Enclosure 4

MFN 12-066, Rev. 2

Marked-Up Pages for ESBWR DCD Section 3L Related to RAI 3.9-291 Response

3L.4.6 Instrumentation and Startup Testing

The ESBWR steam dryer is instrumented with temporary vibration sensors to obtain flow induced vibration data during power operation. The primary function of this vibration measurement program is to confirm FIV load definition used in the structural evaluation is conservative with respect to the actual loading measured on the steam dryer during power operation, and to verify that the steam dryer can adequately withstand stresses from flow induced vibration forces for the design life of the steam dryer. The instrumentation and startup testing program for the ESBWR steam dryer follows NRC regulatory guidance in Reference 3L-10, as described below.

The detailed objectives are as follows:

- Determine the as-built frequency response parameters: This is achieved by frequency response testing the steam dryer components. The results yield natural frequencies, mode shapes and damping of the components for the as-built steam dryer. These results are used to verify portions of the steam dryer analytical model.
- Confirm FIV loading: In order to confirm loading due to turbulence, acoustics and other sources, dynamic pressure sensors are installed on the steam dryer. These measurements will provide the actual pressure loading on the steam dryer under various operating conditions.
- Verify the design: Based on past knowledge gained from different steam dryers, as well as information gleaned from analysis, selected areas are instrumented with strain gages and accelerometers to measure vibratory stresses and displacements during power operation. The measured strain values are compared with the allowable values (acceptance criteria) obtained from the analytical model to confirm that the steam dryer alternating stresses are within allowable limits.

The objective of the steam dryer frequency response test is to identify the as-built frequencies and mode shapes of several key components of the steam dryer at ambient conditions. Different components of the steam dryer have different frequencies and mode shapes associated with them. The areas of interest are the drain channel, the outer hood panel, the inner hood panel, the side panel, and the skirt. These results are used to verify portions of the finite element model of the steam dryer.

The concern is that local natural frequencies may coincide with existing forcing functions to cause resonance conditions. The resonance could cause high stresses to occur in localized areas of the steam dryer. A finite element frequency response analysis can calculate the frequency and mode shape of a component, but they are only ideal approximations to the real values due to variations such as plate thickness, weld geometries, configuration tolerances and residual stresses that affect the assumed boundary conditions in the finite element model. The mode shapes and frequencies determined by the frequency response test are used to validate the finite element frequency response analysis and determine the uncertainty in the finite element model predictions of the frequency response. The FE model and experimental transfer functions are then used to derive frequency dependent amplitude bias and uncertainty of the FE model for key areas of the dryer. This is described further in Reference 3L-6.

The frequency response test is performed following final assembly of the steam dryer. The tests are performed with the steam dryer resting on simulated support blocks similar to the way the steam dryer is seated inside the reactor vessel.

Two types of impact tests are performed on the steam dryer: (1) Dry frequency response test, and (2) Wet frequency response test with the steam dryer skirt and drain channels partially submerged in different water levels (to approximate in-reactor water level). Both tests are conducted in ambient conditions. Temporary bondable accelerometers are installed at predetermined locations for these tests. An instrumented input force is used to excite the steam dryer at several pre-determined locations and the input force and the structural responses from the accelerometers are recorded on a computer. The data is then used to compute experimental transfer functions mode shape, frequency and damping of the instrumented steam dryer components using appropriate software. The temporary sensors are then removed and the steam dryer is cleaned prior to installation in to the reactor vessel.

The steam dryer vibration sensors consist of strain gages, accelerometers and dynamic pressure sensors, appropriate for the application and environment. A typical list of vibration sensors with their model numbers is provided in Table 3L-3. The selection and total number of sensors is based on past experience of similar tests conducted on other BWR steam dryers. These sensors are specifically designed to withstand the reactor environment. The pressure instrument locations are selected to provide a good measure of the acoustic loading through the frequency range of interest. A proper distribution of the steam dryer pressure instruments facilitates accurate assessments of FIV loads. The layout of the steam dryer pressure instrument locations is evaluated using the RPV acoustic FEA Model. The distribution of steamline instruments is determined using the Plant Based Load Evaluation model (Reference 3L-8) to provide an adequate measure of the acoustic loading through the frequency range of interest. The instrument layout permits steam dryer load development with steam dryer data alone, steamline data alone, or a combination using both sets of data. The approach used to determine the number and locations of pressure instruments is described in Subsections 2.3.2 and 4.4.2 of Reference 3L-8 and Subsections 4.4.3.1 and 4.4.4 of Reference 3L-9.

The steam dryer startup test and monitoring power ascension limits are developed on a similar basis as the monitoring limits used for recent extended power uprate replacement steam dryers. The power ascension limits are based on the final FIV analysis performed for the as-built steam dryer. Strain gages and accelerometers are used to monitor the structural response during power ascension. Accelerometers are also used to identify potential rocking and to measure the accelerations resulting from support and vessel movements. The approach used to determine the number and locations of the strain gages and accelerometers is described in Section 9.0 of Reference 3L-6. Specific information utilized to verify the FIV load definition during startup testing is described further in References 3L-5 and 3L-6.

Each of the sensors are pressure tested in an autoclave prior to assembly and installation on the steam dryer. An uncertainty analysis is performed to calculate the expected uncertainty in the measurements.

Prior to initial plant start-up, strain gages are resistance spot-welded directly to the steam dryer surface. Accelerometers are tack welded to pads that are permanently welded to the steam dryer surface. Surface mounted pressure sensors are welded underneath a specially designed dome cover plate to minimize flow disturbances that may affect the measurement. The dome cover

plate with the pressure transducer are welded to an annular pad that is welded permanently to the steam dryer surface. The sensor conduits are routed along a mast on the top of the steam dryer and fed through the RPV instrument nozzle flange to bring the sensor leads out of the pressure boundary. Sensor leads are routed through the drywell to the data acquisition area outside the primary containment.

Pressure transducers and accelerometers are typically piezoelectric devices, requiring remote charge converters that are located in junction boxes inside the drywell. The data acquisition system consists of strain gages, pressure transducers and accelerometer signal conditioning electronics, a multi-channel data analyzer and a data recorder. The vibration data from all sensors is recorded on magnetic or optical media for post processing and data archival. The strain gages, accelerometer and pressure transducers are field calibrated prior to data collection and analysis. The temporary vibration sensors are removed after the first outage.

In addition to the instrumentation on the steam dryer, the main steamlines are instrumented in order to measure the acoustic pressures in the main steamlines. The main steamline pressure measurements with the steam dryer pressure measurements are used as input to an acoustic model for determining the pressures acting on the steam dryer in order to provide a pressure load definition for use in performing confirmatory structural evaluations.

In addition to the elements described above, NRC regulatory guidance (Reference 3L-10) describes elements of the comprehensive vibration assessment program that is implemented prior to and through startup testing. The following regulatory positions for prototype steam dryers address the program elements applicable to the ESBWR steam dryers:

- Position 2.1 provides a description of the vibration and stress analysis program, including specific items that should be included in the vibration and stress analysis submittal prior to implementation of the vibration measurement program.
- Position 2.2 provides a description of the vibration and stress measurement program, which is to verify the structural integrity of reactor internals, determine the margin of safety, and confirm results of the vibration analysis.
- Position 2.3 describes the inspection program for inspection both prior to and following plant operation.
- Position 2.4 describes documentation of results of the program.
- Position 2.5 describes the schedule for conducting the vibration assessment program.

COL Information Item 3.9.9-1-A implements the vibration assessment program. For each of the regulatory positions above, the NRC guidance (Reference 3L-10) explains how the program is to be conducted, how the processes assure structural integrity of the steam dryer, and identifies information and reports that are to be prepared and when the information and reports should be submitted. Steps in the process for the regulatory positions include the following key elements:

Position 2.1: The steam dryer analysis and modeling methodologies for performing a vibration and stress analysis are described in References 3L-5, 3L-6, and 3L-8. NRC guidance specifies that a summary of the vibration analysis program should be submitted to the NRC at least 60 days prior to submission of the description of the vibration measurement and inspection programs (or 120 days if submitted with a description of the vibration measurement and inspection phases description). Thus, a summary of the as-built steam dryer structural analysis

with the applied acoustic loads would be developed and submitted to the NRC. In addition, the supporting information will be available for NRC review for assuring acceptance criteria are met in accordance with ESBWR DCD Subsections 3.9 and 14.3. This analysis is used to correlate results obtained through vibration measurements during power ascension.

Position 2.2: Details of the steam dryer monitoring program are described above and in References 3L-5, 3L-6, and 3L-8. According to NRC guidance, a description of the vibration measurement and inspection phases of the comprehensive vibration assessment program should be submitted to the NRC in sufficient time to permit utilization of the staff's related recommendations (allowing 90 days for staff's review and comment period). This submittal would be focused on the as-built steam dryer monitoring and instrumentation to be used for obtaining vibration measurements, with details of the data acquisition and reduction system (e.g., transducer types, transducer position, measures to maximize quality of data, online data evaluation system, procedures, and bias errors associated with the instruments). During power ascension, the steam dryer instrumentation (strain gages, accelerometers and dynamic pressure transducers) is monitored against established limits to assure the structural integrity of the steam dryer is maintained. If resonant frequencies are identified and the vibrations increase above the pre-determined criteria, power ascension is stopped. The acceptability of the steam dryer for continued operation is evaluated by revising the load definition based on the measured loading, repeating the structural analysis using the revised load definition, and determining revised operating limits based on the results of the structural analysis.

It is expected that subsequent ESBWR units will be monitored using the main steam lines pressure data. Additional information on power ascension testing, acceptance criteria, benchmarking loads, and benchmarking of the FE model for the first and subsequent ESBWR units is included in references 3L-5 and 3L-6.

Position 2.3: Specific steam dryer inspection recommendations for the ESBWR steam dryer design are developed based on the final as-built design and structural analysis results. The steam dryer inspection recommendations are consistent with Reference 3L-2, and consistent with Boiling Water Reactor Vessel Internals Program guidance issued by the BWR owners group specific to reactor internals vibration. According to NRC guidance, a description of the inspection phase would be included in the submittal with a description of the vibration measurement program. This description would identify any inspections that are to be performed prior to and following operation during power ascension, and describe procedures and method of inspections, if any, of the steam dryer.

Position 2.4: According to NRC guidance, results of the comprehensive vibration assessment program should be reviewed and correlated to determine the extent to which test acceptance criteria are satisfied. The preliminary report following startup testing should compare preliminary comparison of data to test acceptance criteria and identify anomalous data that could bear on the steam dryer structural integrity. If results are acceptable, the final report should include a description of any deviations, comparison between measured and analytically determined modes of structural response and hydraulic response for verifying analytical technique, determination of margins of safety, and evaluation of unanticipated observations or measurements that exceeded acceptable limits not specified as test acceptance criteria (as well as disposition of such deviations). If testing or inspections reveal defects or unacceptable results,

the final report should also include an evaluation and description of the modifications or actions planned to justify the structural adequacy of the steam dryer.

Position 2.5: A schedule for conducting the elements of the comprehensive vibration assessment program is inherent in COL Information Item 3.9.9-1-A. NRC guidance specifies that the steam dryer be classified as prototype or non-prototype; that a commitment be made in the DCD or COL application regarding the scope of the comprehensive vibration assessment program; and that certain submittals be made describing the program and results with suggested schedules for the submittals.

With the detailed description above and implementation of COL Information Item 3.9.9-1-A, the instrumentation and startup testing program elements are consistent with NRC regulatory guidance and adequately ensure steam dryer structural integrity.

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3L.5.5.1.3 Steam Dryer

The design of the steam dryer assembly for the ESBWR plant is similar to ABWR.

However, the total steam flow rate of the ESBWR plant is different from past designs. These differences warrant a detailed vibration analysis and test monitoring to assure the adequacy of the new design to withstand the FIV.

In the ABWR initial plant FIV test program of the steam dryer assembly, accelerometers were located on the cover plate and several locations on the skirt, and strain gages were located directly on the skirt, drain channels and hoods (Reference 3L-5). In addition, pressure sensors were used to measure the pressure differentials between the inside and outside of the upper skirt adjacent to the front hood and the lower skirt. The differential pressure fluctuation across the hoods and skirt is the primary forcing function causing vibration of the steam dryer structure.

A dynamic finite element model of the steam dryer assembly is developed using the ANSYS computer code (References 3L-3 and 3L-6). Due to the complicated geometry and the large size of the analytical model, major components may be modeled with coarse meshes such that their dynamic contributions are accounted for in the whole steam dryer assembly vibration responses. Separate refined dynamic finite element models of the major components are then developed to provide a high resolution of the component's response calculation.

The structural material properties and density for the steam dryer components at temperature are used in the model. The effect of the water on the dynamic responses is accounted for by explicitly modeling the dynamic properties of the fluid in the submerged portions of the skirt, drain channels, and the base ring.

Prior analytical models have predicted that the vibration modes are closely spaced. The final as-built structural predictive vibration analysis is performed prior to startup testing for correlation to final measurement results of acoustic loads measured on the steam dryer during startup testing, as elements of a comprehensive vibration assessment program described in Subsection 3L.4.6.

~~Prior analytical models have predicted that the vibration modes are closely spaced.~~

3L.6 REFERENCES

3L-1 GE Hitachi Nuclear Energy, "Reactor Internals Flow Induced Vibration Program", NEDE-33259P-A, Revision 3, Class III (Proprietary), October 2010, and NEDO-33259-A, Revision 3, Class I (Non-proprietary), October 2010.

3L-2 General Electric Company, "BWR Steam Dryer Integrity", Service Information Letter (SIL) 644 Revision 2, August 30, 2006.

3L-3 ANSYS Engineering Analysis System User's Manual, see Table 3D.1-1 for the applicable revision.

3L-4 Elements of Vibration Analysis, Leonard Meirovitch, McGraw Hill Book Co., 1975.

3L-5 GE Hitachi Nuclear Energy, "Steam Dryer - Acoustic Load Definition," NEDE-33312P-A, Revision 2, Class III (Proprietary), October 2010, and NEDO-33312, Revision 2, Class I (Non-Proprietary), October 2010.

3L-6 GE Hitachi Nuclear Energy, "Steam Dryer - Structural Evaluation," NEDE-33313P-A, Revision 2, Class III (Proprietary), October 2010, and NEDO-33313, Revision 2, Class I (Non-Proprietary), October 2010.

3L-7 (Deleted)

3L-8 GE Hitachi Nuclear Energy, "ESBWR Steam Dryer – Plant Based Load Evaluation Methodology," NEDC-33408P-A, Revision 1, Class III (Proprietary), October 2010, and NEDO-33408, Revision 1, Class I (Non-proprietary), October 2010.

3L-9 GE Hitachi Nuclear Energy, "ESBWR Steam Dryer - Plant Based Load Evaluation Methodology Supplement 1," NEDC-33408, Supplement 1P-A, Revision 2, Class III (Proprietary), October 2010, and NEDO-33408, Supplement 1-A, Revision 2, Class I (Non-Proprietary), October 2010.

3L-10 Regulatory Guide 1.20, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Starup Testing," Revision 3, March 2007.