REQUEST FOR ADDITIONAL INFORMATION 858-6126 REVISION 3

10/25/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

SRP Section: 03.08.03 - Concrete and Steel Internal Structures of Steel or Concrete Containments
Application Section: 3.8.3

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

03.08.03-36

The Abstract and other sections of MHI Technical Report MUAP-11013-P (R1) indicate that the purpose of this TR is to present the overall methodology for executing the analysis and design of the Containment Internal Structure (CIS), and subsequently demonstrating the adequacy and safety of the design. The Abstract, Section 4.1, and other sections, also indicate that "ACI 349 (Reference 1) will be used as the basis for design of SC structures. For SC-specific design issues that are not addressed by the ACI 349 code, or where the ACI 349 based approach is not applicable, the code requirements will be supplemented using conservative engineering approaches, available test data, and research results." The applicant is requested to address the following items regarding this overall methodology:

1. For those design aspects where the applicant believes the ACI 349 Code is applicable to the design of SC structures, adequate technical justification should also be provided. In particular, the applicant is requested to specifically identify (a) what equations and provisions of the ACI 349 Code, Chapters 8 through 21, as well as the Appendices, will be utilized, (b) the technical bases for their application to SC modules, and (c) where the use of these various equations and provisions from the ACI Code are described in the TRs. The technical bases should include test data to support the use of these methods unless there is sufficient alternative justification not to do so.

2. For those design aspects in ACI 349 Code that have been determined to be not applicable to SC structures, identify (a) the equations/provisions in Chapters 8 through 21, as well as the Appendices, that are not applicable, (b) what alternative methods are being used, (c) the technical bases for the application of these alternative methods to SC modules, and (d) where these equations and provisions are described in the TRs. While some of this information is provided in MHI TR MUAP-11013-P (R1), it is presented as an overall plan (i.e., not in detail) and does not provide all of the items requested above. As one example, how are the effects of the two out-of-plane bending moments and the in-plane membrane forces in the faceplate addressed simultaneously, which is not required when using reinforced concrete sections having separate rebars in the two perpendicular directions.

3. For those design aspects that are unique to SC structures and are not covered by Items 1 and 2 above (examples of which are identified in Section 1.5 of the MHI TR MUAP-11013-P (R1)), provide the same information requested in Item 2 (b) through 2 (d) above.

4. For construction related aspects of SC structures, describe the criteria and approach that will be implemented. This description should identify the extent of compliance to ACI 349 (Chapters 1 through 7) for SC structures and identify additional requirements to address unique configuration, fabrication, testing, and design of the SC members. Additional topics, beyond those in Chapters 1 through 7 of the ACI 349 Code, should include (but not limited to) the adequacy of construction joints, rate of concrete pour (including consideration of additional stresses in design), assuring no voids in the concrete and at the interface between concrete and faceplate, adequacy of construction inspection without access due to faceplates, and mockup testing to demonstrate adequacy of construction.

03.08.03-37

The statements in the Abstract, Section 4.1, and other sections, of MHI TR MUAP-11013-P (R1), indicate that "the code requirements will be supplemented using conservative engineering approaches, available test data, and research results." The phrase "available test data" should be clarified. Because of the limited experience with the use of SC type structures in general and even more limited experience in its use in nuclear power plants, technical justification for the SC design methods is expected to include test data for the various aspects of design. Where existing test data may not be available or the data exist but the test configuration and/or loading is not adequate, additional testing may be needed, and justification of the approach should not necessarily be limited to only <u>available</u> test data.

03.08.03-38

Section 1.0 of MHI TR MUAP-11013-P (R1) indicates that some of the SC type CIS consist of very thick sections, approximately 10 to 15 feet thick. Explain what provisions in the design, mix, and construction are utilized to minimize the potential issues associated with the use of mass concrete such as cracking due to high heat generation. Identify the issues associated with mass concrete and how they will be addressed for the SC design/construction.

03.08.03-39

Section 1.0 and other sections of MHI TR MUAP-11013-P (R1) refer to various tests of SC type members. The applicant is requested to specifically identify where a description for each of these tests is provided and how these tests address analytical modeling and design aspects of the SC members. The tests and description should demonstrate analytical modeling parameters such as stiffness (load vs. deformation), strength values, failure modes, ductility, hysteresis behavior under cyclic loads, damping, thermal effects, and demonstrate the adequacy of any design equations used for the SC structures. The analytical parameters should be compared to reinforced concrete members and shown to be equal to or better than reinforced concrete members. The tests should also cover the various types of SC members, connections between SC members (including corner connections and connections of different SC types) and connections to reinforced concrete sections. The tests should address SC members loaded to individual loads and combined loads (e.g., membrane plus bending loads, shear plus membrane loads). While MHI TR MUAP-11005-P (R0) provides some test information, it does not appear to provide all of the information requested above.

Also, it appears that some corrections to various sections of the TR should be implemented. Section 1.0, second paragraph, refers to the 1/10th and 1/6th scale tests shown in Figures 1-1 and 1-2, which do not exist. If the intent was to refer to Figures 5-1 and 5-2, then this should be corrected. Section 2.0 should be revised since it indicates that Figures 2-1 through 2-7 have been developed from the drawings provided in References 4 and 5; however, Reference 4 is identified as NRC Regulatory Guide 1.61. Also, Section number 5.3.1 should be revised to section number 5.4, since the title of this subsection is "Task 3 Results" while Section 5.3 is only part of the Task 3.

03.08.03-40

Section 1.0, third paragraph, of MHI TR MUAP-11013-P (R1) refers to industry design guidelines for SC walls in Japan and Korea. The applicant is requested to describe these guidelines and if there are English versions of these guidelines, provide these documents as background material for information. This section of the TR also refers to design specifications for SC walls being developed in the US. If drafts of these documents are available, the applicant is also requested to provide these for background information as well.

03.08.03-41

Section 1.0, fifth paragraph, of MHI TR MUAP-11013-P (R1) states that "In some aspects of structural behavior such as axial tension, compression, flexure, and out-of-plane shear, the behavior of SC walls is similar to that of RC walls." Provide the technical basis for this conclusion which should include test data on SC specimens for the individual loads as well as combined loadings.

03.08.03-42

Sections 1.0, 1.5, and other sections, of MHI TR MUAP-11013-P (R1), state that "For other aspects like ..., or thermal effects, the behavior of SC walls can be different from that of RC walls." Describe the unique aspects of the SC members that are different than reinforced concrete walls when subjected to thermal loads. Explain how the thermal effects are considered in the analysis and design of the SC structures. This should include the effects of thermal cracking in the concrete; relative thermal expansion between the concrete and studs; relative thermal expansion between the concrete/studs and the faceplates; and thermal expansion at discontinuities (e.g., connections to reinforced concrete, connections between different SC types), and localized thermal effects such as proximity to hot piping/penetrations and pipe break. Also, describe how the different rate of thermal expansion between the concrete and steel are considered in the analysis and design of the SC structures. While MHI TR MUAP-11018-P (R0) provides some information about the thermal effects on concrete cracking, it does not appear to provide all of the information requested above.

03.08.03-43

Section 1.0 of MHI TR MUAP-11013-P (R1) states that "This report presents a comprehensive plan for the US-APWR CIS to (1) address the limitations of the small-scale (1/10th and 1/6 scale tests)..." Section 1.1 briefly summarizes the differences between the experimental 1/10th scale test and the actual US-APWR CIS. Based on this brief summary, it appears that some of the differences are not negligible (e.g., f'c = 2,500 psi for the concrete in the test versus 4,000 psi for the US-APWR, yield strength of the tie bars = 82 ksi in the test versus 50 ksi for the US-APWR). Also, Section 1.1 indicates that completion of the comprehensive plan presented in the report provides the framework for applying the results from the 1/10th scale testing to the US-APWR CIS in a conservative and rational manner. Explain how applying this plan provides a framework for applying the results from the 1/10th scale testing to the US-APWR CIS in a conservative manner when a number of the parameters are quite different.

03.08.03-44

Section 1.2 of MHI TR MUAP-11013-P (R1) discusses the 1/6th scale test of the primary shield structure. Provide a description of the various configuration details and material properties to demonstrate that the 1/6th scale test is "identical" to the US-APWR CIS as stated in Section 1.2 of the TR. Explain why only a portion of the primary shield structure is subject to unidirectional cyclic lateral loading during the test. Also, provide the test summary report available for the 1/6th scale test.

03.08.03-45

Section 1.3 of MHI TR MUAP-11013-P (R1) discusses the component tests of SC walls. The TR states that "There are some differences in the section details and fabrication details of the US-APWR SC walls with respect to those in the experimental database. The comprehensive plan presented in this report evaluates these differences...." Also, Section 2.1 of MHI TR 11013-P (R1) indicates that most of the SC-type walls in the CIS have material and geometric parameters that are within the range evaluated in various SC tests. Because of the numerous tests, the differences in some of the section details referred to in Section 1.3 of the TR, and to aide in the evaluation of the many tests that are relied on for the US-APWR design, provide a table for the three SC type walls (Category 1, 2, and 3) which compares the material and geometric parameters used in the US-APWR CIS to the parameters of the test specimens. The parameters to be compared should include overall wall thicknesses, steel faceplate thicknesses, plate to concrete thickness ratios, shear stud sizes and spacings, tie bar sizes and spacings, material properties, anchorage configuration, welds, connections of SC wall sections to other SC wall sections if multiple SC sections are used in the tests, type of loading, purpose of the test and results/conclusions. For the type of loading, the information should identify whether it was pseudo-static pushover, pseudo-static cyclic, dynamic motion, single or multiple directional. For the multidirectional loading explain whether it included only individual loads (membrane, bending, or shear) or also multiple/combined loading (i.e., in-plane combined with out-of-plane forces). It would be helpful if these test data entries in the table are grouped based on the analysis or design aspect of interest (e.g., SC single panel tests for performance under membrane loadings, shear loadings,

flexure loadings, combined loadings, multiple panel tests (e.g., 1/10th, 1/6, etc.), connection tests, etc.).
From the comparisons made in the table described above, if any of the differences are significant or fall outside the range of the test parameters, then the test data should not be relied on for demonstrating the adequacy of the US-APWR SC structures.
The tables should demonstrate that the US-APWR SC type members have been tested for all member forces (membrane, bending, and shear) and their combinations. The staff notes, for example, that the current SC wall component tests described in Section 5.3 do not include some combined loading tests such as flexural loading combined with membrane loading. Also, provide the test summary reports available for the various component tests if they are not included in MHI TR MUAP-11005-P (R0).

03.08.03-46

Sections 1.8 and 4.1 of MHI technical report MUAP-11013-P (R1) state that one of the tasks will consist of “Design of all components for the force and moment demands using ACI 349 design strength equations supplemented with conservative engineering approaches that are correlated to available test data, research literature, and industry recognized design methods.” If no standards or codes exist in the US for SC structures, explain what is meant by industry recognized design methods.

Section 1.8 and the various subsections of Sections 5.0 and 6.0, refer to the use of a nonlinear inelastic finite element (NIFE) modeling approach to correlate the measured and observed behavior from the SC testing performed (Task 3) and then to perform pushover analysis of an NIFE model of the actual US-APWR CIS (Task 4). It appears that these NIFE models will be used to evaluate the 1/10th scale, 1/6th scale, and SC wall component tests. Provide a summary of the different cases that will be analyzed; computer codes used; finite elements selected; modeling approach for the steel plates, concrete, studs, ties, and connections to other SC type members, as well as to the reinforced concrete structures; material properties including stress-strain curves, and the method of load applications. Provide a description of the verification used to demonstrate the adequacy of the concrete finite element and concrete parameters selected for this element, which represent the nonlinear behavior of concrete in the SC model. The above information should be provided for the NIFE benchmarking evaluation under Task 3 against test data and the overall structure performance confirmation for the US-APWR CIS structure under Task 4. Also, explain the differences between the models used in Task 3 and in Task 4.

Also clarify the phrase of "benchmarked NIFE modeling approach." Explain whether the results show already that the NIFE modeling approach is acceptable by comparison to the test data, or adjustments in the NIFE modeling approach are needed in order to match the test results. If adjustments are needed explain why the modeling approach was inadequate and how the adjustments can be implemented with sufficient confidence that it would be valid for the actual US-APWR CIS model.

03.08.03-47

Section 2.1 of MHI TR 11013-P (R1) states that "While a 1/6th scale test was also performed to evaluate the thick primary shield walls, further study is required to assess their stiffness and strength." Explain what is meant by this statement, how and when this further study will be done, and how this information will be used in the analysis and design of the CIS. In addition, explain whether shrinkage and creep effects are considered in the design of the primary shield structure and how the large wall thicknesses were determined, i.e., for shielding requirements or for structural strength.

03.08.03-48

Section 2.2 of MHI TR MUAP-11013-P (R1) describes non-SC structures. For the Category 5 structures, which are massive reinforced concrete sections, provide more descriptive information with figures showing the "thick reinforced concrete blocks," and explain how these blocks are anchored to the basemat of the reactor building complex and possibly to each other.

For the Category 6 structures, which are steel structures with nonstructural concrete fill, (a) provide configuration details for the "steel shape grillages" mentioned in the TR, (b) explain how the Category 6 structures are modeled in the seismic SSI model and separate model(s) to develop member forces, and (c) describe how these structures will be designed. Even though some information is provided in the separate MHI TR MUAP-11018-P (R0), not all of the above requested information is presented in the other TR. Also, a technical basis for only including the steel stiffness properties of this Category 6 structure has not been provided. Even though the concrete is considered to be “nonstructural,” it may provide some stiffness to the members. Therefore, the potential range of stiffness for such members should be considered or an acceptable technical basis needs to be provided for totally neglecting the concrete.

03.08.03-49

Section 3.1 of MHI TR MUAP-11013-P (R1), which corresponds to Task 1-A Dynamic Soil-Structure Interaction Analysis, states that “The effective stiffness and damping values for the finite element model of the CIS will be based on its stiffness before or after concrete cracking as applicable. For seismic plus operating thermal loading conditions, the concrete is expected to be mostly uncracked, and for the seismic plus accident thermal loading conditions, the concrete is expected to be cracked for the category 1 and 2 SC walls as well as the category 4 RC slabs.” If concrete cracking may occur for some of the loading cases, explain why all loading combinations are not evaluated for the range of concrete stiffnesses (i.e., uncracked and cracked conditions). One acceptable approach is to envelop the two sets of seismic responses for concrete stiffnesses (i.e., uncracked and cracked). Then this enveloped seismic loading can be included in the various load combinations. It appears that this enveloping approach is being utilized for developing the US-APWR in-structure response spectra (ISRS) but is not utilized for developing member forces for design.

Also, when analyzing the cracked load combination(s), explain whether the stiffnesses are reduced for all analyses of the individual loads within the load combination being evaluated and not just for the seismic load. If not, provide the basis for not considering the cracked properties for all of the loads.

Section 3.1 makes reference to MHI TR MUAP-11018-P (R0) for additional details regarding the effective stiffness and damping for these analyses. Therefore, any requests for additional information (RAIs) regarding the stiffness and damping of the SC structures will be provided separately as part of the review of MHI TR MUAP-11018-P (R0).

03.08.03-50

Section 3.2 of MHI TR MUAP-11013-P (R1), which corresponds to Task 1-B Seismic Analysis for Structural Design, indicates that the results from Task 1-A will be used in this task to perform equivalent static and/or dynamic response spectrum analysis (RSA) of the CIS to determine the member forces in the various components (walls and slabs) of the CIS for use in design. Provide a description of the two methods of analyses (equivalent static and RSA) which may be used for the CIS. This should include a description of the models, input loading, analysis procedures, assumptions, and discuss any alternative approaches from the guidance presented in SRP 3.7.2, 3.8.3, and Regulatory Guides 1.61 and 1.92. For example, if an equivalent static analysis approach is used, explain whether the approach is consistent with the criteria presented in SRP Section 3.7.2.II.1.B – Equivalent Static Method, and if any differences exist discuss the basis for the alternative methods.

03.08.03-51

Section 4.1 of MHI TR MUAP-11013-P (R1), which corresponds to Task 2-A, Basis of Design Strength Equations and Interaction Equations, states that “Design strength equations will be established for: (i) in-plane force demands, (ii) out-of-plane force demands, (iii) out-of-plane moment demands, and (iv) combinations of in-plane force and out-of-plane moment demands.” Provide further explanation of these set of design strength equations. Explain whether they include: consideration of the combination of loadings such as (a) in-plane membrane forces (tension and compression) along with out-of-plane bending, (b) out-of-plane forces along with in-plane membrane forces (tension and compression), (c) in-plane membrane forces (tension and compression) along with in-plane shear forces, and (d) wherever out-of-plane forces are used in the design strength equations, the twisting moments obtained from the finite element solutions are included along with the out-of-plane finite element moments. This question also affects the information described in Section 4.2, Task 2-B Design Adequacy Check and Section 4.3 Task 2-C, Anchorage/Connection Design and Adequacy Check.

03.08.03-52

Section 4.1 of MHI TR MUAP-11013-P (R1), which corresponds to Task 2-A Basis of Design Strength Equations and Interaction Equations, states that "If necessary, the conservatism of supplemental engineering approaches for the US-APWR project specific SC design may be subsequently confirmed through testing." Similarly, Section 4.1.1 of the report states that "Results of this task will also include the determination of any required confirmatory tests." There are other similar statements regarding the possible future tests in several places of the report. Explain whether the determinations of the what confirmatory tests are needed has been completed, describe these tests, and provide a schedule for the performance of the tests.

In addition, Section 4.1 of MHI TR MUAP-11013-P (R1) indicates that Category 2 and 3 SC-type wall designs will be based on ACI-349 code recommendations implemented with conservative resistance Φ (phi) factors. Explain how these conservative resistance factors were determined and the technical bases for these values.

03.08.03-53

Section 4.3 of MHI TR MUAP-11013-P (R1), which corresponds to Task 2-C, Anchorage/Connection Design and Adequacy Check, states that “For each individual demand type, a conservative connection design philosophy will be selected from the following: (i) full strength with respect to connected components, or (ii) overstrength with respect to seismic force demands, or (iii) ductile design providing adequate structure drift capability. Explain what each of these mean. For example, (a) clarify whether the full strength with respect to connected components means that the connection will be designed to be stronger than both of the connected parts, (b) for the overstrength with respect to seismic force demands approach what are the design criteria for the required overstrength and what are the bases for these criteria, (c) for ductile design providing adequate structure drift capability, why is this identified as an “or” option and not “and” along with the first two approaches, and what are the structure drift criteria and the bases for these criteria.

03.08.03-54

Section 6.1 of MHI TR MUAP-11013-P (R1), which corresponds to Task 4-A, Overall Structure Performance to SSE Loads, describes the nonlinear inelastic finite element (NIFE) model of the entire US-APWR CIS for evaluating its overall structure performance. Regarding the model, explain how the “fracture” referred to in Section 6.1 is considered. Also, explain what and how dynamic characteristics of the linear elastic finite element (LEFE) models of the CIS structure (used in Tasks 1-A and 1-B) will be confirmed using the results of the NIFE analyses.

03.08.03-55

Section 6.2 of MHI TR MUAP-11013-P (R1), which corresponds to Task 4-B, Overall Structure Performance for Beyond-SSE Loads, states that "Limit states for local behavior and failure (for example, strain limits...) will be identified based on the experimental results and the benchmarked NIFE models developed in Task 3." Explain whether these limit states for beyond SSE loads will also include consideration of cyclic/hysteresis and dynamic effects. A comparison of these limit states to corresponding limit states in reinforced concrete structures should also be described. Also, confirm that the purpose of Task 4-B is to identify the seismic margins available beyond SSE loading and not to address the seismic margin type evaluations that are covered by SRP Chapter 19.