April 5, 1996

Mr. Nicholas J. Liparulo, Manager
Nuclear Safety and Regulatory Activities
Westinghouse Electric Corporation
P.O. Box 355
Pittsburgh, Pennsylvania 15230

SUBJECT: OPEN ISSUES IN STANDARD SAFETY ANALYSIS REPORT (SSAR) SECTIONS 3.7 AND 3.8 FOR THE AP600 DESIGN

Dear Mr. Liparulo:

In response to the November 13, 1995, Westinghouse request the Nuclear Regulatory Commission (NRC) Civil Engineering and Geosciences Branch (ECGB) documented its reviews of the current submittals, including (1) AP600 SSAR Sections 3.7 and 3.8 up to and including Revision 4, (2) samples of design calculations, (3) Westinghouse's submittals related to seismic analysis and structural design and (4) information obtained at design review meetings with Westinghouse. In a letter dated February 27, 1996, ECGB provided Westinghouse with the five major unresolved issues for SSAR Sections 3.7 and 3.8. To supplement these major issues, ECGB has provided an overview of all the remaining open issues in SSAR Sections 3.7 and 3.8 (Enclosure). The staff has also identified a few areas in which additional information is required to complete the review. These items are identified as requests for additional information (RAIs) Nos. 230.96 - 230.105 in the document.

The enclosed discussion of open and resolved issues is being sent to you so that Westinghouse and NRC can focus their efforts towards resolution of the identified open issues. Where possible the staff intends to transmit sections early. However, the staff may not be able to follow this course of action for all sections.

The staff expects to have several meetings with Westinghouse to evaluate the AP600 final design and supporting analyses and to resolve the open issues. If you have any questions, please contact me at (301) 415-1118.

Sincerely,
original signed by:
Theodore R. Quay, Director
Standardization Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket No. 52-003

Enclosure: Sections 3.7 and 3.8

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Mr. Nicholas J. Liparulo
Westinghouse Electric Corporation

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AP600

cc: Mr. B. A. McIntyre
Advanced Plant Safety & Licensing
Westinghouse Electric Corporation
Energy Systems Business Unit
P.O. Box 355
Pittsburgh, PA 15230

Mr. John C. Butler
Advanced Plant Safety & Licensing
Westinghouse Electric Corporation
Energy Systems Business Unit
Box 355
Pittsburgh, PA 15230

Mr. M. D. Beaumont
Nuclear and Advanced Technology Division
Westinghouse Electric Corporation
One Montrose Metro
11921 Rockville Pike
Suite 350
Rockville, MD 20852

Mr. Sterling Franks
U.S. Department of Energy
NE-42
Washington, DC 20585

Mr. S. M. Modro
Nuclear Systems Analysis Technologies
Lockheed Idaho Technologies Company
Post Office Box 1625
Idaho Falls, ID 83415

Mr. Frank A. Ross
U.S. Department of Energy, NE-42
Office of LWR Safety and Technology
19901 Germantown Road
Germantown, MD 20874

Mr. Ronald Simard, Director
Advanced Reactor Programs
Nuclear Energy Institute
1776 Eye Street, N.W.
Suite 300
Washington, DC 20006-3706

Ms. Lynn Connor
Doc-Search Associates
Post Office Box 34
Cabin John, MD 20818

Mr. James E. Quinn, Projects Manager
LMR and SBWR Programs
GE Nuclear Energy
175 Curtner Avenue, M/C 165
San Jose, CA 95125

Mr. John E. Leatherman, Manager
SBWR Design Certification
GE Nuclear Energy, M/C 781
San Jose, CA 95125

Barton Z. Cowan, Esq.
Eckert Seamans Cherin & Mellott
600 Grant Street 42nd Floor
Pittsburgh, PA 15219

Mr. Ed Rodwell, Manager
PWR Design Certification
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

Mr. Charles Thompson, Nuclear Engineer
AP600 Certification
U.S. Department of Energy
NE-451
Washington, DC 20585

3 DESIGN OF STRUCTURES, COMPONENTS, EQUIPMENT, AND SYSTEMS

3.7 Seismic Design

The staff conducted four design calculation review meetings at the office of Bechtel Power Corporation (BPC) (consultant to Westinghouse) in San Francisco, California. In addition, the staff, using the SASSI computer program and the soil-structural system model developed by Westinghouse, performed a set of soil-structure interaction (SSI) confirmatory analyses. The purposes of these four design review meetings and the confirmatory analyses were:

- to discuss the open issues as a result of the staff review of Westinghouse's responses to the draft safety evaluation report (DSER) open items,
- to review the design calculations to confirm the staff's findings from the SSAR review and proper implementation of SSAR commitments, and
- to compare the staff's confirmatory analysis results with Westinghouse's design calculations to identify discrepancies, if any, and resolve these discrepancies.

As stated in Section 3.7 of the SSAR, the structures, systems and components (SSCs) of the AP600 standard plant, depending on their function, are seismically classified into three categories: seismic Category I (SC-I), seismic Category II (SC-II) and non-seismic (NS). The definition of these three categories and requirements for the seismic analysis and design of the items classified into these categories are provided in Sections 3.2.1.1 and 3.7.2.8 of the SSAR as follows:

SC-I: Seismic Category I, in general, applies to all safety-related structures, systems and components, and to those structures, systems and components required to support or protect safety-related structures, systems and components. These structures, systems and components are required to be designed to withstand the seismic loads due to the safe shutdown earthquake (SSE), as discussed in Section 3.7 of the SSAR, and other applicable loads without loss of structural integrity and functional capability.

SC-II: Seismic Category II applies to those structures, systems and components that perform no safety-related function, and the structural failure of which during an SSE or interaction with SC-I items could degrade the functioning of a safety-related structure, system or component to an unacceptable level, or could result in incapacitating injury to occupants of the main control room. These structures, systems and components are to be designed so that the SSE will not cause unacceptable structural failure of or interaction with SC-I items.

NS: Non-seismic structures, systems and components are those that are not classified as SC-I or SC-II. The criteria used for the design of these structures, systems and components are described in SSAR Section 3.7.2.

Enclosure

Based on the definition of seismic classification above, Westinghouse, in early SSAR amendments, classified (1) all nuclear island structures including foundation mat as SC-I, (2) Annex I and II buildings, the high bay area of radwaste building and the turbine building as SC-II, and (3) the rest of radwaste building as NS.

The review of the SSAR raised a number of concerns regarding:

- definition of seismic Category II and non-seismic structures
- clarification of the difference between non-Category I and non-seismic structures
- seismic design requirements for non-Category I and seismic Category II structures
- inclusion of general design requirements for seismic Category II structures in Section 3.7 of the SSAR
- justification of using the Zone 3 requirements of the Uniform Building Code (UBC) instead of the seismic Category I seismic design criteria for the analysis and design of the seismic Category II structures

From the review of Westinghouse's later submittal, review of Revision 2 of Sections 1.2.5, 1.2.6, 1.2.7, 1.2.8 and 3.7.2.8 of the SSAR, and discussions with Westinghouse and its consultants during review meetings, the staff found that in Revision 2 of the SSAR, Westinghouse reclassified the Annex I and II buildings as SC-II, and the turbine building and the radwaste building as non-seismic structures. To classify the turbine building and the radwaste building as non-seismic structures is not acceptable to the staff because, as shown in Section 3.7.2.8 of the SSAR, the radwaste building and floors between the turbine building main structure are very close to the nuclear island and the collapse of these structures due to an SSE might cause these structures to either strike or impair the integrity of the nuclear island structures, if they are not designed to the criteria equivalent to those used for the seismic Category II structures. This was Open Item 3.7-1. At this time, no information was provided in the latest revision of the SSAR. This open item remains open.

In Section 3.7.2.8 of the SSAR, Westinghouse also provided the analysis methods and design criteria for seismic Category II and non-seismic structures. The staff's evaluation of the analysis method and design criteria for seismic Category II structures and non-seismic structures is discussed in Section 3.7.2.8 of this chapter.

3.7.1 Seismic Input

As described in the SSAR, the input seismic design response spectra for the SSE are defined at plant finished grade in the free field. The horizontal and vertical design response spectra for the AP600 standard plant were developed, using the Regulatory Guide (RG) 1.60 response spectra as the basis and considering the high frequency amplification effects. The relative values of spectral amplification factors for the design response spectra are shown in SSAR Table 3.7.1-3, and the horizontal and vertical ground response spectra corresponding to 2, 3, 4, 5 and 7 percent of the critical damping are shown in

Figures 3.7.1-1 and 3.7.1-2, respectively. The peak horizontal as well as the peak vertical ground acceleration (PGA) for the SSE is 0.3g. For the standard plant design, the SSE (i.e., the modified RG 1.60 response spectra anchored at 0.3g) was employed to calculate the responses of the seismic Category I structures, systems and components. The staff's evaluation of the adequacy of the proposed design ground motion for the SSE is discussed in Section 2.5 of this report.

Open Item 3.7.1-1 is resolved.

The damping ratios used in the analysis of the AP600 seismic Category I structures comply with the SSE damping ratios specified in RG 1.61. For soil foundations, damping values (soil material damping which is limited to 15 percent of critical damping as specified in Standard Review Plan (SRP) Section 3.7.1) are determined on the basis of the soil shear strains induced in the free field. The approach used by Westinghouse for considering the soil damping complies with the guidelines of Section 3.7.2 of the SRP and is, therefore, acceptable. However, in Table 3.7-1 of early SSAR amendments, Westinghouse proposed to use (1) 20 percent damping for analyzing the cable tray systems (cable tray and supports), (2) 7 percent damping for HVAC (heating, ventilation, and air conditioning) duct systems, and (3) 20 percent damping for fuel assemblies. According to the staff's previous review experience, the damping values of 20 percent for cable tray systems and 7 percent for the HVAC duct systems with welded construction are too high and are not acceptable for the following reasons:

(1) Welded HVAC ductworks should be treated as welded steel structures. According to RG 1.61, 4 percent damping should be used for the seismic analysis of welded HVAC ductworks.

(2) In Table 3.7.1-1 and Figure 3.7.1-13 of the SSAR, a constant damping value of 20 percent was specified for the seismic analysis of cable tray systems. As indicated in the test reports referenced by Westinghouse, a high damping ratio (e.g., 20 percent) was recorded only for the case of (a) high cable fill percentage, (b) no fire protection spray applied and (c) bolted hanger and tray connections. To justify the use of 20 percent damping for the seismic analysis of cable tray systems, Westinghouse should describe in the SSAR how the damping values specified in Table 3.7.1-1 and Figure 3.7.1-13 will be used and provide any limitations for using such a high damping ratio for these systems.

(3) 20 percent damping is not justifiable for cable tray systems with welded frame type supports.

The issue regarding the damping values for cable tray and HVAC systems was Open Item 3.7.1-2.

In Revision 3 of SSAR Section 3.7.1, Table 3.7.1-1 and Figure 3.7.1-13, and Appendices 3G and 3H, Westinghouse (1) used test results to justify the adequacy of 20 percent maximum damping ratio for the cable tray systems, (2) provided guidelines to show how the specified damping ratios for the cable tray systems are to be applied in the analysis, and (3) specified 4 percent damping for the welded HVAC ductworks. The staff's review of the revised SSAR found that the procedure for the use of cable tray damping specified in the SSAR provides technically appropriate guidance to analyze cable tray systems and, therefore, is acceptable. The use of 4 percent damping for welded HVAC ductworks is consistent with the guideline of Regulatory Guide 1.61 for welded structures and is acceptable. For the use of 20 percent damping in the cable tray seismic analysis, the staff's review finds that the maximum cable tray damping ratio for the SSE seismic analysis should be in the range of 10 to 15 percent depending on the type of supports used. For the cable tray system with welded steel frame supports, only 10 percent damping should be assigned to the analysis. On the basis of the review discussed above, the staff concludes that the use of 20 percent damping in the cable tray seismic analysis is not acceptable and Open Item 3.7.1-2 remains open.

Open Item 3.7.1-3 is resolved.

As described in Section 3.7.1 of early SSAR amendments, the four AP600 seismic Category I structures (shield building, containment building, containment internal structures, and auxiliary building) are supported on a common foundation mat and form the nuclear island. The nuclear island foundation, while not precisely rectangular, is approximately 77.4 m (254 ft) long and 35.2 m (115.5 ft) wide. The foundation embedment depth (measurement from finished grade to the bottom of the foundation mat) is 12.04 m (39.5 ft) and the thickness of the foundation mat is 1.83 m (6.0 ft) in the auxiliary building area and is 6.5 m (22 ft) inside the shield building area. From past staff review experience, a thicker foundation mat should be provided to support those four seismic Category I structures. This staff concern was Open Item 3.7.1-4. At this time, Westinghouse is in the process of reevaluating the adequacy of the original design of the six-foot foundation mat. Open Item 3.7.1-4 remains open.

In addition, Westinghouse did not provide any key dimensions such as size of foundation mat, radius of shield building, geometry of shield building roof, and thickness of walls (the periphery walls, shield building wall and major structural walls) in the SSAR. It is the staff's concern that these dimensions are the key parameters for the seismic analyses and any changes to these dimensions will significantly affect the dynamic responses (structural member forces and floor response spectra) of the nuclear island structures. This was Open Item 3.7.1-5. During June 12 through 17, 1995 review meeting, Westinghouse provided the draft of Revision 4 of SSAR Figure 3.7.2-28 (Sheet 1 through 12) for review. In these figures, Westinghouse showed the radius of the shield building and thickness of walls. However, the size of the foundation mat and the geometry of the shield building roof structures were not provided. Westinghouse agreed to provide the information in the next revision of the SSAR. Open Item 3.7.1-5 remains open.

For the design of the nuclear island structures, Westinghouse considered a set of three design site conditions with various shear wave velocities. These three design site conditions are hard rock site, soft rock site and soft-to-medium stiff soil site. For the hard rock site, a uniform shear wave velocity of 2438.4 m/sec (8000 ft/sec) was assumed. For the soft rock site, a shear wave velocity of 731.5 m/sec (2400 ft/sec) at ground surface, increasing to 975.4 m/sec (3200 ft/sec) at a depth of 93.2 m (240 ft) and base rock at the depth of 36.6 m (120 ft), was considered. For the soft-to-medium stiff soil site, a shear wave velocity of 304.8 m/sec (1000 ft/sec) at ground surface, increasing to 731.5 m/sec (2400 ft/sec) at 73.2 m (240 ft) below ground surface, base rock at the depth of 36.6 m (120 ft), was used. For all of these three site conditions, the elevation of ground water is assumed at grade level.

The staff raised a number of concerns regarding the adequacy of using only three generic design site conditions for generating seismic response (structural member forces and floor response spectra) envelopes that are to be used for the design of seismic Category I structures and subsystems such as piping systems and major components of the AP600 standard plant. These concerns are summarized below:

1. Westinghouse was requested to demonstrate that the analysis results generated based on the three selected design site conditions will envelop the seismic responses at sites with different shear wave velocities, such as 457.2 m/sec (1500 ft/sec), 1066.8 m/sec (3500 ft/-sec), etc. This was Open Item 3.7.1-6.

   At the February 28 through March 2, 1995 meeting, Westinghouse indicated that an additional site condition (i.e., the upper bound of the soft-to medium soil site) was considered to be added to the design site conditions. Westinghouse also demonstrated that by adding this site condition, the uncertainties in the range of soil shear wave velocities between 304.8 m/sec (1,000 ft/sec) and 731.5 m/sec (2,400 ft/sec) will be covered. The concern of this open item is similar to that of Open Item 3.7.2.4-12. This issue is to be resolved as part of Open Item 3.7.2.4-12. Therefore, Open Item 3.7.1-6 is considered resolved.

2. Westinghouse should provide, in the SSAR, the basis for not including shallow soil sites in the design of AP600 nuclear island structures. The staff's evaluation of this issue is discussed in Sections 3.7.1.1 and 3.7.2 of this chapter.

3. Westinghouse should use a more recent soil shear strain degradation model other than the model recommended by Seed and Idriss in 1970 for the soil-structure interaction analysis of AP600 nuclear island structures. The staff's evaluation on this issue is discussed in detail in Section 3.7.2 of this chapter.

3.7.1.1 Site Interface Parameters

In Section 2.0 and Table 2.0-1 of early SSAR amendments, Westinghouse specified that the COL applicant will use the following interface site parameters to confirm the adequacy of the AP600 seismic design for a specific site:

- the site-specific ground motion response spectra are bounded by the RG 1.60 design response spectra anchored to 0.3g
- there is no potential fault displacement to be expected at the site
- there is no liquefaction to be expected at the site
- for the foundation soils, the maximum bearing reaction at a corner of the AP600 nuclear island foundation is below 526.68 kPa (11000 lb/ft^2)

- soil shear wave velocity is equal to or greater than 304.8 m/sec (1000 ft/sec)

The above site interface parameters to be used by the COL applicant are reasonable bounding limits for confirming the adequacy of the AP600 seismic design and are therefore, acceptable. The staff's evaluation of potential soil liquefaction is discussed in Section 2.5.4 of this report. However, the staff believes that in addition to these site interface parameters, Westinghouse should commit, in the SSAR, that a potential plant site also needs to meet the following bounding parameters:

(1) for a shallow soil site, the site specific ground response spectra and associated time history should be specified as the free field ground motion at a level that complies with the guidelines of Section 3.7.1.I.1 of the SRP, and

(2) when a seismic SSI analysis is performed for the SSE ground motion, the three components of the site specific ground motion time history must satisfy the response spectrum enveloping criterion of Section 3.7.1 of the SRP for all damping values to be assigned for the structural elements and the enveloping criterion for the power spectral density function (PSDF).

This was Open Item 3.7.1.1-1. The concern related to the location for specifying the ground motion time history for the case of shallow soil sites is discussed in Section 3.7.1 of this report above. This issue is considered resolved. However, Westinghouse needs to commit in SSAR Section 3.7.1 that for a specific site, the three components of the site specific ground motion time history must satisfy the response spectrum enveloping criterion recommended in Section 3.7.1 of the SRP for all damping values to be assigned for the structural elements and the enveloping criterion for the PSDF. Open Item 3.7.1.1-1 remains open.

3.7.2 Seismic System Analysis

The scope of review of the seismic system analysis for the AP600 plant included the seismic analysis methods and acceptance criteria for all seismic category I structures, systems and components. It included review of procedures for modeling, seismic soil-structure interaction, development of envelope response spectra, inclusion of torsional effects, evaluation of Category I structure overturning and sliding, and determination of composite damping. The review also covered design criteria and procedures for evaluation of the interaction of non-seismic Category I structures with seismic Category I structures and the effects of parameter variations on floor response spectra.

AP600 structures, systems and components have been classified in accordance with RG 1.29. However, non-seismic Category I structures, systems and components are further classified into seismic Category II and non-seismic. The staff's evaluation of the seismic classification of structures, systems and components is discussed in Sections 3.2 and 3.7 of this chapter. It is stated in Section 3.7.2 of the SSAR that the AP600 seismic Category I building structures consist of the steel containment vessel, containment internal structures, shield building and auxiliary building. These structures are founded on a common basemat and form the nuclear island structures. The nuclear island foundation mat is also classified as seismic Category I structure. All other building structures are classified as either seismic Category II or non-seismic.

As described in Section 3.7.2 of the SSAR, Seismic Category I structures are analyzed and designed for the SSE specified in Section 3.7.1 of the SSAR and the criteria described in Section 3.7.2 of the SSAR. Seismic Category II building structures are designed for the safe shutdown earthquake using the same methods as are used for seismic Category I structures. Non-seismic structures are analyzed and designed for seismic loads according to the UBC requirements for either Zone 2A with an importance factor of 1.25 or Zone 3 with an importance factor of 1.0. The staff's review of the analysis and design results are discussed in the following sections.

3.7.2.1 Seismic Analysis Methods

Section 3.7.2.1 of the SSAR states that the analysis of seismic Category I building structures (designated in the SSAR as nuclear island structures) consists of: (1) determination of seismic loads (forces and moments) for the design of nuclear island building structural components, and (2) the development of in-structure response spectra (or floor response spectra) which are to be used as input motions for the subsystem (piping and equipment) design.

As described in early SSAR amendments, four major procedural steps were followed for performing seismic analyses and calculating seismic design loads (for floors and walls of the nuclear island structures, except foundation mat, embedded peripheral walls and shield building roof structures):

(1) For the hard rock site (foundation shear wave velocity is 2438.4 m/sec [8000 ft/sec] or greater), an analysis, using a three-dimensional (3D) fixed-base finite element model (Model A) of the nuclear island (NI) structures and the ground motion defined in Section 3.7.1 of the SSAR as input at rock surface, was performed. In this model, the walls and floors were explicitly represented by plate and shell elements. The soil or rock flexibility due to SSI effects was not included in this model, and the BSAP computer program was used to perform the analysis. Seismic loads (forces and moments) obtained from this fixed-base analysis were multiplied by a factor (hereafter called SSI factor) to determine the final design seismic loads for the nuclear island structures. This factor was determined as described below.

(2) An analysis, using BSAP computer code and a three-dimensional fixed-base lumped-mass stick model (Model B) and the same ground motion applied at rock surface used in Step 1 above, was performed. When this model was developed, the lateral restraints were used at floor elevations 25.1 m (82.5 ft) and 30.5 m (100 ft) and the stiffness contribution from the peripheral walls below grade were included in the stick model. The purpose of this analysis is to generate floor response spectra for the hard rock site and develop SSI factors.

(3) When seismic analyses of the NI structures were performed for soil sites, two design site conditions (soft-to-medium stiff soil site and soft rock site) were considered and the SASSI computer code was used.

In these analyses, the NI structures were represented by the three-dimensional lumped-mass stick model, except that the basemat and peripheral walls below the grade level were modeled explicitly. Results from these analyses include seismic forces (axial forces, shear forces and bending moments) and floor response spectra.

(4) The seismic loads (forces and moments) at various locations of the NI structures obtained from SASSI analyses in Step 3 above were compared with those from the BSAP analysis, using Model B, in Step 2 above. For elements where seismic loads obtained from SASSI analyses are larger, the SSI factor was computed as the ratio between SASSI loads (Step 3) to Model B BSAP loads (Step 2). If, for a particular element, the seismic loads from the SASSI analyses for the two design soil conditions were larger than those from the Model B BSAP analysis, the larger of the two calculated SSI factors was used to compute the design seismic loads (see Step 1). If SASSI loads for any structural element were less than those from Model B BSAP analysis, the SSI factor was taken as unity. Thus, the structural design of individual structural elements (shear walls, slabs, etc.), was carried out using the BSAP results (based on Model A) modified by the SSI factors, as appropriate.

For the foundation mat and shield building roof structures, design loads were obtained by equivalent static analyses using nodal accelerations from the analysis based on the 3D lumped-mass stick model. However, the SSAR did not indicate these nodal accelerations were calculated based on Step 2 analysis (Model B, BSAP analysis) or Step 3 analysis (SASSI analysis). Also, the SSAR did not address how the loads used for the design of embedded peripheral walls were calculated.

The design in-structure response spectra were generated by enveloping the in-structure response spectra computed from the SASSI analyses for the two design soil site conditions in Step 3 above and the in-structure response spectra obtained from the Model B BSAP fixed-base analysis in Step 2 above.

As a result of its review of the early versions of the SSAR and Westinghouse's response to the questions raised in its October 1, 1992, January 26, 1994 and March 16, 1994 letters, and during design review meetings, the staff had identified several concerns. These concerns are described as follows:

- To avoid underestimating the seismic response (acceleration, forces and moments), the guidelines of Section 3.7.2 of the SRP state that the effects of high frequency modes should be adequately considered. To account for such effects in the calculation of seismic forces and moments, the SRP guidelines suggest two methods: one uses a sensitivity test in which it is demonstrated that the inclusion of additional modes does not result in more than a 10 percent increase in response; the other (alternative) method uses all the modes having frequencies up to 33 Hz, and account for the remaining higher frequency modes in accordance with the guidelines stated in Appendix A to Section 3.7.2 of the SRP.

  In Section 3.7.2.1 of the SSAR, it states that when the response spectrum method was used to determine the seismic forces and moments for certain structures (specifically, containment internal structures), the method in Appendix A to Section 3.7.2 of the SRP was used. However, when the modal time-history analysis method was used (for all structures other than containment internal structures), Westinghouse did not demonstrate how the effects of higher frequency modes were adequately accounted for in the determination of: (1) in-structure response spectra, and (2) seismic forces and moments. The review of Tables 3.7.2-1 and 3.7.2-4 of the SSAR identified that when a 33 Hz cut-off frequency is used, (1) only 72 percent of the total structural mass participates in the horizontal response and 45 percent of total mass participates in the vertical response for the coupled shield and auxiliary building, and (2) only 51 percent of total mass participates in the horizontal response and 47 percent of total mass participates in the vertical response for overall NI structures. If the modal time history analysis method is used for seismic analyses of the NI structures, Westinghouse should justify the adequacy for not including the high frequency modes in the analyses.

- Open Items 3.7.2.1-1, 3.7.2.1-2, and 3.7.2.1-3 are resolved.

- From its review of early SSAR amendments, the staff found that many different 3D dynamic models (3D stick model, 3D finite element model, 3D stick model coupled with 3D finite element soil foundation model, etc.) and analysis methods (response spectrum analysis method, time history analysis method using BSAP code, time history analysis method using SASSI code, etc.) were used for the seismic analyses of the NI structures. However, it is not clear to the staff which model combined with which analysis method was used for generating what kind of dynamic responses for the design. In the March 16, 1994 letter, the staff requested Westinghouse to clarify this issue. In the May 16, 1994 response, Westinghouse provided a draft of Table 3.7.2-14 of the SSAR, which summarizes the types of model and analysis methods that were used in the seismic analyses of the NI structures, and the types of results that were obtained and where they were used in the design. The staff review of Westinghouse's response found that the information provided in this table is acceptable in general, except that Westinghouse should:

    - add a description of axisymmetrical model used for calculating containment shell stresses,

    - clarify the procedure of using member forces obtained from the stick model to establish the scaling factor which was applied to the in-plane forces of the finite element model for the design of walls and floors, and

    - describe in detail and justify the perturbation made to correct the SASSI member forces to account for erroneous rigid beam stiffness.

This was Open Item 3.7.2.1-4. From its review of Westinghouse's response presented during the review meetings conducted on February 28 through March 2, 1995 and June 12 through 16, 1995, and the review of Section 3.8.2 (Revision 3) and Section 3.7.2 (Draft of Revision 4) of the SSAR, the staff found that Westinghouse (1) provided a description of the axisymmetric model used for calculating containment shell stress in SSAR Subsection 3.8.2.4.1.1, (2) described the procedure of using member forces obtained from the stick model to establish the scaling factor which was applied to the in-plane forces of the finite element model for the design of walls and floors, and (3) presented its justification for the perturbation made to correct the SASSI member forces to account for erroneous rigid beam stiffness. The staff also found that the description of using the axisymmetric model for computing containment shell stresses, the procedure for developing scaling factors, and the justification for the perturbation made to correct the SASSI member forces are consistent with the technical agreement reached during review meetings. On this basis, Open Item 3.7.2.1-4 is resolved contingent upon Westinghouse revising its SSAR as described in the draft of the SSAR, Revision 4.

3.7.2.2 Natural Frequencies and Response Loads

Open Item 3.7.2.2-1 is resolved.

3.7.2.3 Procedure Used for Modeling

The procedure used for developing analytical models for the seismic response analysis of the NI structures is discussed in Section 3.7.2.3 of the SSAR and is summarized as follows:

- Based on the general arrangement drawings, three explicit 3D finite element models were developed for the NI structures. These three finite element models are developed to represent the coupled shield and auxiliary building (SAB), the containment internal structures (CIS), and the steel containment vessel (SCV), respectively. These models were used for determining stiffness properties for the equivalent lumped-mass stick seismic model and, using an equivalent static analysis method, detailed moment and force distribution in individual structural components.

- From these three finite element models, an equivalent lumped-mass stick model was developed for each of the three Category I buildings (i.e. shield/auxiliary building, containment steel vessel and containment internal structures) based on the translational and rotational stiffness of the explicit 3D models. The stiffness values of the stick models were determined by applying unit static forces or moments in the segment of the explicit 3D models corresponding to the element of the lumped-mass stick model.

- The lumped-mass stick model for each of the seismic Category I building structures (shield/auxiliary building, containment steel vessel and containment internal structures) were combined, using rigid links and beams, with the NI basemat and soil foundation to form the soil-structure system model for the SASSI analyses.

The staff, using the guidelines of SRP Section 3.7.2, reviewed the methods and procedures used by Westinghouse for modelling the NI structures. Based on its review of early SSAR amendments, Westinghouse's submittal related to structural modeling (letters dated October 1, 1992, January 26, 1994 and March 16, 1994) and the review of Westinghouse's design calculations, the staff raised several technical concerns. These concerns are summarized in the following:

- Open Items 3.7.2.3-1 and 3.7.2.3-2 are resolved.

- In the submittal dated January 14, 1993, Westinghouse indicated that the second vertical mode for the explicit 3D steel containment vessel is 23.59 Hz, but that for the equivalent seismic lumped-mass stick model is 30.06 Hz. The adequacy of the equivalent seismic lumped-mass model whose second mode frequency is so much higher than that of the detailed model has not been demonstrated. This was Open Item 3.7.2.3-3. During the February 28 through March 2, 1995 meeting, Westinghouse agreed to provide additional information to demonstrate that the second vertical mode from the axisymmetric shell model is corresponding to the local mode of the shell dome and is insignificant to overall responses of the containment vessel. At this time no information was provided to indicate if there are any safety related components near the top of the containment dome which may be affected by the second vertical mode of vibration. Open Item 3.7.2.3-3 remains open.

- Open Items 3.7.2.3-4 and 3.7.2.3-5 are resolved.

- In its letter dated January 26, 1994, the staff raised a concern regarding the possibility of the out-of-phase interaction between the shield building, steel containment vessel, and containment air baffle. As a result of the staff's review of the submittal dated April 14, 1994 and the discussion during the review meetings, Westinghouse agreed to provide, in the SSAR, (1) figures showing the rigid link connectivity of the stick model to the basemat and wall elements below grade, and (2) criteria used to establish the relative displacement between the shield building and steel containment vessel for the design of the air baffle. This was Open Item 3.7.2.3-6. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.3-6 remains open.

- The staff's concerns documented in the letters dated October 1, 1992 and January 26, 1994 are (1) how the 3D containment shell lumped-mass stick model was constructed from the axisymmetric finite element shell model, and (2) how the eccentric masses, such as the polar crane system, equipment hatches and personnel air-locks were included in the 3D lumped-mass model. Based on the staff's review of the November 30, 1992 and March 24, 1994 submittal, and the discussion during the review meeting, Westinghouse agreed, regarding the development of 3D stick model for the containment vessel, to document the responses in the SSAR and justify the deviation of the second vertical mode of vibration between the two models. This was Open Item 3.7.2.3-7. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.3-7 remains open.

  As for the concern of the eccentricities due to major components and equipment, the staff performed a confirmatory analysis to verify how significant these eccentricities would be to the seismic responses of the containment shell. This was Open Item 3.7.2.3-8 and it is resolved.

- Open Item 3.7.2.3-9 is resolved.

In addition to the open items related to the structural modeling discussed above, the staff raised a concern regarding the adequacy of the overall 3D lumped-mass stick model. Westinghouse used a multi-stick (containment vessel, containment internal structures and shield/auxiliary building) lumped-mass model for the seismic analysis of nuclear island structures. This lumped-mass model was developed based on a three dimensional finite element model of each building. However, the equivalent stick lumped-mass model of shield building roof structures was developed by Westinghouse's consultant ANSALDO, an Italian engineering company. From its review of the seismic analysis and design calculations of nuclear structures, the staff found that the seismic member forces of shield building roof structures calculated by combining the roof stick model with the finite element model of remaining structures are significantly different from those calculated by a complete stick model. It is the common understanding in the engineering field that a finite element model can simulate the actual behavior of a structure much more closely than a lumped-mass model. Westinghouse should justify the adequacy of the multi-stick model which was used for generating seismic responses (structural member forces and floor response spectra) for the design of safety related structures, systems and components. This concern is a new open item and is identified as RAI# 230.96.

3.7.2.4 Soil-Structure Interaction

Section 3.7.2 of the SSAR and Appendix 2A to the SSAR state that SSI analyses of the NI structures were performed to determine seismic design loads for building structures, and to develop in-structure response spectra to be used for the subsystem design. Westinghouse used the SASSI computer code to perform SSI analyses. The selection of design site conditions for the 3D SSI analysis cases was based on a number of two dimensional (2D) SASSI parametric analyses in which the following parameters were varied: shear wave velocity of soil and rock, soil layering, depth to base-rock and water table. Westinghouse's selection of these parameters for the 2D SASSI analyses was based on a survey of subsurface soil profiles and a range of soil properties in 22 commercial nuclear power plants located in the United States. Seismic design loads for the structural design and in-structure response spectra for the subsystem design were developed by enveloping the responses from two, 3D SASSI SSI analyses and a fixed-base BSAP analysis, with one exception that for the design of peripheral walls below the grade, Westinghouse used soil pressure calculated from the 2D SASSI analyses. The fixed-base analysis was performed to calculate the seismic response for the hard-rock foundation. Two soil site conditions, (i.e., soft rock site and soft-to-medium stiff soil site) were selected by Westinghouse to cover a wide range of soil conditions for performing SSI analyses. The sitting geometry and dynamic soil properties of these two site conditions are:

- for the soft rock site, the depth of soil layer measured from ground surface to bedrock is 36.6 m (120 ft), and the shear wave velocity varies linearly from 731.5 m/sec (2400 ft/sec) to 853.4 m/sec (2800 ft/sec) with ground water at the grade

- for the soft-to-medium stiff soil site, the depth to bedrock is 36.6 m (120 ft) and the shear wave velocity varies linearly from 304.8 m/sec (1000 ft/sec) to 518.2 m/sec (1700 ft/sec) with ground water at the grade

Westinghouse used the SASSI computer code to perform the SSI analysis for each of these two site conditions.

The staff reviewed the SSAR and Westinghouse's submittals dated January 22, 1993, March 24, 1994, May 11, 1994, May 20, 1994, May 11, 1994, May 17, 1994, May 11, 1994, May 20, 1994 and May 17, 1994. In addition, in order to develop bases for its conclusions, the staff, using the lumped-mass stick models (2D and 3D) provided by Westinghouse, performed a set of SSI confirmatory analyses. The details of these analyses are discussed in Appendix A to this report. The review of the SSAR and submittal, and confirmatory analyses resulted in a number of open items. These open items are summarized as follows:

- Open Items 3.7.2.4-1, 3.7.2.4-2, 3.7.2.4-3, and 3.7.2.4-4 are resolved.

- From reviewing the SSAR, the staff found that the strain-dependent shear modulus and hysteretic damping data used in the SSI analysis were based on 1970 data developed by Seed and Idriss for sandy soils. Since then, newer soil degradation models have been developed and published. A comparison of shear strain degradation curves presented in the SSAR (Seed & Idriss 1970 curves) with the more recent industry results showed that the Seed & Idriss 1970 curves always overestimate the shear strain degradation. According to the independent analyses, using various soil degradation models performed by the staff (NUREG/CR-5956), the staff found that the analysis results based on more recent publications are much higher than those based on the 1970 Seed & Idriss curves. In the May 11, 1994 submittal and the discussions during the review meeting, Westinghouse agreed to provide additional information for the staff review. This was Open Item 3.7.2.4-5. At the February 28 through March 2, 1995 review meeting, Westinghouse agreed (1) to use the soil strain degradation model developed by Idriss in 1990 to replace the 1970 Seed-Idriss soil strain degradation model in the final 3D SASSI analyses, and (2) to include it in the SSAR. According to Westinghouse, the results from these 3D SASSI analyses will be used in the final design of AP600. The use of the soil strain degradation model developed by Idriss in 1990 is acceptable to the staff based on the studies performed in NUREG/CR-5956. The concern of this open item is considered technically resolved. However, Open Item 3.7.2.4-5 will be resolved when Westinghouse documents this reference in the future revision of SSAR Section 3.7.2.

- Open Item 3.7.2.4-6 is resolved.

- As stated in the SSAR, the peripheral walls of AP600 nuclear island structures below finished grade are designed based on soil pressure obtained from 2D SSI analyses. The model used for the 2D SSI analyses of the nuclear structures did not include the adjacent seismic Category II structure (the radwaste building) and non-seismic structures (turbine building and annex buildings). In the January 22, 1993 and May 20, 1994 submittal, Westinghouse justified that these non-seismic Category I structures are relatively lighter than Category I structures and the effect of structure-to-structure interaction on the NI structures is negligible. The staff's concern is that the localized through-the-soil SSI effect of non-seismic Category I structures on the design of Category I peripheral walls could be significant and this effect was not included in the design. In addition, the potential for pounding between structures should also be reasonably evaluated. These two issues were Open Item 3.7.2.4-7. At the June 12 through 16, 1995 meeting, Westinghouse agreed to evaluate the localized through-soil SSI effect of non-seismic Category I structures on the design of embedded seismic Category I walls and the potential for pounding between structures. However, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.4-7 remains open.

- Westinghouse used linear variation in soil profile through the depth of soil layers. From the review of existing literature, it is evident that the assumption of linear variation of soil profile is unrealistic for typical sandy soils. Westinghouse should use a realistic variation with depth of soil profile, such as a parabolic distribution, for the AP600 SSI analyses. This was Open Item 3.7.2.4-8. At the February 28 through March 2, 1995 meeting, Westinghouse agreed to use a parabolic variation of soil profile in the SSI analyses. The concern of using linear variation in soil profile through the depth of soil layers is considered technically resolved. Westinghouse should document its commitment in the future revision of SSAR Section 3.7.2. Open Item 3.7.2.4-8 will be resolved when the revised SSAR is submitted for the staff review.

- Westinghouse did not show that the Poisson's ratio values assumed for soils above the water table are consistent with the values for silty sands with densities high enough for a shear wave velocity of 304.8 m/sec (1000 ft/sec). In addition, Westinghouse erroneously indicated in the third paragraph of Section 3.7.2.4 of the SSAR that the SHAKE computer code was used to compute a strain compatible Poisson's ratio and other parameters. These two issues regarding Poisson's ratio of soil foundation was Open Item 3.7.2.4-9. At the February 28 through March 2, 1995 meeting, Westinghouse presented its calculation and demonstrated that the calculated responses are insignificant to the Poisson's ratio. In addition, Westinghouse agreed to make correction regarding the use of the SHAKE computer code for computing strain compatible Poisson's ratio. This concern is considered technically resolved. Open Item 3.7.2.4-9 will be resolved when Westinghouse revises SSAR Section 3.7.2.4.

- Open Items 3.7.2.4-10 and 3.7.2.4-11 are resolved.

- In the March 16, 1994 letter, the staff questioned whether the envelope of seismic responses obtained based on the three selected site conditions can truly envelop the seismic responses calculated for other site conditions, such as a site with shear wave velocity equal to 731.5 m/sec (2400 ft/sec) or 1066.8 m/sec (3500 ft/sec). During the review meetings, Westinghouse restated its basis documented in Appendix 2A to the SSAR that the selected three site conditions will cover a wide range of potential site conditions in the states. This was Open Item 3.7.2.4-12.

  At the February 28 through March 2, 1995 meeting, Westinghouse was considering adding the upper bound (plus 100 percent) of soft-to-medium soil site profile as an additional design site condition in the SSI analysis to cover the uncertainties between the soft-to-medium soil and soft rock sites. However, the 3D seismic analyses performed by Westinghouse used only three site conditions that were selected on the basis of two dimensional (2D) parametric studies. A large number of parameters were subjectively considered, but not all significant parameter combinations were analyzed. As such, the staff raised a major concern whether the envelope of analysis results from the limited number of 3D analysis cases reasonably cover the broad range of potential site-conditions for which the AP600 standard plant is to be designed.

In order to strengthen the basis of its conclusion for the seismic review, the staff performed a confirmatory SSI analysis. In this confirmatory analysis (3.7-1), the site condition selected was the upper bound of the soft rock site used by Westinghouse with a shear wave velocity of the supporting material equal to 1,066.8 m/sec (3,500 ft/sec). This site condition is not one of site conditions considered in the AP600 design. A comparison shows that results (floor response spectra) from the confirmatory analysis exceed the seismic design envelope floor response spectra at several locations in the nuclear island structures. There is an indication that the three design site conditions documented in early SSAR amendments may not adequately cover the spectrum of potential sites in the United States and the plant subsystems (piping and components) will be under-designed if a AP600 plant is located at one site with a shear wave velocity of the supporting material equal to 1,066.8 m/sec (3,500 ft/sec). Westinghouse should reconsider the adequacy of using the existing site conditions for the design of AP600. Open Item 3.7.2.4-12 remains open.

3.7.2.5 Development of Floor Response Spectra

As described in the SSAR, floor response spectra at various elevations and locations of NI structures were generated for each of the three selected site conditions: hard rock site with fixed-base time domain modal time-history analysis (BSAP analysis), soft rock site with frequency-domain time-history analysis (SASSI analysis), and soft-to-medium stiff soil with frequency-domain time history analysis (SASSI analysis). These response spectra were then enveloped, peak-broadened by plus and minus fifteen percent (±15 percent), and smoothed to develop a design in-structure spectrum envelope in accordance with RG 1.122. A set of 3D structural stick models (models for steel containment vessel, containment internal structures, shield building and auxiliary building) combined with the support foundation was used for these analyses. The effects of the spatial combination of three components of the earthquake ground motion time history were considered in the analysis. As such, the coupling effects have been accounted for. The staff's evaluation of the adequacy of the approach for combining responses due to three components of the input ground motion is discussed in Section 3.7.2.6 below.

Based on the resolution for Open Items 3.7.2.2-1, 3.7.2.3-5 and 3.7.2.4-1, and other open items related to SSI concerns, Open Item 3.7.2.5-1 is considered resolved.

3.7.2.6 Three Components of Earthquake Motion

Section 3.7.2.6 of the SSAR states that the seismic analyses of AP600 NI structures were performed considering the simultaneous occurrences of the two horizontal and the vertical components of earthquake ground motion (ground motion time history or ground response spectra). However, in seismic analyses, the three components of earthquake were applied either simultaneously (time history analysis) or separately (response spectrum analysis and modal time history analysis).

In the time history analyses with the three earthquake components applied simultaneously, the responses of the three earthquake components were combined within the analytical procedure at each time step. When the three earthquake components were applied separately for the case of time history analyses, the corresponding responses from the three individual analyses were combined algebraically at each time step to obtain the total acceleration response time history. In some cases, the peak responses from the three individual analyses were combined to obtain the total peak response using either the square root of the sum of squares (SRSS) technique or the 1.0, 0.4, and 0.4 direct combination technique. The SRSS or the 1.0, 0.4 and 0.4 direct combination technique was also applied to the response spectrum method of analysis. For axisymmetric structures, such as the steel containment vessel and shield building roof structure, only one horizontal peak response and the vertical peak response were combined using either the SRSS or the 1.0, 0.4, and 0.4 direct combination technique.

The staff found the above techniques used for combining the responses to the three earthquake components resulted in a conservative calculation of peak responses and are therefore, acceptable. Accordingly, the November 30, 1992, March 24, 1994 and May 20, 1994 responses to the concerns related to the spatial combination of responses due to the three earthquake components (NRC letters dated October 1, 1992, January 26, 1994 and March 16, 1994) meet the guideline of the SRP and are considered resolved. However, Westinghouse should revise the SSAR and provide a list of analysis cases showing how and where each of the three combination techniques was applied. This was Open Item 3.7.2.6-1. In the draft of Revision 4 of SSAR Section 3.7.2.6 and Table 3.7.2-16, Westinghouse provided a description of how and where each of the three techniques for combining seismic responses due to the three components of earthquake ground motion is to be used. At the June 12 through 16, 1995 meeting, Westinghouse also demonstrated that the 1.0, 0.4, 0.4 combination method always gives reasonable results. Based on its review of this draft SSAR revision, the staff found that the description of how and where each of the three combination techniques was applied in the design calculations meets the guideline of RG 1.92. The staff also, from its review of design calculations, found that the difference of results obtained using the square-root-of-the-sum-of-squares (SRSS) method and the 1.0, 0.4, 0.4 combination method is insignificant. Because the use of the SRSS method for combining the spatial responses due to the three earthquake components meets the guideline of RG 1.92, the concern of this open item is considered technically resolved. Open Item 3.7.2.6-1 will be resolved when Westinghouse submits its revision to the SSAR.

3.7.2.7 Combination of Modal Responses

In Section 3.7.2.7 of the SSAR, Westinghouse stated that modal responses based on the response spectrum analysis method were combined using the SRSS technique unless the modes were closely spaced. For closely spaced modes, either the grouping method, the ten percent method, or the double sum method described in Section C of RG 1.92 was used. On this basis, these modal response combination techniques are acceptable to the staff. However, Westinghouse should revise the SSAR and provide a list of analysis cases showing where each of the three combination techniques for closely spaced modes was applied. This was Open Item 3.7.2.7-1. In the draft of Revision 4 of SSAR Section 3.7.2.6 and Table 3.7.2-16, Westinghouse described how and where the modal combination technique was applied for calculating seismic responses. Therefore, the concern of this open item is considered technically resolved. Open Item 3.7.2.7-1 will be resolved when Westinghouse submits its revision to the SSAR.

3.7.2.8 Interaction of Seismic Category II and Non-seismic Structures with Seismic Category I Structures

As described in Section 3.2.1 of the SSAR, non-seismic Category I structures include the seismic Category II and non-seismic structures. In the June 27, 1994 submittal, Westinghouse classified the structures adjacent to the NI structures as follows:

- Annex Building: non-seismic
- Turbine Building: non-seismic
- High Bay Area of Radwaste Building: Category II
- Single story Area of Radwaste Building: non-seismic

In Section 3.7.2.8 of early SSAR amendments and in the June 27, 1994 submittal, Westinghouse also described the interaction requirements for the NI structures with the seismic Category II structure and non-seismic structures as follows:

- The collapse of a non-seismic structure will not cause the non-seismic structure to strike a seismic Category I structure or components.

- The collapse of a non-seismic structure will not impair the integrity of seismic Category I structures or components.

- The structure is classified as seismic Category II and is analyzed and designed to prevent their collapse under the SSE.

Contingent upon an acceptable resolution to Open Item 3.12.3.7-1, Open Item 3.7.2.8-1 is resolved.

In addition, as shown in Figure 1.2-2 of the SSAR, these building structures are very close to the NI structures. It is obvious that the interaction requirements stated above cannot be met if these building structures are classified as non-seismic and are not analyzed and designed for the SSE. These structures should be reclassified as seismic Category II. This was Open Item 3.7.2.8-2. At the June 12 through 16, 1995 meeting, Westinghouse agreed to revise the SSAR and reclassify the non-seismic structures adjacent to nuclear island structures as seismic Category II. However, at this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.8-2 remains open.

On page 3.7-1 of Section 3.7 of early SSAR amendments, in the June 27, 1994 submittal, and in the proposed revision of Section 3.7.2 of the SSAR, Westinghouse stated that the seismic design of seismic Category II structures is based on the same input ground motion (i.e., SSE) and acceptance criteria used for the seismic Category I structures. Seismic Category II building structures are to be analyzed for the SSE using the same methods as were used for seismic Category I structures. For seismic Category II concrete structures, load combinations and load factors are in accordance with American Concrete Institute (ACI) 318, except that the load factor for the SSE is taken as 1.0. Allowable stresses for seismic Category II steel structures are in accordance with American Institute of Steel Construction (AISC) with a 60 percent increase permitted for SSE instead of a 33 percent increase. As for the non-seismic structures, page 3.7-3 of Section 3.7.2 of the SSAR indicated that these structures were analyzed and designed for seismic loads according to UBC requirements for Zone 2A.

From the review of Westinghouse's submittal dated June 27, 1994, January 22, 1993, June 27, 1994, June 27, 1994, June 27, 1994) and June 27, 1994, the staff raised several concerns. These concerns are summarized in the following:

- Westinghouse was requested to provide the basis for classifying the single story portion of the Radwaste Building as non-seismic and the high bay area of the Radwaste Building as seismic Category II. This was Open Item 3.7.2.8-3. In Revision 2 of SSAR Section 3.7.2, Westinghouse clarified that the radwaste building is a small steel framed building. If it were to impact the nuclear island or collapse during an SSE, it would not impair the integrity of the concrete nuclear island. Westinghouse's justification is based on judgement and does not provide an adequate basis to the staff. During the June 12 through 16, 1995 meeting, Westinghouse committed to reconsider the classification of this building and revise the SSAR. However, at this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.8-3 remains open.

- If Category II structures are designed using load factors and allowable stresses as discussed, then the stress level can exceed yield stress (for AISC) or load demand can be equal to the ultimate load capacity (for concrete sections). In such a case, Westinghouse should demonstrate that the seismic Category II structures designed using the load factor method and allowable stresses in accordance with AISC with a 60 percent increase permitted for SSE will not collapse during an SSE or these structures possess enough margin (reserved ductility) to prevent collapse. However, Westinghouse did not indicate that any such design evaluation has been performed. This was Open Item 3.7.2.8-4. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.8-4 remains open.

- To avoid the collapse of annex and turbine buildings towards the NI structures, Westinghouse proposed, during the review meeting, a method for the design of bracing systems. In the design, the bracing systems for preventing these structures to be deformed toward the NI structures are twice as strong as those to be used for the opposite direction for which the bracing systems are designed according to UBC Zone 2A requirements. The seismic design of these buildings proposed by Westinghouse is not acceptable because:

  - There are many conditions (e.g., inherent material variability, differences in tolerances, the effect of construction sequences and temperature conditions) that can cause uneven loading. The collapse strength of two supposedly identical braces can differ by more than 50 percent. Thus, the proposed method does not ensure collapse away from NI structures.

- For a large structural system when subjected to a seismic level (SSE) higher than the design level (UBC Zone 2A requirements), it is probable that some structural members will be stressed beyond elastic limit or fail at the initiation of the earthquake motion. The effects of one or several such localized failures on the progression of collapse, especially under continuing vibratory loads (that will cause load reversal), are quite uncertain. It is further complicated by the significant difference in the compression and tension capacity of the braces.

These concerns had not been addressed by Westinghouse. This was Open Item 3.7.2.8-5.

As stated in Revision 2 of SSAR Section 3.7.2.8, the annex building is reclassified as seismic Category II and is designed for the SSE using the same methods that are used for seismic Category I structures (Revision 2 of SSAR Section 3.7.2). Westinghouse will reconsider the classification of the radwaste building (see Open Item 3.7.2.8-3 above). As for the turbine building (a light weight steel framed structure), because it is located 5.49 m (18 ft) away from nuclear island structures and the failure of this building will not be expected to impair the safety related structures, systems and components, Westinghouse classified this building as non-seismic structure and will design it based on UBC Zone 3 requirements with an importance factor of 1.0. On the basis of (1) classifying the annex building as seismic Category II, (2) locating the turbine building 5.49 m (18 ft) away from the nuclear island structures and (3) the design criteria used meeting the SRP Section 3.7.2.8 guidelines, the staff concludes that the classification of the annex and turbine buildings and the criteria used for the design will provide reasonable protection against earthquake loads to prevent any damages to the seismic Category I structures, systems and components. However, as stated in SSAR Section 3.7.2.8, Revision 2, there are floors located between the turbine building and the nuclear island to provide access to the nuclear island. Westinghouse should demonstrate that the collapse of these floors will not impair the integrity of seismic Category I structures, systems and components. In addition, Westinghouse was requested to reconsider the classification of the radwaste building. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.8-5 remains open.

- Open Item 3.7.2.8-6 is resolved.

- For the evaluation of seismic margin, Westinghouse should demonstrate and document in the SSAR that both seismic Category II and non-seismic structures can withstand an earthquake up to 0.5g without collapse. This was Open Item 3.7.2.8-7. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.8-7 remains open.

3.7.2.9 Effects of Parameter Variations on Floor Response Spectra

In Section 3.7.2.9 of the SSAR, the effects of parameter variation have not been explicitly considered. To account for such effects, the peaks of the floor spectra were broadened by ±15 percent as recommended in Section 3.7.2 of the SRP and RG 1.122. The staff found this acceptable. This issue is especially significant when one considers the additional uncertainties associated with the modular construction (e.g. due to the presence of cross diaphragms in module walls, module anchorages to the building concrete, module connections, etc.). The staff's evaluation of modular construction used in the AP600 design is discussed in Section 3.8.3.

Open Item 3.7.2.9-1 is resolved.

3.7.2.10 Use of Constant Vertical Static Factors

Vertical seismic response was explicitly considered in the SSI and fixed-base seismic analyses. Therefore, equivalent vertical static factors were not used to compute seismic design loads of major structures. Therefore, this issue is not applicable to the AP600 design.

3.7.2.11 Method Used to Account for Torsional Effects

Open Items 3.7.2.11-1 and 3.7.2.12-2 are resolved.

3.7.2.12 Comparison of Responses

For the fixed-base (representing hard rock site) case, the response spectrum analysis method was used to calculate the moments and forces, and the modal time-history analysis method was used to calculate the in-structure acceleration response spectra. Even though the response spectrum analysis was performed based on a detailed finite element model and the modal time-history analysis was performed based on an equivalent lumped-mass stick model, in-structure response spectra and member forces at various floor elevations obtained by these two methods can be meaningfully compared. Especially, the base-shear comparison will indicate the effect of neglecting the contributions from the higher modes (above 33 Hz) in the modal time-history analysis results. The staff position stated in Section 3.7.2.II.12 of the SRP indicates a need for such a comparison to demonstrate approximate equivalency between the response spectrum and the time history methods of analyses. However, Westinghouse justified, in early SSAR amendments, that in the seismic analyses performed, two different models were used. Therefore, a comparison of responses calculated by alternative methods is not necessary. The staff does not consider this an acceptable justification since the equivalence of the two different methods of analyses has not been established. For structural models with significant contributions from higher modes of vibration, the results of the response spectrum analyses can be defined. This was Open Item 3.7.2.12-1. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.12-1 remains open.

3.7.2.13 Methods of Seismic Analysis of Dams

Open Item and COL Action Item 3.7.2.13-1 are resolved.

3.7.2.14 Determination of Seismic Category I Structure Overturning Moments

The staff's evaluation of dynamic stability (sliding, flotation and overturning) of NI structures is discussed in Section 3.8.5 of this chapter.

3.7.2.15 Analysis Procedure for Damping

The staff's evaluation of the analysis procedure for damping is discussed in Section 3.7.1 of this chapter.

3.7.2.16 Confirmation of Plant-Specific Seismic Design Adequacy

The seismic design bases for the AP600 SSCs are essentially defined by an SSE with the peak acceleration of 0.3g and the design is based on the enveloped results from a limited number of site conditions (soft-to-medium stiff soil site, soft rock site and hard rock site). It is the staff's concern that if these design bases are not satisfied or if the seismic analysis response envelope used for the design can not envelop the results obtained from some potential plant site conditions not included in the three site conditions stated above, the basis established for the design certification will no longer apply. In its letter dated March 16, 1994, the staff requested Westinghouse to commit in the SSAR that the COL applicant should perform an analysis and evaluation using the design basis earthquake ground motion and plant specific site conditions to confirm the design adequacy of the AP600 design. This was COL Action Item 3.7.2.16-1 and Open Item 3.7.2.16-1. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.2.16-1 and COL Action Item 3.7.2.16-1 remain open.

3.7.3 Seismic Subsystem Analysis

The review scope of this section covers the seismic input motion, seismic analysis methods, and modeling procedure to be used for the analysis and design of subsystems such as miscellaneous steel platforms, steel frame structures, tanks, cable trays and supports, HVAC ductwork and supports, and conduit and supports. The review of analysis and design criteria for piping systems is discussed in Section 3.12 of this chapter. The staff's evaluation of the design of subsystems other than piping is discussed in Sections 3.8.3 and 3.8.4 of this chapter.

3.7.3.1 Seismic Input Motion

The envelopes of the in-structure seismic response spectra generated according to procedures described in Section 3.7.2 of the SSAR are to be used as input motions for the analysis of these subsystems. The staff's evaluation of the in-structure response spectrum envelopes are discussed in Section 3.7.2 of this report.

3.7.3.2 Analysis Methods

In Section 3.7.3.1 of the SSAR, Westinghouse states that one of four analysis methods is used for the seismic analysis of subsystems: modal response spectrum analysis method, time history analysis method, equivalent static analysis method, and "design by rule" method. The staff's evaluation of the adequacy of these analysis methods is discussed below:

- Open Item 3.7.3.2-1 is resolved.

- Section 3.7.3.5 of early SSAR amendments states that the equivalent static analysis method involves the calculation of equivalent horizontal and vertical static forces applied at the center of gravity of various subsystem masses. If the subsystem can be characterized as a single degree of freedom system, the equivalent static forces will be computed by multiplying the spectral acceleration corresponding to the calculated natural frequency of the subsystem to the total mass of the subsystem. If the subsystem is characterized or modeled as a multi-degree of freedom system, the seismic forces will be computed by multiplying the peak spectral acceleration multiplied by a factor of 1.5 to the total mass of the subsystem. The SSAR also states that this analysis method may be used for the design of steel platforms, cable trays and supports, conduit and supports, HVAC ducts and supports and other substructures.

The procedure for applying the equivalent static analysis method to analyze the AP600 subsystems does not meet the guideline of Section 3.7.2 of the SRP, because as recommended in the SRP, (1) the system must be realistically represented by a simple model, and (2) the design and associated simplified analysis should account for the relative motion between all points of support. Based on the staff's review experience, subsystems such as steel platforms and steel frame structures cannot be modeled as a single degree of freedom system or a simple multi-degree of freedom system. Westinghouse should justify using this method to analyze these subsystems. This was Open Item 3.7.3.2-2. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.7.3.2-2 remains open.

- Open Item 3.7.3.2-3 is resolved.

3.7.3.3 Procedure Used for Modeling

In Section 3.7.3.3 of early SSAR amendments, Westinghouse did not specifically provide modeling procedures for subsystems other than piping systems. The staff letter dated January 26, 1994 requested Westinghouse to:

- provide detailed modeling procedure and analysis method for miscellaneous steel platforms and steel structural frames
- provide modeling procedures for cable trays and supports, conduit and supports and HVAC systems
- consider of potential amplification of motion through the steel frames and platforms in the piping analyses

From its review of Westinghouse's April 14, 1994 submittal, the staff found that the technique used for modeling these subsystems, as described in Section 3.7.3.3 of the SSAR, meets the guideline of Revision 2 of Section 3.7.2 of the SRP, and is therefore acceptable. In addition, Westinghouse addressed the third item above in Rev. 1 to Section 3.7.3.8.3 of the SSAR. From its review of Revision 2 of the SSAR, the staff found that the January 26, 1994 commitment has been incorporated in the SSAR. Confirmatory Item 3.7.3.3-1 is resolved.

As for the issue regarding the consideration of potential amplification of motion through the steel frames and platforms (frames and platforms between main structures and piping systems) in the piping analyses, Westinghouse stated in Section 3.7.3.8.3 of the SSAR that the deformation criteria were applied to model these miscellaneous steel structures. The criteria state that if the deflection of the frames due to dynamic loading is less than 0.3 cm (0.125 in), the frames are considered as rigid and the amplification effect through these frames is negligible. If these frames cannot be considered as rigid, they will be modeled as part of pipe supports. The staff's evaluation of this issue will be discussed in Section 3.12.3.

3.7.3.4 Analysis Procedure for Damping

The staff's evaluation of damping values assigned to each subsystem and the procedure for calculating composite damping of subsystems is discussed in Sections 3.7.1 and 3.7.2 of this chapter.

3.7.3.5 Analysis of Seismic Category I Tanks

Three seismic Category I tanks are included in this section. The spent fuel pit is a reinforced concrete tank and is located in the auxiliary building. The in-containment refueling water storage tank is constructed as an irregular shape steel structural module and is located between the steel containment shell and containment internal structures. The passive containment cooling water storage tank is an axisymmetrical reinforced concrete structure and is located at the top of the shield building. In the seismic analysis, both the spent fuel pit and the passive containment cooling water storage tank were modeled together with NI structures, and the in-containment refueling water storage tank (IRWST) was modeled with the internal structures. The staff's evaluation of the seismic input, modeling procedure and analysis methods applied for these three tanks is discussed in Section 3.7.2 of this chapter, and the design of these tanks is discussed in Section 3.8.4 of this chapter. However, Westinghouse should indicate in the SSAR that there are no safety related flexible wall tanks (field erected or building supported) other than these three tanks in the AP600 design. This was Confirmatory Item 3.7.3.5-1. At this time, no information was provided in the latest revision of the SSAR. Confirmatory Item 3.7.3.5-1 remains confirmatory.

3.8 <u>Design of Category I Structures</u>

3.8.1 Concrete Containment

This section is not applicable to the AP600 design.

3.8.2 Steel Containment

3.8.2.1 Description of Containment

As described in Section 3.8.2.1 of the SSAR and shown in Figures 1.2-12, 1.2-13 and 3.8.2-1 of the SSAR, the AP600 containment vessel is a thin cylindrical steel-shell structure. The vessel consists of a cylindrical shell with an inner radius of 19.8 m (65 ft) and a wall thickness of 4.13 cm (1.625 in). The wall thickness of the lower course of the cylindrical shell is increased to 4.44 cm (1.75 in) to provide margins in the event of corrosion in the embedment transition region. The top of this cylindrical shell is covered by a smooth ellipsoidal head and the bottom is enclosed by another ellipsoidal head that is embedded into a concrete foundation below an elevation of 30.5 m (100 ft). The cylindrical portion of the containment vessel is provided with two T-ring stiffeners and one box-girder stiffener. The box-girder serves as a crane girder supporting a crane bridge. The location of the two equipment hatches and two personnel airlocks are shown in Figure 3.8.2-1 of the SSAR. Other attachments to the vessel include the containment air baffle, walkway, cable trays, heating, ventilation and air conditioning (HVAC) ductworks, concrete on the external stiffeners, other penetrations and the containment recirculation unit platform. However, in Section 3.8.2 and .. Figures 1.2-12, 1.2-13 and 3.8.2-1 of early SSAR amendments, Westinghouse did not the provide radius and thickness of the knuckle region and the dome. In its submittal dated April 28, 1994, Westinghouse stated that the containment vessel head is ellipsoidal with a major diameter of 39.6 m (130 ft) and a height of 11.5 m (37.625 ft). The thickness of the vessel heads is 4.13 cm (1.625 in). Westinghouse was requested to include these geometrical properties in the SSAR, because they are important in developing models for the seismic analysis and analyses against combined load conditions. This is a new open item and is identified as RAI# 230.97.

Open Item 3.8.2.1-1 is resolved.

3.8.2.2 Applicable Codes, Standards and Specifications

In Sections 3.8.2.2 and 5.2.1.1 of early SSAR amendments, Westinghouse states that the 1992 edition of American Society of Mechanical Engineers (ASME) Code, Section III, Subsection NE, "Metal Containment" was used for the design and construction of the steel containment vessel. Sections 3.8.2.2 also states that nonpressure parts of steel structures such as ladders, walkways and handrails were designed to the requirements of AISC N690 Standards. The use of the 1992 edition of ASME code for the steel containment design is not acceptable at this time. If the 1992 edition of ASME code is used for the steel containment vessel design, Westinghouse should identify the differences between the 1992 edition and the 1989 edition of ASME code, and submit an analysis of the differences to the staff for review and acceptance. This was Open Item 3.8.2.2-1. At this time, no information was provided in the latest revision of the SSAR to address this issue. Open Item 3.8.2.2-1 remains open.

Westinghouse is committed to use AISC N690 Standards modified in accordance with the staff guideline discussed in Section 3.8.4 of this chapter for the design of nonpressure parts of steel structures. This is acceptable to the staff.

3.8.2.3 Loads and Load Combinations

In Table 3.8.2-1 of the SSAR, Westinghouse summarizes the design loads, load combinations and the ASME service limits for the containment vessel design. Based on the guidelines of Section 3.8.2 of the SRP and the load combinations recommended in Section 3.8.2.II.3.b of the SRP, the load combinations listed in Table 3.8.2-1 of early SSAR amendments for the containment vessel design are acceptable, except the following issues need to be resolved by Westinghouse:

(1) For the load combination corresponding to design conditions, the design external pressure was not included.

(2) For Level A Service Limits:

- The load case of multiple safety relief valve (SRV) actuation was not considered.

- The external pressure was not included in the LOCA (loss of coolant accident) case.

- The multiple SRV loads with a small/intermediate pipe break accident case was not considered.

- For the load combination indicated in the second to last column of Table 3.8.2-1 of the SSAR, the external pressure of 2.5 psi is combined with "T_0" and "R_0." Westinghouse should clarify whether the 2.5 psi external pressure is in combination with the normal operating plant condition or LOCA accident condition.

(3) The load combinations for Level B Service Limits were not considered in the design.

(4) For Level C Service Limits:

- The external pressure was not considered in the case of a LOCA in combination with the SSE.

- For the case of an operating plant condition in combination with the SSE, it is not clear that operating pressure associated with T_0 and R_0 were considered.

- The load combination related to multiple SRV actuation, in combination with a small or intermediate pipe break accident and SSE, was not considered.

- For the load combination indicated in the last column of Table 3.8.2-1 of the SSAR, the external pressure of 3.0 psi is combined with "T_0" and "R_0." Westinghouse should clarify if this was in combination with load combinations (iii)(c)(1) or (iii)(c)(2) of Section 3.8.2.II of the SRP.

(5) For Level D Service Limits:

- The external pressure was not considered for the case of a LOCA in combination with the SSE and local dynamic loadings.

- The load combination related to multiple SRV actuation in combination with a small or intermediate pipe break accident and SSE and local dynamic loadings was not considered.

The concerns regarding loads and load combinations used for the containment vessel design were identified as Open Item 3.8.2.3-1. At this time, no information was provided in the latest revision of the SSAR to address this issue. Open Item 3.8.2.3-1 remains open.

3.8.2.4 Design and Analysis Procedures

In Section 3.8.2.4 of the SSAR, Westinghouse states that the design and analysis procedures used for the steel containment vessel are in accordance with the requirements of Subsection NE of Section III of the ASME Code. In the analyses, Westinghouse considered various load combinations by (1) performing separate analysis for each individual design load, and (2) combining the obtained stresses according to the required load combinations. An inherent assumption in this process is that individual loads produce linear stresses and the combined response is essentially in linear state. The approach used by Westinghouse is commonly applied in the industry and, thus, is acceptable. For the evaluation of shell buckling and the determination of buckling margin, same linear combination of stresses from individual analyses was used by Westinghouse. The staff's review of buckling evaluation is discussed below.

Analysis for Design Conditions

Open Item 3.8.2.4-1 is resolved.

The staff's evaluation of the adequacy of the containment vessel analyses and design is based on the review of the SSAR, the audit of design calculations, and meeting discussions with Westinghouse. The open items from the staff's evaluation are summarized below:

Load Application

Open Item 3.8.2.4-2 is resolved.

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 air locks. Westinghouse was requested to demonstrate that calculated stresses in the vicinity of the concentrated masses such as equipment hatches and personnel air locks 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 the 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 local masses, and (4) methods for evaluating the compressive strength of the containment shell in the vicinity of major penetrations. Westinghouse's commitment technically resolves the concern of Open Item 3.8.2.4-3. The staff's final conclusion for this open item will be drawn after Westinghouse submits the revised SSAR.

Westinghouse designed the containment vessel by considering the internal and external pressures (not including wind) to be uniform. Because the peak internal and external pressures vary slowly with time, the consideration of these loads as uniform static loads is acceptable to the staff. The SSAR also specifies the magnitude of design internal pressure loads as 6.89 kPa (1 psi) for the operating condition, 310.26 kPa (45 psig) for the accident condition, and 17.24 kPa (2.5 psid) and 20.68 kPa (3.0 psid) for the external pressure loads due to the condition of losing containment cooling and extreme low external temperature. The adequacy of these design pressure loads is evaluated in Section 6.2.

Open Items 3.8.2.4-4, 3.8.2.4-5, 3.8.2.4-6, and 3.8.2.4-7 are resolved.

Stress Analysis

A shell of revolution finite difference model was developed for the containment shell stress analysis. This model was analyzed by Chicago Bridge & Iron (CB&I) in-house computer program, E0781B, for various design loads. During the audit meeting, Westinghouse was requested to provide the validation package of this computer code for the staff review. This was Open Item 3.8.2.4-8. At the August 30 through 31, 1995 meeting, the staff reviewed the validation package for the CB&I computer program "E0781B" and found that relatively simple problems had been tested. The staff questioned whether this computer code was capable of analyzing the complex AP600 containment vessel. The staff believed that a more complicated structural model should be used for the validation. In order for Westinghouse to complete its validation of this computer code, the staff provided Westinghouse the containment vessel model used in the staff's confirmatory analysis (Reference 2) on October 16, 1995. At this time, no information was provided by Westinghouse for the staff review. Open Item 3.8.2.4-8 remains open.

In the seismic stress analysis, because of the nature of the shell of revolution finite-difference model and the limitation of the computer code, the mass of the polar crane, major penetrations, and other attached weights were distributed around the circumference of the dynamic model. As discussed in Section 3.8.2.4.1 of the SSAR, non-axisymmetric loads such as earthquake loads and crane loads are non-axisymmetric loads but are mathematically represented by Fourier harmonics. The containment vessel is an axisymmetric structure and is modelled as such. For these reasons, the containment vessel and applied loads are reasonably represented in the model and are therefore, acceptable. However, the envelope of peak acceleration profiles used by Westinghouse, as discussed in Section 3.7.2 of this chapter, did not include the effect of eccentric masses from major penetrations and polar crane. Also, as discussed in the "Load Application" section above, Westinghouse should perform dynamic analysis instead of equivalent static analysis to calculate stresses due to earthquake loads. The staff's evaluation of the modeling of eccentric masses and the adequacy of using equivalent static analysis method for the containment vessel is discussed in a later section of this report.

Instead of performing detailed finite element stress analysis for vessel penetrations, Westinghouse, as stated in early SSAR amendments, used the area-replacement rule for the penetration reinforcement design. The use of the area-replacement rule is based on the guidelines of the ASME Code and results in conservative design; therefore, it is acceptable in tension regions where it is applicable. However, Westinghouse should demonstrate that the area-replacement rules are applicable in the region of concentrated masses such as the lower equipment hatch and the two personnel airlocks for buckling due to compression. In addition, this region is close to the lower spring line and concrete embedment which may limit the stress redistribution that is implicit in the area-replacement rule. This was Open Item 3.8.2.4-9. In Revision 3 of SSAR Section 3.8.2.4.1.2, Westinghouse provided analysis methods for evaluating the potential buckling of containment shell in the region of major penetrations (such as equipment hatches and personnel air locks) and the region close to lower spring line due to compression. Westinghouse agreed to provide its response to this open item as a part of resolution for Open Item 3.8.2.4-3. Contingent upon an acceptable resolution to Open Item 3.8.2.4-3, the staff concludes that Open Item 3.8.2.4-9 is resolved.

Open Issues 3.8.2.4-10, 3.8.2.4-11, 3.8.2.4-12 and 3.8.2.4-13 are resolved.

Buckling Evaluation

As described in the January 22, 1993 submittal, Westinghouse checked the buckling of the cylindrical portion of the containment remote from the base and penetrations using ASME Code Case N-284. The vessel head was analyzed and evaluated for buckling under external pressure using the criteria in NE-3133 of Section III of the ASME Code. The use of the ASME Code Case N-284 and NE-3133 criteria for the evaluation of containment vessel buckling was previously found acceptable during the staff's review of the System 80+ design.

In the December 22, 1992 submittal, Westinghouse claimed that the area-replacement rule, which was used to design the reinforcement for the penetration, can satisfy stability requirements. This is not acceptable. Westinghouse was requested to evaluate the buckling potential in the vicinity of the base and the large penetrations under various load conditions. This was Open Item 3.8.2.4-14. Because the concern of this open item is covered by the issues raised in Open Items 3.8.2.4-3 and 3.8.2.4-10, Open Item 3.8.2.4-14 is considered resolved contingent upon an acceptable resolution to Open Items 3.8.2.4-3 and 3.8.2.4-10.

Open Items 3.8.2.4-15 and 3.8.2.4-16 are resolved.

3.8.2.5 Structural Criteria

As stated in SSAR Section 3.8.2.5, the containment vessel is designed, fabricated, installed, and tested according to the ASME Code, Section III, Subsection NE. The stress intensity limits are according to the ASME Code, Section III, Paragraph NE-3221 and Table NE-3221-1. Critical buckling stresses are checked according to the provisions of ASME Code, Section III, Paragraph NE-3222 or ASME Code Case N-284. The use of ASME Code, Section III, Subsection NE for evaluating the potential buckling of containment vessel meets the guideline of SRP Section 3.8.2.II.5 and the ASME Code Case N-284 criteria for the evaluation of containment vessel buckling was previously found acceptable during the staff's review of the System 80+ design. On this basis, the structural criteria committed by Westinghouse in SSAR Section 3.8.2.5. are acceptable.

3.8.2.6 Materials, Quality Control, and Special Construction Techniques

SSAR Section 3.8.2.6 describes that materials for the containment vessel, including the equipment hatches, personnel air locks, penetrations, attachments, and appurtenances meet the requirements of NE-2000 of the ASME Code. The basic containment material is SA537, Class 2 plate. In providing corrosion protection, the containment vessel is coated with inorganic zinc coating, except for those portions fully embedded in concrete. The inside of the vessel below the operating floor and up to eight feet above the operating floor also has a phenolic top coat. Below elevation 100 feet, the vessel is fully embedded in concrete with the exception of the few penetrations at low elevations. Seals are provided inside and outside the vessel so that moisture will not be trapped next to the steel vessel just below the top of concrete.

Westinghouse also committed, in the SSAR, that the quality control program involving welding procedures, erection tolerances, and nondestructive examination of shop-fabricated and field-fabricated welds conforms with Subsections NE-4000 and NE-5000 of the ASME Code, Section III.

Based on Westinghouse's commitments stated above, the staff concludes that the material used for the containment vessel, including corrosion protection, and quality control program meet the guidelines of SRP Section 3.8.2.6 and, therefore, are acceptable.

As for construction techniques, Westinghouse described, in the SSAR, that the containment vessel is designed to permit its construction using large subassemblies. These subassemblies consist of two heads and three ring sections, and will be assembled in an area near the final location, using plates fabricated in a shop facility.

3.8.2.7 Testing and Inservice Inspection Requirements

As stated in Section 3.8.2.7 of the SSAR, Revision 3, the inservice inspection of containment vessel will be performed according to ASME Code Section XI, Subsection IWE. The inservice inspection program for the containment vessel will be described in the Combined License application. The containment vessel inservice inspection will be performed in accordance with a program meeting the requirements of ASME Code, Section XI which will ensure that the containment vessel integrity is maintained during the plant operation.

3.8.3 Concrete And Steel Internal Structures Of Steel Containment

3.8.3.1 Description of the Containment Internal Structures

As stated in Section 3.8.2 of the SSAR, the containment internal structures include the reinforced concrete and steel structures inside the containment pressure boundary, and provide support to the reactor coolant system (RCS) components and related piping systems and radiation shielding. These structures consist of the primary shield wall, reactor cavity, secondary shielding walls, in-containment refueling water storage tank (IRWST), refueling cavity walls, operating floor, intermediate floor and steel platforms, and containment vessel support concrete structure.

Most of the concrete and steel internal structures are designed utilizing structural modules. Below elevation 29.9 m (98 ft), steel modules, designated as "L" type modules, are designed to act as forms for constructing the reinforced concrete base structure. These "L" type form modules are constructed from steel plates and reinforced by horizontal angles and vertical tee sections. The form modules are left in place following the concrete pour and curing period.

Section 3.8.3.1 and Appendix 3A of the SSAR briefly describe the form modules. The arrangement and layout of the form modules are shown on Figure 3A-1 (sheets 1-10) in Appendix 3A of the SSAR. No details of the form modules in terms of welding, bracing, connections, etc. are provided. Since the form modules serve only as forms and are not relied upon to take any loads during operation of the plant, it is concluded that the form modules are not safety related and thus the description provided for the form modules is sufficient.

Above elevation 29.9 m (98 ft), structural steel modules ("M" type) are used for the containment internal wall structures. Following erection, the M modules are filled with concrete. The modules serve as the upper portion of the primary shield wall, refueling cavity walls, secondary shield walls, and a portion of the IRWST tank walls, and provide support to the operating floor and other steel framing and steel platforms.

The "M" type structural steel modules are also used to serve as the west wall of the IRWST. The tank wall module consists of stainless steel plates stiffened with structural steel sections in the vertical and horizontal directions.

Structural steel floor modules are used for the operating floor at elevation 41.2 m (135.25 ft). They consist of structural tee sections welded to steel plates and stiffened by angles. The floor modules are supported by steel girders with the flange and a portion of the web located above the plate. Steel reinforcing bars are placed above the plate. Following erection of the floor modules, concrete is poured on the modules to create a composite section.

A description of all of the structural modules discussed above is provided in Section 3.8.3.1 and Appendix 3A of the SSAR. The arrangement, layout, and details of the modules are presented in Figures 3A-1 through 3A-6 of the SSAR. An area for which there are no details in the early version of the SSAR is the connection between the M wall modules themselves and the connections between the M modules and other type of modules. In addition, further review of some of the detailed drawings is required as part of a structural design audit to be conducted for the modules. This was Open Item 3.8.3.1-1. Westinghouse is currently developing the connection details. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.3.1-1 remains open.

The reactor vessel support structure, supported by the bottom head of the containment steel shell, is a reinforced concrete structure which starts from elevation 21.8 m (71.5 ft) to elevation 33.5 m (109.83 ft) and provides support to all other containment internal structures. As shown in Figure 1.2-12 of the SSAR, no shear studs were provided at the interface between the reactor vessel support structure and containment steel shell. In the previous review meetings, the staff raised a concern regarding the potential overturning of the reactor vessel support structure during an SSE and requested Westinghouse to demonstrate the dynamic stability of this structure. In the April 28, 1994 submittal, Westinghouse provided its justification to demonstrate that the reactor vessel support structure will be stable during an SSE and showed that the factor of safety is 2.5 against overturning. This is acceptable to the staff. However, Westinghouse did not demonstrate that this structure will not lift up during an SSE. The staff's concern is that any uplifting of the reactor vessel support structure will cause impact between this structure and the containment shell, and will affect the integrity of safety-related items supported by this structure. This was Open Item 3.8.3.1-2. At the April 25 through 27, 1995 meeting, Westinghouse indicated that additional analyses of the containment internal structures and nuclear island basemat response to seismic loads were in progress, and that these analyses would demonstrate that liftoff of one side of the containment internal structures basemat is not significant. At this time, Westinghouse has not submitted the results and conclusions of these additional analyses for staff review. Consequently, Open Item 3.8.3.1-2 remains open.

3.8.3.2 Applicable Codes, Standards, and Specifications

Section 3.8.3.2 of the SSAR lists the applicable codes, standards, and specifications applicable to the design, materials, fabrication, construction, inspection, and testing of the modules. For some modules, the design utilize the Industry Standard American National Standards Institute (ANSI)/AISC N690-1984, which the staff has not officially endorsed. However, the staff has developed an interim technical position which accepts the use of this standard for advanced reactors when supplemented by a number of provisions. A copy of the staff's technical position on the use of the N690 standard was provided during the meeting with Westinghouse on January 21, 1994. In the May 16, 1994 submittal, Westinghouse only proposed revising Section 3.8.4.5 of the SSAR. Section 3.8.3 of the SSAR should also be revised to reflect the staff's technical position regarding the use of the ANSI/AISC N690 Standard. This was Open Item 3.8.3.2-1. SSAR Revision 3 only revised Section 3.8.4.5 "Structural Criteria" to include the staff's technical position. For completeness, Section 3.8.3.5 needs to be revised accordingly. Also, the limitation of using this standard should be included in Sections 3.8.3.2 and 3.8.4.2 of the SSAR. The concern of Open Item 3.8.3.2-1 is considered technically resolved. Open Item 3.8.3.2-1 will be resolved when the identified sections are modified in a future SSAR revision.

Open Items 3.8.3.2-2 and 3.8.3.2-3 are resolved.

Section 3A.1 of Appendix 3A of the SSAR states that the codes and standards applicable to the design of the structural modules are according to those previously given in Section 3.8.2.2.1 of the SSAR. The SSAR should be corrected, since Section 3.8.2.2.1 does not exist. This was Open Item 3.8.3.2-4. Westinghouse has acknowledged the reference error and has committed to revise Appendix 3A accordingly in a future SSAR revision. The concern of Open Item 3.8.3.2-4 is considered technically resolved. Open Item 3.8.3.2-4 will be resolved when the identified sections are modified in a future SSAR revision.

For the concrete-filled steel M modules, it is not clear that the ANSI/AISC N690 Standard and the ACI-349 Code are directly applicable. For example, the AISC/N690 Standard is primarily applicable to steel structures. Section Q1.11 of the Standard does cover composite construction. However, Section Q1.11.1 states that composite construction shall consist of steel beams or girders supporting a reinforced concrete slab, so interconnected that the beam and slab act together to resist bending. This definition does not cover unreinforced concrete-filled steel shear walls. Similarly, the ACI-349 Code generally covers reinforced concrete structures, not unreinforced concrete-filled steel shear walls. Westinghouse was requested to provide justification to show the applicability of these codes and standards for the design of M-Type concrete filled modules. This was Open Item 3.8.3.2-5. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study which was in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.2-5 remains open at this time.

In Revision 3 of Sections 3.8.3.2 and 3.8.4.2 of the SSAR, a new paragraph related to welding activities was added. This paragraph states that the AP600 welding activities for seismic Category I structural steel, including building structures, structural modules, cable tray supports and HVAC duct supports are accomplished in accordance with written procedures and meet the requirements of the American Institute of Steel Construction (AISC N-690). The weld acceptance criteria will be as defined in NCIG-01, Revision 2. In addition, the weld seam of the plates forming part of the IRWST will be examined by liquid penetrant examination and vacuum box examination after fabrication to confirm that the boundary does not leak. In meeting the welding acceptance criteria of NCIG-01, Revision 2, the welding activities committed by Westinghouse in the SSAR will ensure that seismic Category I steel structures and component supports will perform in service as designed and is, thus, acceptable.

3.8.3.3 Loads and Load Combinations

The loads and load combinations specified for containment internal structures are the same as those for other seismic Category I structures as described in Section 3.8.4 of the SSAR, except that wind (W), tornado (W_t), and precipitation (N) loads are not considered. They are acceptable to assess the structural adequacy for operations-related loads. However, the construction-related loads associated with utilization of modular construction methods have not been addressed. In Westinghouse's May 20, 1994 submittal, a proposed revision to Section 3.8.3.6.1 of the SSAR identifies ASME NQA-2, Part 2.2, 1989 Edition as the governing standard for structural module packaging, transportation, receiving, storage, and handling. The requirements of NQA-2 are more qualitative than quantitative, and it has not been commonly applied to massive structural modules, such as the M modules. Consequently, a more quantitative definition of construction-related loads is needed for the M modules. The entire construction process, from off-site fabrication to final on-site placement, should be addressed. In general, combination with operations-related loads is not necessary unless a significant residual condition exists which could degrade the in-place structural capacity. This was Open Item 3.8.3.3-1. Westinghouse has committed to include additional information on the construction process in a future SSAR amendment. Upon submittal, the staff will review the additional information. Open Item 3.8.3.3-1 remains open.

Another loading unique to concrete-filled M modules is the hydrostatic pressure against the steel walls, during the on-site concrete pour. This construction induced stress will remain following the curing of the concrete, and it will act concurrently with all other design loads. In early amendments of the SSAR, Westinghouse did not provide a description of the methods for considering this hydrostatic pressure. This was Open Item 3.8.3.3-2. Westinghouse has committed to address this issue in a future SSAR revision. Upon submittal, the staff will review the additional information. Open Item 3.8.3.3-2 remains open.

In the meeting held on July 11 through 14, 1994, the staff raised concerns that the design of the IRWST should consider the combination of the load due to automatic depressurization system (ADS) actuation and the SSE load, and the thermal loading should be considered in the internal structural steel frame design. This was Open Item 3.8.3.3-3. No definitive response has been received from Westinghouse on this issue. Accordingly, Open Item 3.8.3.3-3 remains open.

During the April 25 through 27, 1995 meeting, the hydrodynamic analysis of the IRWST for the ADS actuation, as described in Revision 1 of Appendix 3F to the SSAR, was reviewed in detail. Several concerns about the consideration of the ADS loads in the IRWST design were raised by the staff. Westinghouse indicated that new test results would be incorporated into the Appendix 3F and would be included in the analysis. The concern regarding the need to include the new test results in the future revision of Appendix 3F to the SSAR needs to be resolved.

3.8.3.4 Design and Analysis

Open Item 3.8.3.4-1 is resolved.

As a result of the review of early SSAR amendments and meetings with Westinghouse, a number of concerns related to the development of seismic model of the containment internal structures were raised. According to Westinghouse's May 19, 1994 submittal, Appendix 3A of the SSAR is to be revised to clarify the seismic modeling of the containment internal structures. The proposed revision of the SSAR described in the submittal states that a 3D lumped-mass stick model of the containment internal structures was developed based on the structural properties obtained from the finite element model using 3D shell elements. The equivalent thickness of shell elements and the equivalent modulus of elasticity are derived from the composite axial and bending stiffnesses computed from the listed equations. However, a review of the equations and description provided with the proposed SSAR revision raises a number of concerns on the approach used for developing the model. These concerns are summarized below:

- Open Item 3.8.3.4-2 is resolved.

- The equation for the bending stiffness is valid only if the steel and concrete truly behave as a composite section. Because there are no shear studs to bind the steel plates and concrete together, Westinghouse needs to demonstrate the adequacy of the design based on the assumption of a composite section. This was Open Item 3.8.3.4-3. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-3 remains open.

- The equation for bending stiffness includes an approximation in calculating the moment of inertia; it assumes the thickness of the steel face plates relative to the concrete is very small. When the bending moment of inertia was calculated, Westinghouse did not consider the thickness of the steel plates. This approximation may be applicable for internal structural wall modules such as "M" type module. However, for other wall modules such as the modules in the auxiliary building, this assumption may lead to inaccurate results. This was Open Item 3.8.3.4-4. At the December 6 through 8, 1995 meeting, Westinghouse indicated that the minimum module wall thickness to be used in the auxiliary building is 30 inches. For this wall thickness, the approximation for seismic modeling introduces an error on the order of 1 percent, which the staff considers acceptable. Open Item 3.8.3.4-4 is considered technically resolved, and will be resolved when a future revision to the SSAR identifies the wall thickness for the modules in the auxiliary building.

- The behavior of the concrete is three dimensional in view of the 76.2 cm (30 inch) and 121.9 cm (48 inch) wall thicknesses. Interaction effects at contact faces between concrete and steel may generate non-negligible through-thickness normal stresses. Deformation compatibility is enforced only at discrete locations such as the horizontal angle stiffeners. For these reasons and the design details shown, it is not clear to the staff whether the equations presented are adequate to develop appropriate equivalent properties for the isotropic shell model. In addition, Westinghouse should demonstrate that the assumptions made are realistic to represent the 3D behavior of the basic concrete-filled steel module. A local 3D solid model of the module geometry/materials should be used as the basis for developing equivalent isotropic shell properties or for justifying the equations currently used. This was Open Item 3.8.3.4-5. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-5 remains open.

- The staff raised the concerns regarding the stiffness degradation, ductility, and margins of the modules through meeting discussions. Based on the early SSAR amendments and meetings with Westinghouse, the staff found that the justification provided for resolution of these concerns rely primarily on the tests performed in Japan.

  Justification for the seismic modeling of internal structural modules was provided in the May 19, 1994 submittal. The justification primarily relies upon a few tests conducted in Japan on concrete-filled steel wall structures. Comparisons are provided to demonstrate similarities between AP600 modules and test samples. The referenced tests performed in Japan appear to demonstrate that the use of concrete-filled steel modules results in a better design, compared to conventional reinforced concrete structures. However, there are a number of differences in the tested configurations when compared to the AP600 modules (e.g. studs versus horizontal angles, tie rods between the two face plates, only shear or axial loads were applied versus multi load application, etc.).

  One of the Japanese tests actually demonstrated that in compression, the initial stiffness is approximately 80-percent of the calculated stiffness. The referenced tests were only performed for one load at a time, either compression or shear. The "M" modules, however, would be subjected to biaxial bending, shear, and compression or tension. In addition, the limited information included in the published technical papers for these tests is insufficient to support generic conclusions. Further review by the staff and discussions with Westinghouse are needed to determine the possible resolution of this issue. Items relating to the seismic modeling of the containment internal structures were collectively Open Item 3.8.3.4-6. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-6 remains open.

- Open Item 3.8.3.4-7 is resolved.

Details of the methods and procedures for the design of the structural modules inside containment are described in Appendix 3A of the SSAR. This appendix states that the modules with concrete fill are designed with minimal reliance on the concrete fill for strength. They are generally designed as a steel structure in accordance with the requirements of the ANSI/AISC N690 Standard. In a few cases where credit is taken for the concrete, the Appendix states that the ACI 349 Code is used.

Section 3A.3.1 of the SSAR describes the design procedures for the wall modules. For in-plane loads under axial compression, the design assumes that the compressive loads are distributed to the concrete and steel plates in proportion to the stiffness of the concrete and steel. However, the design of the wall modules allows buckling of the steel plates between the horizontal stiffeners over a portion of the plate between the vertical diaphragm webs. This approach leads to a number of questions that have not been addressed. After buckling of the steel plates occurs, the loads will completely shift to the concrete. Westinghouse was requested to demonstrate the integrity of concrete of the wall systems. This was Open Item 3.8.3.4-8. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issued was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-8 remains open.

Another concern which needs to be addressed by Westinghouse is the interaction effect of the vertical compressive stresses with the other perpendicular in-plane horizontal stresses and shear stresses. The post buckling theory utilized to calculate an effective width of the steel plates does not consider these other stress components. This was Open Item 3.8.3.4-9. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-9 remains open.

As described in Section 3A.3.1.2.2 of the SSAR, the diaphragm web plates with the two face plates form a vertical box section. Because they provide the major structural steel strength in this direction, the walls are designed to span in the vertical direction. Thus, out-of-plane loads causing out-of-plane moments are only resisted by one way action of the wall. The out-of-plane moments about the vertical axis are stated to be secondary. This assumption needs to be justified for its adequacy because the moment of inertia about the vertical axis does not appear to be much smaller than the moment of inertia about the horizontal axis. The assumption, one way action of the walls, also needs to be verified because the horizontal span of the walls is comparable to the height of the walls. If biaxial bending is required, then the combined stress equations in Section 3A.3.1.3 of the SSAR will need to be revised to reflect realistic action of the walls. This was Open Item 3.8.3.4-10. At the April 25 through 27, 1995 meeting, Westinghouse indicated that this issue was being addressed in the module behavior study in progress at that time. Some preliminary results were presented at the meeting. The staff is awaiting Westinghouse's completion of the study and submittal of the results and conclusions; Open Item 3.8.3.4-10 remains open.

One of the critical areas in designing structures from individual modules is the connection between modules. The May 17, 1994 submittal refers to the detail drawings presented in the SSAR for the various joints and connections. However, no details are provided for the welds between adjacent wall modules and at the intersection of modular walls. The design of the connection details should be completed and reviewed by the staff. This was Open Item 3.8.3.4-11. The subject of connection details is also addressed in Open Item 3.8.3.1-1. Following submittal of the connection details in a future SSAR Revision, the staff will evaluate them for acceptability. Open Item 3.8.3.4-11 remains open.

As stated in the SRP, a review of a design report is required to provide the staff with design and construction information more specific than that contained in the SSAR. The design report can assist the staff to plan and conduct a structural review. A design report for the containment internal structures was not available for review previous review meetings. The June 30, 1994 submittal states that Westinghouse will compile design summary reports using the format and attributes described in Appendix C to Section 3.8.4 of the SRP. The design summary reports would incorporate the criteria acceptable to the staff and would not be completed until July 1995. This was Open Item 3.8.3.4-12. Westinghouse has not submitted the design summary reports, originally scheduled for completion in July 1995. Open Item 3.8.3.4-12 remains open.

A structural design review is also required for the containment internal structures, particularly because of the unique design details and modular construction techniques. The objective of the review is to investigate the manner in which the structural design criteria were implemented, to verify that the key structural design calculations have been performed in an acceptable way, and to identify and assess the safety significance of particular areas where the containment internal structures were designed and analyzed using methods not covered by the SRP guidelines. This was Open Item 3.8.3.4-13. Completion and submittal of the design summary reports must precede the structural design review. Consequently, Open Item 3.8.3.4-13 remains open.

In summary, from the review of early SSAR amendments, the concerns raised by the staff regarding the structural module design are focused on the "M" type module which consists of two steel face plates with diaphragm plates and angle stiffeners, and is filled with lean concrete between these face plates. As described in the SSAR, composite behavior of the steel and concrete is assumed in determining structural member stiffness of the seismic model. In the design stress analysis, the loads are assumed to be primarily resisted by the steel face plates, with limited reliance on the concrete to carry a portion of design loads. The staff's concerns are (1) the assumed composite stiffness behavior needs to be verified, (2) neglecting the composite behavior in the design stress analysis needs to be justified, and (3) the acceptable design and acceptance criteria that can be applied to this type of structural element design need to be developed.

In response to these concerns, Westinghouse initiated a module behavior study of the "M" type Modules. Some preliminary design results were presented in the April 25 through 27, 1995 design review meeting. At that time, the study was still in progress. Subsequent to this meeting, Westinghouse informed the staff of its intention to significantly modify the "M" module design and design criteria. It is the staff's understanding that the new design will utilize an array of shear studs between the steel face plates and concrete; this modification will ensure that composite steel/concrete behavior is achieved. The design criteria will be based on the ACI 349 code for concrete; the steel face plates will be treated as reinforcing steel in meeting the code requirements. Westinghouse should complete the new design of these modules and submit the design results for the staff review. This is a new open item and is identified as RAI# 230.98.

3.8.3.5 Acceptance Criteria

General acceptance criteria for the containment internal structures are described in Section 3.8.3.5 of the SSAR. Reference is made to ACI-349 for concrete components and AISC-N690 for steel components. Allowable stresses for each load combination are presented in Tables 3.8.4-1 and 3.8.4-2 for steel and concrete structures, respectively. The May 17, 1994 submittal provides supplemental acceptance criteria for inclusion in Section 3.8.4 of the SSAR based on the staff's position (see Section 3.8.3.2 above). This supplemental acceptance criteria should also be included or referenced in Section 3.8.3.5 of the SSAR. This was Open Item 3.8.3.5-1. This issue is also addressed in Open Item 3.8.3.2-1, where the emphasis is on the status of N690 as an applicable standard. SSAR Revision 3 updated Section 3.8.4.5 to include specific supplemental criteria, per the staff technical position. However, Section 3.8.3.5 needs to be updated to cover the same issue for containment internal structures. Reference to acceptance criteria of the staff technical position should also be included in Sections 3.8.3.2 and 3.8.4.2. Open Item 3.8.3.5-1 will be resolved when Westinghouse revises the SSAR to address this issue.

Additional guidance on allowable stresses for wall and floor modules are presented in Appendix 3A of the SSAR. These acceptance criteria are appropriate and acceptable provided that the related open items described above are resolved.

Additional acceptance criteria should be developed for loads and deformations related to fabrication, shipping, and construction/erection of the modules. These would include static loads due to lifting, handling, tie down, fit-up, and other operations, as well as dynamic loads such as vibration and impact loads due to railway shipment. Vibration loads should be specified to ensure that they do not contribute to fatigue usage; otherwise, these additional cyclic loads need to be included in the design fatigue analysis. Excess deformation may also arise beyond the dimensional tolerances which are accounted for in the design analysis. These distortions be might developed during the fabrication, handling, shipping, storage, and/or fit-up at the time of assembling the modules. The SSAR should describe the additional acceptance criteria which are needed to address these loads and deformations during the fabrication, shipping, and construction/erection of the modules. This was Open Item 3.8.3.5-2. At the December 6 through 8, 1994 meeting, Westinghouse committed to provide additional information in the SSAR pertaining to acceptance criteria for construction-related loads. At this time, Westinghouse has not provided any additional information for staff review. Consequently, Open Item 3.8.3.5-2 remains open.

3.8.3.6 Materials, Quality Control, and Construction Techniques

Section 3.8.3.6 of the SSAR refers to Section 3.8.4.6 of the SSAR for the materials and quality control program used in the construction of the containment internal structures. Section 3.8.4.6 of the SSAR describes the concrete ingredients and the reinforcing steel (which presumably are used to anchor the modules). Additional information related to the materials not covered in Section 3.8.4.6 of the SSAR is presented in Sections 3A.5 and 3A.7 of the SSAR. Section 3A.7 states that the structural steel modules are designed using A36 plates and shapes. Nitronic 33 (ASTM 240, designation S2400, Type XM-29) stainless steel plates are used on the surfaces of the modules in contact with water during normal operation or refueling. A description of the sleeve used to attach the reinforcing steel to the modules is presented in Section 3A.5 of the SSAR.

As indicated above, Section 3.8.4.6 of the SSAR is referenced for the description of the quality control program. The staff evaluation of this program is discussed in Section 3.8.4 of the SSAR.

Section 3.8.3.6.1 of the SSAR covers special construction techniques. The May 20, 1994 submittal proposed to revise this section of the SSAR. The draft revision states that the use of concrete-filled steel structures is a proven construction method and has been used in the nuclear industry for years. Most of the examples cited, however, are not comparable to the proposed concrete-filled steel modules for AP600 containment internal structures in the SSAR. In addition, the construction techniques for the AP600 have not been fully described in the SSAR. Therefore, a comparison could not be made. This was Open Item 3.8.3.6-1. At the December 6 through 8, 1994 meeting, Westinghouse committed to provide additional information in the SSAR pertaining to modular construction techniques. At this time, Westinghouse has not provided any additional information for staff review. Consequently, Open Item 3.8.3.6-1 remains open.

The May 17, 1994 submittal provide additional information regarding the placement and curing of the concrete inside the M modules. Because the steel plates will remain (unlike wood forms), and in view of the height of the walls, the procedure for the in-place concrete pour is a special process. The process used and steps taken to ensure that voids, especially adjacent to the bottom face of horizontal stiffeners, will not occur should be included in the SSAR. The fitup and joining procedures for on-site assembly of modular units are also special processes and should be described in the SSAR. The May 17, 1994 submittal also refers to a construction plan which still needs to be reviewed by the staff. The issue regarding the construction techniques was Open Item 3.8.3.6-2. At the December 6 through 8, 1994 meeting, Westinghouse committed to provide additional information in the SSAR pertaining to special construction processes such as on-site fitup/joining and in-place concrete pour. At this time, Westinghouse has not provided any additional information for staff review. Consequently, Open Item 3.8.3.6-2 remains open.

3.8.4 Other Category I Structures

In addition to the containment vessel and internal structures, the nuclear island structures include the shield building and the auxiliary building. Figures 1.2-4 through 1.2-13 of early SSAR amendments showed detailed floor plans and cross-sections of these buildings. However, Westinghouse provided only the dimensions between column lines in the floor plans and did not provide any key dimensions such as size of foundation mat (thickness and overall dimensions), overall dimensions and wall thickness of the auxiliary building, radius and wall thickness of the shield building, the geometry (radii and wall thickness) of the shield building roof structures including the passive containment cooling water storage tank, geometry of containment internal structures (structural modules), and thickness of major structural walls in the SSAR. Building dimensions should be provided in the SSAR. This was Open Item 3.8.4-1. During June 12 through 17, 1995 review meeting, Westinghouse provided the draft of Revision 4 of SSAR Figure 3.7.2-28 (Sheet 1 through 12) for review. In these figures, Westinghouse showed the radius of the shield building and thickness of walls. However, the size of foundation mat and the geometry of the shield building roof structures were not provided. Westinghouse agreed to provide these information in the next revision of the SSAR. Open Item 3.8.4-1 remains open.

3.8.4.1 Description of the Structures

<u>Shield Building</u>

As described in the Section 3.8.4 of the SSAR, the shield building is a cylindrical reinforced concrete structure. The layout of this structure and its interface with other seismic Category I building structures is shown in Section 1.2 of the SSAR. Major features of the shield building including shield building cylindrical structure, shield building roof structure, annulus areas (lower, middle and upper), air inlet, passive containment cooling water storage tank, air diffuser, air baffle and air inlet plenum. The shield building roof is a reinforced concrete shell structure supporting the passive containment cooling water tank and air diffuser. The shield building cylindrical shell supports the roof structure. The floor slabs and structural walls of the auxiliary building are structurally connected to the cylindrical shell at various elevations.

Open Item 3.8.4.1-1 is resolved.

<u>Auxiliary Building</u>

The auxiliary building is a reinforced concrete and structural steel structure and is supported on the common nuclear island foundation mat. There is a total of five stories in this building: three stories above ground and two stories located below grade. The floor slabs and the structural walls of this building are structurally connected to the cylindrical section of the shield building. The major structures located in this building are the main control room, spent fuel pool, fuel transfer canal, new fuel storage area, cask loading and wash down pit, and 150-ton cask handling crane. The inside of the walls and floors of the spent fuel pool, fuel transfer canal and cask loading and wash down pit is lined with stainless steel plate for corrosion and leak prevention. The new fuel storage area is also a reinforced concrete structure. Structural modules are used in several areas of the auxiliary building. These are discussed below, under a separate heading.

Containment Air Baffle

The containment air baffle is part of the Passive Containment Cooling System. The air baffle is located inside the shield building and is primarily supported by the containment vessel. A series of thin metal panels are used to construct a shell which surrounds the containment vessel. The air baffle separates the downward air flow entering the air inlets from the upward air flow that cools the containment vessel and flows out of the discharge stack located at the top of the shield building. The air baffle is a seismic Category I structure and is designed to withstand the wind and tornado loads defined in Section 3.3 of the SSAR as well as the seismic loads. The baffle panels are also designed to accommodate displacements between individual panels due to containment pressure and thermal growth. The detailed description of the air baffle, including its function, is provided in Section 3.8.4.1.3 of the SSAR. The detailed configuration is shown in Figure 3.8.4-1 of the SSAR. At the April 25 through 27, 1995 meeting, Westinghouse presented a new design for the air baffle and the attachment to the containment vessel. The new design is described in SSAR Revision 3.

Open Item 3.8.4.1-2 is resolved.

Supports of Seismic Category I Raceway Systems

The seismic Category I raceway systems include the seismic Category I cable tray and HVAC ductwork systems. As indicated in Sections 3.8.4.1.4 and 3.8.4.1.5 of the SSAR, the cable trays systems are supported by channel type struts made out of cold rolled channel type sections. The supports for HVAC ductwork systems consist of structural steel members or cold rolled channel type sections. These supports are attached to walls, floors and ceiling of structures as required by the arrangement of the raceway systems. Spacing of the supports is determined by allowable loads and stresses of the raceways and supports. Longitudinal and transverse bracings are also provided where required.

Structural Modules

Section 3.8.4.1.2 of early SSAR amendments describes the structural modules used in the auxiliary building. Steel structural modules in the auxiliary building are located at the south side of the building, extending from elevation 20.3 m (66.5 ft) to elevation 41.2 m (135.25 ft). The modules include the spent fuel pool, fuel transfer canal, and cask loading/wash down pit. The locations of the modules are shown on Figure 3.8.4-5 of the SSAR. The structural modules are built up with steel structural shapes and plates. Concrete is used where required for shielding, but reinforcing steel is not normally used. From reviewing the SSAR, it is not clear whether the details of the modules for the auxiliary building are the same as the M wall modules that are used inside containment. Westinghouse should provide more details for these modules in the SSAR, and indicate any difference between these modules and those located inside the containment. This was Open

Item 3.8.4.1-3. In Revision 3 of the SSAR, Westinghouse has not provided any design details related to structural modules located in the auxiliary building. Therefore, Open Item 3.8.4.1-3 remains open.

Finned Floor Modules are used for the ceiling of the main control room (floor at elevation 41.22 m [135.25 ft]) and for the ceiling of the instrumentation and control room (floor at elevation 35.81 m [117.5 ft]). The details are shown in Figure 3.8.4-6 of SSAR Revision 3. A finned floor consists of a 61 cm (24 in) thick concrete slab poured over a stiffened steel plate ceiling. The fins are rectangular steel plates welded perpendicular to the bottom of the ceiling plate. Shear studs are welded to the top of the ceiling plate to ensure composite section behavior of the concrete slab and steel ceiling plate.

3.8.4.2 Applicable Codes, Standards, and Specifications

Section 3.8.4.2 of the SSAR provides a partial list of codes and standards used for the design of AP600 NI structures. This SSAR section also states that nationally recognized industry standards, such as the ASTM, ACI and AISC standards, are used to specify material properties, testing procedures, fabrication, and construction methods. In Sections 3.8.4.2 and 3.8.4.4 of the SSAR, Westinghouse states that the design and analysis procedures for the seismic Category I structures other than the containment vessel and the containment internal structures are in accordance with the 1990 version of the ACI-349 Code for reinforced concrete structures and with the 1984 version of the AISC-N690 standards for steel structures. The allowable stresses for cable trays and strut supports are based on American Iron and Steel Institute (AISI) provisions. The ductworks and supports are designed according to the AISI provisions and the AISC-N690 standards, respectively.

The staff's review of Section 3.8.4.2 of early SSAR amendments identified several issues. These issues are summarized below:

- Open Item 3.8.4.2-1 and Confirmatory Item 3.8.4.2-1 are resolved.

- The early amendments of the SSAR indicated that the ACI-349-90 Code was utilized to design reinforced concrete structures. The use of the ACI-349-90 Code for the design is not wholly acceptable at this time, because the staff has only approved the use of the 1980 version of the ACI-349 Code (Section 3.8.4 of NUREG-1503). If Revision 1990 of the ACI-349-85 Code is used, Westinghouse should identify the differences between the 1980 version of the ACI-349 Code and Revision 1990 of ACI-349 Code and submit an analysis of the differences to the staff for review and acceptance. This was Open Item 3.8.4.2-2. At the June 12 through 16, 1995 meeting, the staff indicated that during its review of ABB-CE's System 80+ standard plant design, the staff concluded that the use of the ACI-349-85 Code for the design of seismic Category I reinforced concrete structures is acceptable, except that the staff position on the design requirements for the steel embedments should be satisfied. However, the staff has never endorsed the use of the 1990 version of the ACI 349-85 code for the design of the seismic Category I structures. Therefore, if the 1990 version of the ACI 349-85 Code is selected to be used for the design, Westinghouse should identify the differences between this version of the code and the ACI 349-85 Code, and submit an analysis of these differences to the staff for review and acceptance.

At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.2-2 remains open.

- Open Item 3.8.4.2-3 is resolved.

- Currently, the staff has not accepted Appendix B to the ACI-349 Code for the design of steel embedments. In its submittal dated May 17, 1994, Westinghouse indicated that the conformance to the staff position on ACI-349 provisions (Appendix B to the ACI-349 Code) for the design of steel embedments will be addressed by April 1995 when the ACI-349 Code Committee's decision on the staff position becomes available. This is not acceptable to the staff, because the use of Appendix B to ACI-349 Code for the design of steel embedments may lead to a nonconservative result. This was Open Item 3.8.4.2-4. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.2-4 remains open.

3.8.4.3 Loads and Load Combinations

Section 3.8.4.3.1 of the SSAR provides the definition for each individual load corresponding to load cases of normal loads, severe environmental loads, extreme environmental loads and abnormal loads. Section 3.8.4.3.2 of the SSAR defines combined load conditions for the AP600 design. The staff's review of early SSAR amendments finds that the definition of the design loads and load combinations meets the guidelines of Section 3.8.4 of the SRP and is therefore acceptable. However, several issues related to design loads and load combinations were raised by the staff. These issues are summarized below:

- The civil/structure design criteria submitted by Westinghouse on May 2, 1994 provide the definition of the maximum live load and operating live load, and state that the operating live load is the only live load to be considered in the seismic analysis. The criteria also state that for NI structures, 25 percent of the maximum live load shall be used to represent the operating live load portion to be included in the seismic load for local member design. The inclusion of 25 percent of the maximum live load to represent the operating live load portion of seismic loads is not acceptable. Westinghouse should include the 25 percent of maximum live load in the dynamic model and perform seismic analysis to calculate seismic responses (in-structure response spectra, structural member forces and dynamic lateral soil pressure due to earthquake). In addition, the SSAR did not explain how the live load was considered in the dynamic model for calculating seismic responses. The issue regarding the consideration of live load in the seismic model was Open Item 3.8.4.3-1. During the June 12 through 16, 1995 meeting, the staff indicated that Westinghouse should incorporate the staff position on the modeling of live load and combination of live load with SSE in the SSAR. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.3-1 remains open.

- Open Items 3.8.4.3-2 and 3.8.4.3-3 are resolved.

- In early SSAR amendments, Westinghouse did not commit to design all subcompartments located in the auxiliary building for global pressure and temperature effects due to pipe rupture, and did not indicate that the actual pressure and temperature loads are to be used for the design.

This issue was Open Item 3.8.4.3-4. In Revision 3 of SSAR Section 3.8.4, Westinghouse committed to design these subcompartments with a global pressure of 5 psi and temperature effects. Therefore, Open Item 3.8.4.3-4 is resolved. However, the adequacy of the design pressure of 5 psi and the design temperatures listed in the SSAR are reviewed under Section 6.2.1.2 (Open Item 6.2.1.2-1).

At the April 25 through 27, 1995 meeting, the containment air baffle was reviewed in detail. As noted above, Westinghouse presented a new design concept at the meeting and subsequently documented it in SSAR Revision 3. Independent of the final design details, several issues were raised by the staff at the meeting concerning the loads on the air baffle. First, Westinghouse should address the significance of fluctuations in the air flow with respect to flow-induced vibrations and cyclic fatigue. Second, the magnitude of the differential air pressure across the baffle panels cannot be considered finalized until the staff accepts Westinghouse's scale model wind tunnel test results as being applicable to the full scale structure in Section 21.5.7.4 (Open Item 21.5.7.4-1) of this report. Issues relating to loads on the air baffle need to be resolved by Westinghouse.

3.8.4.4 Design and Analysis Procedures

Auxiliary building structures are primarily reinforced shear wall structures consisting of vertical shear/bearing walls and floor slabs supported by structural steel framing. The structural steel framing was used to support the concrete slabs and roofs, and was designed for vertical loads. In Section 3.8.4.3 of the SSAR, Revision 3 Westinghouse provided the loads considered in the analysis and design. According to Section 3.8.4.4 of the SSAR, Revision 3 in-plane seismic forces are obtained from the response spectrum analysis of the 3D finite element fixed base models. These results are modified to account for soil-structure interaction and accidental torsion effects. The out-of-plane bending and shear loads, lateral earth pressure, hydrostatic and hydrodynamic pressure loads and wind loads, obtained from hand calculations, are considered in the shear wall and floor slab design. The exterior auxiliary building walls below grade were also designed to resist the worst case of lateral earth pressure loads (both static and dynamic), soil surcharge loads, and loads due to external flooding.

For the analysis and design of the shield building and the passive containment cooling water storage tank, a 3D finite element model is used. Seismic loads calculated based on the 3D lumped-mass stick model are considered as equivalent static loads which are equal to the product of calculated accelerations and lumped masses. The seismic response of the water in the tank is analyzed by a separate response spectrum analysis to a finite element model with input defined by the floor response spectra.

From its review of Section 3.8.4.4 of early SSAR amendments and Westinghouse's submittal dated May 17, 1994, the staff found that the approach (modeling techniques and analysis methods) described in the SSAR for computing seismic member forces of structures including raceway systems and HVAC ductworks, the consideration of design loads, and the approach for shear wall and floor slab design meet the guidelines of Sections 3.7.2 and 3.8.4 of the SRP, and thus, are reasonable and acceptable. However, a number of concerns were identified. These issues are summarized below:

- The SSAR did not describe what kind of model was developed for the shield building including the passive containment cooling water storage tank and auxiliary building under design loads other than the SSE, and which computer code was used to perform the analysis. In addition, the SSAR did not described which specific combined design load conditions were considered in the design calculation. This was Open Item 3.8.4.4-1. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.4-1 remains open.

- During an early design calculation audit, the staff found that the final design calculation for the shield building and the passive containment cooling water storage tank was not available for the review. This was Open Item 3.8.4.4-2. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.4-2 remains open.

- Open Item 3.8.4.4-3 and COL Action Item 3.8.4.4-1 are resolved.

- The SSAR states that the below grade exterior walls of Category I structures are designed to resist the worst case lateral earth pressure loads. In its submittal dated May 20, 1994, Westinghouse stated that the embedded portion of the exterior walls of the NI are designed for dead loads, live loads, SSE loads, hydrostatic loads due to groundwater and probable maximum flood, static soil pressure loads, surcharge loads and soil pressure induced by the SSE. The soil pressure is based on at-rest soil pressure and the soil pressure induced by the SSE is based on the soil pressure calculated using the Mononobe-Okabe formula multiplied by a factor of 2. Two-dimensional SSI analysis results are also used to establish the soil pressure induced by the SSE and to verify the structural integrity of the walls. Westinghouse's May 20, 1994 submittal is acceptable, because it conforms with the guidelines of Section 2.5.4 of the SRP, except for the following:

  - During an early design calculation audit, Westinghouse agreed that the pressure to be used for the wall design will not be less than the pressure used in the sliding and overturning evaluation of the NI. However, the staff audit found that the soil pressure used for the design of walls was much lower the soil passive pressure used for the NI sliding analysis.

  - The dynamic soil pressure due to the structure-to-structure interaction effects from the adjacent structures (turbine building, annex buildings and radwaste building) was not considered in the wall design.

  This was Open Item 3.8.4.4-4. In response to this open item, Westinghouse, at the June 12 through 16, 1995 meeting, agreed to (1) justify why the soil pressure used for the design of exterior embedded walls is much lower than the soil pressure used for the nuclear island sliding analysis, and (2) consider the dynamic soil pressure due to the structure-to-structure interaction effects from the adjacent structures in the design of exterior embedded nuclear island walls. At this time, no information has been provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.4-4 remains open.

- Open Item 3.8.4.4-5 is resolved.

- Westinghouse did not provide analysis procedures and design details of the spent fuel pool, including fuel racks, fuel transfer canal and new fuel storage area. This was Open Item 3.8.4.4-6. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.4-6 remains open.

- As part of design and analysis procedures, Westinghouse should prepare and document design reports for all seismic Category I structures, in accordance with the guideline of Appendix C of Section 3.8.4 of the SRP. In its June 30, 1994 submittal, Westinghouse agreed to prepare a design report for each of the following structures and buildings:

  - the nuclear island basemat
  - the auxiliary building
  - the containment internal structures
  - the shield building

  Westinghouse also stated that these design reports will not be included in the SSAR, but will be available for NRC audit, and will be updated during construction to incorporate as-procured and as-constructed information. The staff finds that Westinghouse's commitment of preparing the design report for each of safety-related structures meets the guidelines of Appendix C to Section 3.8.4 of the SRP and, thus, is acceptable. However, the list of components provided in Westinghouse's June 30, 1994 submittal should include (1) the IRWST (as part of containment internal structures), and (2) the air baffle (as part of shield building). The concern regarding the design report was Open Item 3.8.4.4-7. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.4.4-7 remains open.

- Open Item 3.8.4.4-8 is resolved.

- The staff has completed its review of Appendix 3G and 3H to Revision 3 of the SSAR which respectively describes the codes and standards, loads, load combinations, analysis and design methodology for the cable trays and cable supports, and HVAC ducts and duct supports. The staff has identified the following items that need to be clarified by Westinghouse so that the staff may finalize its safety evaluation of analysis and design methodology for AP600 cable tray, HVAC ducts and their support. Those positions of the items below relative to HVAC are included in this section to address DSER Open Item 3.9.3.1-6.

  - Appendices 3G and 3H state that the live load consists of 250 pounds to be applied only during construction on the raceway systems (cable trays and HVAC ducts) at a critical location to maximize flexural and shear stresses. This load is not combined with seismic loads. Westinghouse should state in both of these SSAR appendices that all removable items that have been used during construction or maintenance will not be attached to these systems during operation and that all loads will be considered as dead loads under operating conditions.

- Appendices 3G and 3H specify an allowable stress of 1.6 times the basic allowable for the load combination that includes dead and seismic loads. Westinghouse needs to provide the basis for using the stress limit coefficient of 1.6 for the service load combination including SSE. In particular, Westinghouse needs to justify this factor for compressive stresses. Appendix 3H needs to be clarified to provide equations and methodology for calculating duct stresses due to pressure loads.

- Seismic load effects on ducts include global and local effects. Appendix 3H should be clarified to describe the global effects to be determined by beam type analyses and local effects which may be assessed by analyses of panels bounded by stiffeners and subjected to pressures due to inertial loads. Appendix 3H states that ductwork within partially or fully vented buildings are subject to wind effects. However, ductwork exposed to wind/tornado should also be designed for missiles due to tornados in addition to pressure due to these effects. Finally, Westinghouse needs to describe the procedure for the analysis, design and qualification of cable tray and duct support anchorages into concrete.

In addition to the open items discussed above, two issues were raised by the staff during its review of design calculations and are identified as requests for information. These two issues are as follows:

230.99 In the design of peripheral embedded walls of nuclear island structures, the SSAR states that the embedded exterior walls of seismic Category I structures are designed to resist the worst case lateral earth pressure loads. However, during the design review meetings, the staff found that (1) the soil pressure used for the design of walls was much lower than the soil passive pressure used for the NI sliding analysis, and (2) the dynamic soil pressure due to the structure-to-structure interaction effects from the adjacent structures (turbine building, annex buildings and radwaste building) was not included in the wall design. In addition, for resisting the high shear stress due to the external earth pressure (both static and dynamic), Westinghouse applied heavy shear reinforcement at locations such as the junction between walls and foundation mat. With relatively small thickness of walls (the wall thickness at junction with the foundation mat is 3 ft), the congestion of reinforcement at these locations may cause reduction of shear resistance of walls. Westinghouse should consider these concerns in the final design of these walls.

230.100 The following concerns regarding analysis and design of shield building roof structures need to be addressed by Westinghouse:

a. The vertical component of the earthquake ground motion tends to increase (add to) the water pressure against the passive containment cooling system (PCS) tank walls. This pressure should be considered in the design of outer tank wall and the connection between tank wall and conical roof. However, the staff found, during the meeting discussion with Westinghouse, that the design loads for the outer tank wall are very low. Westinghouse should demonstrate and justify the adequacy of these design loads.

b. Because the slope of the conical shell is relatively shallow (35 degree), a high horizontal component of the in-plane seismic force in the conical shell due to vertical excitation of the tank under an SSE should be expected to apply at the top of the tension ring beam which supports the conical shell. This horizontal force will (1) induce high hoop stress in the tension ring beam and cause the tension ring beam to be significantly cracked, and (2) produce torsional moment on the tension ring beam and bending moment at the top of supporting columns to the tension ring beam. Westinghouse should consider these two effects in the tension ring beam design.

c. The precast panels of the shield building roof are temporarily supported on the containment vessel during construction. Westinghouse's analysis calculated the maximum reaction loads applied on the containment vessel dome and also indicated that these maximum reaction loads would be reduced as, during construction, increasing number of conical roof panels are installed, and the stiffness of the overall structure increases as each panel is erected. Westinghouse should evaluate the significance (potential of buckling) of these construction loads to the containment vessel dome.

3.8.4.5 Structural Modules

Westinghouse's May 17, 1994 submittal states that the steel structural modules in (1) the auxiliary building, and (2) the ceilings of the main control room and the instrumentation and control room are designed similar to the structural modules of the containment internal structures described in Appendix 3A of the SSAR. The staff's concern is that if there are differences in the details of these modules, as discussed above, Appendix 3A would need to include a description of criteria used for these different configurations and applications. This was Open Item 3.8.4.5-1. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.4.5-1 remains open.

Revision 3 of SSAR Section 3.8.4.1.2 states that the finned-floor modules are designed as reinforced concrete slabs in accordance with the ACI-349 Code. The steel panels are designed and constructed in accordance with AISC-N690. For positive bending, the steel plate with fin stiffeners are in tension and act as the bottom reinforcement. For negative bending, compression is resisted by the stiffened plate and the tension side is resisted by the top steel reinforcement. Westinghouse provided the design details of the finned-floor modules in Figure 3.8.4-6 of the SSAR. Based on the resolution of Open Items 3.8.3.2-1 and 3.8.3.2-2, the staff finds that this design meets the requirements of the ACI-349 Code for reinforced concrete slabs and AISC-N690 for steel panels, and is therefore acceptable.

Section 3.8.4.6.2 of early amendments SSAR covers quality control for other Category I structures and is also referenced by Section 3.8.3.6 of the SSAR for containment internal structures. Section 3.8.4.6.2 of the SSAR only states that the quality assurance program is described in Chapter 17 of the SSAR and conformance to RG 1.94 is as described in Section 1.9 of the SSAR. However, Section 1.9 of the SSAR states that RG 1.94 is not applicable to AP600 design certification because it is the responsibility of the COL applicant. Chapter 17 of the SSAR discusses quality assurance (QA) during design, procurement, fabrication, inspection and/or testing of nuclear power plant items and services. This section of the SSAR references two Westinghouse topical reports dealing with quality assurance. The staff's review of these documents identified that certain aspects of quality control which are applicable to modular construction are not adequately addressed. Quality control requirements related to the entire process from fabrication to erection should be addressed. The requirements should cover items such as fabrication and assembly tolerances, handling requirements, verification of proper fitup, load testing prior to lifting/handling operations, erection, and tolerances. The extent of adherence to industry codes and standards regarding quality control requirements (e.g. ACI-349 Code, AISC Specifications, and AWS Code) should also be described. This was Open Item 3.8.4.5-2. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.4.5-2 remains open.

3.8.4.6 Structural Criteria

It is stated in Sections 3.8.4.2 and 3.8.4.5 of the SSAR that the analysis and design of reinforced concrete structures conform to the ACI-349-90 Code, and the analysis and design of steel structures conform to AISC-N690 Standards. The ACI-349 Code and AISC-N690 standards were reviewed and found acceptable during the staff's review of the General Electric Advanced Boiling Water Reactor (ABWR) and Combustion Engineering System 80+ designs, and are therefore acceptable for the design of the NI structures.

3.8.5 Foundations

The AP600 NI structures consisting of reactor containment vessel, containment internal structures, the shield building, and the auxiliary building are supported on a common foundation mat. The NI foundation mat, while not precisely rectangular, is approximately 77.4 m (254 ft) long and 35.2 m (115.5 ft) wide. The thickness of the mat is 1.8 m (6.0 ft) in the auxiliary building area, and is 6.4 m (21.0 ft) at the periphery, and 1.8 m (6.0 ft) at the center in the shield building and containment vessel area. However, the exact dimension of the foundation is not provided in early SSAR amendments. This was Open Item 3.8.5-1. At the June 12 through 16, 1995 meeting, Westinghouse provided the key dimensions of nuclear island foundation mat (draft Revision 4 of the SSAR, Figure 3.7.2-28) during this meeting. This open item is technically resolved. However, Westinghouse should show the dimension between the center of the containment and the edge of the basemat in this figure. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.5-1 is resolved contingent upon Westinghouse revising its SSAR as described above.

It is stated in the early amendments of SSAR Section 3.8.5.2 that ACI-349-90 Code, "Code Requirements for Nuclear Safety Related Structures," was used for the design of the NI foundation mat. The use of the ACI-349 Code for the design of the foundation mat is acceptable to the staff. However, in Section 3.8.3 of the SRP, the staff has only accepted the 1980 version of the ACI-349 Code with an exception of the use of Appendix B for which the staff position on the design requirements for the steel embedments should be satisfied. If the ACI-349-90 Code is used, Westinghouse should identify the differences between the 1980 version of ACI-349 Code and Revision 1990 of ACI-349 Code and submit an evaluation of the differences to the staff for review and acceptance. This was Open Item 3.8.5-2.

In response to this open issue, as discussed at the February 27 through March 2, 1995 review meeting, Westinghouse justified using 1990 Edition of ACI-349 Code by stating that the differences between the 1980 and 1990 edition were published in ACI Journals prior to publication of the 1985 edition and the 1990 supplement. The revisions incorporated in the 1985 edition were primarily to make the ACI-349 code consistent with revisions incorporated the ACI-318-83 Building Code. The revisions in the 1990 supplement were primarily in Appendix B, which is addressed separately in the response to Open Item 3.8.4.2-4. The ACI 349-85 code was endorsed for use in the CE System 80+ application. Based on the justification described above, Westinghouse stated that the 1990 edition of the ACI-349 code should be appropriate for the AP600 design.

At the June 12 through 16, 1995 meeting, the staff indicated that during its review of CE's System 80+ standard plant design, the basis of the staff's conclusion of using ACI 349-85 Code is that the use of this code for the design of seismic Category I reinforced concrete structures is acceptable, except that the staff position on the design requirements for the steel embedments should be satisfied. However, the staff has never endorsed the use of the 1990 version of the ACI 349-85 code for the design of the seismic Category I structures. Therefore, if the 1990 version of the ACI 349-85 Code is selected to be used for the design, Westinghouse should identify the differences between this version of the code and the ACI 349-85 Code including those published in the ACI journals, and submit an analysis of these differences to the staff for review and acceptance. Open Item 3.8.5-2 remains open.

The loads and load combinations for the foundation mat design, as stated in Section 3.8.5.3 of early SSAR amendments, are based on the requirements described in SSAR Section 3.8.4.3 and Table 3.8.4-2. In addition, the NI structures, including the foundation mat, were checked for resistance against sliding and overturning due to the SSE, winds and tornados, and against floatation due to floods and ground water according to the load combinations presented in Table 3.8.5-1 of the SSAR and the formulas described in Sections 3.8.5.5.2, 3.8.5.5.3 and 3.8.5.5.4 of the SSAR. The use of the design loads described in Section 3.8.4.3 of the SSAR and the load combinations tabulated in Table 3.8.4-2 of the SSAR meet the guidelines of Section 3.8.4 of the SRP for the foundation mat design and are therefore, acceptable. However, the staff believes that the effect of accident pressure should also be combined with other design loads when the foundation mat is designed. This was Open Item 3.8.5-3. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.5-3 remains open.

As for the evaluation of dynamic stability (overturning, sliding and floatation) of the NI structures, including foundation mat, in Table 3.8.5-1 of early SSAR amendments, Westinghouse did not include the buoyancy effect when the potential overturning and sliding were evaluated. In addition, the energy balance method (the safety factor against overturning of the NI structures during an SSE is defined as the ratio of the potential energy required to cause overturning about one edge of the structure to the maximum kinetic energy in the structure due to the SSE) was used for evaluating overturning of the NI structures. The factor of safety against overturning of the NI structures due to an SSE should be assessed using the moment balance method (the factor of safety against overturning is defined as the ratio of the restoring moment to the overturning moment due to an SSE) rather than the energy balance method. The concern regarding potential overturning and sliding was Open Item 3.8.5-4. In Revision 3 of SSAR Section 3.8.5.5.4, Westinghouse replaced the energy balance method by the moment balance method for checking the overturning of the nuclear island. In this SSAR section, Westinghouse also stated that the resisting moment is equal to the nuclear island dead weight minus maximum SSE vertical force and buoyancy force from ground water table multiplied by the distance from the edge of the nuclear island to its center of gravity. The procedure committed in the SSAR of using the moment balance method and calculating the resisting moment for evaluating overturning of the nuclear island meets the guideline of SRP Section 3.8.5 and is acceptable. However, Westinghouse did not commit, in the SSAR, to consider the buoyancy effect in evaluating the potential sliding. In addition, as shown in Table 3.8.5-1 of the SSAR, Westinghouse did not include the buoyancy effect in the load combinations for evaluating the potential of overturning and sliding. Westinghouse should include the buoyancy effect in evaluating the potential sliding and in the load combinations of SSAR Table 3.8.5-1. Therefore, Open Item 3.8.5-4 remains open.

As described in the SSAR, the NI structures including the foundation mat are reinforced concrete shear-wall structures consisting of vertical shear/bearing walls and horizontal floor slabs. The walls carry the vertical loads from the upper structures to the basemat. The lateral loads such as seismic forces are transmitted from the roof and floor slabs through the vertical walls to the basemat. These walls also provide stiffness to the basemat and distribute the foundation loads between them.

The foundation mat was analyzed, using a three dimensional (3D) finite element model, with Version 4.4.A135 of the ANSYS computer program. This 3D finite element model includes the foundation mat, auxiliary building, shield building, containment shell and containment internal structures, and extends to elevation 100 ft for the auxiliary building and to elevation 236 ft for the shield building to consider the interaction of the basemat with the overlying structures. The model also considers the effect of interaction between the basemat and the supporting soil. To represent the flexibility of the soil, the elastic foundation stiffness of the soil was included in the basement elements by a system of horizontal spring elements uniformly distributed on the basemat nodes. Horizontal bearing reactions on the side walls below grade were neglected. As described in the SSAR, the consideration of only the horizontal springs to represent the flexibility of the soil foundation without including the vertical soil springs is not acceptable to the staff. This was Open Item 3.8.5-5. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.5-5 remains open.

In the analysis, the dead and live loads above elevation 100 ft were applied as concentrated loads on the nodes of the supporting walls and as distributed loads on the top edge of the supporting walls. Below elevation 100 ft, the dead and live loads are applied as inertia forces and uniformly distributed loads. The SSE loads due to the structures above elevation 100 ft are applied as static concentrated loads to the nodes at elevation 100 ft and an equivalent static acceleration is applied to the structural model below elevation

100 ft. The spatial components of the SSE loads were combined based on 100, 40, 40 rule as described in Section 3.7.2.6 of the SSAR. As stated in Section 3.7.2 of this report, the use of 100, 40, 40 rule for combining spatial components of the SSE loads is acceptable to the staff.

Because basemat lift-off occurs under most of the combined load conditions, an iterative process was applied in the analyses. Westinghouse performed the basemat analysis using the iterative process for two of the 12 most critical load combination cases. These 12 critical load combination cases were determined based on the results from the first linear analysis (the analysis without iteration). However, the use of only two of the 12 criterical load combination cases is not consistent with Section 3.8.5.4 of the SSAR, which states that 12 load combination cases were used. The basis of using only two load combination cases for the basemat lift-up analysis was Open Item 3.8.5-6. At this time, no information was provided in the latest revision of the SSAR. Open Item 3.8.5-6 remains open.

The results from these analyses include forces, shears and bending moments in the foundation mat, bearing pressures under the foundation mat, and the uplifted areas of the foundation mat. The required reinforcing steel was determined by considering both the reinforcement envelope based on the first linear analysis for 48 load combination cases and the reinforcement envelope for the full iteration of the 12 most critical load combination cases. The reinforcements of the final basemat design are shown in Figure 3.8.5-3 of the SSAR.

The staff review of the foundation mat design was based on:

- the review of SSAR and design criteria
- the review of Westinghouse's responses to the RAIs raised by the staff as a result of the SSAR review
- audit of design calculations

As a result of the staff's review of early SSAR amendments and Westinghouse's responses to the staff's concerns documented in its letters dated October 1, 1992, January 26, 1994 and March 16, 1994, and the discussion with Westinghouse during the review meetings, a number of issues were identified. These issues are discussed below:

- Open Item 3.8.5-7 is resolved.
- Westinghouse was requested to provide the validation package of INITEC's in-house computer programs for review. In addition, Westinghouse should verify the adequacy of the post-processed results which were used to produce complete reinforcing steel requirements from the results of the ANSYS analysis. Westinghouse committed to perform additional review of the analyses of the NI foundation mat. The concern regarding validation of INITEC's in-house computer programs and verification of the post-processed results was Open Item 3.8.5-8. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-8 remains open.

- Westinghouse should provide rationale for demonstrating the adequacy of using a 6-foot thick foundation mat, especially the foundation mat underneath the containment vessel. In the review meeting, Westinghouse committed to perform additional review of the basemat analysis and to use simplified analysis, using ACI 336 procedures, to verify the design adequacy. This was Open Item 3.8.5-9. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-9 remains open.

- Based on the staff's past licensing review experience, the unevenly distributed construction loads on the foundation mat, especially for the foundation mat with large dimensions and irregular shape, can be very significant and may cause severe foundation cracks. Westinghouse should provide the basis for demonstrating the design adequacy in coping with the unevenly distributed construction loads. This was Open Item 3.8.5-10. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-10 remains open.

- Westinghouse should provide the basis for using a uniform Winkler spring in the foundation analyses instead of the expected variable stiffness from edge to center of the foundation mat, for staff review. In addition, the staff raised a concern regarding the basis of using only one soil condition (soft rock case) for the design of the foundation mat. During the review meeting, Westinghouse committed to perform additional analyses for evaluating the effects of:

    - local soft spots of soil foundation

    - soil springs to the foundation mat design with non-uniform stiffnesses

    - soil stiffness corresponding to other soil conditions used in the design.

    This was Open Item 3.8.5-11. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-11 remains open.

- In the NI foundation mat design, Westinghouse should consider the seismic shear and moments due to the out-of-phase vibration between the shield building, containment shell, and containment internal structures. Westinghouse agreed to perform additional analyses and design for the seismic shears and moments due to out-of-phase vibration between shield building, containment shell and internal structures. This was Open Item 3.8.5-12. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-12 remains open.

- Open Items 3.8.5-13, 3.8.5-14, 3.8.5-15, and 3.8.5-16 are resolved.

- Westinghouse did not include the construction loads and the sequence of these loads in the design of the NI foundation mat. This was Open

Item 3.8.5-17. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-17 remains open.

- As indicated in Figures 1.2-12 through 1.2-17 of the SSAR, Westinghouse did not provide overhangs at the end of the NI foundation mat for having enough rebar development length or use special end plates for rebar anchorage to resist the bending moments due to the soil pressure (static and dynamic) against peripheral walls. This was Open Item 3.8.5-18. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-18 remains open.

- For evaluating foundation uplift potential, the hard rock site condition should be considered for determining foundation mat design forces. The effect of impact between the foundation mat and the rock, and the load concentration at edges and corners, should also be considered in the design. This was Open Item 3.8.5-19. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-19 remains open.

- The staff review of design calculations found that the shear modulus of the subgrade soil used for the foundation design was based on a foreign test, and soil stress attenuation with depth seems counter-intuitive. The references used for the foundation design should be validated by an independent U.S. reference. This was Open Item 3.8.5-20. At this time, no information was provided either in the latest revision of the SSAR or for the staff review. Open Item 3.8.5-20 remains open.

During the week of July 11 through 15, 1994, the staff and its consultants conducted a design calculation review at the Bechtel Power Corporation (Westinghouse's consultant) office in San Francisco, California. In this meeting, the staff reviewed INITEC's (a Westinghouse consultant) Design Calculation 1010-CCC-001 for the AP600 NI foundation mat. INITEC, with the 3-D finite element model, combined specified load conditions and analyzed the foundation mat by the ANSYS computer code. The results obtained from the ANSYS analyses were then input into INITEC's in-house post processor programs for the reinforced concrete design. From the staff's review of this report, the following concerns were identified:

- Among those 12 most critical load combinations, only two combined load conditions, namely normal and extreme combined load conditions, were considered in INITEC's analyses and design of the NI basemat. In neither of the load combinations were the design-basis accident load and associated thermal effect considered. Without inclusion of the accident load and thermal effect in the combined load conditions, the INITEC analyses is inconsistent with the commitment in Table 3.8.4-2 of the SSAR.

- While the plots of the foundation mat elements and nodes were provided in the design calculations, the elements of the containment internal structures and walls were not shown.

- The basis for determining the element size was not discussed in the design calculations.

- When the foundation mat under the shield building was modeled, the horizontal element planes were vertically offset from radially arranged adjacent elements. This offset could cause spurious bending moments and shears if the in-plane forces are present in these elements.

- A total of 149 horizontal (north-south and east-west) soil springs were used to connect the soil foundation and the basemat nodal points. However, the number of soil springs are much less than the total number of nodal points. INITEC assumed that the horizontal spring locations were uniformly distributed among the basemat elements. When certain portions of the basemat uplifted due to SSE loads, the horizontal soil springs within this portion of basemat still provided restraints to the basemat. This is unrealistic when compared with the true behavior of the basemat.

- The development of the axial forces (in plane membrane forces) in the basemat should depend on the locations of, and the magnitudes of, the horizontal restraints. However, the horizontal restraints provided by the exterior walls and the edge of the basemat were neglected in the calculations. Neglecting these horizontal restraints may cause under-design of the flexural reinforcements.

- The package of the ANSYS computer output was not available for review.

- The review of the verification package for the post processor program "ARMAR2" indicated that some significant errors were made in the determination of the concrete shear capacity, calculation of applied shear forces, and calculation of flexural reinforcements for bending and axial forces.

Based on the discussion above, the staff concludes that the foundation mat design performed by INITEC is not acceptable. Westinghouse should verify the adequacy of the original basemat design and make corrections, if necessary. In its letter dated August 2, 1994, Westinghouse committed to:

- perform an independent review of the existing design calculations

- verify the adequacy of the INITEC's in-house post-process computer programs used for the foundation mat design

- perform simplified analyses to confirm the adequacy of the existing design results

- provide the independent review results for the staff review

This is Open Item 3.8.5-21. Although the procedures used for the AP600 foundation mat design appear reasonable, no information was provided for the staff review at this time. Open Item 3.8.5-21 remains open.

In addition to the open items listed above, four issues were raised by the staff during its review of design calculations:

230.101 In developing bounding pressure distributions for use in the foundation mat design, the soil stiffness parameters used in the analysis should be varied over a range from soft soil to hard rock in determining pressure distribution underneath the foundation mat. In addition, the variation of soil stiffness along the basemat length should also be considered in the development of bounding soil pressures.

230.102 Since the basemat is only six feet thick in the auxiliary building area, the effect of large cut-outs of pits to the overall design of basemat could be significant.

230.103 Settlements induced by the construction procedure and loads may lead to significant locked-in stresses. These settlement induced stresses (both immediate and long term) and construction loads should be included in the design of the mat foundation.

230.104 Since normal site investigations may overlook the local soft and/or hard spots existing in the supporting soil foundation, the effect of the possible soft/hard spots on the local soil pressure computation should be evaluated and included in the design.

230.105 In order to resist high shear stresses, Westinghouse applied heavy shear reinforcement in the area of auxiliary building (especially the mat foundation at the junction of the shield and auxiliary buildings). With relative small thickness of foundation mat (the mat thickness at junction between the shielding and auxiliary buildings is 6 ft), the congestion of reinforcement at these locations may cause reduction of the shear resistance of foundation mat.

Westinghouse should consider these concerns in the final foundation mat design. These concerns are new open items and are identified as RAIs# 230.101 - 105.

should be varied over a range from soft soil to hard rock in determining pressure distribution underneath the foundation mat. In addition, the variation of soil stiffness along the basemat length should also be considered in the development of bounding soil pressures.

230.102 Since the basemat is only six feet thick in the auxiliary building area, the effect of large cut-outs of pits to the overall design of basemat could be significant.

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