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NSD-NRC-97-4981
DCP/NRC0737
Docket No.: STN-52-003

February 11, 1997

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: T. R. QUAY

SUBJECT: AP600 CONTAINMENT OPEN ITEMS

Dear Mr. Quay:

Attached are responses to resolve DSER open items, requests for additional information, and a telecon item related to AP600 containment structural issues. The responses include draft SSAR changes that will be included in Revision 11 of the AP600 SSAR. The list below includes the DSER item number or RAI number and the open item tracking system (OITS) number.

DSER OI 3.8.2.4-3 (681)
DSER OI 3.8.2.4-20 (698)
DSER OI 3.8.2.4-28 (706)
DSER COL 3.8.2.4-1 (1888)
Telecon Item June 23, 1995 (2515)
RAI 220.100 (3269)
RAI 220.101 (3270)
RAI 220.102 (3271)

These responses provide a way to resolve these items and will permit the NRC staff to provide input for the final safety evaluation report.

If you have any questions please contact Donald A. Lindgren at (412) 374-4856.

C L Hag for BAM

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/jml

Attachment

cc: D. Jackson, NRC
T. Cheng, NRC

E004 1/1

Open Item # 681- DSER Open Item 3.8.2.4-3

Based on the staff's review experience of other nuclear power plants, local high stresses may occur in the vicinity of the concentrated masses such as the equipment hatches and personnel airlocks. Westinghouse was requested to demonstrate that calculated stresses in the vicinity of the concentrated masses such as equipment hatches and personnel airlocks based on an equivalent static analysis bound the local stresses computed by the dynamic analysis. This was open item 3.8.2.4-3. In the August 30 through 31, 1995 review meeting, Westinghouse stated that detailed analyses and design of the containment vessel in vicinity of concentrated masses are beyond the scope of the AP600 standard design. However, Westinghouse agreed to expand SSAR Section 3.8.2.4.1.2 to include:

1. A detailed description of methods to be used for the dynamic analysis of local masses
2. The approach for analyzing the local buckling potential of the containment shell adjacent to major penetrations.
3. The stress redistribution criteria to be applied for the shell adjacent to the local masses, and
4. Methods for evaluating the compressive strength of the containment shell in the vicinity of major penetrations.

<u>Westinghouse Response</u>

Replace existing SSAR subsection 3.8.2.4.1.2 with the following:

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 dynamic response of the local concentrated mass is considered in local analyses of the shell and is included in the design.~~ 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 as follows:

1. The upper airlock and equipment hatch penetrations are modeled in individual finite element models. The lower airlock and equipment hatch are modeled in a combined finite element model (Figure 3.7.2-8) including the boundary conditions representing the embedment. The finite element models include a portion of the shell sufficient that the boundary conditions do not affect the results of the local analyses.

2. Surface loads are applied for pressure and inertia loads on the shell included in the model. Loads corresponding to the stresses in the unpenetrated vessel at the location of the penetration, obtained from the axisymmetric analyses described in the previous subsection, are applied as boundary conditions for the local finite element models.

3. The out-of-plane stiffness of the containment vessel is determined for unit radial loads and moments at the location of the penetration. The frequency of the local radial and rotational modes are calculated using single degree of freedom models with mass and rotational inertias of the penetration. Seismic response accelerations for the radial and rotational modes are determined from the applicable floor response spectra for the containment vessel. Equivalent static radial loads and moments are calculated from these seismic response accelerations

4. Radial loads and moments due to the local seismic response and due to external loads on the penetration are applied statically at the location of the penetration. These loads are applied individually corresponding to the three directions of input (radial, tangential and vertical). The three directions of seismic input are combined by the square root sum of the squares method or by the 100%, 40%, 40% method as described in subsection 3.7.2.

5. Stresses due to local loads on the penetration (step 4) are combined with those from the global vessel analyses (step 2). Stresses are evaluated against the stress intensity criteria of ASME Section III, Subsection NE. Stability is evaluated against ASME Code Case N-284, Revision 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 16 foot diameter equipment hatch located at elevation 112′ 6″ and the personnel airlock located at elevation 110′ 6″ are in close proximity to each other and to the concrete embedment. Design of these penetrations uses the finite element model shown in Figure 3.8.2-7. Static analyses are performed for dead loads and containment pressure. Response spectrum analyses are performed for seismic loads. Stresses are evaluated as described for the single penetrations in step 5 above.

Finite element analyses are performed to confirm that the design of the penetration in accordance with the ASME code provides adequate margin against buckling ~~safety factors~~. A finite element ANSYS model, as shown in Figure 3.8.2-7, represents the portion of the vessel close to the embedment with the lower equipment hatch and personnel airlock. This is analyzed for external pressure and axial loads and demonstrates that the penetration reinforcement is sufficient and precludes buckling close to the penetrations. ~~and that the~~ The lowest buckling mode occurs in the shell away from the penetrations and embedment.

Open Item # 698 - DSER Open Item 3.8.2.4-20

Westinghouse should provide the leakage estimate through penetrations such as equipment hatches and personnel airlocks.

<u>Westinghouse response</u>

The treatment and the description of the leakage modeling in the severe accident fission product source term analysis is found in chapter 45 of the PRA report, Revision 3. The leakage area in the severe accident is equal to that corresponding to the specified containment leakage of 0.12% at design basis conditions. There is no increase in leakage area caused by containment pressurization. The ultimate pressure capacity for containment function is calculated to occur once the general membrane stresses in the shell reach yield. Thus the general membrane shell remains elastic for pressures up to this ultimate capacity and increased leakage area is not expected due to pressure. Leakage after general membrane yield of the containment cylinder is assumed as containment failure as discussed in the response to RAI 220.99 in letter NSD-NRC-96-4904, dated 12/9/96.

Open Item #706 - DSER Open Item # 3.8.2.4-28

Westinghouse should provide in the SSAR an assessment of the pressure capability of the main steamline and main feedwater line bellows, a corresponding failure probability distribution curve, and the impact on the overall cumulative failure probability curve.

Westinghouse response

This is the same question as RAI 480.191. See response to RAI 480.191 provided in letter NSD-NRC-96-4904, dated 12/9/96.

Open Item #1888 - DSER Open Item # 3.8.2.4-1

The COL applicant should demonstrate that EPAs to be used shall be at least as strong as the AP600 SCV.

Westinghouse response

Additional information has been included in SSAR subsection 3.8.2.4.2.5, Revision 7. See also response to RAI 220.102 (OI# 3271).

Open Item #2515 - Telecon June 23, 1995

Westinghouse should address the issue of fatigue and [illegible]on of containment bellows. The number of thermal cycles and loading information included in the design specification should be addressed. The material requirements and effect of corrosion should also be included.

Westinghouse response

SSAR section 3.8.2.1.5, Rev 7 has been revised to include material and additional information on the displacement cycles. Fatigue is evaluated in accordance with ASME subsection NE as stated in SSAR subsection 3.8.2.1.5. Bellows materials are stainless steel or nickel alloy. Corrosion is not expected; if there is any degradation it would be observed by inservice inspection or testing. The bellows are included in the ISI of the containment vessel as well as the containment leak rate testing.

DSER Open Item # 3269 (NRC letter dated 4/4/96) RAI # 220.100

In SSAR Section 3.8.2.4.2.3, the factor of safety (FS) of 1.67 is used for equipment hatch covers ASME Service Level C limits.

Westinghouse estimated the critical buckling pressures for equipment hatches as 1.45 MPa (196 psig) for a 6.7 m (22 ft) diameter hatch and 1.21 MPa (161 psig) for a 4.9 m (16 ft) diameter hatch based on the classical buckling capacity of spherical shells subjected to external pressure and the capacity reduction factors specified in Baker et al., "Structural Analysis of Shells,"pp. 253-254, McGraw-Hill, 1972, and in ASME Code Case N-284. The corresponding ASME Service Level C limits are 908 kPa (117 psig) and 763.2 kPa (96 psig) using the factor of safety (FS) of 1.67 as specified in Code Case N-284, respectively.

For the FS to be applied to the Service Level C pressure capacity, Westinghouse considered the equipment hatch cover buckling due to external pressure as the local buckling (FS = 1.67 from Code Case N-284). The hatch cover is a complete shell by itself with its own independent boundary and is subjected to pressure on its convex side due to the containment internal pressure. Therefore, the staff position is that the global buckling (FS = 2.5 from NE-3222) is the appropriate value. The ASME Service Level C pressure capacity is 763.2 kPa (96 psig) with FS of 1.67 and 545.4 kPa (64.4 psig) with an FS of 2.5.

Based on Code Case N-284, the local buckling is defined as the buckling of the shell plate between stiffeners. The flange of the cover can act as a stiffening element around the periphery of the spherical cap. However, the stiffening effect is limited to $(Rt)^{1/2}$ or 35.3 cm (13.9 in) from the edge. The entire arc length from the center of the hatch cover to the flange is 255.3 cm (100.5 in). The remaining 218.4 cm (86 in) arc should be considered as unstiffened, therefore, the global buckling criteria should be applied to this unstiffened region. In the draft safety evaluation report (DSER), the staff noted that Westinghouse's assumption of local buckling for the equipment hatch cover under external pressure was not acceptable. The staff requested that Westinghouse increase the thickness or use stiffeners (e.g., ABB-CE System 80+ design) to meet the ASME Service Level C limits at the ambient temperature of 908 kPa (117 psig) for a 6.7 m (22 ft) diameter hatch and 763.2 kPa (96 psig) for a 4.9 m (16 ft) diameter hatch. This was Open Item 3.8.2.4-30.

The staff performed independent analysis for the equipment hatch covers using the ALGOR computer code with fixed boundary conditions and no imperfection. Using ALGOR, the staff predicted the buckling pressure, Pbuckling, as 1.38 MPa (185.12 psig) and 1.57 MPa (212.96 psig) for 4.9 m (16 ft) and 6.7 m (22 ft) equipment hatch covers, respectively. In both cases, the buckling was predicted to occur near the top portion.

For the reasons discussed above, the staff considers the equipment hatch covers buckling as a global failure mode. There is a potential for radioactive gas leakage through the equipment hatch sleeve/gasket once buckling occurs. Thus, the leaktight integrity of the containment is jeopardized. On this basis, the staff finds that a higher FS of 2.5 based on NE-3222 should be applied.

Westinghouse Response

The SSAR will be revised to show capacities using the factor of safety of 2.5. Information will be retained with a factor of safety of 1.67 using Code Case N 284, the use of which has been endorsed by ASME (see attached letter dated 2/6/96). At the design temperature of 280° F, the capacity is 62 psig with a safety factor of 2.5, and 90 psig with a safety factor of 1.67. The PRA report shows that none of the more likely severe accident sequences exceed either of these pressures.

SSAR changes

3.8.2.4.2 Evalu. .on of Ultimate Capacity

The capacity of the containment vessel has been calculated for internal pressure loads for use in the probabilistic risk assessment analyses and severe accident evaluations. Each element of the containment vessel boundary was evaluated to estimate the maximum pressure at an ambient temperature of 100°F corresponding to the following stress and buckling criteria:

- Deterministic severe accident pressure capacity corresponding to ASME Service Level C limits on stress intensity, ASME paragraph NE-3222 and ASME Code Case N-284 for buckling of the equipment hatch covers, and 60 percent of critical buckling for the top head. The deterministic severe accident pressure capacity corresponds to the approach in SECY 93-087, to maintain a reliable leak-tight barrier approximately 24 hours following the onset of core damage under the more likely severe accident challenges. This approach was approved by the Nuclear Regulatory Commission as outline in the Staff Requirements Memorandum on SECY-93-087 - Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light Water Reactor (ALWR) Designs, Dated July 21, 1993.

- Best estimate capacity corresponding to gross membrane yield at the ASME-specified minimum yield stress (SA537, Class 2, yield stress = 60 ksi, ultimate stress = 80 ksi), and critical buckling for the equipment hatch covers and top head.

The results are shown in Table 3.8.2-2. The analyses at a temperature of 100°F are described in the following paragraphs for each element. The critical regions identified in this table are then examined further for their response at higher temperatures. This results in the best-estimate capacity based on the ASME-specified minimum yield properties. The evaluation considered the containment boundary elements including:

- Cylindrical shell
- Top and bottom heads
- Equipment hatches and covers
- Personnel airlocks
- Mechanical and electrical penetrations

The evaluation identified the most likely failure mode to be that associated with gross yield of the cylindrical shell. Loss of containment function would be expected to occur because the large post-yield deflections would lead to local failures at penetrations, bellows, or other local discontinuities.

3.8.2.4.2.3 Equipment Hatches

SECY 93-087 permits evaluation of certain severe accident scenarios against ASME Service Level C limits. The equipment hatch covers were evaluated for buckling against ASME paragraph NE-3222 and according to ASME Code, Case N-284. Use of ASME Code, Case N-284 for this application was confirmed to be appropriate by ASME. The containment internal pressure acts on the convex face of the dished head and the hatch covers are in compression under containment internal pressure loads. The critical buckling capacity is based on classical buckling capacities reduced by capacity reduction factors to account for the effects of imperfections and plasticity. These capacity reduction factors are based on test data and are generally lower-bound values for the tolerances specified in the ASME Code.

The critical buckling pressures are 195 psig for the 22-foot-diameter hatch and 160 psig for the 16-foot-diameter hatch at an ambient temperature of 100°F. For the Service Level C limits in accordance with paragraph NE 3222, a safety factor of 2.50 is specified, resulting in capabilities of 78 psig (22-foot-diameter) and 64 psig (16-foot-diameter). For the Service Level

C limits in accordance with Code Case N284, a safety factor of 1.67 is specified, resulting in capabilities of 117 psig (22-foot-diameter) and 96 psig (16-foot-diameter).

Typical gaskets have been tested for severe accident conditions as described in NUREG/CR-5096 (Reference 25). The gaskets for the AP600 will be similar to those tested with material such as Presray EPDM E 603. For such gaskets the onset of leakage occurred at a temperature of about 600°F.

3.8.2.4.2.8 Summary of Containment Pressure Capacity

The ultimate pressure capacity for containment function is expected to be associated with leakage caused by excessive radial deflection of the containment cylindrical shell. This radial deflection causes distress to the mechanical penetrations, and leakage would be expected at the expansion bellows for the main steam and feedwater piping. There is high confidence that this failure would not occur before stresses in the shell reach the minimum specified material yield. This is calculated to occur at a pressure of 144 psig at ambient temperature and 120 psig at 400°F. Failure would be more likely to occur at a pressure about 15 percent higher based on expected actual material properties.

The deterministic severe accident pressure that can be accommodated according to the ASME Service Level C stress intensity limits and using a factor of safety of 1.67 for buckling of the top head is determined by the capacity of the 16-foot-diameter equipment hatch cover and the ellipsoidal head. The maximum capacity of the hatch cover, calculated according to ASME paragraph NE-3222, Service Level C, is 64 psig at an ambient temperature of 100°F and 62 psig at 280°F. When calculated in accordance with ASME Code, Case N-284, Service Level C, the maximum capacity is 96 psig at an ambient temperature of 100°F and 93 psig at 280°F. The maximum capacity of the ellipsoidal head is 104 psig at 100°F and 92 psig at 280°F.

The maximum pressure that can be accommodated according to the ASME Service Level C stress intensity limits, excluding evaluation of instability, is determined by yield of the cylinder and is 125 psig at an ambient temperature of 100°F and 110 psig at 280°F. This limit is used in the evaluations required by 10 CFR 50.34(f).

Table 3.8.2-2

CONTAINMENT VESSEL PRESSURE CAPABILITIES

Containment Element		Pressure Capability				
		Deterministic Severe Accident Capacity[1]			**Maximum Pressure Capability**[2]	
Temperature		100°F	280°F	400°F	100°F	400°F
Cylinder		125 psig	110 psig	104 psig	144 psig	120 psig
Ellipsoidal Head		104 psig	92 psig	87 psig	174 psig	145 psig
22-foot equipment hatch	F.S = 1.67	117 psig	114 psig	110 psig	195 psig	184 psig
	F.S = 2.50	78 psig	76 psig	73 psig		
16-foot equipment hatch	F.S = 1.67	96 psig	93 psig	90 psig	160 psig	151 psig
	F.S = 2.50	64 psig	62 psig	60 psig		
Personnel airlocks[3]		>163 psig	>163 psig	>163 psig	>300 psig	>300 psig

Notes:

1. The buckling capacity of the ellipsoidal head is taken as 60 percent of the critical buckling pressure calculated by the BOSOR-5 nonlinear analyses; the buckling capacity at higher temperatures is calculated by reducing the capacity at 100°F by the ratio of yield at 100°F to yield at the higher temperature. Evaluations of the equipment hatch covers are shown both for ASME paragraph NE-3222 (F.S. = 2.50) and Code Case N-284 (F.S. = 1.67). Evaluations of the other elements are according to ASME Service Level C~~ and include use of Code Case N284~~.

2. The estimated maximum pressure capability is based on minimum specified material properties.

3. The capacities of the personnel airlocks are estimated from test results.

Open Item # 3270 - RAI # 220.101 (NRC letter dated 4/4/96)

Westinghouse evaluated an additional BOSOR-5 analysis with stress-strain curves accounting for the effects of residual stresses on the buckling of cylindrical shells due to axial compression and/or external pressure. The failure mode was found to be an axisymmetric plastic collapse resulting from excessive vertical displacements at the pole. The maximum displacement was 1.09 m (43 in) at 1.45 MPa (195 psig). This information was requested by the staff to be provided in SSAR as discussed in RAI 6 (NRC letter dated September 14, 1995). In its response (NTD-NRC-96-4617 dated January 4, 1996), Westinghouse stated that the plastic collapse is bounded by the case for knuckle buckling without specific information. Provide this information in the SSAR.

Westinghouse Response

Revised the second paragraph of SSAR subsection 3.8.2.4.2.2 as follows :

The top head was analyzed using the BOSOR-5 computer code (Reference 1). This code permits consideration of both large displacements and nonlinear material properties. It calculates shell stresses and checks stability at each load step. Yield of the cylinder started at a pressure of 144 psig using elastic - perfectly plastic material properties, a yield stress of 60 ksi, and the von Mises yield criterion. Yield of the top of the crown started at an internal pressure of 146 psig. Yield of the knuckle region started at 152 psig. A theoretical plastic buckling pressure of 174 psig was determined. At this pressure, the maximum effective prebuckling strain was 0.23 percent in the knuckle region where buckling occurred and 2.5 percent at the crown. The maximum deflection at the crown was 15.9 inches. A similar analysis was performed using nonlinear material properties considering the effects of residual stresses; buckling did not occur in this analysis, and failure would occur once strains at the crown reach ultimate. The failure mode was found to be an axisymmetric plastic collapse resulting from excessive vertical displacements at the crown. The maximum displacement was 43 inches at 195 psig.

Open Item # 3271 - RAI # 220.102 (NRC letter dated 4/4/96)

In SSAR Section 3.8.2.4.2.5, mechanical and electrical penetrations are designed for a pressure of 90 psig at design temperature (280 F) for ASME Service Level C limits. In SSAR Section 3.8.2.4.2.8, however, the ASME Service Level C limit is 92 psig at 280 F from the containment ellipsoidal head plastic buckling. Clarify which pressure represents the ASME Service Level C limit at design temperature for the containment.

Westinghouse response

The SSAR revision proposed in the response to Open Item # 3269 shows pressures corresponding to the ASME Service Level C limit at design temperature for the containment based on three different acceptance criteria. When the capacity is evaluated against ASME Service Level C limits, including stability limits with a factor of safety of 2.5, the pressure capacity at design temperature is 62 psig and is limited by the 16' diameter equipment hatch as shown in proposed SSAR Table 3.8.2-2.

The American Society of Mechanical Engineers

345 East 47th Street
New York, NY 10017

February 6, 1996

Chicago Bridge and Iron Company
Attn: Thomas J. Ahl, Principal Engineer
800 Jorie Blvd.
Oak Brook, IL 60522-7001

Subject: Section III Code Case N-284, (Approval Date: August 25, 1980)

Reference: NI95-01

Dear: Mr. Ahl:

Our understanding of the questions in your inquiry and our replies are as follows:

Question (1): Is it the intent of ASME Code Section III Case N-284 that paragraphs -1712.1.3, -1512(b), -1620, the Factors of Safety given in paragraphs -1400(a), (b), and (c), and the equation,

$$\sigma_\phi = \sigma_\theta \le \frac{\sigma_{ieL} \times \alpha_{iL} \times \eta_\phi}{FS}$$

(for equal biaxial compression)

may be used is place of paragraph -1713.1.2(b) or paragraph -1713.2.3(a) to determine the allowable external pressure (Pe) of unstiffened spheres or unstiffened spherical segments with a tension ring at the boundary?

Reply (1): Yes.

Question (2): For an unstiffened sphere or an unstiffened spherical segment, does the reference to general stability in -1400 of Code Case N-284 apply?

Reply (2): No.

Respectfully,

Nathan Lane, Secretary
Technical Inquiry Committee
(212) 705-7005

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