MITSUBISHI HEAVY INDUSTRIES, LTD.
16-5, KONAN 2-CHOME, MINATO-KU
TOKYO, JAPAN

December 26, 2008

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-08309

Subject: **MHI's Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code"**

Reference: 1) Letter from the NRC (ML083090739) to Y. Ogata (MHI), "Mitsubishi Heavy Industries, Inc.-Request for Additional Information on Topical Report MUAP-07034-P,Revision 0、"FINDS: Mitsubishi Fuel Assemblies Seismic Analysis Code" dated on December 2, 2008

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") responses entitled "MHI's Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code". In the enclosed document, MHI provides the responses for RAI's all items of those in Reference 1 within the allotted 30 day response time-frame that is given from the date of the formal RAI issuance.

As indicated in the enclosed materials, this document contains information that MHI considers proprietary, and therefore should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential. A non-proprietary version of the document is also being submitted in this package (Enclosure 3). In the non-proprietary version, the proprietary information, bracketed in the proprietary version, is replaced by the designation "[ ]".

This letter includes a copy of the proprietary version (Enclosure 2), a copy of non-proprietary version (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all materials designated as "Proprietary" in Enclosure 2 be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

D081
NRO

Enclosures:

1. Affidavit of Yoshiki Ogata

2. MHI's Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code" (proprietary)

3. MHI's Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code" (non-proprietary)

CC: J. A. Ciocco
C. K. Paulson

<u>Contact Information</u>

C. Keith Paulson, Senior Technical Manager
Mitsubishi Nuclear Energy Systems, Inc.
300 Oxford Drive, Suite 301
Monroeville, PA 15146
E-mail: ck_paulson@mnes-us.com
Telephone: (412) 373 – 6466

ENCLOSURE 1

Docket No.52-021
MHI Ref: UAP-HF-08309

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, being duly sworn according to law, depose and state as follows:

1. I am General Manager, APWR Promoting Department, of Mitsubishi Heavy Industries, Ltd ("MHI"), and have been delegated the function of reviewing MHI's US-APWR documentation to determine whether it contains information that should be withheld from disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential.

2. In accordance with my responsibilities, I have reviewed the enclosed "MHI's Partial Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code" and have determined that portions of the report contain proprietary information that should be withheld from public disclosure. Those pages containing proprietary information are identified with the label "Proprietary" on the top of the page and the proprietary information has been bracketed with an open and closed bracket as shown here "[ ]". The first page of the technical report indicates that all information identified as "Proprietary" should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a).

3. The information in the report identified as proprietary by MHI has in the past been, and will continue to be, held in confidence by MHI and its disclosure outside the company is limited to regulatory bodies, customers and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and is always subject to suitable measures to protect it from unauthorized use or disclosure.

4. The basis for holding the referenced information confidential is that it describes the unique code and files developed by MHI for the fuel of the US-APWR and also contains information provided to MHI under license from the Japanese Government. These code and files were developed at significant cost to MHI, since they required the performance of detailed calculations, analyses, and testing extending over several years. The referenced information is not available in public sources and could not be gathered readily from other publicly available information. MHI knows of no way the information could be lawfully acquired by organizations or individuals outside of MHI and the Japanese Government.

5. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of supporting the NRC staff's review of MHI's Application for certification of its US-APWR Standard Plant Design.

6. Public disclosure of the referenced information would assist competitors of MHI in their design of new nuclear power plants without the costs or risks associated with the design of new fuel systems and components. Disclosure of the information identified as proprietary would therefore have negative impacts on the competitive position of MHI in

the U.S. nuclear plant market.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information and belief.

Executed on this 26th day of December, 2008.

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure 3

UAP-HF-08309, Rev.0

MHI's Partial Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P(0) "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code"

December 2008
(Non Proprietary)

INTRODUCTION

This report documents MHI's responses to the NRC's Request for Additional Information (RAI) dated December 2 2008 concerning the Topical Report MUAP-07034-P(0) "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code".

QUESTION-1 **Request for detailed description of the in-elastic impact tests**

In UAP-HF-08139 Rev.0, pages D-44 through D-53, Mitsubishi briefly describes the impact tests that were performed for verification of the in-elastic impact model. Section 5.2 (p. D-44) describes the mockup fuel assembly and states that the weight is [ ] kgf. Additional weight ([ ]kgf) is also mentioned for simulating multiple collisions. Table 5.2-1 lists the increasing drop height sequences used in Case 5.2-1 and Case 5.2-2. Figure 5.3-2(1) compares the measured and predicted impact force for each sequential drop height for Case 5.2-1. Figure 5.3-3(1) compares the measured and predicted impact forces for Case 5.2-2.

1.1 From the discussion in Section 5.2, the drop heights listed in Table 5.2-1 and the impact force histories in Figures 5.3-2(1) and 5.3-3(1), we do not understand when the additional mass was added to the tests. Was it added progressively to a total of [ ] kgf, all at once, and at what test sequence number for each test? Please provide a detailed discussion of the load sequences of both cases 5.2-1 and 5.2-2.

1.2 Using Figure 5.3-2(1) below as an example, please explain the discontinuity in the predicted force from test 45 to 46 (see added lines). Please explain the large decrease in predicted force compared to the more gradual decrease in the measured force from test 45 to 46 and beyond.

[

Force (kgf)

]

Test Sequence

Figure 5.3-2(1) Case 5.2-1 Impact Force

1.3 Please discuss the large differences between measured and predicted impact forces shown in Figure 5.3-3(1) for Case 5.2-2.

RESPONSE

1.1 The additional weight of [ ] lbf ([ ]) kgf is applied throughout each test sequence listed in Table 5.2-1 for cases 5.2-1 and 5.2-2. The only difference in the two cases is in the progression of drop heights and their repetition sequence.

1.2 In the test, the deformation of the grid spacer cell progresses gradually after buckling of the cell wall, which results in a gradual decrease of the force, as opposed to the immediate loss of load, due to buckling, modeled in the FINDS code. Since the gradual deformation is not modeled in the FINDS code, the FINDS code will predict a step change in the force when buckling is predicted, between steps 45 and 46 in the test sequence, to occur.

1.3 Since there will be some variability in the grid spacer deformation characteristics among the different grid spacer samples in the tests, the averaged performance of the grid spacer is modeled in the FINDS code. Therefore it is not expected that the FINDS code will give a close match of the forces of the tests on every grid spacer specimen. On the other hand, the FINDS code predicts the grid deformation larger than the tests and this is conservative because greater deformation potentially increases fuel assembly's lateral deflection therefore bending stress also increases.

QUESTION-2 Request for description of FINDS input to the loss-of-coolant accident (LOCA) analysis

MUAP-07034-P (page 1-1) references MUAP-07008-P, Appendix D, to describe the method of using FINDS for LOCA analysis. However Appendix D does not describe how the FINDS LOCA input is generated or used.

2.1 Please describe how the FINDS LOCA input forcing function is generated. Also discuss how it is input to the FINDS code, that is, as an acceleration history or what? When is it considered separately or in combination with the seismic loads?

RESPONSE

The analysis of the fuel assemblies' response to LOCA by the FINDS code is performed apart from the seismic response analysis. An acceleration history of the core plates during LOCA is input to FINDS code for analyzing the fuel assemblies' response. To generate the LOCA acceleration history, an analysis of the reactor coolant system's (RCS) thermal hydraulic transient and an analysis of the reactor vessel and core internal's dynamic responses are needed. The RCS thermal hydraulic transient during the blowdown stage of LOCA is analyzed using the MULTIFLEX code which is shown in Section 3.9.1.2.1 of Reference 2-1. The abrupt RCS pressure reduction, due to the pipe break, results in the propagation of a high speed pressure wave in the RCS. The time required for the propagation of the wave circumferentially around the core barrel creates a pressure differential across the core barrel. This pressure differential results in the vibration of the core internals and core barrel. The 3-dimensional dynamic response of the reactor vessel and core internals (due to the pressure fluctuations inside the reactor vessel analyzed by the MULTIFLEX code) are analyzed by the ANSYS FEM code. The horizontal time history displacements of the upper and lower core plates and the vertical loads between the core plates and the fuel assembly nozzles are calculated in this FEM analysis. A flow chart of the analytical procedure is shown in Figure 2-1.

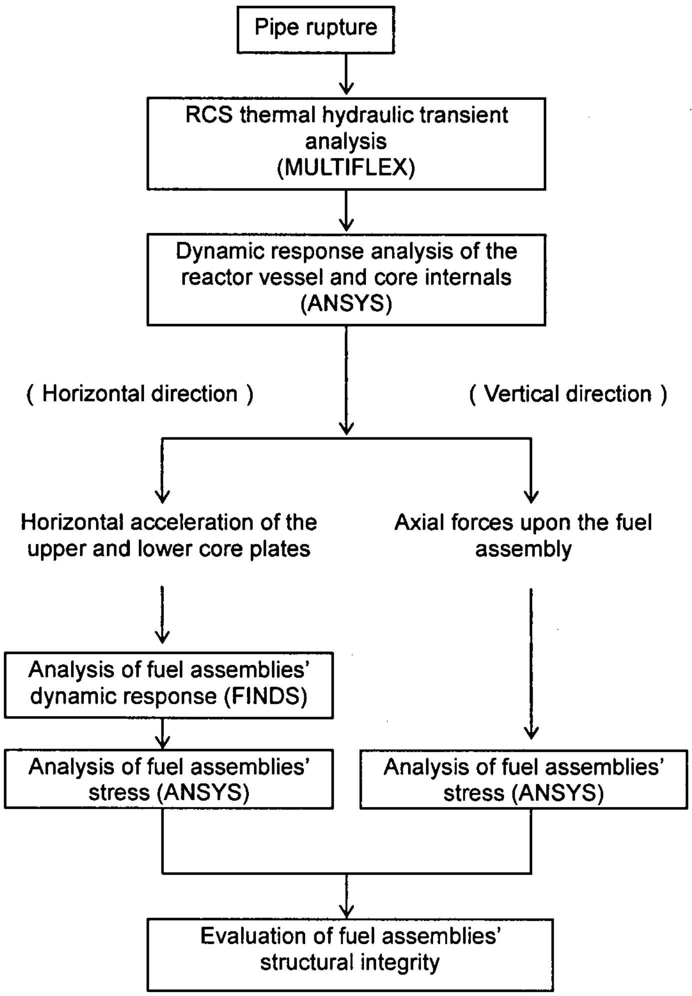


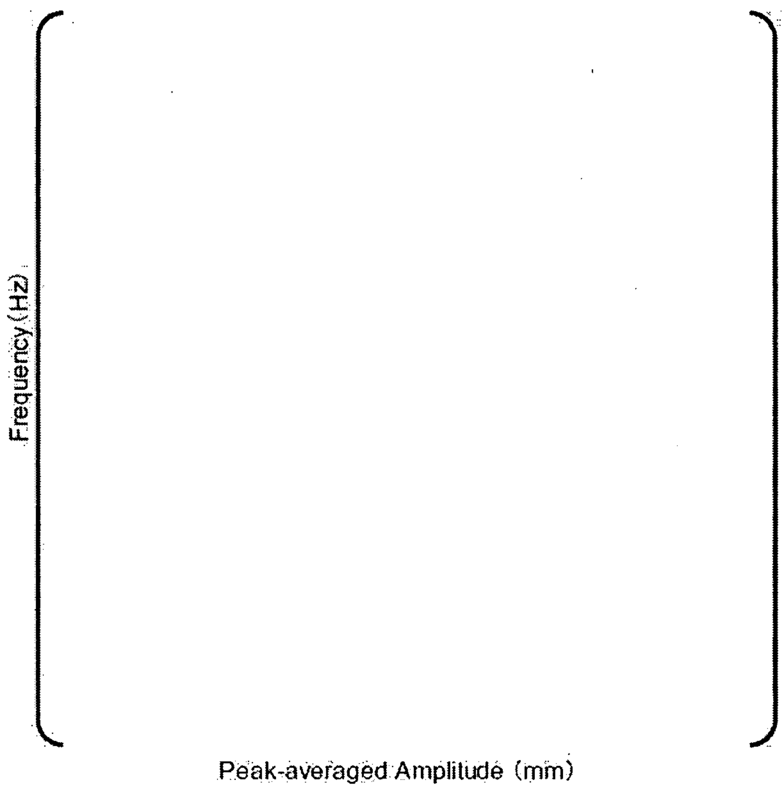
Figure 2-1 Flow Chart for determining fuel assembly response and stresses due to LOCA

QUESTION-3 Request for discussion on uncertainty band on the FINDS results

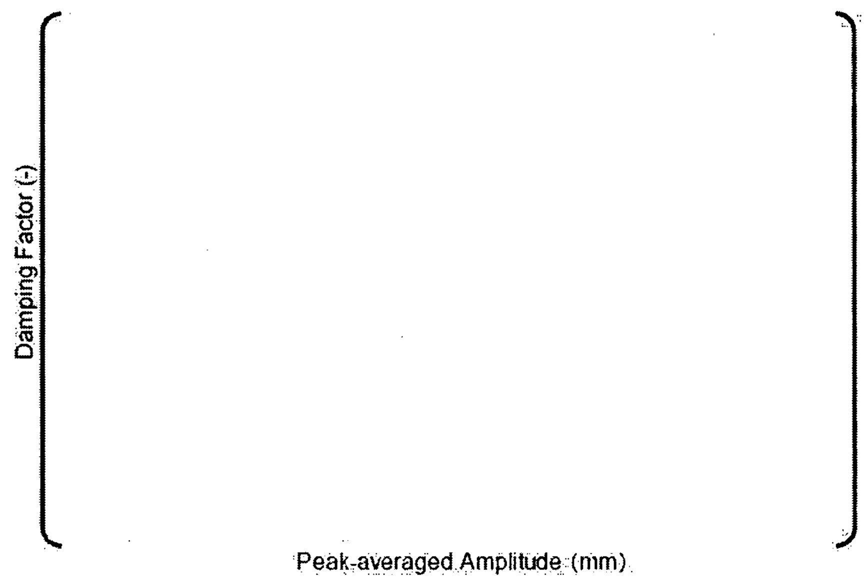
The FINDS code predicts the bending displacements of the fuel assemblies, which are applied to an ANSYS finite element model of the fuel rods to predict the applied bending stresses in the fuel rods. Therefore, the accuracy of the bending stresses is a direct function of the accuracy of the FINDS displacement solution. The FINDS results are a function of: 1) the input seismic acceleration histories; 2) the elastic modulus of the fuel rods; 3) and the testing based damping and frequency function that account for the grid spacer nonlinearities.

3.1 Please discuss and provide FINDS analysis results showing the uncertainty band on the FINDS results for the expected range of material properties and the damping and frequency sensitivities. This will provide additional verification of the accuracy of the FINDS fuel rod displacement solution for application to the code based stress analysis.

3.2 FINDS validation tests show occasional mismatches with experimental data. For example, Figure 5.3-2(1) shows some data points with considerable error relative to the test data. Please discuss how errors in predicting impact force, plastic deformation, and coefficients of restitution affect fuel assembly nodal displacement results in FINDS and quantify how they contribute to the uncertainty band.



3.3 The amplitude-dependant frequency relationship is defined with experimental methods. Plots of the data show that for a given amplitude, the frequency can fall within a band of roughly[ ]Hz (see the upper half of Figure 3.5-3, reproduced above). Please demonstrate with a reasonable FINDS comparison case the effect of defining the amplitude-dependant frequency relationship with an upper bound curve fit and a lower bound curve fit. At a minimum, report peak plastic deformation, peak reaction force, and peak nodal displacement for each analysis.



3.4 The amplitude-dependant damping is also defined experimentally. For a given amplitude, the damping factor can vary up to about[ ]. See the lower half of Figure 3.5-3, reproduced above. Demonstrate with a reasonable FINDS comparison case the effect of defining the amplitude-dependant damping relationship with an upper bound curve fit and a lower bound curve fit. At a minimum, report peak plastic deformation, peak reaction force, and peak nodal displacement for each analysis.

RESPONSE

3.1 Figure 3.1-1 and Figure 3.1-2 show the FINDS predicted variation of vibrational displacement at the grid spacer's elevation and the grid spacer impact force, respectively, for reactor peripheral fuel assemblies when Young's modulus of the beam model is varied [ ] percent from its original value. The upper and lower core plate displacement histories used in the large shaker table test for the S_1 wave were input to FINDS. The S_1 wave and S_2 wave which is described later are those that were used in the Japanese government sponsored vibration test[3-1]. For the [ ] percent change in Young's modulus the displacement and the impact force, changed by [ ] percent and [ ] percent, respectively, from the original analysis. The sensitivity of these two characteristics to Young's modulus is not 1:1 due to the non-linearity of the FINDS code but is equal to or less than the Young's modulus variation of [ ] percent. Figure 3.1-3 shows the FINDS predicted variation in grid spacer plastic deformation in reactor peripheral fuel assemblies when Young's modulus is varied [ ] percent using the S_2 upper and lower core plate displacement time history as input. The variation in plastic deformation due to Young's modulus variation has a slightly inconsistent sensitivity but the difference is small. Most importantly, there is a negligible effect on the maximum plastic deformation, which is about the same as the original result of [ ] inch ([ ]) mm.

The effect of the uncertainty band for damping and frequency is discussed in the response to RAIs 3.3 and 3.4.

Displacement by Sensitivity Analysis (mm)

Displacement by Original Analysis (mm)

Figure 3.1-1 Predicted Sensitivity of Vibrational Displacement to Young's Modulus

Force by Sensitivity Analysis (kgf)

Force by Original Analysis (kgf)

Figure 3.1-2 Predicted Sensitivity of Grid Spacers' Impact Force to Young's Modulus

Plastic Deformation by Sensitivity Analysis (mm)

Plastic Defomation by Original Analysis (mm)

Figure 3.1-3 Predicted Sensitivity of Grid Spacers' Plastic Deformation to Young's Modulus

3.2 The models in FINDS used to predict grid impact force and plastic deformation are based on test results and these analytical results are reasonable or conservative compared to the measured results even though there can be significant variability between measured and predicted. The magnitude of the loads and grid deformations are most sensitive to the seismic wave's frequencies and acceleration amplitudes. However, the determination of the grid's dynamic characteristics from testing are conservatively incorporated into the FINDS code. Firstly the grid impact strength defined by its initial buckling load is set conservatively incompliance with SRP 4.2, Appendix A, Section III.1 paragraph 2. Secondly, grid impact stiffness prior to the initial buckling load can be considerably high which will result in the initial buckling load being calculated at lower input accelerations. And lastly, the grid spacer's plastic deformation is set conservatively high in the FINDS code, as shown in Figure 5.3-2(2) and 5.3-3(2). An additional small effect is that by inputting grid characteristics to the FINDS code that result in the initiation of plastic deformation earlier (initial buckling load) and with higher than tested deformation rates, the available lateral space in the core for fuel assembly lateral displacement (bending stress) is increased.

3.3 The upper and lower bounds of the amplitude-dependent frequency which are inputted to FINDS are shown in Figure 3.3-1. The seismic wave input is that from the large shaker table test using the S_1 wave. The influence of this variability in amplitude-dependent frequency on vibrational displacement at each grid spacer's elevation and the grid spacer impact force in reactor peripheral fuel assemblies are shown in Figure 3.3-2 and Figure 3.3-3, respectively. The influences on the displacement and grid spacer's impact force are estimated to be approximately[ ] percent and [ ] percent, respectively. As for the grid spacer's plastic deformation in the fuel assemblies, the resulting influence, using the S_2 wave and the same amplitude-dependent frequency variation, is a slightly inconsistent sensitivity, but the difference is small, as can be seen in Figure 3.3-4.

3.4 The upper and lower bounds of amplitude-dependent damping which are inputted to FINDS are shown in Figure 3.4-1. The seismic wave input is that from the large shaker table test using the S_1 wave. Figure 3.4-2 and Figure 3.4-3 show the resulting influence on vibrational displacement at each grid spacer's elevation and grid spacer's impact force, respectively. Figure 3.4-4 shows the grid spacer's plastic deformation sensitivity, using the same damping variation and the S_2 wave. Compared with the influence of amplitude-dependent frequency variation (discussed in 3.3), the influence of damping variability has a very small effect on vibrational displacement, grid spacer impact force and plastic deformation.

The sensitivity studies described in 3.1, 3.3 and 3.4 show that the uncertainties associated with material properties, frequency and damping independently result in variations of up to [ ] percent in vibrational displacement, grid spacer's impact force and plastic deformation. It is, however, very difficult to quantify the influence in general on the fuel assembly's response in the FINDS code analysis due to the dependence on the frequency spectrum and magnitude of the acceleration waves. Thus, MHI is planning to perform a parametric study to determine the sensitivity to material property and frequency and damping variations by using acceleration waves of the US-APWR plant itself and to include these results and conclusions in the report, "Evaluation Results of US-APWR Fuel System Structural Response to Seismic and LOCA Loads", to be submitted in March, 2009.

Frequency (Hz)

Peak-averaged Amplitude (mm)

Figure 3.3-1 Amplitude Dependency of 1st Mode Natural Frequency with Upper and Lower Bounds

Displacement by Sensitivity Analysis

Displacement by Original Analysis (mm)

Figure 3.3-2 Predicted Sensitivity of Vibrational Displacement to Amplitude-Dependent Frequency

Force by Sensitivity Analysis (kgf)

Force by Original Analysis (kgf)

Figure 3.3-3 Predicted Sensitivty of Grid Spacer Impact Force to Amplitude-Dependent Frequency

Plastic Deformation by Sensitivity Analysis (mm)

Plastic Defomation by Original Analysis (mm)

Figure 3.3-4 Predicted Sensitvity of Grid Spacer Plastic Deformation to Amplitude-Dependent Frequency Variation

Damping Factor (-)

Peak-averaged Amplitude (mm)

Figure 3.4-1 Amplitude Dependency of 1st Mode Damping Factor with Upper and Lower Bounds

Displacement by Sensitivity Analysis

Displacement by Original Analysis (mm)

Figure 3.4-2 Predicted Senstivity of Vibrational Displacement to Amplitude-Dependent Damping

Force by Sensitivity Analysis (kgf)

Force by Original Analysis (kgf)

Figure 3.4-3 Predicted Sensitivity of Grid Spacer Impact Force to Amplitude-Dependent Damping

Plastic Deformation by Sensitivity Analysis (mm)

Plastic Defomation by Original Analysis (mm)

Figure 3.4-4 Predicted Sensitivity of Grid Spacer Plastic Deformation to Amplitude-Dependent Damping

QUESTION-4 Request for example calculations showing the combination of stress results using the square-root sum of the squares (SRSS) method

MUAP-07008-P, Appendix D, Section D.4.0, Evaluation Methodology of Fuel Assembly Response and Strength, discusses how the FINDS displacement results are applied to an ANSYS finite element model of the fuel assembly to calculate the stresses in the fuel rods due to horizontal seismic excitation. The text further states that the SRSS method is used to combine stresses.

4.1 Please provide a detailed example of how the ANSYS bending stresses in the fuel rods are combined with all the other stress components using the SRSS method. Given the example stress components in Table 4-1 and the reference coordinate system in Figure 4-1, show how the stress components are added and/or SRSS'd to predict the stress intensity for comparison with the code stress limits. (Note, an alternate nomenclature for the stresses is acceptable provided that all components are described). Please also show the applicable stress limits as a multiple of the allowable stress intensity, Sm. Please reference where in the code Sm is obtained and what temperature is assumed.

Table 4-1 Example stress components for SRSS combination

Load	Mean Axial Stress (3-direction)	Hoop Stress	Axial Bending Stress from Acceleration in 1-direction	Axial Bending Stress from Acceleration in 2-direction
Normal Loads	S3m	Sh		
SSE Earthquake				
Axial S3 accel.	S3sse			
Horizontal S1 accel.			S3sse_1	
Horizontal S2 accel.				S3sse_2
OBE Earthquake				
Axial S3 accel.	S3obe			
Horizontal S1 accel.			S3obe_1	
Horizontal S2 accel.				S3obe_2
LOCA				
Axial S3 accel.	S3loca			
Horizontal S1 accel.			S3loca_1	
Horizontal S2 accel.				S3loca_2

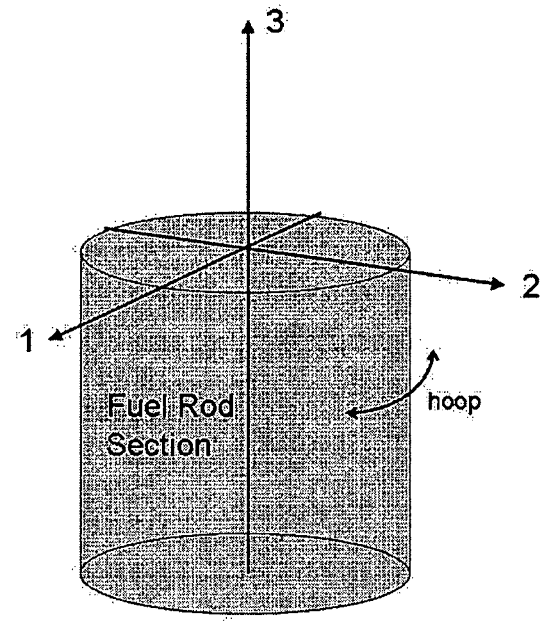


Figure 4-1 Example stress coordinate system corresponding to Table 4-1

RESPONSE

The method of combining normal loads with seismic and LOCA loads is described as follows by using the example stress components in Table 4-1.

The basis for the multiplier on the allowable stress intensity, Sm, is described in Sec 3.2.1 of MUAP-07008 as 1.5. To determine Sm, the cladding temperature which corresponds to the stresses shown in the equations is assumed. For example, the cladding stresses for the limiting rod described in Section 3.4 of Reference 4-1 are calculated at [ ] deg.F at the beginning of life.

QUESTION-5 **Request for discussion of spacer grid spring relaxation and its effect on FINDS results at end of life conditions**

According to MUAP-07016P, spacer grid springs are expected to relax to 10 percent or 5 percent of their initial values by end of life, due to irradiation. Spacer grid spring stiffness is expected to be a factor in the FINDS code's experimentally-determined amplitude-dependant frequency and damping curves.

5.1 Please discuss the effects of spacer spring relaxation on the amplitude dependant frequency relationship and the amplitude dependant damping relationship. For both relationships, estimate the effect of reducing the spacer spring force to 5 percent of its initial value.

RESPONSE

The effect of grid spacer spring relaxation on the vibration characteristics of the fuel assembly is evaluated by an ANSYS FEM analysis. The analysis model and method were described in the previous response to the NRC's RAIs on the Topical Report MUAP-07034. The RAI response describing the analysis model and methods was provided in Section 2.2 of Appendix A in Reference 5-1.

For the analysis model with relaxed spring force, the spring forces are determined as [ ] percent of the initial value for the top grid spacer, [ ] percent for the middle grid spacers and [ ] percent for the bottom grid spacer, respectively.

The both of the analysis models are supported at the top and bottom end and [ ] inch ([ ] mm) of initial displacements are given to the middle grid spacer elevation. The displacements are released quickly and the time history displacements at the middle grid spacer positions are calculated. Based on the time history displacement data, the amplitude dependence of frequency and damping of the fuel assembly with the relaxed spring force are estimated as shown in Figure 5-1.

The amplitude dependence of the frequency and damping factor is caused by the contact and slippage mechanism between the fuel rods and grid spacers. As the vibration amplitude increases the natural frequency decreases, and conversely, the damping factor increases due to slippage at the contact points.

[ ]

The vibration characteristics input to FINDS for the fuel assembly with relaxed springs have been obtained from the analysis results of an ANSYS FEM model.

Frequency (Hz)

Peak-average amplitude (mm)

(a) Natural frequency

Damping factor (-)

Peak-average amplitude (mm)

(b) Damping factor

Figure 5-1 Amplitude Dependence of 14-ft fuel assembly frequency and damping using ANSYS FEM Analysis

QUESTION-6 Request for discussion related to spacer grid crush effects

The FINDS inelastic impact model accounts for the structural crush and collapse of the spacer grids resulting from impact. This is done in a separate calculation that tracks spacer grid crush as a change in gap size and impact stiffness. Plastic deformation in the spacer grid does not appear to affect the fuel assembly beam characteristics, the amplitude dependence of frequency or damping, or any other parameters associated with the beam representation of the fuel assembly. In the most severe cases of impact imaginable, every cell of the spacer grids could collapse such that the fuel rods bunch together with little gap remaining. This degree of impact is expected to significantly alter the dynamic response of the fuel assemblies, including the frequency, damping, and fundamental beam characteristics.

6.1 What is the intended range of use of the FINDS code, in terms of the number of spacer grid cells crushed?

6.2 Please demonstrate that a fuel assembly which experiences the maximum amount of spacer grid crush relevant to a FINDS analysis is still adequately modeled by the standard FINDS modeling approach.

6.3 Spacer grid crush is expected to be affected by spring relaxation due to irradiation. Discuss the effect of reducing spacer grid spring forces to [ ] percent of their starting value to represent the end of life condition.

RESPONSE

6.1 The grid spacer's plastic deformation observed in the single span fuel assembly impact test described in Section 5 of Appendix D of Reference 5-1 was about [ ] inch ([ ] mm) at maximum. As results of the simulation analysis for the test, it was confirmed that the FINDS inelastic impact model for the grid spacer predicted the deformation conservatively up to the deformation at least. In this deformation range, a few to several rows of cells in the grid spacer are slightly laterally shifted (parallelogram effect), but the deformation of cells in the deformed rows is very small since the deformation tends to be distributed to the several rows within the grid spacer. The deformed profile of a grid spacer, obtained by a pendulum impact test, will be shown in the report to be submitted in March, 2009. In case that the deformation over [ ] inch ([ ] mm) is calculated by FINDS analysis, the additional tests with single span fuel assemblies will be perform to enhance the validated range of the grid spacer deformation.

6.2 The grid spacer plastic deformation observed in the large shaker table test was about [ ] inch ([ ] mm) and the FINDS code accurately or conservatively simulated the fuel assembly's response in terms of displacement and grid deformation. The grid spacer deformation always initiates in a non-control rod guide thimble row since they have no thimble support against buckling. Therefore, such a small magnitude of grid spacer deformation will not have a measurable influence on the fuel assembly skeleton and the fuel assembly's vibrational characteristics. This insensitivity would be retained for greater deformation since the fuel assembly skeleton is negligible affected by deformation of a non-thimble row.

6.3 MHI performed pendulum type grid spacer impact tests at operating temperature using as-built grid spacers and grid spacers with reduced grid spacer spring force (as low as [ ] percent of the initial value). Details of the tests will be discussed in the report to be submitted in March, 2009. The results indicate small decreases in the buckling load and dynamic stiffness of the grid spacers with the reduced spring force compared with the as-built grid spacers. This data indicates that there is only a small influence on the grid spacer's impact behavior due to grid spacer spring relaxation. The quantitative evaluation of the influence on the fuel assemblies' response analysis using FINDS will be reported in March, 2009.

QUESTION-7 Request for discussion related to end of life properties on FINDS's inelastic impact model

Embrittlement of the spacer grid material is expected by end of life. It is understood that the yield strength increases, but the concern is that the ductility decreases. This loss of ductility is expected to be relevant to the spacer grid crush behavior. Instead of absorbing energy due to plastic deformation during cell crush, the spacer grids are expected to deform by a reduced amount, then fracture. This end of life spacer grid crush behavior is expected to differ from the experimentally-determined beginning of life crush behavior.

7.1 Discuss how end of life material properties would affect FINDS's inelastic impact model. How are end of life properties included in fuel assembly design calculations using FINDS? Are separate FINDS analyses run to represent beginning-of-life and end-of-life conditions? If not, explain how the changes in fuel assembly response due to irradiation are accounted for using FINDS. Discuss how the change in spacer grid spring stiffness and spacer grid embrittlement affect the FINDS results.

7.2 Estimate a set of end-of-life inputs for a FINDS analysis of the U.S. Advanced Power Water Reactor fuel assemblies and compare the FINDS results for end-of-life inputs with the similar results for the beginning-of-life input.

RESPONSE

7.1 In the irradiated condition, the relaxation of grid spacer spring force and the grid spacer material embrittlement affect the crush behavior of the grid spacer.

To investigate the effect of the relaxation of grid spacer spring on crush behavior, MHI has conducted impact tests using grid spacers with beginning of life and with relaxed grid springs. The spring force is [ ] percent of the beginning of life value for the relaxed spring case. According to the tests, impact strength and the stiffness of the grid spacers with the relaxed grid spring force are slightly lower compared with those with the beginning of life spring force.

The effect of grid spacer material embrittlement on grid spacer crush behavior will be estimated by the grid spacer impact tests MHI is planning to perform in the first quarter of 2009 and will be described in the report to be submitted in March 2009. For the grid spacers in the tests, relaxed spring force will be considered and the embrittlement of the spacer material will be simulated by hydrogen charging to high ppm levels. The results will be compared with those in which only spring force relaxation is considered.

Based on the investigations for the effect of spring relaxation and the material embrittlement on the grid spacer crush behavior, the inelastic impact model of FINDS for the irradiated grid spacer is being developed and is used for the seismic and LOCA analysis by FINDS. FINDS analyses are conducted for a row of fuel assemblies with a mixture of beginning of life fuel assemblies and relaxed grid spring force fuel assemblies. Another FINDS analysis using a full row of beginning-of-life fuel assemblies will be performed and the results will be compared to the mixed row analysis.

7.2 The differences in the FINDS analysis input between fuel assemblies with beginning of life versus relaxed grid spring force are considered in the amplitude dependence of natural frequency and damping factor and in the FINDS inelastic impact model.

The effect of grid spacer spring relaxation on the vibration characteristics of the fuel assembly is evaluated by an ANSYS FEM analysis. The analysis results are shown in the response for RAI 5.

The amplitude dependence of natural frequency and damping factor for beginning of life and irradiated fuel assemblies for the FINDS analysis will be determined based on the prediction by the ANSYS FEM model and will be used for vibration analyses under seismic or LOCA conditions, as discussed in the response for RAI 7.1.

The FINDS inelastic impact model for the grid spacers with relaxed spring force will be modeled and considered in the FINDS analysis, as also discussed in the response for RAI 7.1.

The FINDS analysis model will contain a mixture of the fuel assembly characteristics associated with beginning-of-life grid spring force and relaxed grid spring force. The analysis for the uniform beginning-of-life fuel assembly case will also be performed and compared with results from the analysis using the mixture of fuel assemblies with beginning of life and relaxed spring force grids.

The information above will be included in the report to be submitted in March 2009.

QUESTION-8 Questions regarding the operational range and limitations of the FINDS code

The FINDS code is used to model the dynamic response of fuel assemblies in a nuclear reactor core during seismic and LOCA events. The fuel assemblies are modeled as linear-elastic beam structures and are enhanced in realism through the use of experimentally-determined amplitude-based correction factors and an inelastic spacer grid impact model. This approach will reasonably yield a model that is valid within a certain operating range. If input loads are too high, the model is expected to calculate unrealistic results. On the other side of the analysis, output parameters such as reaction forces and nodal displacements are expected to stay within a certain realistic range. Excessively high results could indicate that the calculations have exceeded the valid operating range.

8.1 Please identify the valid range of loading inputs.

8.2 Please identify the valid range of nodal deflection results.

8.3 Please identify the valid range of reaction force results.

8.4 Please provide a reasonable basis for each of the above ranges.

8.5 Considering the amplitude-dependant properties of frequency and damping, are FINDS analyses limited by the range of data collected, or is extrapolation used to extend the operating range?

RESPONSE

8.1 The valid range of FINDS code is limited by the nodal deflection results and the grid spacer deformation results. The valid range for these results are described in the response for RAI 8.2 and 8.3 respectively.

8.2 The valid range of nodal deflection results can be determined as [ ] inch ([ ] mm), at least, by the following reasons.

As described in Section 2.2 of Appendix D of Reference 5-1, the vibration analyses for single beam have been conducted by the FINDS and the general structural analysis code ANSYS using a random acceleration wave. It was confirmed that the nodal displacement calculated by FINDS shows good agreement with the one calculated by the ANSYS, up to the range of [ ] inch ([ ] mm), at least. In the analysis, the natural frequency and the damping of 1st mode were assumed as constant independent of amplitude.

In the FINDS analysis for a row of fuel assemblies in core, the amplitude dependence of natural frequency and damping is considered. The relationship can be determined based on the experiment results from the lateral pluck test shown in section 2.1 of Appendix A of Reference 5-1, or the estimation by the ANSYS FEM analysis described in the response for RAI-5 to cover the maximum deflection of [ ] inch ([ ] mm).

8.3 Because the reaction force is limited by grid spacer buckling, it is discussed in terms of the grid spacer deformation. The valid range of the deformation can be determined as [ ] inch ([ ] mm) by the following reason. As described in response for RAI 6.2, the grid spacer plastic deformation observed in the large shaker table test was about [ ] inch ([ ] mm) and the FINDS code accurately or conservatively simulated the fuel assembly's response in terms of displacement and grid deformation. In addition, as mentioned in the response to RAI 6.1, the grid spacer's plastic deformation observed in the single span fuel assembly drop test was about [ ] inch ([ ] mm) and the FINDS inelastic impact model for the grid spacer predicts the deformation conservatively.

8.4 As described in the response for RAI-5, [ ] inch ([ ] mm) of initial displacement is given to the middle grid spacer elevation of the ANSYS FEM model and is released quickly to calculate the time history displacement data of the grid spacer and to obtain the amplitude dependence of natural frequency and damping shown in Figure 5-1. By simulating the time history displacement data and the amplitude dependence by the FINDS code, the vibration characteristics of the FINDS model can be adequately determined up to the displacement of [ ] inch ([ ] mm).

For grid spacer deformation, as mentioned in the response to RAI 6.1 and 8.3, the grid spacer's plastic deformation observed in the single span fuel assembly drop test was about [ ] inch ([ ] mm) and the FINDS inelastic impact model for the grid spacer predicts the deformation conservatively. Therefore, the FINDS inelastic model can be applicable up to the deformation at least.

8.5 The grid spacer deformation in operation is expected to be well within the range of [ ] inch ([ ] mm) mentioned above. As for the fuel assembly's vibrational characteristics, there will be a possibility that the analyzed displacement of the US-APWR fuel assembly will exceed [ ] inch ([ ] mm). For such a case a vibration test with a mockup fuel assembly or the additional ANSYS analysis will be conducted to obtain frequency and damping values for higher amplitudes and the data will be used to verify the vibrational models in the FINDS code.

REFERENCES

(2-1) "Design Control Document for the US-APWR", MUAP-DC003 Revision 1, August 2008.

(3-1) "Proving Test on the Seismic Reliability for Nuclear Power Plant", Nuclear Power Engineering Test Center, March 1987

(4-1) "US-APWR Fuel System Design Evaluation", MUAP-07016-P (Proprietary) and MUAP-07016-NP (Non-Proprietary), February 2008.

(5-1) MHI's Responses to the NRC's Requests for Additional Information on Topical Report MUAP-07034-P "FINDS: Mitsubishi PWR Fuel Assemblies Seismic Analysis Code", UAP-HF-08139-P (Proprietary) and MUAP-07016-NP (Non-Proprietary), August 2008.