Enclosure 2

MFN 10-308 Revision 1

NEDO-33259-A, Revision 3, "Reactor Internals Flow Induced Vibration Program"

Non-Proprietary Information

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Licensing Topical Report

REACTOR INTERNALS FLOW INDUCED VIBRATION PROGRAM

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Please Read Carefully

The information contained in this document is furnished for the purpose of supporting the NRC review of the certification of the ESBWR, with the information here being used as ESBWR supporting reference. The only undertakings of GE Hitachi Nuclear Energy (GEH) with respect to information in this document are contained in contracts between GEH and participating utilities, and nothing contained in this document shall be construed as changing those contracts. The use of this information by anyone other that for which it is intended is not authorized; and with respect to any unauthorized use, GEH makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

SUMMARY OF CHANGES
NEDO-33259-A REVISION 3

Location	Comment
All	"-A" is added to the document number for this revision denoting NRC acceptance of this revision for ESBWR design certification.
Cover Page	Copyright date updated
Page ii	NON-PROPRIETARY INFORMATION NOTICE updated
Page ii	IMPORTANT NOTICE REGARDING THE CONTENTS OF THIS REPORT updated
S2.0, 4th, 5th and new 6th sentences	Revised to change the classification of the ESBWR vessel internals vibration program from non-prototype to prototype and to clarify the requirements for prototype plants, in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1
Section 3.0	Deleted "Prototype" from title and the first sentence, and added new third sentence in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 3.
S5.1, new 1st sentence	Added sentence to reference new Table 7, in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1.
S5.2, 4th paragraph, new 3rd-to-last sentence	Added sentence to reference new Table 7, in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1.
S5.3, new last sentence	Added sentence to reference new Table 7, in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1.
S5.4, new last sentence	Added sentence to reference new Table 7, in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1.
Table 7	Added table in response to RAI 3.9-75 S01. Reference MFN 06-464 Supplement 9, Revision 1.
Attachment 1	Added the NRC letter describing the acceptance of this revision of this Licensing Topical Report. The NRC letter as well as Enclosure 1 of the letter, which contains the Final Safety Evaluation for this Licensing Topical Report, has been added to the end of this document.

Acknowledgments

This document is the result of the technical contributions from many individuals and organizations in addition to the authors of this document. At the GE Hitachi Nuclear Energy (GEH), significant contributions to the development of BWR flow induced vibration technology has occurred over several decades. The names of these contributors are too numerous to list but are gratefully acknowledged here.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

In Appendix 3L of the ESBWR Design Control Document (DCD), a process is described for evaluation of the ESBWR reactor internal components with respect to flow induced vibration (FIV). The purpose of this report is to provide the complete FIV evaluation of all reactor internals that includes both part 1 and part 2 as described by in Reference 1 except for the steam dryer, which will be evaluated in separate reports. This report provides additional details, for components that required additional work to evaluate and test for FIV, and to provide data for components that are considered acceptable and require no additional work. For those components where additional evaluation is being performed, the evaluation method, the results and conclusions are provided. For components requiring testing during the startup of the first ESBWR, the type and locations of sensors are identified. The plant that is used for comparison purposes that is closest to the ESBWR configuration is the Advance Boiling Water Reactor (ABWR). Three ABWR plants are currently in operation in Japan, and the first plant completed an FIV program that included analysis, testing and inspection as outlined in regulatory guide 1.20. Since the steam dryer FIV programs is covered in separate reports, this report focuses on the following components:

- Chimney Head/Steam Separator Assembly
- Shroud/Chimney Assembly
- Top Guide
- Core Plate
- Standby Liquid Control (SLC) piping
- Control Rod Drive Housings (CRDH)
- Control Rod Guide Tubes (CRGT)
- In-Core Monitor Guide Tubes (ICMGT)
- In-Core Monitor Housings (ICMH)
- Chimney and Chimney Partitions

The remaining reactor internal components that are not specifically identified in the referenced document, or in this report, are basically proven by past trouble-free BWR experience and have designs and flow conditions that are similar to prior operating BWR plants; e.g., the feedwater spargers and guide rods (guides, chimney assembly, chimney head and steam dryer in place during installation).

This report includes:

1. A list showing the locations and types of FIV sensors used in the ABWR FIV test (Table 1).
2. A list of similarities and differences between the ABWR and the ESBWR component design configurations (Table 2).
3. A determination of the ESBWR components natural frequencies based on the data from Table 2.

4. Data from the prototype ABWR FIV test that includes the lowest predicted natural frequencies of components, the dominant response frequencies during the FIV test, and the maximum zero-to-peak stress intensities calculated on the basis of strain gage measurements (Table 3).
5. Flow velocities in the ESBWR are compared to the ABWR (Table 3).
6. Comparison of the calculated ESBWR and ABWR lower plenum stresses (Table 4).
7. Assessments of the likelihood that FIV will not be an issue.
8. Detailed evaluation methodology, results, and conclusions for components requiring detailed evaluation.
9. Type and locations of sensors for monitoring FIV behavior during startup of the first ESBWR.

2.0 SUMMARY

Based on the evaluations performed in this report, the components that are evaluated in greater depth and will be part of the ESBWR FIV prototype test program are: the shroud/chimney assembly, the chimney head/steam separator assembly, the chimney, steam dryer and the SLC lines. The steam dryer will be evaluated in separate reports. For the remaining components, it has been concluded that no further evaluations are necessary since they are not susceptible to FIV. The ESBWR FIV program is considered to be a prototype per Reference 2. Under this program, analysis, measurements and full inspection of the reactor internals of the first plant are required. The ESBWR internals are similar to the ABWR internals; therefore, analyses and measurements from the ABWR FIV program are used to the extent possible.

3.0 DISCUSSION ON ABWR FIV TEST AND INSPECTION PROGRAM

The ABWR reactor internals preoperational test program was performed in Japan. Although the program was carried out under the jurisdiction of the Japanese Ministry of International Trade and Industry (MITI), it also complied with the requirements of the U.S. Regulatory Commission (NRC) Regulatory Guide 1.20, Rev. 2 for a prototype design. MITI has classified these ABWR reactor internals as prototype. Subsequent favorable operational experience has demonstrated structural adequacy of the ABWR reactor internals with respect to FIV. The program included analyses, measurements and inspections of reactor internals components deemed critical. Strain gages, accelerometers and linear variable differential transformer (LVDT) type relative displacement sensors were used for monitoring vibration levels. A total of [[ ]] sensors of different types were used to obtain vibration data on 11 different reactor internals component structures. The sensor locations were determined based upon the analytically predicted mode shapes for each structure, or in some cases, based upon the locations of past adverse inservice vibration phenomena. A variety of steady state and transient conditions that could be expected to occur during the life of the plant were included in the program. Test data were evaluated for five different testing conditions. The maximum zero to peak stress intensities calculated on the basis measurements during the ABWR startup FIV test program are shown in Tables 3 and 4.

The type of sensors, their locations and the basis for their locations are shown in Table 1.

4.0 GENERAL DISCUSSION OF REACTOR INTERNAL COMPONENT EVALUATIONS

4.1 Comparison of the ESBWR reactor internals component design to the ABWR design (Table 2).

A dimensional comparison of the ESBWR and the ABWR component designs is shown in Table 2. Also, see Figure 1, which shows the ABWR reactor pressure vessel with the reactor internals and Figure 2, which shows the same information for ESBWR. In general, the ABWR and ESBWR have the same components except that the ESBWR now includes a chimney, which has been added to increase natural circulation flow. Also, the fundamental flow paths within the ESBWR reactor vessel are essentially the same, but the flow path is now extended by the chimney. In addition to the inclusion of the chimney, the other major difference in the ESBWR reactor internals components design, compared to the ABWR design, is the standby liquid control piping (see Figure 3). Also, there are components that the ESBWR does not have such as the high pressure core flooder (HPCF) coupling or low pressure flooder (LPFL) spargers. The other traditional BWR components have dimensional differences that are shown in Table 2.

4.2 Comparison of ESBWR FIV behavior to ABWR (Table 3)

Table 3 shows the lowest predicted natural frequencies, the dominant response frequencies, and the maximum zero-to-peak stress intensities calculated on the basis of strain gage measurements made during the ABWR prototype FIV test. The data was extracted from the ABWR prototype FIV test report. Calculations based on the test results showed a maximum calculated zero-to-peak stress intensity of [[ ]]. This stress intensity is much less than the 68.9 MPa limit that is more conservative than the lowest S_a value shown in the design fatigue curve for austenitic stainless steel, Figure I-9.2.1 of the ASME Code, Section III.

Table 3 also compares flow velocities that might induce vibrations due to vortex shedding from cylindrical components. The flow velocities were determined by using the geometry of the flow areas and coolant flow rates of [[ ]] for the ABWR and [[ ]] for the ESBWR. When calculating the flow velocities in the ESBWR RPV bottom head, [[ ]]. These maximum flow velocities were used to calculate the vortex shedding frequencies shown in Table 3.

Table 3 also shows the calculated natural frequencies of the ESBWR components. These calculations were performed using the natural frequencies reported for the ABWR as a reference basis to predict the ESBWR natural frequencies using classical formulas to account for the component geometry differences (dimensional analysis techniques).

5.0 SPECIFIC REACTOR INTERNAL COMPONENT EVALUATIONS

5.1 Chimney Head/Steam Separator Assembly

As shown in Table 7, the differential pressure across the ESBWR steam separator is 27% less than for the ABWR. However, the ESBWR Chimney Head and Steam Separator assembly differs from earlier BWR designs in that the Chimney Head geometry is now flat compared to the domed shape on the traditional Shroud Head. Note that in the ESBWR, it is called a chimney head /steam separator assembly compared to prior BWR product lines, which have called it the shroud head/steam separator assembly, since the chimney is an additional component in ESBWR to which the head now attaches.

Additionally, the steam separator standpipes are longer, which will result in a lower natural frequency. Due to this change, the chimney head/steam separator assembly is selected for further evaluation. Restraints in the separator/standpipe "forest" are designed to increase the natural frequency and to minimize vibration responses to flow conditions. Accelerometers will be provided for the ESBWR prototype FIV test to confirm the adequacy of the design.

5.2 Shroud/Chimney Assembly

As shown in Figures 1 and 2, there are differences between the major components forming the ABWR core circulation path compared to the ESBWR design. For ABWR, the major core structure components, starting from the bottom attachment to the reactor pressure vessel (RPV), are the shroud support, shroud, top guide assembly, and the shroud head /steam separator assembly. These components form a complete assembly that is a freestanding structure, which has a full circumferential support between the RPV and the shroud. Also, there are bolted connections between the shroud and top guide assembly and also between the top guide assembly and shroud head/steam separator assembly.

In comparison to the ABWR, the ESBWR design has shroud support legs (12), shroud support ring, shroud, top guide, chimney, and chimney head/steam separator assembly. This assembly is also a freestanding structure; however, there are also eight lateral restraints at the top of the chimney structure that provide translational and torsional restraint that transmit loads through the RPV. Also, the support of the shroud involves the use of 12 support legs, each laterally braced, that provide a load path from the shroud to the RPV. For the ESBWR, there are bolted connections at the shroud to top guide, top guide to chimney, and chimney to chimney head.

The shroud/chimney/steam separator assembly is essentially an axisymmetric structure and the flow is also axisymmetric. Hence, no significant torsional excitation is expected. Any minor torsional forces from the non-axisymmetric structural elements, such as chimney internal partitions and separator structural ties, can be readily resisted by the lateral torsional restraints. Also, since the ESBWR flow is more uniform than the ABWR, any torsional fluid forces would be even smaller than in an ABWR. This more uniform flow behavior, in addition to the lateral torsional restraint at the top of the chimney, will result in an ESBWR torsional response that is less than the comparable ABWR response.

Because of the addition of the upper lateral restraint within the vessel, the ESBWR shroud/chimney calculated fundamental natural frequency is higher than that of the ABWR in spite of the ESBWR shroud/chimney/separator structure being taller. Table 5 shows that the fundamental frequency of the ABWR shroud/separator is [[ ]], while that of the ESBWR shroud/chimney/separator structure is [[ ]]. Because the flow velocity in the annulus between the RPV and the shroud for the ESBWR is higher due to a narrower annulus width, the pressure forces are also higher. Furthermore, due to the presence of the chimney, the total pressure force on the ESBWR shroud/chimney/separator structure is higher than that for the ABWR. These higher forces are partially compensated by the presence of the upper lateral restraint in the shroud/chimney/separator structure. In spite of the higher pressure forces, the calculated shroud/chimney/separator structure response is relatively small. In addition, as shown in Table 7, the differential pressure across the ESBWR shroud is 33% less than for the ABWR. Pertinent information comparing the ESBWR and ABWR shrouds, which supports the above statements, is shown in Table 5. Details of the analyses are provided below.

5.2.1 Shroud/Chimney Structure Dynamic Model and Response

Because of the essentially axisymmetric nature of the shroud chimney structure, the stiffening effects of the chimney/separator head, the top guide, and core plate, the shell modes of the shroud/chimney structure are greatly attenuated. Furthermore, the axisymmetric nature of the flow and related flow forces results in the beam response modes being dominant. Thus, a beam model of the structure is used to determine its FIV response. Two beam models, one for the ABWR and one for the ESBWR, have been created for comparison purposes. A comparison of the natural frequencies and dynamic responses of the ESBWR and the ABWR is provided in Table 5, which shows that the fundamental frequency of the ABWR shroud/separator is [[ ]], while that of the ESBWR shroud/chimney/separator structure is [[ ]].

To calculate the FIV response of ESBWR Shroud/Chimney/Separator structure, measured pressure time histories in the ABWR RPV-Shroud annulus were suitably scaled to define pressure time histories in the ESBWR RPV-Shroud/Chimney annulus. The scale factors were computed as the square of the ratio of ESBWR annulus fluid velocity to the corresponding value for the ABWR. Both the ABWR shroud and the ESBWR Shroud/Chimney structures were then analyzed using fluid forces resulting from the corresponding annulus pressure time histories to determine comparative responses of the Shroud/Chimney/Separator structure. During the prototype ABWR FIV test, the movement of the top guide was measured together with the shroud. The pressure time history was further normalized such that the calculated ABWR response would be equal to the measured ABWR response.

Using the results of these dynamic analyses, the accelerations and stresses at two locations along the shroud were obtained and are tabulated in Table 5. The ESBWR shroud stress is [[ ]] at the top guide elevation and is [[ ]] at the core plate elevation. These stresses are negligible compared to the allowable value of 68.9 MPa. The calculated forces and moments along the entire shroud/chimney/separator structure are used for calculating stresses as described below.

5.2.1.1 FIV Stress Analysis Results and Evaluation

Using the forces and moments derived from the dynamic model, maximum bending stresses in the Chimney Head & Steam Separator Assembly were calculated. The maximum predicted stress, including a fatigue strength reduction factor of [[ ]], is [[ ]], which occurs in the standpipes at the Chimney Head end. The calculated alternating peak stress intensity due to vibratory loads, which are continually applied during normal operations, is limited to 68.9

MPa for stainless steel. Thus, it is concluded that the FIV stresses are well below allowable values.

5.2.1.2 ESBWR Shroud Support Legs

The forces and moments obtained from the time history dynamic response analyses of the shroud/chimney/separator structure were used for obtaining maximum bending stresses in the support legs. The value computed is [[ ]]Mpa, which is much below the allowable limit of 68.9 MPa. A similar calculation for shroud support leg lateral braces shows that the maximum stress in the braces is [[ ]]Mpa, which is even less that that in the legs.

5.2.2 ESBWR Startup Instrumentation

The ABWR shroud was instrumented with strain gages during the ABWR prototype FIV test. The movement of the shroud was measured with displacement sensors located on the OD of the top guide. For the ESBWR, [[ ]] accelerometers, [[ ]] apart, will be placed near the calculated maximum acceleration elevation to measure the radial and tangential motion of the shroud/chimney/separator assembly. The maximum acceleration location is near the separator support ring. In addition, [[ ]] additional accelerometers, [[ ]] apart, will be placed at the midpoint of the chimney to measure chimney motion. A summary description of these sensors is contained in Table 6.

5.3 Top Guide Assembly

The ESBWR top guide is made from a solid forging that is the same as the ABWR design in the arrangement and size of the cells. The thickness of the Top Guide is 152.4 mm. In the dynamic model of the RPV and Internals, the Top Guide was modeled as a spring-mass system to account for the potential effect of its own natural frequency for FIV response. The spring, which represents the lateral stiffness of the Top Guide, connects the node representing the Top Guide to the node on the shroud at the elevation of the Top Guide. The dynamic analysis of the RPV and Internals model, under fluid-induced loads, was performed to obtain the maximum force in the spring representing the Top Guide. This force was determined to be [[ ]] and used in a subsequent detailed stress analysis of the Top Guide. The subsequent resulting peak stress value is considerably lower than the allowable value of 68.9 MPa. As shown in Table 7, the differential pressure across the ESBWR top guide is 71% less than for the ABWR.

5.4 Core Plate Assembly

The ESBWR core plate assembly is a similar design to the ABWR and BWR/6. The ESBWR Core Plate is a 210 mm stiff structure. In the dynamic model of the RPV and Internals, the Core Plate, like the Top Guide, was modeled as a spring-mass system to account for the potential effect of its own natural frequency for FIV response. The spring, which represents the lateral stiffness of the Core Plate, connects the node representing the Core Plate to the corresponding node on the shroud at the elevation of the Core Plate. The dynamic analysis of the RPV and Internals model, under fluid-induced loads, was performed to obtain the maximum force in the spring representing the Core Plate. This force was determined to be [[ ]]and used in a subsequent detailed stress analysis of the Core Plate. The subsequent resulting peak stress is considerably lower than the allowable value of 68.9 MPa. As shown in Table 7, the differential pressure across the ESBWR core plate is 82% less than for the ABWR.

5.5 Standby Liquid Control (SLC) Lines

The SLC line is a new ESBWR component that is located in the down-comer flow region in the annulus between the RPV and the chimney. The design is shown in Figure 3. Since the configuration of the SLC line has a new geometry and a location within the RPV, this component is analyzed in detail (described below) and will be included in the ESBWR prototype FIV test program.

A finite element beam model of the SLC line was constructed and analyzed for FIV induced stresses (Reference 3). The SLC line is supported at six places: the top vertical segment is supported at the RPV at two places along its [[ ]] length; the horizontal circular segment by two symmetrically placed supports at the shroud; and the two vertical segments in the bottom [[ ]] length were supported at the shroud by one support in each segment.

The fundamental frequency of the SLC line was determined to be [[ ]], which is over [[ ]] times (and well separated from) the vortex shedding frequency of [[ ]] and, therefore, is of no concern.

The SLC piping in the annulus will be instrumented during startup of the first ESBWR. A summary description of these sensors is shown in Table 6.

5.6 Control Rod Drive Housings (CRDH), Control Rod Guide Tubes (CRGT), In-Core Monitor Housings (ICMH) and In-Core Monitor Guide Tubes (ICMGT)

From Table 3 it is seen that the calculated natural frequencies of the CRGTs, ICMHs and ICMGTs of the ESBWR are higher than those reported for the ABWR. That is because the CRGTs, ICMHs and ICMGTs of the ESBWR have shorter lengths and have the same diameters, wall thicknesses, and mass per unit length. The increase in natural frequency effectively moves these components away from the dominant response frequency recorded by the ABWR test, and the values are high enough that FIV is not a concern. These components are exposed to lower flow velocities, and the corresponding vortex shedding frequencies are approximately a factor of [[ ]] less than those in the ABWR. In comparing the calculated natural frequencies to the associated vortex shedding frequencies, the component natural frequencies are, in all cases, much higher than the corresponding vortex shedding frequency. Therefore, FIV will not be a concern. These results are consistent with BWR operating plant experience where no FIV problems have ever been found in the lower region of the reactor vessel.

Since the ABWR flow induced vibration test did not reveal any significant vibration of the CRGTs, ICMHs, and ICMGTs and the peak stress intensities were well below the ASME Code limits, these ESBWR components have no FIV issues. The calculation described below confirms this.

The stresses due to flow induced vibrations (FIV) of reactor internal structures are determined by their structural characteristics and the fluid forces acting on them. For the calculation of stresses, the structural characteristics are defined by the natural frequencies and mode shapes. In the case of the ABWR, these frequencies were obtained from finite element models and confirmed by startup test data. The structural characteristics of the ESBWR (geometry, solid and fluid mass distributions, material properties and boundary conditions) are, except for the overall length, identical to the ABWR. Since the structural natural frequencies are inversely proportional to the square of the overall length, the ESBWR frequencies can be derived from the corresponding

ABWR frequencies by using the ratio of length squared. The corresponding normalized mode shapes will essentially be the same.

The stresses due to flow-induced vibrations of reactor internal structures are also determined by the fluid forces from coolant flow. The dominant excitations are from vortex shedding and flow turbulence. The key parameter characterizing these excitations is the coolant flow velocity. These velocities are higher in the ABWR; however, for calculating the stresses in the ESBWR, these forces have conservatively been assumed to be the same.

The CRGT and ICMGT stresses in ESBWR can thus be calculated by geometrically scaling the corresponding ABWR stresses. The ESBWR stresses thus obtained are presented in Table 4 along with the other data used in the calculation. These stresses are about 50% of the ABWR stresses for both the CRGT and ICMGT/ICMH structures.

It is therefore concluded that the CRGTs, ICMHs and ICMGTs can be excluded from the ESBWR prototype FIV test program and no instrumentation will be installed.

Based on previous BWR/5 experience, the CRDHs were not included in the ABWR FIV test program. Since the ESBWR CRDHs are rigid structures that are welded to the RPV bottom head and have [[ ]] times higher natural frequencies due to their shorter lengths and lower flow velocity in the bottom head, there will be no FIV issues with the ESBWR CRDHs. Therefore, the ESBWR CRDHs will not be instrumented during the prototype FIV test.

5.6.1 Shroud Instrumentation During ESBWR Startup

Due to the addition of the chimney in the structure, the shroud/chimney/separator structure will be more heavily instrumented than the ABWR was. In addition to [[ ]] accelerometers, [[ ]] apart, placed at the calculated maximum ESBWR shroud/chimney/separator acceleration elevation and [[ ]] accelerometers, [[ ]] apart, placed at the midpoint of the chimney, [[ ]] additional strain gages will be placed at the maximum calculated stress locations. These [[ ]] strain gages will be placed on the shroud above the shroud upper support ring along the calculated principal stress directions at the highest stress point. A summary of these sensors is found in Table 6.

5.7 ESBWR Chimney

5.7.1 ESBWR Chimney Scaled Model Tests

Because the chimney structure is unique to the ESBWR, a series of tests to simulate chimney partition FIV characteristics during normal ESBWR operation was performed.

Three scaled model tests were performed: a 1/6 scale, a 1/12 scale and one almost full scale (References 4 and 5). The tests use a mixture of air and water to simulate two-phase flow inside the chimney. Air was supplied by a compressor and the water was supplied by a water pump. The air and water were combined in a mixer at the chimney inlet and flow through the simulated chimneys. After passing through the chimney, the air-water mixture is separated and the water returned to the storage tank, and the air is exhausted to the atmosphere. A total of twelve pressure sensors were installed at ten elevations on the simulated chimney. There were two pressure sensors installed at each of two elevations.

The two smaller scale models were used to investigate the effect of model size on the test results. The test results show that the magnitude of the pressure fluctuations tend to [[ ]]. The smaller scaled model tests were also used to investigate the effects of inlet air/water mixing conditions on the pressure measurements. The tests showed that the inlet mixing condition had little influence on the test results.

To investigate the correlation of pressure fluctuation between cells, the [[ ]]-scale flow channel [[ ]] was divided into four. Correlation of pressure fluctuation between cells was evaluated using the test data. The correlation coefficients are [[ ]]. Therefore, it is concluded that the pressure fluctuations in each cell is [[ ]].

5.7.2 Chimney FIV Response

Test results from the large-scale model show a maximum peak-to-peak pressure of [[ ]]. This test result is used to calculate the FIV stresses in the chimney partitions. For stress evaluations, a Finite Element Model (FEM) using ANSYS Version 5.6 with plate and solid 3 D elements was developed. The FEM was used to extract the eigenvalues. Eigenvalue analysis shows the lowest frequency of the chimney is [[ ]]. Since the pressure forcing function from the tests is dominant around [[ ]], the chimney structure responds statically.

To calculate FIV response, the peak test pressures of [[ ]] were applied uniformly on four sides in one cell and the opposite pressure applied in adjacent cells. The calculated response results show the maximum stress occurs [[ ]]. Using a fatigue strength reduction factor of 2 for welded joints from ASME Code Sec. III Table NG-3352-1, the maximum stress intensity is [[ ]], which is sufficiently below the allowable value of 68.9 MPa.

5.7.3 Chimney FIV Experience at the Dodewaard Plant.

Dodewaard was the first and only naturally circulating BWR with a chimney similar to the ESBWR, and the two-phase flow velocity and void fraction were similar to those of the ESBWR. The structural characteristics of the chimneys for ESBWR and Dodewaard are similar. The Dodewaard plant operated for more than 20 years without any reported FIV issues. This experience gives added confidence the ESBWR will operate reliably without FIV problems.

6.0 REFERENCES

1. 26A6642AN Rev. 4 DCD Appendix 3L "Reactor Internal Flow Induced Vibration Program".
2. Regulatory Guide 1.20, Comprehensive Vibration Assessment Program for Reactor Internals during Preoperation and Initial Startup Testing, Revision 3, March 2007.
3. ESBWR SLC Piping FIV Stress Analysis Report, CE-OG-0110, Rev. 1, June 2007.
4. Large-Scale Chimney Partition FIV Report, CE-OG-0115, Rev. 0, March 2007.
5. FIV Study Report on ESBWR Chimney, Hitachi Report CE-OG-0095, Rev. 1, November 2006.

Table 1:
ABWR Prototype FIV Test sensor Types, Locations, and Location Basis

Equipment Item	Location on Equipment	Sensor Type	Basis for Location
[[			

Table 1: ABWR Prototype FIV Test sensor Types, Locations, and Location Basis			
			]]

Table 2: Comparison of ESBWR Reactor Internals Component Design to ABWR (All dimensions are in mm)			
FEATURE	**ABWR**	**ESBWR**	**Difference**
RPV			
Nominal ID	[[		
Minimum ID			
Shroud			
Upper shell OD			
Lower shell OD			
Wall thickness upper shell			
Wall thickness lower shell			
Total height			
Height upper shell			
Upper flange OD			
Upper flange ID			
Upper flange height			
Upper flange width			
Lower flange OD			
Lower flange ID			
Lower flange height			
Lower flange width			
Core plate support OD			
Core plate support ID			
Core plate support height			
Core plate support width			
Annulus RPV/Shroud			
Upper width			
Lower width			
Top Guide Assembly			
Overall OD			
Overall thickness			
Core Plate Assembly			
Core plate OD			
Core plate rim ID			

Table 2:
Comparison of ESBWR Reactor Internals Component Design to ABWR
(All dimensions are in mm)

FEATURE	ABWR	ESBWR	Difference
Core plate rim height			
Core plate thickness			
Overall height			
Beam thickness			
Beam height			
Chimney/Shroud Head and Separators			
Overall height			
Chimney/Shroud head OD			
Height cylindrical portion			
Chimney/Shroud head height			
Number of separators			
Separator height			
Separator OD			
Standpipe OD			
Standpipe maximum height			
Separator pitch			
Overall diameter of separators			
Distance lower guide ring from the bottom			
Distance upper guide ring from the bottom			
Thickness of dome or plate			
OD of upper and lower rings			
Thickness of upper and lower guide rings			
Width of upper and lower guide rings			
ESBWR Chimney (ABWR Top Guide Shell)			
Shell OD			
Shell ID			
Shell thickness			
Total height			
Upper flange OD			
Upper flange ID			
Upper flange width			
Lower flange OD			
Lower flange ID			
Lower flange cross section			
Lower flange height at OD			
Lower flange height at ID			

Table 2: **Comparison of ESBWR Reactor Internals Component Design to ABWR** **(All dimensions are in mm)**			
FEATURE	**ABWR**	**ESBWR**	**Difference**
Chimney Partition			
Upper flange OD			
Upper flange ID			
Lower flange OD			
Lower flange ID			
Upper and lower flange width			
Upper and lower flange thickness			
Partition thickness			
Partition height			
Partition pitch			
Total height partition			
CRD Housing			
OD			
Wall thickness			
Length inside reactor (Max. length at center location including stub tube)			
Control Rod Guide Tube			
OD			
Wall thickness			
Length			
Feedwater Sparger			
OD			
Wall thickness			
Length			
ICM Housing (incl. guide tube and stub tube)			
OD			
Wall thickness			
Length inside reactor (incl. guide tube and stub tube)			
ICM Guide Tube			
OD			

Table 2: Comparison of ESBWR Reactor Internals Component Design to ABWR (All dimensions are in mm)			
FEATURE	**ABWR**	**ESBWR**	**Difference**
Wall thickness			
Length			
Guide Rod			
OD			
Wall thickness			
Total length upper and lower guide rod			
Standby Liquid control Lines			
-Upper vertical portion			
OD			
Wall thickness			
Approximate length			
- Header			
OD			
Wall thickness			
Approximate length			
- Lower vertical portion			
OD			
Wall thickness			
Approximate length			]]

Table 3:
Comparison of ESBWR FIV Behavior to ABWR

	ABWR		ESBWR		ABWR			ESBWR
Component	Lowest analytically predicted natural frequency (Hz)	Flow velocity m/sec	Natural frequency based on ABWR calculations (Hz)	Flow velocity m/sec	Dominant response during flow test (Hz)	Maximum zero to peak stress intensity calculated on the basis of strain gage measurements during flow test. Limit is 68.9 MPa (7.0 kg/mm^2)	Calculated vortex Shedding Frequency (Hz)	Calculated vortex Shedding Frequency (Hz)
Shroud	[[							
Chimney								
Top Guide								
Control Rod Guide Tube								
In-core Housings								
In-core Guide Tubes								
CRD Housings								]]

Table 4:
Calculation of ESBWR Component Maximum Stresses From ABWR Data.

Component	Length (mm)		Lowest Analytically Predicted Natural Frequency (Hz) (See Note 1 Below)		Calculated Vortex Shedding Frequency (Hz)		Maximum (0-Peak) Stress Intensity on the Basis of Strain Gage Measurements During Flow Test. (MPa / kg/mm^2)	Predicted Maximum Stress Intensity (MPa / kg/mm^2) (Note 3)
	ABWR	ESBWR	ABWR	ESBWR	ABWR	ESBWR	ABWR	ESBWR
Control Rod Guide Tube	[[							
CRD Housing								
In-Core Guide Tubes								
In-Core Housing (including ICGT)								

]]

Table 5:
Comparison of ESBWR and ABWR Shroud/Separator FIV Response

Response Quantity	ABWR	ESBWR
Shroud First Lateral Frequency	[[	
Shroud Stress at Top Guide Elevation		
Shroud Stress at Core Support Elevation		
Shroud Horizontal Acceleration at Top Guide Elevation		
Top Guide Mass Acceleration		
Shroud Horizontal Acceleration at Core Support Elevation		
Core Plate Mass Acceleration		
Top Guide 'Spring' Force		
Core Support Plate 'Spring' Force		]]

[[

]]

Table 6: ESBWR Prototype FIV Test Sensor Types, Locations, and Location Basis			
Equipment Item	**Location on Equipment**	**Sensor Number and Type**	**Basis for Location**
[[			
			]]

Table 7:
Comparison of ESBWR and ABWR Pressure Differentials at Normal Plant Operation

Component	ABWR Pressure Differential (Mpa)	ESBWR Pressure Differential (Mpa)	Pressure Differential Comparision
Top Guide	[[		ESBWR is 71% less than ABWR
Core Plate			ESBWR is 82% less than ABWR
Shroud			ESBWR is 33% less than ABWR
Steam Separator		]]	ESBWR is 27% less than ABWR

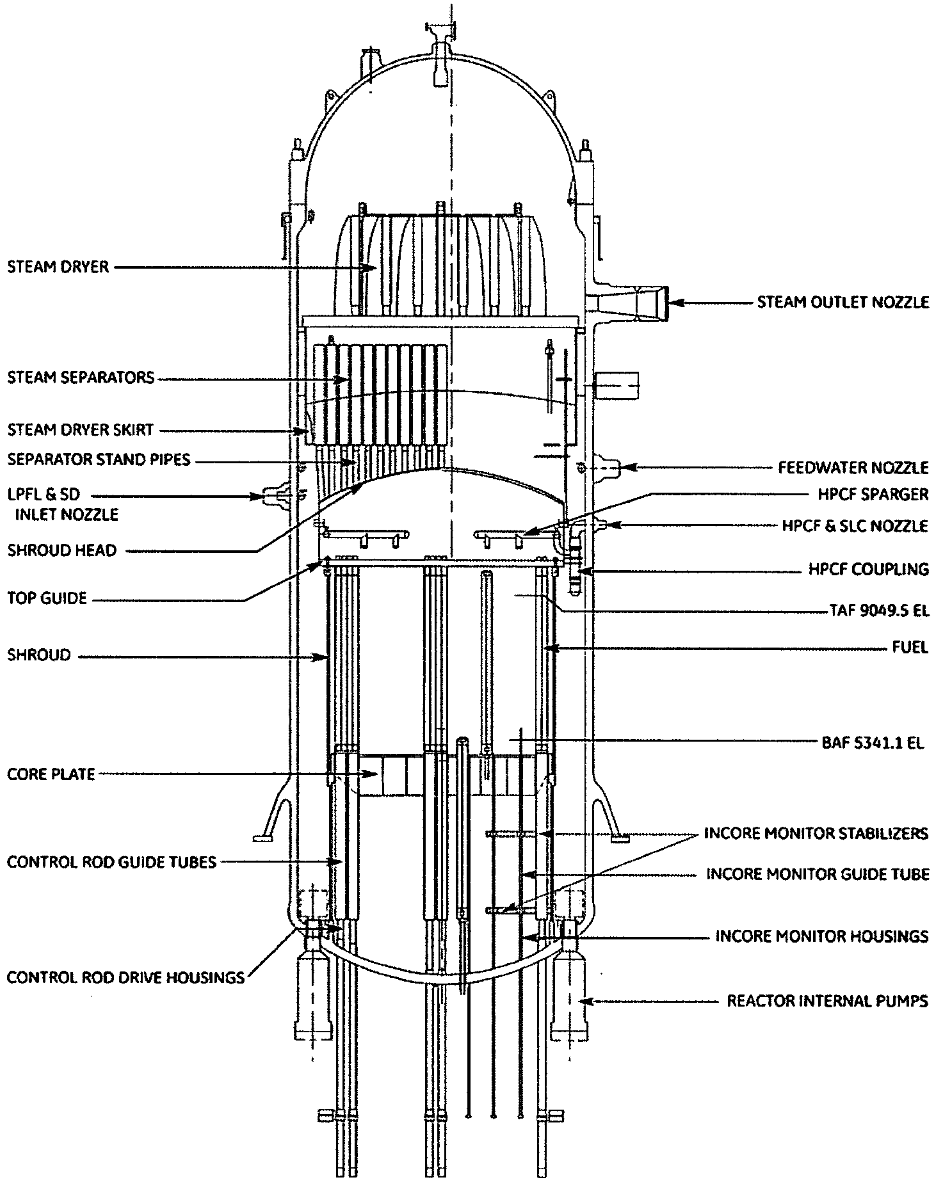

Figure 1. ABWR RPV Assembly

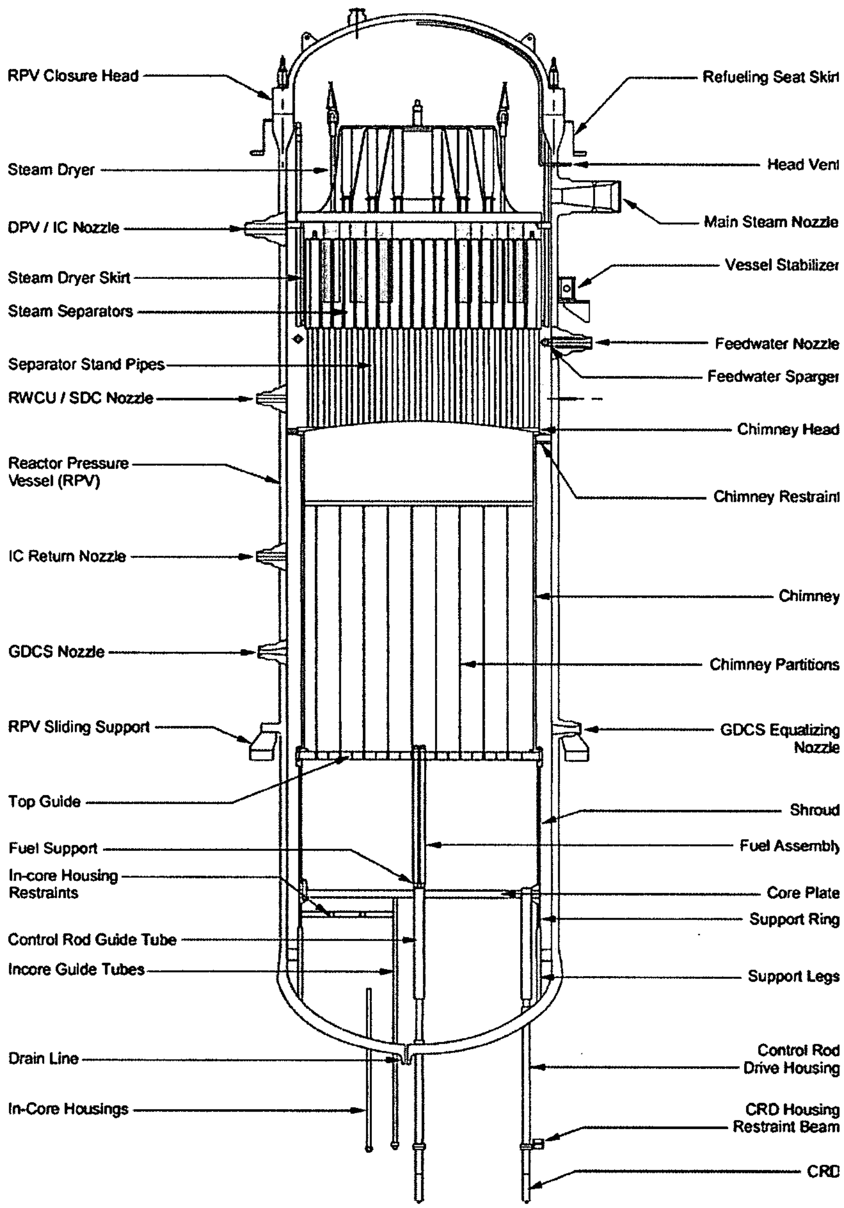

Figure 2. ESBWR Reactor Assembly

[[

]]

Figure 3. ESBWR Standby Liquid Control Injection Piping/Headers and Nozzles

NEDO-33259-A Revision 3

Attachment 1

NRC SAFETY EVALUATION

REACTOR INTERNALS FLOW INDUCED VIBRATION PROGRAM

Rec.
10/4/10

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 28, 2010

10-305

Mr. Jerald G. Head
Senior Vice President, Regulatory Affairs
GE Hitachi Nuclear Energy
3901 Castle Hayne Road MC A-18
Wilmington, NC 28401

SUBJECT: FINAL SAFETY EVALUATION FOR GE HITACHI NUCLEAR ENERGY FOR LICENSING TOPICAL REPORT NEDE-33259P

Dear Mr. Head:

On August 24, 2005, GE Hitachi (GEH) Nuclear Energy submitted the Economic Simplified Boiling Water Reactor (ESBWR) design certification application to the staff of the U.S. Nuclear Regulatory Commission. Subsequently, in support of the design certification, GEH submitted license topical report (LTR) NEDE-33259P. The staff has now completed its review of NEDE-33259P.

The staff finds NEDE-33259P, acceptable for referencing for the ESBWR design certification to the extent specified and under the limitations delineated in the LTR and in the associated safety evaluation (SE). The SE, which is enclosed, defines the basis for acceptance of the LTR.

The staff requests that GEH publish the proprietary and non-proprietary versions of the LTR listed above within 1 month of receipt of this letter. The accepted version of the topical report shall incorporate this letter and the enclosed SE and add an "-A" (designated accepted) following the report identification number.

If NRC's criteria or regulations change, so that its conclusion that the LTR is acceptable is invalidated, GEH and/or the applicant referencing the LTR will be expected to revise and resubmit its respective documentation, or submit justification for continued applicability of the LTR without revision of the respective documentation.

Document transmitted herewith contains sensitive unclassified information. When separated from the enclosures, this document is "DECONTROLLED."

Pursuant to 10 CFR 2.390, we have determined that the enclosed SE contains proprietary information. We will delay placing the non-proprietary version of this document in the public document room for a period of 10 working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any additional information in Enclosure 1 is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.390.

The Advisory Committee on Reactor Safeguards (ACRS) subcommittee, having reviewed the subject LTR and supporting documentation, agreed with the staff's recommendation for approval following the October 20, 2010, ACRS subcommittee meeting.

Sincerely,

for

David B. Matthews, Director
Division of New Reactor ~~Licensing~~
Office of New Reactors

Docket No. 52-010

Enclosure:
1. Safety Evaluation (Non-Proprietary)
2. Safety Evaluation (Proprietary): Applicant only

cc: See next page

cc:

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Legislative Director
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Safety Evaluation Report For Reactor Internals Flow-Induced Vibration Program NEDE-33259P

Introduction

The purpose of Licensing Topical Report (LTR) NEDE-33259P, "ESBWR Reactor Internals Flow Induced Vibration Program (Refs. 1, 2, 3)," is to provide the complete flow-induced vibration (FIV) evaluation of all economic simplified boiling-water reactor (ESBWR) reactor internals except for the steam dryer, which is evaluated in LTR NEDE-33313P, ESBWR Steam Dryer Structural Evaluation (Ref. 4). LTR NEDE-33259P provides data for components that are considered acceptable because of similarity with components with successful operating experience and provides details for components that required additional work to evaluate and test for FIV. For those reactor internals where additional evaluation is performed, the evaluation method, the results and conclusions are provided. For reactor internals requiring testing during startup of the first ESBWR, the type and locations are identified.

The original version of LTR NEDE-33259Pand its two revisions have been submitted to the U.S. Nuclear Regulatory Commission (NRC) (Refs. 1, 2, 3). The original LTR (Rev. 0) was released during the time frame of the issuance of the first ESBWR Design Control Document (DCD) Sections 3.9.2 and 3.9.5. These original documents lacked sufficient organization, content, and analysis. As a result, the NRC staff formulated several requests for additional information (RAIs) on Revision 0 LTR. These RAIs were treated as the RAIs for DCD Sections 3.9.2 and 3.9.5. The applicant responded promptly to some of these RAIs, and its evaluation is incorporated into the Safety Evaluation Report (SER) prepared for the DCD Sections 3.9.2 and 3.9.5. For the remaining RAIs (RAIs 3.9-49, 3.9-51, 3.9-53, 3.9-72, 3.9-75, 3.9-76, 3.9-78, 3.9-79, 3.9-96, 3.9-132, and 3.9-140 (Ref. 5)), the applicant referred to Revision 1 of the LTR.

The applicant submitted its response to the remaining RAIs in Revision 1 to LTR NEDE-33259P. This report will be referred to as Revision 1 LTR. The staff reviewed Revision 1 LTR and formulated additional RAIs (RAIs 3.9-233 through RAI 3.9-242 (Ref. 6)). Later, the staff reviewed the applicant's responses to these RAIs and found them acceptable, thus resolving all FIV issues associated with Revision 1 LTR.

Revision 2 to LTR NEDE-33259P was submitted on June 11, 2009. This report will be referred to as Revision 2 LTR. Modifications of Revision 1 LTR were made to produce Revision 2 LTR and mainly reflect the design changes and FIV analyses made since the issuance of Revision 1 LTR. The staff's review of Revision 2 LTR was not made through the issuance of new RAIs, but rather was addressed and resolved via an NRC audit held at GEH, in Wilmington, NC on August 25, 2009. Based on the review of Revision 2 LTR and on audit presentations, the staff formulated questions and formally submitted them to the applicant for written response in an audit report (Ref. 7). This report includes the applicant's responses to staff audit questions related to reactor internals, except for those related to the steam dryer.

This report presents the staff evaluation of Revision 1 LTR and Revision 2 LTR. To provide better understanding of FIV design margins and an historical record, this SER includes all RAIs issued and discussed in the review of Revision 1 LTR, even though some have become obsolete because of design changes made since the issuance of Revision 1 LTR. Because most FIV issues were resolved in the review of Revision 1 LTR, they have not been reopened in the review of Revision 2 LTR.

The applicant considered the ESBWR to be a Non-Prototype Category II through Revision 6 of DCD Tier 2 (Ref. 9), but revised its classification to Prototype in Revision 7 (Ref. 10). For further information, see the discussion of RAI 3.9-75 S02 at the end of Section 3.9.2.4.3 in the SER for DCD Section 3.9.2.

Summary

The applicant supplied a complete FIV evaluation of all reactor internals, except the steam dryer, in the LTR and its responses to NRC staff questions and RAIs.

Revision 1 LTR provides additional design details and analyses for components that remained to be evaluated for FIV analysis and testing at the time the original version of the LTR was issued. Revision 1 LTR gives the evaluation method, results and conclusions for those components that required additional evaluation. For components requiring testing during the startup of the first ESBWR, the type and locations of sensors are given. Revision 1 LTR focuses on the following components:

- chimney head/steam separator assembly
- shroud/chimney assembly
- top guide
- core plate
- standby liquid control (SLC) piping
- control rod drive housings
- control rod guide tubes (CRGT)
- in-core monitor guide tubes (ICMGT)
- in-core monitor housings (ICMH)
- chimney and chimney partitions

The remaining reactor internals components that are not specifically identified in Appendix 3L of the ESBWR DCD, or in Revision 1 LTR, have designs and flow conditions that are similar to prior operating boiling-water reactor (BWR) plants, and the applicant considers them proven by past trouble-free BWR experience. The plant that is used for comparison purposes, because it is closest to the ESBWR configuration, is the advanced boiling-water reactor (ABWR). Revision 1 LTR notes that three ABWR plants are currently operating in Japan. The first plant completed an FIV program that included analysis, testing and inspection as outlined in Regulatory Guide 1.20, Revision 2 (Ref. 11). Most important, the Japanese plants have been operating without FIV incidences.

As presented in Revision 2 LTR, the main design changes made since the issuance of Revision 1 LTR are: (1) the elimination of the core support brackets and replacement with core support legs and a support ring; (2) changes in the design of the core plate and chimney head from reinforced plates to solid plates; and (3) redesign of the chimney partition to be removable for refueling. Recalculations showed that stresses remained well below design limits for the internal structures. Some details of the partition design remain unfinished but will be done within the modeling assumptions used in the analysis results given in Revision 2 LTR. Also, as discussed below, the analysis will be rechecked by the applicant as part of inspections, tests, analyses, and acceptance criteria (ITAAC) closure. The design changes did not affect instrumentation for startup testing, except for the relocation of strain gauges at calculated maximum stress locations. The plant used for comparison purposes continues to be the ABWR.

Regulatory Criteria

The following regulatory requirements and guidelines provide the basis for the acceptance criteria for the NRC staff's review:

- Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50 (Ref. 12), "Domestic Licensing of Production and Utilization Facilities," and 10 CFR 50.55a, "Codes and Standards," as they relate to codes and standards

- General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, as it relates to structures and components being designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed

- GDC 2, "Design Bases for Protection against Natural Phenomena," of Appendix A to 10 CFR Part 50, as it relates to systems, components, and equipment important to safety being designed to withstand appropriate combinations of the effects of normal and accident conditions with the effects of natural phenomena safe-shutdown earthquake

- GDC 4, "Environmental and Dynamic Effects Design Bases," of Appendix A to 10 CFR Part 50, as it relates to systems and components important to safety being appropriately protected against the dynamic effects of discharging fluids

- RG 1.20, Revision 3, "Comprehensive Vibration Assessment Program for Reactor Internals during Preoperational and Initial Startup Testing" (Ref. 13)

Staff Evaluation of Revision 1 LTR

The staff's review of Revision 1 LTR addressed and resolved many FIV issues that were not reopened in the review of Revision 2 LTR. This section describes all the Revision 1 LTR issues and their resolution, including RAIs made obsolete by design changes made since the issuance of Revision 1 LTR.

1. Shroud/Chimney/Separator Structure

According to Section 5.2.1 of Revision 1 LTR, the applicant used a beam model to determine FIV dynamic response, because of the axisymmetric nature of the structure and the fluid flow field and forces. Also, the eight restraints located at the top of the chimney structure were assumed to provide translational and torsional restraint that transmits loads through the reactor pressure vessel (RPV). Because of the restraints, modal analysis found the fundamental beam frequency for the much longer ESBWR structure to be higher than that of the ABWR structure. Any torsional motion, argued to be small, would be readily resisted by the restraints. Section 5.2 and Table 5 of Revision 1 LTR indicate that the restraints are an important feature of the design in maintaining the low stresses in the ESBWR. Revision 1 LTR did not discuss details of the design and the consequences of alternate modeling scenarios of the restraints.

In RAI 3.9-233 (Ref. 6), the staff requested the applicant to elaborate on the design and modeling of the restraints (or supports) as they relate to FIV structural dynamic analysis and the insertion and removal of the chimney during initial fabrication and refueling. In particular, are the physical supports and gaps adjustable and how are the supports modeled (e.g., as simple supports) in dynamic structural analysis? If the eight lateral restraints are not engaged, what are the modal characteristics of the shroud/chimney/separator structure? What is the uncertainty that the beam model of the support employed in the modal analysis is representative of the physical support? How are impact forces at the gaps accounted for?

In its response to RAI 3.9-233 (Ref. 14), the applicant stated that as described in its response to RAI 3.9-238, the chimney partition is structurally separated from the chimney cylinder except at the top of the partitions. To reflect this structural feature, the analysis models the chimney partitions and chimney cylinder as separate beams. The chimney partition beam model is structurally connected to the chimney cylinder beam model at the top and to the top guide at the bottom through the locating pins. The chimney cylinder beam model is connected to the RPV beam model at the eight top lateral restraints. The upper chimney support where the chimney is restrained by the RPV, is modeled as simply supported. Because the dimensional tolerances at the chimney cylinder restraints are such that it is possible for the chimney lugs to be touching the RPV bracket, modeling the chimney top as simply supported is realistic.

When the tolerance stack-up is at the other extreme, a small gap is possible and the chimney cylinder behaves like a cantilevered beam. In such a situation, the system becomes nonlinear and, theoretically, a modal analysis to obtain the natural frequencies and mode shapes is not appropriate. In a nonlinear system, the response may be periodic, depending on the nature of the forcing function. However, the period depends upon the amplitude of the vibration. To overcome this theoretical barrier, analysts have used the "equivalent linearization" method. In the equivalent linearization process, vibration amplitude is first assumed and an equivalent linear spring is determined for that particular amplitude. The equivalent linear spring rate for a particular vibration amplitude is a rate that minimizes the error between the real spring rate (a bilinear curve in the case of a gap) and the linear spring rate. This equivalent linear spring rate is then used in a linear model to calculate the vibration response amplitude per the description in the original version of the LTR (Ref. 1). The response amplitude is then compared to the assumed amplitude. If there is reasonable agreement, the process is terminated. If the amplitudes do not agree, an iterative process is started until there is reasonable agreement.

For the ESBWR chimney FIV response analysis, a linear model with a calculated stiffness to simulate a simple support is developed. For the other extreme where the chimney cylinder behaves as a cantilever, a zero spring rate is used. For the case where the gap may be closed during part of a vibration cycle, equivalent linear stiffness of 50 percent and 10 percent of simply supported case stiffness is determined. Table 1 of the applicant's response (reproduced below) shows the results from these cases.

From the results in Table 1, the applicant concluded that the effect of the gap is minimal. The small displacement because of FIV forces is consistent with the intent of the chimney restraint support, (i.e., it is meant to resist seismic forces, not FIV forces). The effect of a large gap may increase stresses in the shroud but the stresses are negligibly small and any increase is of little significance.

[[

]]

The staff finds the applicant's response acceptable because the applicant provided details of the restraints and how the analysis using finite element method (FEM) was performed for various gap conditions. The stress results shown in Table 1 for bounding gap conditions are insignificant, because of flow in the annulus between the chimney and RPV. Therefore, RAI 3.9-233 is closed.

In calculating the FIV response of the ESBWR shroud/chimney/separator structure, the applicant used the measured [[

The calculated ESBWR stresses were well below design limits.

The applicant's use of the ABWR's [[

]] is reasonable, unless the fluid forces generated in ABWR's shroud head/steam separator create a significant FIV excitation source.

In RAI 3.9-234 (Ref. 6), the staff requested the applicant to elaborate on the possibilities of other excitation sources and potential fluid forces created by the head/steam separators and their possible effects on FIV excitation of the ESBWR shroud/chimney/separator structure.

In its response to RAI 3.9-234 (Ref. 15), the applicant referred to its response to RAI 3.9-236 (Ref. 15). After review and staff acceptance of the applicant's response to RAI 3.9-236 (see below), the staff concurs that an acceptable response to RAI 3.9-234 was incorporated into the response to RAI 3.9-236. Therefore, RAI-3.9-234 is closed.

The applicant used the forces and moments determined in the dynamic analysis of the ESBWR shroud/chimney/separator structure subject to fluid pressures in the annulus to analyze the stresses in the chimney head and steam separator assembly (Section 5.2.2 of Revision 1 LTR) and the shroud support bracket (Section 5.7 of Rev. 1 LTR). Stresses in the chimney head and steam separator assembly were found to be a small fraction (10 percent) of the allowable stresses. Stresses in the shroud support bracket were even smaller. However, the applicant did not provide any analysis for the upper chimney restraints.

In RAI 3.9-235 (Ref. 6), the staff asked the applicant to provide the loads transmitted to the RPV and the stresses in the upper chimney restraints, in the case that the upper restraints are engaged. The staff also asked the applicant to elaborate on the uncertainties in the calculated stresses to account for ambiguities in the support provided by restraints excitation sources.

In its response to RAI 3.9-235 (Ref. 15), the applicant stated that it supplied the requested information in its response to RAI 3.9-233 (Ref. 15) (see above); the staff finds that the loads transmitted to the RPV were reported in RAI 3.9-233, but the stresses in the restraint were not. However, the shear loads due to FIV are small, especially in comparison to the seismic loads used to design the supports. Therefore, the staff concludes that support stresses due to FIV will be insignificant and RAI 3.9-235 is closed.

Section 5.1 of Revision 1 LTR indicated that the flat-shaped chimney head/separator assembly has replaced the proven dome-shaped design of the shroud head/separator assembly. In RAI 3.9-236 (Ref. 6), the staff requested the applicant to provide the rationale for the change to the new flat-shaped chimney head/separator assembly design in the ESBWR, the pertinent details of the structural design as they relate to structural dynamic analysis, the pertinent details of the internal flow conditions and their potential for FIV excitation. Also, the staff asked the applicant to discuss the stresses in the chimney head/separator assembly's separator/standpipe "forest" and in individual separator/standpipe units that are caused by internal flow.

In its response to RAI 3.9-236 (Ref. 15), the applicant stated that the chimney head/separator assembly is designed as a slightly curved plate to optimize the performance of the reactor internals. In the TRACG analysis, maximizing of the water volume outside and above the core boundary was necessary to ensure that the water level in the core could be maintained within the design criteria. Therefore, a change from a dome-shaped head to an essentially flat head optimized the amount of fluid on the exterior to the core and increased the inventory of available fluid to flood the core. The head design has a slight curvature in order to reduce stresses within the structure and to lower the overall weight of the structure.

The dominant FIV excitation of the separators/separator head comes from the turbulence of the two-phase flow inside the separator. There is a small periodic forcing function because the swirling flow behaves like an unbalanced wheel. The force is zero if swirling flow is uniform. Because of flow turbulence, the flow is slightly nonuniform. The nonuniformity is random, so acting forces are random and have different phases. Therefore the aggregate effect on the separator head is minimal.

From the beam model, the maximum stress occurs at the end of the standpipes and is less than [[ ]]. This is negligibly small when compared to the allowable 68.9 MPa (10,000 psi). The response to RAI 3.9-239 discusses the reliability of the individual separators.

In review of the applicant's response to RAI 3.9-236 the staff finds the applicant explained the pertinent design details, identified the internal flow through the forest of separator standpipes as the only significant flow excitation source of the separator head, and provided the maximum stresses [[ ]] created at the connection of the separator standpipe to the separator head. Further, the applicant referred to their response to RAI 3.9-239, which staff had already reviewed and accepted. In the response to RAI 3.9-239, the applicant included a summary of testing and stress measurements made on an individual separator under prototypic flow conditions (previously reported in response to RAI 3.9-56) that showed maximum stress levels of [[ ]] are well below the acceptance criteria of 68.95 MPa (10,000 psi) stress. When the [[ ]] due to the interconnected separators responding as a unit (the "forest") to all the internal flows is added, the stresses in the separator tubes are still acceptable. Therefore, RAI 3.9-236 is closed.

2. SLC Lines

In Section 5.5 of Revision 1 LTR, the applicant designated the SLC line as a new ESBWR component that is located in the down-comer flow region in the annulus between the RPV and the chimney. A diagram of the design showed that the SLC line has a new geometry and location within the RPV. Revision 1 LTR also summarized the manner of support for the SLC line and the results of an FEM modal analysis showed that the SLC line fundamental frequency [[ ]] was well above predicted vortex shedding frequency [[ ]] because of the down-comer flow, and that the associated SLC line stresses will be minimal. The staff concurs that the avoidance of significant stresses due to self-generated vortex shedding excitation must be considered. However, Revision 1 LTR did not discuss stresses generated by other excitation sources.

In RAI 3.9-237 (Ref. 6), the staff asked the applicant to elaborate on stresses created in the SLC line due to the dynamics of the supports. Section 5.5 stated that each SLC line is said to be supported at two locations on the RPV and 4 locations on the shroud. The staff asked the applicant to supply the analyses that show the stresses in the SLC line are below design limits, because of the relative dynamic motion of the shroud and the RPV in higher vibration modes.

[[

]]. Because both longitudinal and lateral supports of the SLC line are provided, both beam and shell mode induced motion of the supports appear to be important.

In its response to RAI 3.9-237 (Ref. 16), the applicant stated that the stiffness of the SLC lines is very small when compared to that of a much larger structure like the ESBWR shroud and RPV. Although a small shroud or RPV displacement may result in significant stresses in the shroud and RPV, a similar SLC line displacement will result in much lower stresses. [[

]] The unamplified stresses due to support motion are classified as secondary stresses per the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) (Ref. 17) and have much higher stress allowable. The applicant stated that therefore they are of no concern.

The shroud/chimney/steam separator assembly is essentially an axisymmetric structure and the flow is also axisymmetric. Hence, no significant shell mode, other than n=0 and n=1 will be excited. Any minor unbalance forces because of the nonaxisymmetric structural elements such as chimney internal partitions, and separator structural ties will result in small shell mode responses. Because the ESBWR flow is more uniform than in the ABWR, fluid forces would be even smaller than in the ABWR. Therefore, any shell mode responses will be smaller in the ESBWR than in the ABWR. In summary, SLC support motion will result in negligible stresses on the SLC lines. Therefore, stresses due to support motion will be much below the allowable limits.

The staff's review of the response to RAI 3.9-237, which identified a potential FIV problem with the SLC finds that the applicant analyzed the potential and showed that stresses will be much below allowable limits. In particular, the applicant explained that the maximum displacement response of the ABWR shroud, which supports one end of the SLC, was primarily at [[

]]. Thus, static deformation and stresses of the flexible SLC will be small. Therefore, RAI 3.9-237 is closed.

3. Chimney Partition

The chimney contains a welded crate-like structure with cells that channels the flow from different groups of individual fuel assemblies upward to the steam separators. The structure is called the chimney partition, extends nearly the whole length of the chimney. Because the chimney structure is unique to the ESBWR, the applicant performed a series of tests to simulate and measure chimney partition flow characteristics during normal ESBWR operation. These tests formed the basis of the FIV analyses reported in Section 5.8 of Revision 1 LTR. Three scale model tests were performed: a 1/6 scale, a 1/12 scale, and one almost full scale. The tests used a mixture of air and water to simulate two-phase flow inside the chimney. Air was supplied by a compressor and the water was supplied by a water pump. The air and water were combined in a mixer at the chimney inlet and flowed through the simulated chimneys. Twelve pressure sensors were used to measure dynamic pressures at 10 elevations on the simulated chimney.

Two smaller scale models were used to investigate the effect of model size on the test results. They showed that the magnitude of the pressure fluctuations tends to [[

]]. The applicant also used the smaller scale model tests to show that the effects of inlet air-and-water mixing conditions had little influence on the pressures measured. In addition, the correlations of the pressures between the cells of the chimney partition were found to be [[ ]]. Test results from the large scale model show a maximum peak-to-peak pressure of [[ ]].

To estimate the FIV stresses in the chimney partition, the applicant input the test results into an ANSYS Version 5.6 FEM model that employed both plate and solid three dimensional elements. The FEM was first used to extract the eigenvalues, which showed the lowest frequency of the chimney to be [[ ]]. Because the pressure forcing function from the flow tests was dominant around [[ ]], a static analysis was used to calculate FIV response. The peak test pressure of [[ ]] was applied uniformly on four sides in one cell and the opposite pressure applied in adjacent cells. The calculated response results show that the maximum stress occurs [[ ]]. Using a fatigue strength reduction factor of two for welded joints from ASME Code Section III Table NG-3352-1, the applicant found the maximum stress intensity to be [[ ]], well below the allowable value of 68.9 MPa (10,000 psi).

The staff agrees that internal partition flow results in acceptable stresses for the assumptions of the FEM model, but did not understand the modeling of partition boundary conditions, and the effects, if any, of the deformation of the chimney, and the possibility of other boundary conditions.

The staff noted that in response to RAI 3.9-140 (Ref. 18), (formulated in an FIV review of DCD Section 3.9.5), the applicant reported that the FEM model of the partition assumed the outermost ends of the partition were essentially fixed ends. The response to RAI 3.9-140(c) implied that the partition is attached along the entire length of the chimney. However, at the time of the applicant's response to RAI 3.9-140, the design of the connections to provide such rigidity was still in progress. Therefore, in RAI 3.9-238 (Ref. 6), the staff requested the applicant to elaborate on the design of the chimney partition and its connections to the chimney, the sensitivity of the boundary condition assumptions on the calculated partition stresses, and why motion of the chimney because of flow in the annulus between the chimney and the RPV does not create additional significant stresses in the partition.

In its response to RAI 3.9-238 (Ref. 15) the applicant stated that as described in Section 9.1.4.15 of DCD Revision 5, the chimney partitions are designed to be removable for refueling. To facilitate proper alignment of the lower end of the chimney partitions to the top guide structure, alignment pins are necessary. Therefore, there is a secure lateral support at the lower end of the chimney partitions at the pin interface with the top guide. There is also a secure lateral support at the top of the chimney partitions that can be readily released for chimney removal. At the edges of the peripheral chimney partitions there are vertical plates attached to the partitions to stiffen and reduce stresses at the outer partition locations. Therefore, the only interface with the chimney cylinder is at the top of the chimney partitions, because contact along the length of the partition structure is not expected. The chimney partition is restrained laterally at the bottom by the top guide through the locating pins.

The chimney partition is free to move in the axial direction but restrained in the radial and tangential directions by the chimney cylinder. The fluid forces acting on the outer chimney cylinder surfaces are derived from the ABWR measurement as described in Section 5.2.1 of Revision 1 LTR. The vibration of the chimney cylinder resulting from these forces is transmitted to the chimney partition through the restraints. As described in the applicant's response to RAI 3.9-233 (Ref. 7), the chimney partition is modeled as a beam separated from the chimney cylinder beam except at the top of the chimney partition where they are connected. Therefore, any chimney cylinder vibration induced by the flow between the RPV and the shroud/chimney annulus is transmitted to the partition through this upper connection. The partition vibration stresses induced by the cylinder vibration are automatically accounted for in the chimney partition and chimney cylinder models. The boundary conditions at the top and bottom of chimney partitions are clearly defined. From the beam model the maximum partition stress is [[ ]]. This is negligibly small when compared to the allowable 68.9 MPa (10,000 psi). In view of the small value of these stresses, any possible increase as a result of alternate boundary conditions is not of any significance.

In its response to RAI 3.9-238, the applicant described the connection between the chimney and the partition and stated that it was included in the FEM FIV analysis of upper internals structures subject to the flow between the chimney and the RPV. Staff's review of the FIV analysis found stresses in the partition due to flow in the annulus to be very small and not of concern. Therefore, RAI 3.9-238 is closed.

4. ESBWR Instrumentation

In Section 5.1 of Revision 1 LTR, the applicant stated that the steam separator standpipes are longer than those in the ABWR, which will result in a lower natural frequency. Because of this change the applicant selected the chimney head/steam separator assembly for further evaluation. The applicant stated that restraints in the separator/standpipe "forest" were designed to increase the natural frequency and to minimize vibration responses to flow conditions. Accelerometers will be provided for the ESBWR prototype FIV test to confirm the adequacy of the design. However, the staff did not understand how the instrumentation proposed in Table 6 of Revision 1 LTR is adequate to accomplish the confirmation.

In Section 5.2.4 of Revision 1 LTR, the applicant stated that for the ESBWR, [[ ]] accelerometers, [[ ]] degrees apart, will be placed near the calculated maximum acceleration elevation to measure the radical and tangential motion of the shroud/chimney/separator assembly. The maximum acceleration location is near the separator support ring. [[ ]] additional accelerometers, [[ ]] degrees apart, will be placed at the midpoint of the chimney to measure chimney motion. These are clearly intended to confirm the analysis and design of the shroud/chimney, but the applicant did not discussed the adequacy of the instrumentation is not discussed.

In RAI 3.9-239 (Ref. 6), the staff asked the applicant to elaborate on the rationale for and the location of the instrumentation intended to confirm the adequacy of the design of the steam separator assembly. In light of RAI 3.9-236, the staff asked the applicant to comment on whether the instrumentation will measure/confirm stresses induced by internal flow in the individual separators.

In its response to RAI 3.9-239 (Ref. 16), the applicant stated that there are [[ ]] accelerometers installed on the upper guide ring of the steam separator assembly. Because of their location on the relatively rigid upper ring, these accelerometers measure the gross motion of the separator assembly rather than the acceleration of the individual separators. Dynamic analyses of the separator/chimney/shroud structure and the ABWR shroud structures show that the maximum FIV stresses from gross motion occur at the roots of the standpipes. Therefore, it can be concluded that dynamic analysis results show the accelerometer placement is appropriate.

The reliability of the individual separators has been confirmed through out-of-reactor tests. As stated in the response to RAI 3.9-56 (Ref. 19) during development testing of the particular separator used in the ESBWR, hot tests were conducted to determine the FIV response of the separator using various flow rates. During the test, the maximum flow rate through the steam separator was [[ ]] quality. This is higher than the ESBWR maximum separator flow of [[ ]]. Test results show a maximum FIV stress of less than [[ ]] that is well below the acceptance criteria of 68.95 MPa (10,000 psi). Thus the applicant concluded that separator FIV effects are acceptable. Furthermore, satisfactory operating experience in many BWRs and the ABWR, with higher flow rates, give added assurance that FIV induced stresses are acceptably low in the individual steam separators.

Because the applicant justified the instrumentation locations for the out-of-reactor testing to assess the adequacy of the steam separator assembly due to overall FIV motion and the adequacy of the individual tubes to maintain FIV stresses well below the acceptance criteria for internal flow that exceeded ESBWR operating conditions, the staff concludes that RAI 3.9-239 is closed.

In RAI 3.9-240 (Ref. 6), the staff asked the applicant to elaborate on the redundancy the instrumentation on the shroud/chimney structure provides, in the case of loss of one or more of the transducers. The staff also asked the applicant to discuss whether the instrumentation enables the calculation of the motion of the supports of the SLC lines.

In its response to RAI 3.9-240 (Ref. 20), the applicant stated that as described in the Revision 1 LTR, the shroud/chimney structure will have two levels of accelerometers with four sensors at each level, for a total of eight accelerometers. In addition, two strain gauges will be placed near the shroud bottom at the maximum stress location, along the principal stress directions. In theory, two accelerometers, 90 degrees apart, will be sufficient to define the motion of the shroud chimney structure. Given the frequencies and mode shapes of the shroud/chimney structure, the motion of all other points on the structure can be determined using finite element analysis results. In addition, based on past experience of their use in many BWRs indicates that the reliability of accelerometers for one startup cycle is very high. Therefore, it can be concluded that the eight accelerometers provide adequate redundancy. The two strain gauges at the bottom of the shroud provide additional redundancy.

The SLC line has its own set of instrumentation and does not rely on the measurements made on the shroud/chimney structure for stress calculation during startup. The SLC support motions are not used to calculate the SLC line stresses. Instead, two strain gauges are placed directly near the points of calculated maximum stresses of an SLC line. The strain measurements will allow accurate determination of the SLC maximum stresses. Inference of the SLC support motion from measured SLC strains and accelerations are subject to considerable error and uncertainty and is deemed unnecessary. Based on these explanations, the staff finds that the instrumentation plans for the shroud/chimney and SLC are adequate. Therefore, RAI 3.95-240 is closed.

In Section 5.5 of Revision 1 LTR, the applicant found that FIV excitation of the SLC is of no concern, because the fundamental frequency of the SLC line was determined to be [[ ]], which is over [[ ]] times higher and well separated from the vortex shedding frequency of [[ ]]. However, the applicant gave no explanation for the use of the [[ ]] sensors to be placed on the SLC lines.

In RAI 3.9-241 (Ref. 6), the staff asked the applicant to elaborate on the rationale for the selection and location of the sensors to be placed on the SLC lines. The staff also asked the applicant to comment on whether the motion measured by the shroud/chimney instrumentation and the accelerations measured on the SLC lines will be comparable.

In its response to RAI 3.9-241 (Ref. 20), the applicant stated that one SLC line is instrumented. Two strain gauges, on one SLC line shroud penetration at the bottom, along the principal stress directions, are used. Two accelerometers, on one SLC line near the end of the circular header, are used to measure radial and tangential accelerations. The locations of these sensors are based on the dynamic analysis results of a three-dimensional finite element model of the SLC line. The strain gauges are located near the points of the calculated maximum principal stresses. The two accelerometers are located near the points of maximum calculated accelerations.

Eight accelerometers at two levels of the shroud/chimney structure measure the acceleration of the shroud/chimney structure. The dynamic structural characteristics, such as the natural frequencies and mode shapes, of the SLC line and shroud/chimney structures are different from each other. The forcing functions acting on these structures, including the forcing frequencies and amplitudes, are also different. Thus, even though some of the natural and forced frequencies of the shroud/chimney structure may appear as response frequencies in the SLC piping, their magnitudes are indeterminate. Because sensors are mounted directly on the SLC piping, the SLC piping stresses can be determined directly using the sensor signals. There is no need to use the support motion for stress determination. The staff finds the applicant's plans for instrumentation of SLC piping adequate to determine its stresses. Therefore, RAI 3.9-241 is closed.

In Section 5.7.2 of Revision 1 LTR, the applicant stated that because of the addition of the chimney in the structure, the shroud/chimney/separator structure will be more heavily instrumented than in the ABWR. [[ ]] strain gauges will be placed at the maximum calculated stress locations in addition to the [[ ]] accelerometers, [[ ]] degrees apart, placed at the calculated maximum ESBWR shroud/chimney/separator acceleration elevation and the
[[ ]] accelerometers, [[ ]] degrees apart, placed at the midpoint of the chimney. These
[[ ]] strain gauges will be placed on the shroud above the support bracket along the calculated principal stress directions at the highest stress point. However, the applicant did not state the stress levels predicted for the shroud above the support bracket are not given.

In RAI 3.9-242 (Ref. 6), the staff asked the applicant to elaborate on the rationale for the selection and location of the sensors to be placed on the shroud above the support bracket and to provide predicted stresses. If these are not the maximum stresses, the staff asked the applicant to provide the value and location of the maximum stresses for the shroud/chimney/separator assembly.

In its response to RAI 3.9-242 (Ref. 15), the applicant stated that the shroud support design has been changed from "shroud support brackets" to "shroud support legs". As before, strain gauges will be placed near the points of maximum calculated principal stresses. Placement of strain gauges near the principal stress locations will obviate the need for extrapolation of stresses based on the results of finite element model analyses. Based on the loads generated by the beam model described in the response to RAI 3.9-233 (Ref. 15), the maximum bending stresses are less than [[
]] and occur at the lateral brace location on the shroud leg. In light of the new design details, the staff finds the rationale and location for the strain gauges on the support legs acceptable. Therefore, RAI 3.9-242 is closed.

In response to a past-unresolved RAI 3.9-77 S01 (Ref. 21) developed in the DCD review, the applicant indicated that it would be resolved in Revision 1 LTR, which was then to be released shortly. For tracking purposes, the staff asked RAI 3.9-77 S01 again during the review of Revision 1 LTR, renumbered as RAI 3.9-243 (Ref. 6).

In RAI 3.9-243 (Ref. 6), the staff asked the applicant to provide the justification for extrapolating the stresses in the ESBWR top guide from stresses calculated in the ABWR, based on the guide plate lateral load results from the beam model analyses. In particular, the applicant was to comment on any differences in stress concentrations on the boundary and stress patterns on
the boundary and interior in the ABWR and ESBWR top guides. All of these would have to be the same or very similar in the ABWR and the ESBWR for the extrapolation to provide a reasonable estimate of the stress in the ESBWR top guide.

In its response to RAI 3.9-243 (Ref. 22), the applicant referred to its response to RAI 3.9-77 S01 (Ref. 21) and RAI 3.9-77 S02 (Ref. 23). The applicant performed additional calculations and made clear that the actual ESBWR top guide geometry was analyzed subject to the scaled loads from ABWR and that the stresses are well below allowable. The applicant did not rely on extrapolation of stresses from the ABWR. The staff finds acceptable its review of the response to RAI 3.9-243 and the response to RAI 3.9-77 S02. RAI 3.9-77 was closed. Therefore, RAI 3.9-243 is closed.

Staff Evaluation of Revision 2 LTR

In Revision 2 LTR, Table 2 compared Revision 1 LTR and Revision 2 LTR and summarized the changes in the design of the core plate and chimney head from reinforced plates to solid plates. The ESBWR core plate is no longer constructed like its counterpart in the ABWR, and the chimney head construction, is changed to a solid plate forming a shallow head, similar to the shroud head in ABWR. Also, the core support brackets were eliminated and replaced with core support legs and a support ring. The applicant gave details of the changes in the design of these structures during the NRC audit in Wilmington, NC on August 25, 2009 (Ref. 7), using the applicant's computer model of the reactor internals. In particular, the applicant showed how the chimney cylinder and chimney partition are attached to each other, the top guide, and are supported and restrained by the RPV and RPV bracket. The applicant also explained the modeling of the structures and supports for the dynamic analysis of shroud/chimney structure. The modeling assumes pinning of the chimney to the RPV, as was assumed in the analyses of Revision 1 LTR. Although not yet designed, the pinning will be accomplished using multiple removable wedge configurations that have been employed in past reactors.

The flow rate through the reactor internals appeared to have been increased by 16 to 17 percent, since the issuance of Revision 1 LTR, but the applicant explained during the audit that mean flow rates were used in past calculations but the maximum expected flow rates were used for analyses in Revision 2 LTR. This change is reflected in the increase in vortex shedding frequencies for selected components in Tables 3 and 4 of Revision 2 LTR, where vortex-shedding excitation is considered. The stresses of the below core components given in Table 4 remain the same in Revision 1 LTR and Revision 2 LTR, but, if the increases in flow rate were taken into account, the low stress levels would remain low.

During the audit, the applicant supplied the out-of-reactor test report on an individual separator to explain the basis for finding separator FIV effects acceptable, even with the higher flow rates used in Revision 2 LTR. This report had been referenced in the earlier LTRs and was reviewed during the audit.

Minor dimensional changes were made in other reactor internal components, but they are not expected to affect FIV considerations. In particular, the applicant discussed the computer model of the SLC line, attachments to the shroud and RPV, and location of the vibration monitoring instrumentation during the audit. Also reviewed was the ESBWR SLC Piping FIV Stress Analysis Report, CE-OG-0110, Revision 1, June 2007.

Based on the audit presentations and review of Revision 2 LTR, the staff formulated questions and formally submitted them to the applicant for written response in an audit report (Ref. 7).

The audit questions that the staff submitted to the applicant included the following:

<u>Audit Question 7:</u> In NEDE-33259, Revision 2, the support of the ESBWR shroud was changed from Revision 1. Show the [[

]].

<u>Audit Question 8:</u> Explain the planned supports for the [[

]]

<u>Audit Question 9:</u> Verify that FIV stress analysis of the internal components has been repeated that accounts for the [[

]]

The applicant's response to Audit Question 7 (Ref. 8) stated that as explained in the audit meeting, the design of the shroud support in the [[

]]

The staff's reviewed of the applicant's response to Audit Question 7 finds that the applicant showed the change to leg supports for the shroud in the audit. In its response, the applicant explained the similarity of the supports to past BWRs that have operated successfully for years without any adverse FIV effects on the structures below the core and downstream from the leg supports. Instrumentation on CRD and in-core housing during startup testing has confirmed the adequacy of the design. Therefore, Audit Question 7 is closed.

The applicant's response to Audit Question 8 (Ref. 8) stated that for the chimney partition assembly that will be designed to be removable at refueling outages, [[

]]

The staff reviewed the applicant's response to Audit Question 8 and finds that the applicant adequately explained the changes to allow removal of the partition. As a result of the review of the analysis results, the staff found that design work remains on (1) providing essentially pinned supports at many circumferential locations between the chimney and the RPV and (2) creating essentially fixed supports for the longitudinal edges of the chimney, concepts for both of which were also discussed in the audit meeting. The development of these supports is necessary to allow previous FIV analysis to remain valid. In its response, the applicant committed to complete the support designs and reanalysis to confirm the support designs. Therefore, Audit Question 8 is closed, and (inspection, test, analysis, and acceptance criteria) ITAAC Item 8a will provide verification of the final design of the chimney partition and of the FIV analysis of the chimney partition and the shroud/chimney/separator assembly that confirms their design. The staff has reasonable assurance based on the applicants commitment to meet the ASME code requirements, and the ITAAC will verify that the design of the chimney and partitions will meet the requirements of ASME Code Section III, Subsection NG-1122(c). The staff confirmed the addition of this ITAAC into Table 2.1.1-3 in Revision 7 of the DCD Tier 1 (Ref. 10).

The applicant's response to Audit Question 9 (Ref. 8) stated that the evaluation work reported in Revision 2 LTR does include the newly designed components such as the [[

]]

The staff's review of the applicant's response to Audit Question 9, finds that the applicant did discuss the work in Revision 2 LTR and showed the analysis in References (9-1) through (9-3). In its response, the applicant confirmed that all necessary FIV analyses have been repeated for the newly designed components. Therefore, Audit Question 9 is closed.

Conclusions

The staff found that the applicant's FIV evaluations of the ESBWR's reactor internal components, excluding the steam dryer, are compliant with the requirements of GDC 1, 2, and 4, and with 10 CFR Part 50 and 10 CFR 50.55a. FIV analysis and the testing performed should provide adequate design of the reactor internal components to safely withstand the FIVs resulting from coolant flow under steady-state conditions. The design of the internal components is complete with one exception. ITAAC, Item 8a requires the applicant to verify the final design of the chimney partition and an FIV analysis of the chimney partition and the shroud/chimney/separator assembly that confirms their design. The staff finds reasonable assurance that the design of the chimney and partitions will meet the requirements of ASME Code Section III, Subsection NG-1122(c). This conclusion is based on the following findings:

1. Every internal component has been reviewed for potential FIV excitation. Components that have construction similar to those already existing and functioning in currently operating reactors were identified. FIV excitation potential for these components was analyzed and shown to be more robust because of their modified designs, than those in currently operating reactors.

2. Internal components that were not similar to the designs in currently operating reactors were designed, analyzed, and conservatively redesigned, as necessary, to minimize component stresses and responses, based on the current knowledge of FIV excitation mechanisms. Most of the flow and pressure data used in the analyses were obtained from reduced-scale model testing, full-scale out-of-reactor FIV testing under simulated flow conditions, and results from the FIV testing of Japan's first ABWR reactor.

3. Having identified and analyzed the components that were new to this reactor design, the applicant choose accelerometers and strain gauge instrumentation and their placements for use during start-up FIV testing to confirm the adequacy of the component designs.

4. For each new component, the staff reviewed the design, FIV test data or results, FIV analyses, and startup test instrumentation and the operating conditions for which startup testing will be performed. For staff questions, the staff obtained further information until it could confirm the adequacy of the evaluations.

References

1. GEH, LTR NEDE-33259P, "ESBWR Reactor Internals Flow Induced Vibration Program – Part 1," January 2006 (ADAMS Accession No. ML060180316).

2. GEH, LTR NEDE-33259P, "ESBWR Reactor Internals Flow Induced Vibration Program," Revision 1, December 2007 (ADAMS Accession No. ML073460623).

3. GEH, LTR NEDE-33259P, "ESBWR Reactor Internals Flow Induced Vibration Program," Revision 2, June 2009 (ADAMS Accession No. ML091660436).

4. GEH, LTR NEDC-33313P, Revision 1, "ESBWR Steam Dryer Structural Evaluation," July 2009 (ADAMS Accession No. ML092170644).

5. Letter from Lawrence Rossbach, (NRC), to David H. Hinds, (GEH), "Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application – RAI Numbers 3.9-3 through 3.9-175," October 10, 2006 (ADAMS Accession No. ML062760404).

6. Letter to Chandu Patel, (NRC), to Robert Brown, (GEH), "Request for Additional Information Letter No. 220 Related to NEDE-33312P, "ESBWR Steam Dryer Acoustic Load Definition," NEDE-33313P, "Steam Dryer Structural Evaluation," NEDC-33408P, "ESBWR Steam Dryer-Plant Based Load Evaluation Methodology," NEDE-33259P, "Reactor Internals Flow Induced Vibration Program," and ESBWR Design Control Document, Revision 5 - RAI Numbers 3.9-205 through 3.9-246," July 29, 2008 (ADAMS Accession No. ML082060534).

7. Audit Report, "Report of the August 25, 2009, and September 9, 2009, Regulatory Audit of Reactor Pressure Vessel Internals of the Economic Simplified Boiling Water Reactor at General Electric Hitachi (GEH) Office in Wilmington, NC," September 15, 2009 Proprietary Version (ADAMS Accession No. ML092570429).

8. Letter from Richard E. Kingston, (GEH), to NRC, "Response to NRC Report of the August 25, 2009, and September 9, 2009, Regulatory Audit of Reactor Pressure Vessel Internals of the Economic Simplified Boiling Water Reactor," October 8, 2009 (ADAMS Accession No. ML092860177).

9. GE-Hitachi "Design, Control Document Tier 2", Revision 6, September 2009 (ADAMS Accession No. ML092680561).

10. GE-Hitachi, "ESBWR Standard Plant Design, Revision 7 to Design Control Document Tier 1 and Tier 2," March 29, 2010 (ADAMS Accession No. ML101340143.)

11. Regulatory Guide 1.20, Revision 2, "Comprehensive Vibration Assessment Program for Reactor Internals during Preoperational and Initial Startup Testing."

12. U.S. Code of Federal Regulations, *Title 10, Energy*, Part 50, "Domestic Licensing of Production and Utilization Facilities."

13. Regulatory Guide 1.20, Revision 3, "Comprehensive Vibration Assessment Program for Reactor Internals during Preoperational and Initial Startup Testing."

14. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 220, 338 and 339 Related to ESBWR Design Certification Application - DCD Tier 2, Section 3.9 - Mechanical Systems and Components; RAI Numbers 3.9-223, 3.9-260, 3.9-265, 3.9-266 and 3.9-221 S01," July 31, 2009 (ADAMS Accession No. ML092160844).

15. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 220 Related to ESBWR Design Certification Application - DCD Tier 2, Section 3.9 - Mechanical Systems and Components; RAI Numbers 3.9-233 through 3.9-236, 3.9-238,and 3.9-242," December 19, 2008 (ADAMS Accession No. ML083590252).

16. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 220 Related to ESBWR Design Certification Application - DCD Tier 2, Section 3.9 – Mechanical Systems and Components; RAI Numbers 3.9-237 and 3.9-239," October 29, 2008 (ADAMS Accession No. ML083080087).

17. American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code, Section III, Subsection NG," Divisions 1 2001 Edition and Addenda through 2003, New York, NY, 2004.

18. Letter from David H. Hinds, (GEH), to NRC, "Response to Portion of NRC Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application - DCD Section 3.9 - RAI Numbers 3.9-4 through 3.9-11, 3.9-17, 3.9-18, 3.9-23, 3.9-26, 3.9-27, 3.9-29, 3.9-32, 3.9-34 through 3.9-36, 3.9-38 through 3.9-40, 3.9-44, 3.9-46 through 3.9-55, 3.9-57, 3.9-59, 3.9-60, 3.9-67, 3.9-72 through 3.9-76, 3.9-79, 3.9-80, 3.9-91 through 3.9-94, 3.9-96 through 3.9-99, 3.9-101, 3.9-102, 3.9-104, 3.9-105, 3.9-108, 3.9- 110, 3.9-132, 3.9-140, 3.9-142, 3.9-147, 3.9-150, 3.9-151, and 3.9-153," November 22, 2006 (ADAMS Accession No. ML063410346.).

19. Letter from James C. Kinsey, (GEH), to NRC, "Response to Portion of NRC Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application - Steam Separator Skirt - RAI Number 3.9-56," August 1, 2007 (ADAMS Accession No. ML072150048).

20. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 220 Related to ESBWR Design Certification Application - DCD Tier.2, Section 3.9 – Mechanical Systems and Components; RAI Numbers 3.9-240 and 3.9-241," October 29, 2008 (ADAMS Accession No. ML083080069).

21. Letter from James C. Kinsey, (GEH), to NRC, "Response to Portion of NRC Request for Additional Information Letter Number 67 Related to ESBWR Design Certification Application - Dynamic Testing and Analysis of Systems, Components, and Equipment - RAI Numbers 3.9-49 S01, 3.9-53 S01, 3.9-59 S01, 3.9-72 S01, 3.9-73 S01 3.9-76 S01, 3.9-77 S01, 3.9- 78, 3.9-79 S01 and

3.9-96 S01, and - Reactor Pressure Vessel Internals - RAI Numbers 3.9-132 S01 and 3.9-147 S01," February 4, 2008 (ADAMS Accession No. ML080370162).

22. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 220 Related to ESBWR Design Certification Application - DCD Tier 2, Section 3.9 – Mechanical Systems and Components; RAI Number 3.9-243," January 21, 2009 (ADAMS Accession No. ML090210578).

23. Letter from Richard E. Kingston, (GEH), to NRC, "Response to Portion of NRC RAI Letter No. 166 Related to ESBWR Design Certification Application - DCD Tier 2, Section 3.9 – Mechanical Systems and Components; RAI Number 3.9-77, Supplement 2," December 11, 2008 (ADAMS Accession No. ML083460610).

Enclosure 3

MFN 10-308 Revision 1

Affidavit

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, Mark J. Colby, state as follows:

(1) I am the Manager, New Plants Engineering of GE-Hitachi Nuclear Energy Americas LLC (GEH), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Enclosure 1 of GEH's letter, MFN 10-308 Revision 1, Mr. Richard E. Kingston to U.S. Nuclear Regulatory Commission, entitled *Submittal of Accepted Versions of NEDE-33259P, "Reactor Internals Flow Induced Vibration Program,"* dated October 15, 2010. GEH text proprietary information in Enclosure 1, which is entitled *NEDE-33259P-A, Revision 3, "Reactor Internals Flow Induced Vibration Program"* is identified by a dotted underline inside double square brackets. [[This sentence is an example.{3}]] Figures and large equation objects containing GEH proprietary information are identified with double square brackets before and after the object. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit that provides the basis for the proprietary determination. Note that the GEH proprietary information in the NRC's Final Safety Evaluation, which is enclosed in NEDE-33259P-A, Revision 3, is identified with underlined text inside double square brackets. [[This sentence is an example.]]

(3) In making this application for withholding of proprietary information of which it is the owner or licensee, GEH relies upon the exemption from disclosure set forth in the Freedom of Information Act (FOIA), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for trade secrets (Exemption 4). The material for which exemption from disclosure is here sought also qualifies under the narrower definition of trade secret, within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975 F2d 871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704 F2d 1280 (DC Cir. 1983).

(4) The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b. Some examples of categories of information that fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GEH's competitors without license from GEH constitutes a competitive economic advantage over GEH and/or other companies.

b. Information that, if used by a competitor, would reduce their expenditure of resources or improve their competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information that reveals aspects of past, present, or future GEH customer-funded development plans and programs, that may include potential products of GEH.

d. Information that discloses trade secret and/or potentially patentable subject matter for which it may be desirable to obtain patent protection.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to the NRC in confidence. The information is of a sort customarily held in confidence by GEH, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GEH, not been disclosed publicly, and not been made available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary and/or confidentiality agreements that provide for maintaining the information in confidence. The initial designation of this information as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure are as set forth in the following paragraphs (6) and (7).

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, who is the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or who is the person most likely to be subject to the terms under which it was licensed to GEH. Access to such documents within GEH is limited to a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist, or other equivalent authority for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GEH are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary and/or confidentiality agreements.

(8) The information identified in paragraph (2) above is classified as proprietary because it identifies detailed GE ESBWR design information. GEH utilized prior design information and experience from its fleet with significant resource allocation in developing the system over several years at a substantial cost.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GEH asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply

the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GEH. The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial. GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GEH would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GEH of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

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 15th day of October 2010.

Mark J. Colby
GE-Hitachi Nuclear Energy Americas LLC