REQUEST FOR ADDITIONAL INFORMATION 272-1585 REVISION 0

3/10/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

SRP Section: 03.09.02 - Dynamic Testing and Analysis of Systems Structures and Components
Application Section: 3.9.2.3

QUESTIONS for Engineering Mechanics Branch 1 (AP1000/EPR Projects) (EMB1)

03.09.02-42

RAI 3.9.2-19

In DCD Tier 2, Subsection 3.9.2.3, the applicant made a commitment to ensure the structural and functional integrity of the reactor and steam generator internals under vibratory loadings and thereby assure conformance with GDC 1 and 4.

The staff's review of Subsection 3.9.2.3 indicated that not all the information and documents are provided. Most notably the DCD does not include any dynamic analysis of the steam generator internals, the steam separator, and the safety relief valves, nor does it indicate the design lifetime of the steam generators. According to SRP 3.9.2 and RG 1.20, the applicant is expected to evaluate potential adverse flow effects for the steam generator internals, including the steam separator. The applicant is therefore requested to provide the following:

If the steam generators for the MHI US APWR are classified as prototypes, provide a complete analysis of dynamic responses of structural components within the steam generator caused by steady and operational transient flow conditions. A detailed summary of the assessment of the potential of any adverse flow effects, such as flow-induced vibrations and acoustic resonances, should also be provided. If the steam generators are classified as non-prototypes, provide the dynamic analysis for the components with deviations from the prototype design or operating conditions. The analysis should be accompanied by the expected bias and uncertainty errors. If the steam generator internal structures are a non-prototype design, provide reference to the analysis of the prototype steam generator and give a brief summary of the results. Alternatively, the applicant may prefer to provide a reference document that describes the details of the vibration analysis of the steam generator and includes a brief summary of the results in Subsection 3.9.2.3 of the DCD.

The staff needs this information to assure conformance with GDC-1 and 4. Revise Subsection 3.9.2.3 of the DCD to include the dynamic analysis of the steam generator internals.

03.09.02-43

RAI 3.9.2-20

Previous experiences from boiling water reactors (BWRs) indicated that excitation of acoustic resonances in the standpipes of safety valves are likely to be detrimental to the safe operation of the plant. The potential for a similar occurrence also exists in the standpipes of PWRs.

According to SRP 3.9.2 and RG 1.20, the applicant is expected to evaluate potential adverse flow effects for the steam delivery system, including the safety relief valves and the steam separator. The applicant is requested to analyze the potential of flow-excited acoustic resonance occurring in the standpipes of the safety relief valves (or in any other blind standpipes), which are mounted on the main steam lines exiting the steam generators. If any acoustic resonance is anticipated, explain the countermeasure(s) that will be implemented to avoid or mitigate the resonance. Alternatively, the applicant may provide a reference document that includes the requested information and refer to that document in Subsection 3.9.2.3 of the DCD. The staff needs this information to assure conformance with GDC-1 and 4. Revise Subsection 3.9.2.3 of the DCD to include the analysis of the potential of flow-excited acoustic resonance occurring in the standpipes of safety relief valves.

03.09.02-44

RAI 3.9.2-21

In MHI technical report MUAP-07023-P, the applicant described the methodology used to analyze the dynamic responses of the reactor internals. The methodology consists of performing 1/5 scale model tests to characterize the dynamic fluid forces and validate the computational tools used to simulate the dynamic responses. The details of the vibration analysis of the reactor internals are presented in the technical report MUAP-07027-P. The applicant has used the scale model tests to validate the forcing function definitions and the structural models for dynamic analysis, the details of the model geometry and test conditions, in comparison to the US APWR.

The staff reviewed these documents and found that neither the DCD nor the scale model test report (*1/5 Scale Model Flow Test Report MUAP-07023-P*) discussed the geometry differences between the scale model and the US APWR. The staff needs this information to complete the review of adverse flow effects and to evaluate the validation procedure of the models used to describe the forcing functions and the structural response. The applicant is requested to provide details of any deviations in the 1/5 scale model geometry from the US APWR geometry and operating conditions. Comparison of Fig. 3-2 in the technical report MUAP-07023-P with Fig. 2.1-1 in the technical report MUAP-07027-P suggests that the small-scale model reflects the geometry of the 4-loop reactor rather than that of the US APWR, with the exception of including the neutron reflector. Explain the effects of these differences on the validity of the model test results and their applicability to the US APWR. Discuss how the effects of using a shorter core in the scale model [corresponding to 3.66 m (12 ft) instead of 4.27 m (14 ft)] and effects of other differences are accounted for in assessing potential adverse flow effects, in defining the fluid forcing functions and in the scaling of the forcing functions from the model to the full-size reactor. Review of these issues is necessary to assure conformance with GDC-1 and 4. Revise the 1/5 scale model test report to include the requested information.

03.09.02-45

RAI 3.9.2-22

Apart from the requirement of geometric similarity, when flow-induced vibration mechanisms are investigated by means of model tests, the model and prototype must also be dynamically similar. The applicant used the 1/5 scale model to confirm the reactor structural integrity against flow-induced vibration and static loading. It is therefore essential that the model tests be dynamically similar to the prototype. Deviations of the model parameters from dynamic similarity should be shown to be conservative; otherwise flow excitation mechanisms that occur under the prototype test conditions may not be reproduced in the model tests.

The staff's review indicated that neither the DCD nor the scale model test report (*1/5 Scale Model Flow Test Report MUAP-07023-P*) discussed the dynamic similarity of the scale model tests despite its importance to the reproduction of flow-induced vibration mechanisms. The applicant is requested to compare the relevant dimensionless parameters for the 1/5 scale model tests and the full size reactor at normal operation conditions to demonstrate dynamic similarity between the small scale model and the prototype. Examples of dimensionless parameters include, but are not limited to, fluid-elastic parameter, Strouhal number, reduced velocity, and the ratio of excitation to resonance frequencies. The staff needs this information to complete the review of adverse flow effects and evaluate conformance with GDC-1 and 4. Revise the 1/5 scale model test report to demonstrate the dynamic similarity of the scale model tests and refer to the satisfaction of dynamic similarity criteria in Subsection 3.9.2.3 of the DCD.

03.09.02-46

RAI 3.9.2-23

In the technical report MUAP-07027 the applicant used the resonance frequencies of the small-scale model to validate the FE dynamic simulation of the small-scale model. However, for the US-APWR, it is not clear whether the FE simulation has already been validated (for example, by comparison with the results of the 4-loop reactors). SRP Section 3.9.2 recommends that uncertainties and bias errors in FE simulations be estimated from comparisons with measurements made on structures similar in construction to the reactor internals being modeled.

The staff reviewed the Subsection 3.9.2.3 of the DCD and the MHI technical reports and found that the applicant did not include sufficient information about the experiments performed to validate the structural models nor did the applicant provide any validation results, except a comparison of resonance frequencies for the 1/5 SMT which is included in Report #MUAP-07027-P. In particular, full-scale validation tests of reactor internals (e.g. tests of existing 4-loop reactors) are not mentioned. Validation of the structural models is needed to complete the review of the dynamic responses of reactor internals, including the potential of adverse flow effects. The applicant is requested to explain the methodology used to validate the structural models of the prototype reactor internals and provide typical results of the validation tests together with the bias errors and uncertainties which are expected in the results of structural modelling. Briefly describe the measurements performed to determine the structural resonance frequencies, the mode shapes and the frequency response functions (FRF). Accurate structural modelling is essential for reliable evaluation of the dynamic responses of the reactor internal structures. Review of these issues is necessary to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to include the methodology used to validate the structural models and refer to this methodology in Subsection 3.9.2.3 of the DCD.

03.09.02-47

RAI 3.9.2-24

The applicant has used the SYSNOISE model to describe the acoustic forcing function within the reactor vessel of the US APWR. Therefore, additional information about the validation of this model and its associated uncertainty and bias errors is needed to complete the review process.

In the MHI technical report MUAP-07027-P (*Comprehensive Vibration Assessment Program for US-APWR Reactor Internals*), the applicant used very simple geometries (an annulus and a cylinder) to validate the SYSNOISE model. The staff reviewed the technical report and found that this “validation” approach is inadequate because the geometry of the reactor and cooling system is much more complex than an annulus or a cylinder. According to SRP 3.9.2 and RG 1.20, the applicant is expected to validate the analytical tools by measurements made on structures similar in construction to the reactor internals being modelled. The staff needs this information to complete the review of the models that are used to describe the acoustic forcing functions and the resulting acoustic and structural responses. The applicant is requested to explain the method used to validate the SYSNOISE model of the reactor acoustic environment. Discuss the bias and uncertainty errors in the model predictions. The validation procedure may include comparisons of SYSNOISE predictions with in-plant measurements of existing 4-loop reactors and with tests of the 1/5 scale model of the APWR. Clarify any differences between the predicted and measured values of acoustic resonance frequencies and frequency response functions. Provide the requested comparisons for various locations within the reactor vessel. Review of these issues is needed to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to include the requested information.

03.09.02-48

RAI 3.9.2-25

The applicant has used the SYSNOISE model to describe the acoustic forcing function within the reactor vessel of the US APWR. The reliability and associated bias and uncertainty errors of the reactor acoustic model results depend on the sound attenuation coefficient (i.e. acoustic damping) assumed at various locations along the flow path. The use of appropriate sound attenuation coefficients is therefore necessary to ensure that the reactor internal structures are designed to quality standards commensurate with the importance of their safety functions.

The staff reviewed the Subsection 3.9.2.3 of the DCD and found that the applicant did not provide any information about the sound attenuation coefficient used in the acoustic model of SYSNOISE. The value(s) of this coefficient and the method used to validate these values are needed to complete the review of the dynamic responses of reactor internal structures, including the potential of adverse flow effects. The applicant is requested to discuss the value(s) of the sound attenuation coefficient which is used in:

(a) the validation of the SYSNOISE model against the test results of the 1/5 scale model, and
(b) computing the acoustic loading on the reactor internals of the US APWR by means of the SYSNOISE model

Also, in each of the above two cases, substantiate the used value(s) and explain how these values were validated. The staff requests this information to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to address the sound attenuation coefficient and its validation methods and refer to this information in Subsection 3.9.2.3 of the DCD.

03.09.02-49

RAI 3.9.2-26

The applicant presented the details of the vibration analysis of the reactor internals in the MHI technical report MUAP-07027-P.

The staff reviewed Subsection 3.9.2.3 of the DCD and the technical report MUAP-07027-P, and found the DCD and the vibration assessment report did not give a clear overview of the procedure. For example, it is clear that scale model tests were performed and a finite element model of the scale model geometry was developed to validate the FE simulation. However, it is not clear how the dynamic response of the US APWR was calculated. Is it calculated by scaling up the SMT results/simulation, or by means of a finite element simulation of the prototype geometry and forcing functions? If it was the later case, explain the validation procedure of the prototype simulation. The applicant is requested to explain the procedure used to perform the dynamic analysis of the reactor internal structures and to compute the resulting dynamic stresses. The requested information is needed to complete the review of the dynamic responses of reactor internals caused by steady state and operational flow transient conditions and to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to explain more clearly how the dynamic response of the prototype reactor internals was calculated.

03.09.02-50

RAI 3.9.2-27

In DCD Tier 2, Subsection 3.9.2.3, the applicant made a commitment to performing a comprehensive vibration analysis program for the first US-APWR. The DCD and the vibration analysis report MUAP-07027-P, address various excitation mechanisms, including vortex shedding, flow turbulence, and fluid-elastic instability excitations. The strength of these excitation mechanisms is obviously dependent on the value of the cross-flow velocity component.

The staff's review showed that the DCD included only qualitative information about the velocity distributions, and the methodology used to determine the cross-flow velocities was described rather vaguely. Accurate predictions of the cross-flow velocity distributions over various structures of the reactor internals are essential for reliable evaluation of the effects of flow-induced vibration. Also, validation of the cross-flow velocities used in the flow-induced vibration analysis is needed to complete the review of the dynamic responses of reactor internals, including the potential of adverse flow effects. The applicant is requested to explain the methodology used to determine the cross-flow velocity over various components of the reactor internals, such as the cross-flow velocities near the exit nozzles and over the core supporting structures (upper and lower support columns, guide tubes and instrumentation support structures). If the flow velocity distributions were assumed to be similar to the existing 4-loop reactors, provide evidence to substantiate this assumption. Identify the critical structural components with regard to cross-flow induced vibrations (FIV) and explain the method used to deal with non-uniform velocity distribution along the lengths of these components (e.g. whether partial admission factors were used or uniform velocity distributions were assumed). Review of these issues is needed to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to include the methodology used to determine the cross-flow velocity distributions and refer to this methodology in Subsection 3.9.2.3 of the DCD.

03.09.02-51

RAI 3.9.2-28

The applicant stated that the RCPs of the US APWR deliver 27% higher flow rate at 10% higher head than the existing 4-loop reactor coolant pumps. It is not clear how this increase in the pump capacity is accounted for in the acoustic forcing function, or in the acoustic source representing the pump excitation. Section 3.3.4 of the vibration assessment report MUAP-07027-P stated that: "*The RCP pulsation amplitudes at each rotation speed are assumed as shown in Table 3.3-3.*"

The staff reviewed the relevant documents and found that the DCD did not provide sufficient information regarding the effect of increasing the capacity of the RCP on the acoustic excitation generated by the pumps, and that the vibration assessment report MUAP-07027-P did not explain the basis for the assumed pulsation amplitudes. The applicant should substantiate the assumed values of pressure pulsations. Appropriate modeling of the pump acoustic excitation is essential to evaluate the dynamic responses of the reactor internal structures. This information is needed to ensure proper modeling of the pump acoustic excitation, which is used to compute the acoustic and structural responses of the reactor internals. The applicant is requested to describe the effect of using RCP with higher flow rates and delivery heads on the acoustic excitation generated by the pumps. Review of the acoustic sources generated by the RCP is required to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to describe how the higher capacity of the pumps is accounted for in the acoustic excitation source and to substantiate the assumed values of pulsation amplitudes. Refer to this information in Subsection 3.9.2.3 of the DCD.

03.09.02-52

RAI 3.9.2-29

In Subsection 3.3.1 of the vibration assessment report MUAP-07027-P the applicant stated that: “The methodology of the turbulence force generation proposed by Au-Yang (Reference 4) is applied for the down comer forcing function with some modifications.”

The staff’s review indicated that neither the technical report nor the DCD gave any information as to what were these modifications. Clarification of these modifications is necessary to ensure that an appropriate methodology has been used to develop the flow-induced forcing function in the down comer. The requested information will help the staff evaluate the flow-induced forcing function in the down comer, which is used to compute the dynamic responses of the reactor internal structures. The applicant is requested to describe the modifications made in the methodology suggested by Au-Yang to define the turbulence excitation forces. The reason for introducing these modifications should also be clarified. Review of these methodology modifications is therefore necessary to assure conformance with GDC-1 and 4. Revise the vibration assessment report to include a description of these modifications as well as the reasons for introducing them. Refer to these additions in Subsection 3.9.2.3 of the DCD.

03.09.02-53

RAI 3.9.2-30

In Subsection 3.4.2 of the vibration assessment report MUAP-07027-P the applicant discussed the alternating stress Sa_{FIV} resulting from flow-induced forces. A stress index factor K is used to account for structural discontinuity. The value of the stress index K clearly affects the maximum alternating stress level and the safety margin with respect to the ASME Code of fatigue limit.

The staff review of the relevant documents showed that the DCD did not discuss the stress index K, and the vibration assessment report did not give the values that were used for welds and structural discontinuities. The applicant is requested to discuss the assumed values of the stress index for structural discontinuities (factor K) that are used in the equation of the alternating stress (Sa_{FIV}) given in page 46 of the vibration assessment report MUAP-07027-P. In particular, provide the values used for welds and for joints of components with different thicknesses. Review of this safety margin is essential to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to include the value of K used in the alternating stress equation.

03.09.02-54

RAI 3.9.2-31

In Sub-section 3.3.3 of the vibration assessment report MUAP-07027-P the applicant stated that the power spectral density (PSD) of the down comer is used to calculate the flow-induced vertical forces generated by the flow through the holes in the lower core support plate and in the upper core plate, but did not clarify why this approach was used.

The applicant should elaborate on the differences that may result in the flow-induced vertical forces if the PSD of a jet flow issuing from an orifice is used (instead of that of the down comer), and explain the physical mechanism that causes the atypical discontinuities depicted in the force PSD given in Fig. 3.3-8 of the vibration assessment report. Also, discuss and substantiate the correlation lengths and the joint acceptance coefficients that are used to compute the total integrated vertical forces on the reactor internals. The applicant is requested to explain the reasons for using the power spectral density (PSD) function which is measured in the down comer, rather than the PSD of orifice flow, to calculate the flow-induced vertical forces generated by the flow through the holes in the lower core support plate and in the upper core plate.

The staff recognizes the difficulties involved in responding to this RAI and is therefore prepared to review a response that states the current value of safety margin and gives a realistic estimate of the change in this safety margin that will result by considering a more representative PSD to calculate the flow-induced vertical force. The requested information will help the staff evaluating the flow-induced vertical forces, which are used to compute the dynamic responses of the reactor internal structures. Review of the effect of using a more representative PSD of the pressure fluctuations is therefore necessary to assure conformance with GDC-1 and 4. Revise the vibration assessment report to include a brief description of the effect of the PSD characteristics on the margin of safety.

03.09.02-55

RAI 3.9.2-32

Section 3.9.2 of the SRP and RG 1.20 recommend the validation of all numerical models and forcing functions that are used in the design process. Obviously, the reliability and associated bias and uncertainty errors of these tools depend on the acceptance criteria of their predictions. The staff is concerned about the rigor of the acceptance criteria used by the applicant to validate the computational models and forcing functions. To explain the gist of this RAI, the applicant is referred to Table 3.3-5 and Fig. 3.4-2 of the vibration assessment report MUAP-07027-P. In the table, the validation is judged acceptable although the reactor design is much more complex than the simple annulus/cylinder geometry used to validate the SYSNOISE model, and in Fig. 3.4-2, the analysis predictions of the core barrel and neutron reflector displacements are judged acceptable although their predicted PSDs do not seem related to those measured. The acceptance criteria for the prediction and validation of structural models (FE programs), acoustic excitations (SYSNOISE) and forcing function definitions need to be clarified to ensure that the reactor internal structures are designed to quality standards commensurate with the importance of their safety functions.

The DCD does not provide any information about the acceptance criteria used to validate the computational tools used to analyze the dynamic responses of the reactor internal structures. In addition, the comparisons provided in the report are not adequate to confirm validation of the analysis tools. The applicant is requested to discuss the acceptance criteria used to evaluate the suitability of the analytical and/or computational tools to calculate the dynamic responses of the reactor internal structures. The staff requests this information to assure conformance with GDC-1 and 4. Revise the comprehensive vibration report to adequately address the acceptance criteria of the analysis results and refer to the acceptance criteria in Subsection 3.9.2.3 of the DCD

03.09.02-56

RAI 3.9.2-33

In MHI technical report MUAP-07023-P the applicant described the 1/5 scale model tests performed to analyze the dynamic responses of the reactor internals, and the details of the vibration analysis of the reactor internals are presented in the technical report MUAP-07027-P.

In general, the staff found the text provided in the technical reports MUAP-07023-P and MUAP-07027-P inadequate. For example, the 1/5 Scale Model Flow Test Report has only 3 pages of text. It is therefore rather difficult to evaluate the data and results included in these reports. In order to be able to complete the review, without having to generate many additional RAIs, the applicant is requested to provide revised versions of the MHI technical reports MUAP-07023-P and MUAP-07027-P with expanded text to provide sufficient explanation of the included tests and results. On each table and figure included in these reports, the applicant is requested to give the relevant information, such as: considered geometry (e.g. SMT, prototype of US-APWR, J-APWR or 4-loop PWR) and source of data (e.g. measurements, FE simulation, or scaling up from SMT results). The requested revisions of the reports would allow the staff to better understand the technical information in the submitted documents and related issues addressed in the DCD. The requested information is needed to assure conformance with GDC-1 and 4.

03.09.02-57

RAI 3.9.2-34

The applicant stated in the MHI technical report MUAP-07023 that the scale model tests were performed with either 77 or 85 Guide Tubes (GTs).

The staff reviewed the technical report and found that the applicant did not explain why these numbers of GTs were chosen for the model tests. The applicant is therefore requested to explain the reason(s) of choosing these numbers of GTs for the model tests and to elaborate on the significance of these numbers of GTs, in comparison to the total numbers of GTs that will be used during normal operation of the US-APWR. The requested information is needed to assure conformance with GDC-1 and 4.

03.09.02-58

RAI 3.9.2-35

The applicant stated in Table 2.1-1 of the vibration assessment report MUAP-07027 that the flow velocity in the vessel exit nozzle of the US-APWR will be increased, compared with the current 4-loop reactors.

The technical report does not provide any discussion regarding possible adverse flow effects on the structural components that will be subjected to flow velocities higher than those in the 4-loop reactor. FIV analysis of the structural components which are exposed to higher flow velocities than in the 4-loop reactors is needed to ensure that these structures are designed to quality standards commensurate with the importance of their safety functions. The applicant is requested to discuss the analysis performed and the tests planned to demonstrate that adverse flow effects will not cause unanticipated excessive flow-induced vibrations or structural damage to the *reactor piping systems and the internal structures in the upper core plenum near the exit nozzles*. The requested information is needed to assure conformance with GDC-1 and 4.