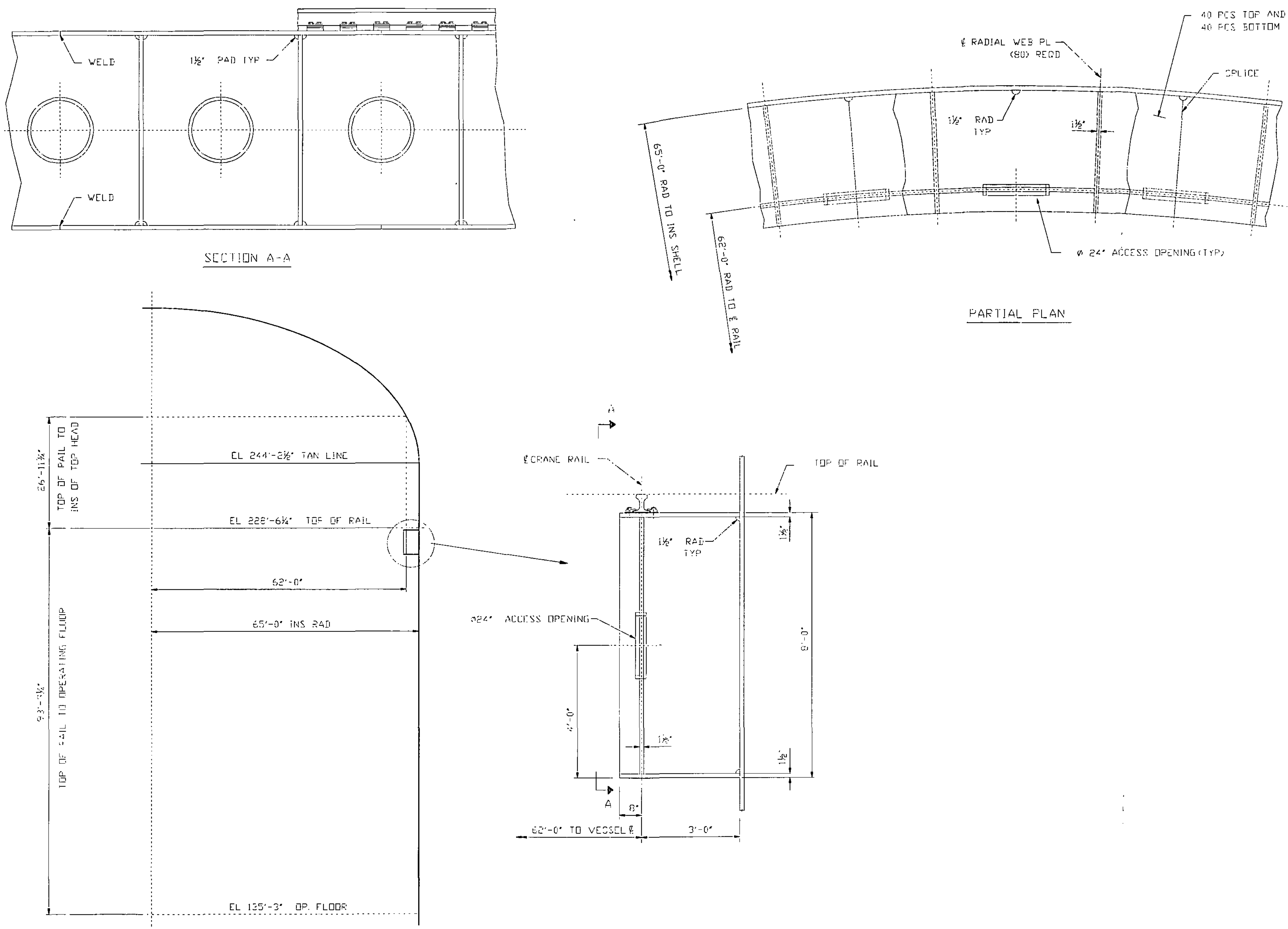

Figure 3.8.2-1 (Sheet 3 of 3)

Containment Vessel General Outline

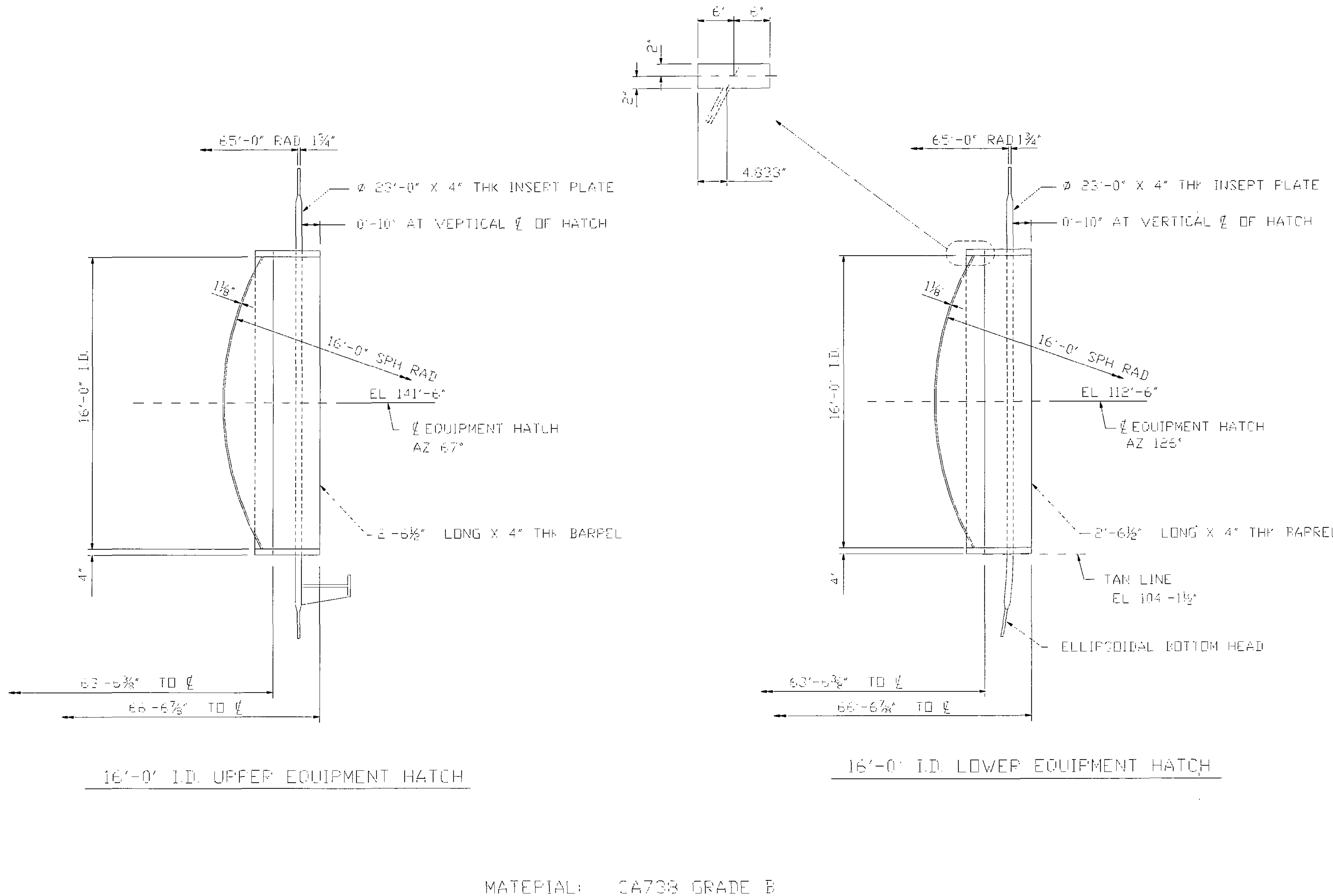

Figure 3.8.2-2

Equipment Hatches

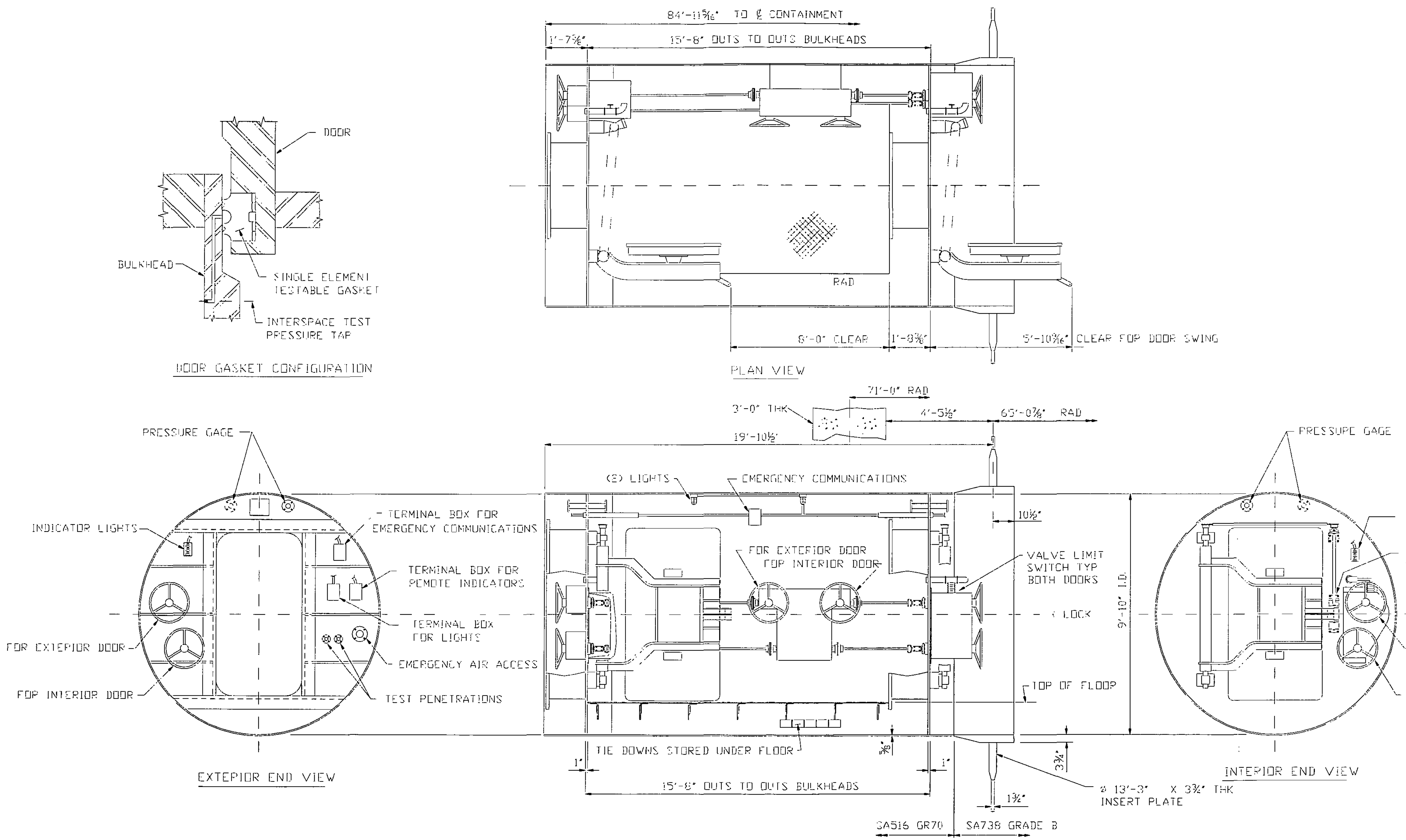

Figure 3.8.2-3

Personnel Airlock

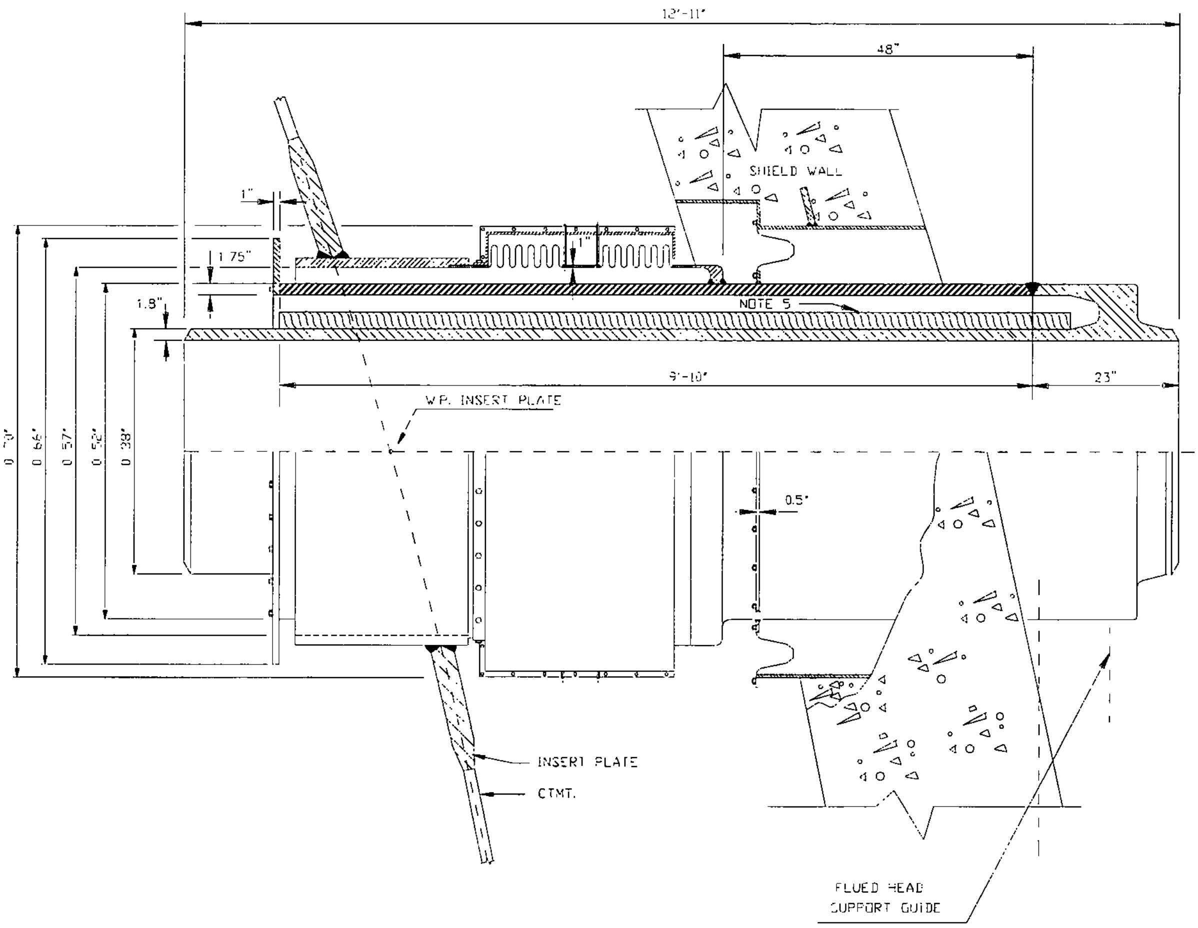

Figure 3.8.2-4 (Sheet 1 of 6)

Containment Penetrations Main Steam

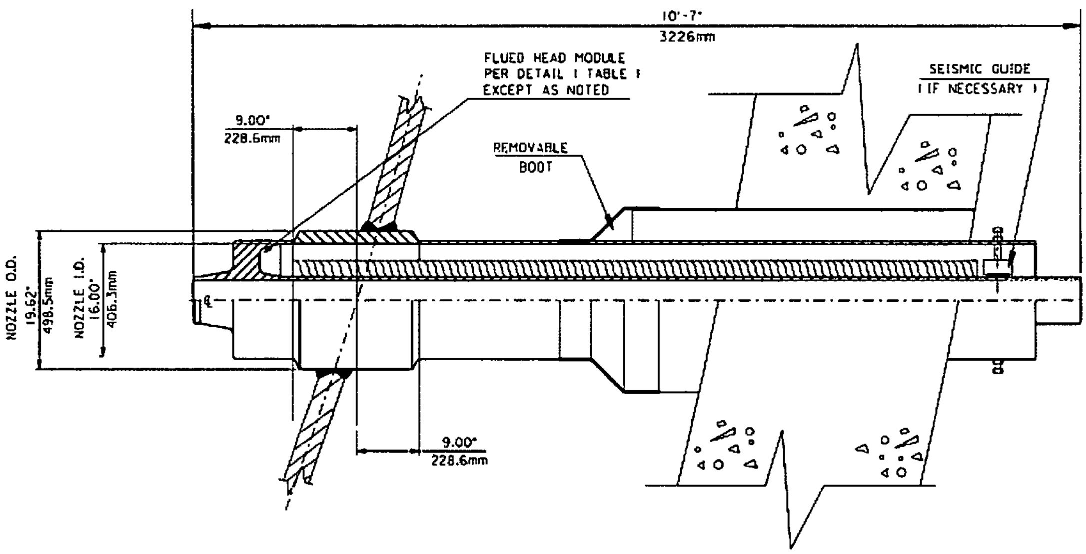

Figure 3.8.2-4 (Sheet 2 of 6)

Containment Penetrations Startup Feedwater

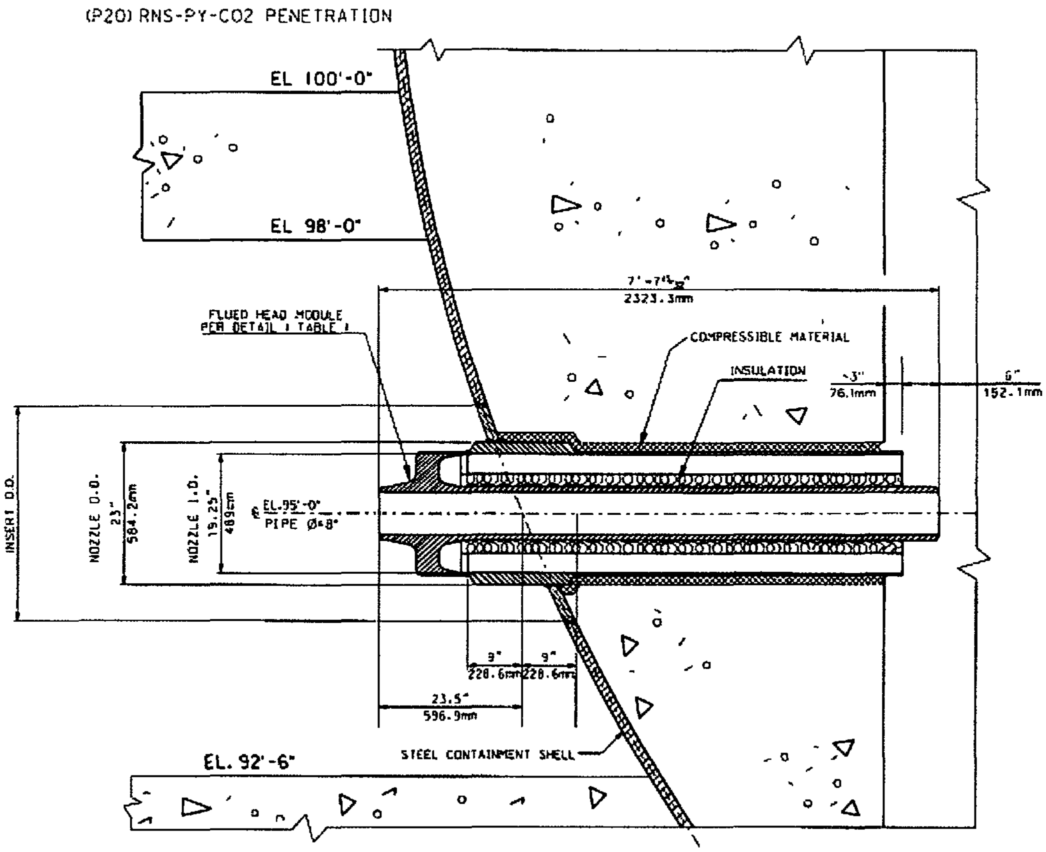

Figure 3.8.2-4 (Sheet 3 of 6)

Containment Penetrations Normal RHR Piping

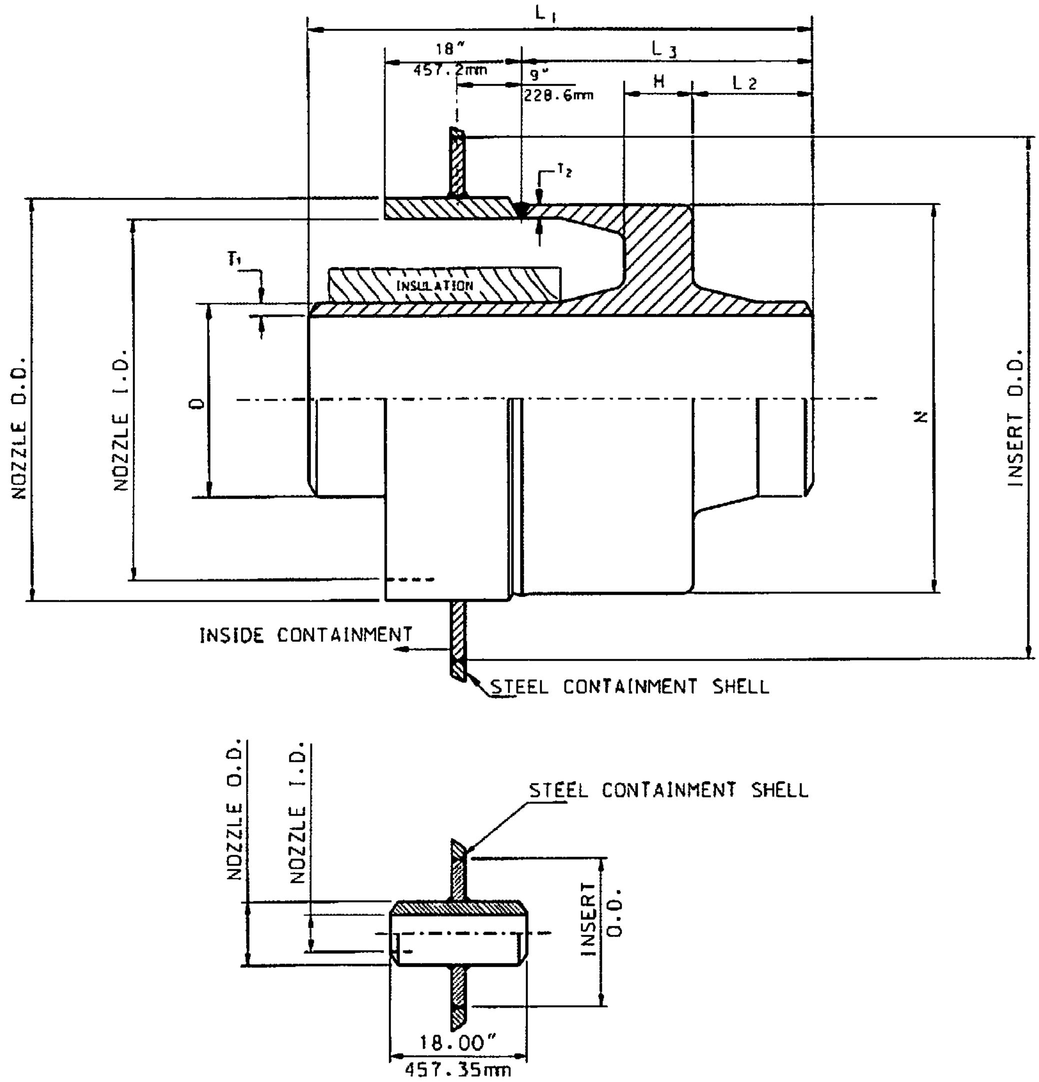

Figure 3.8.2-4 (Sheet 4 of 6)

Containment Penetrations

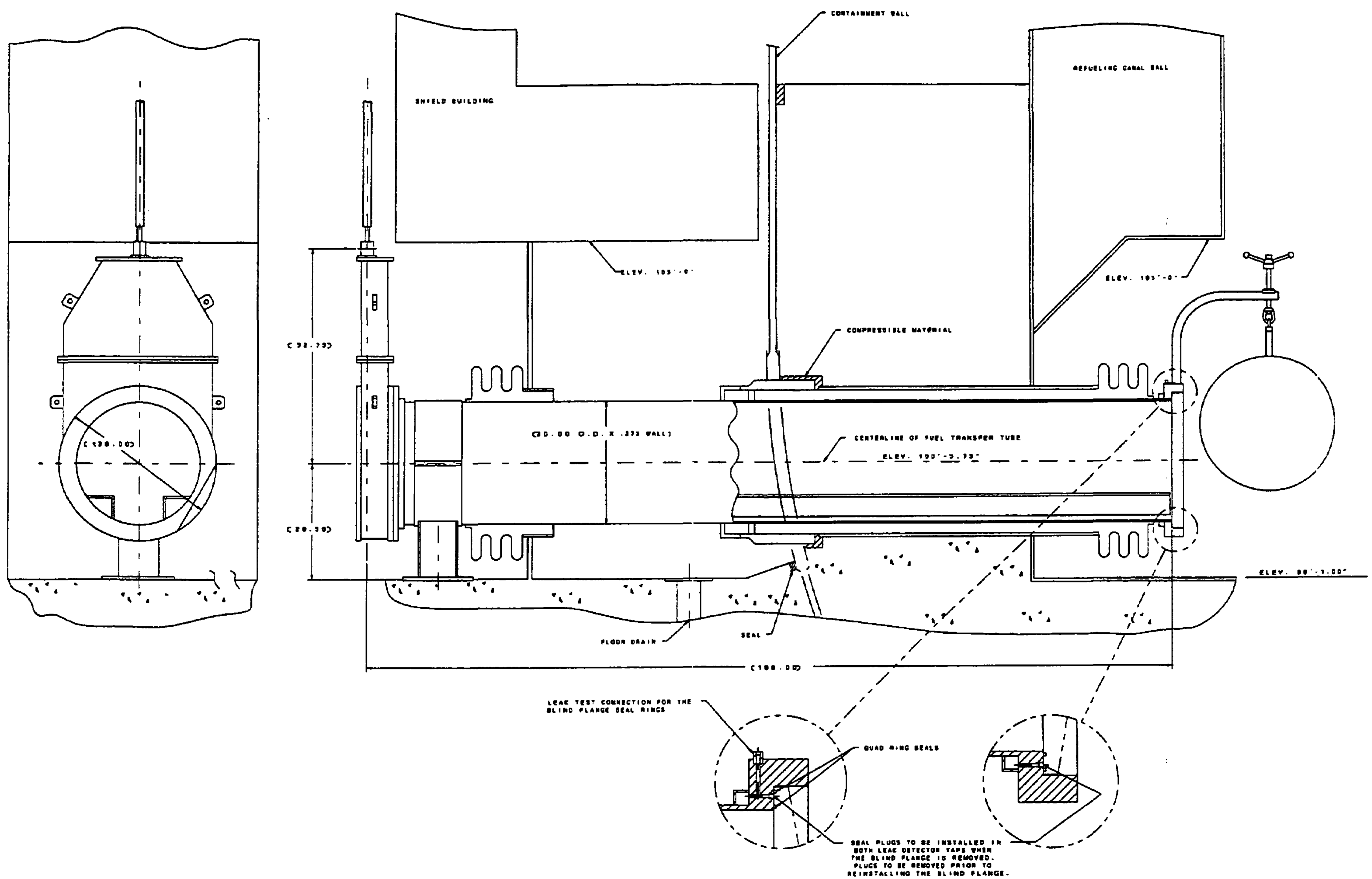

Figure 3.8.2-4 (Sheet 5 of 6)

Containment Penetrations
Fuel Transfer Penetration

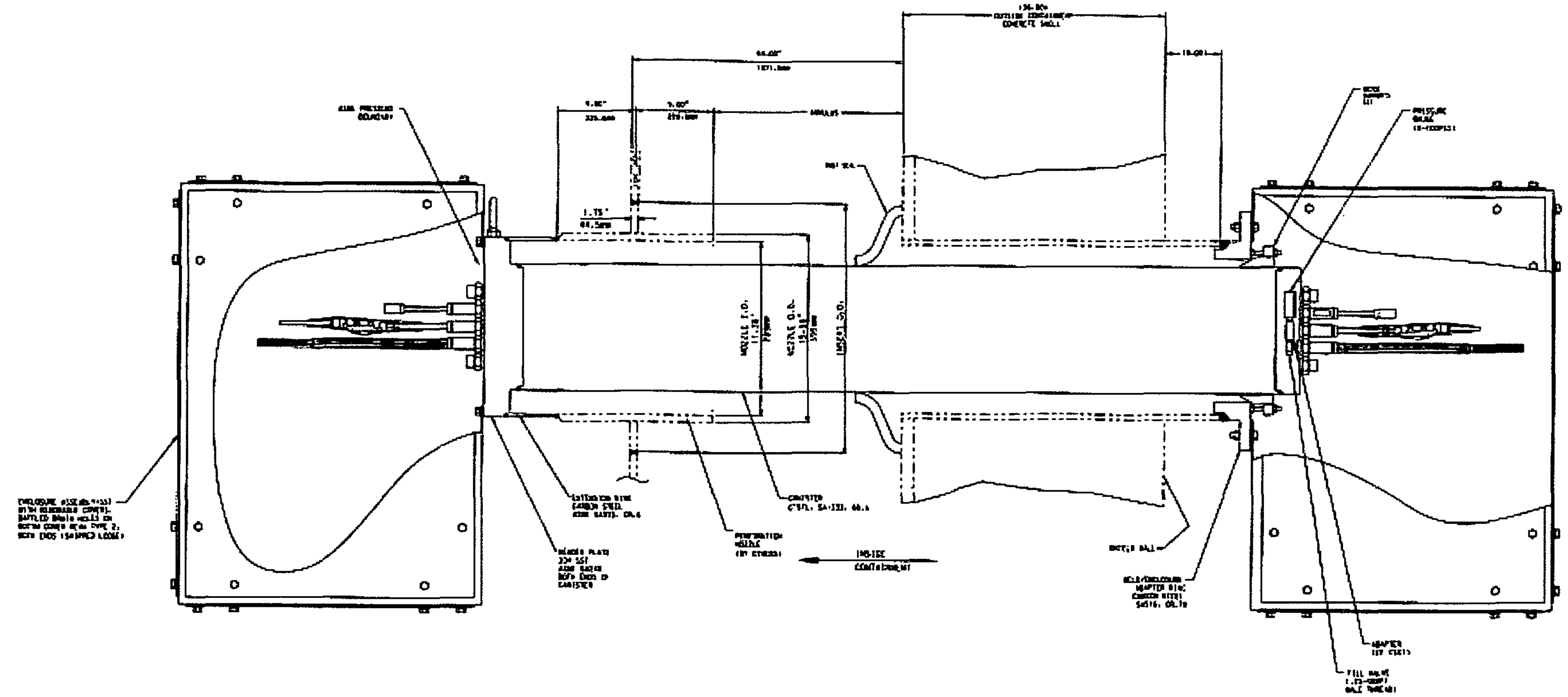

Figure 3.8.2-4 (Sheet 6 of 6)

Containment Penetrations
Typical Electrical Penetration