# ENCLOSURE 2

# MFN 03-078

## Response to NRC RAI numbers (1-5, 10-12, 25-27, 31, 32, 144-146, 151, 152, 160, 167, 177, 262, 277, 290, 294, 308, 312-315, 346, 360, 363, 380, 381, 383-385, and 389-405)

Q1. The ESBWR input deck for ECCS/LOCA analysis (Gdl-nl2.inp) defines the axial flow area fractions of all rings at level 23 [[

]] Is this true? If it is, is it physical? (In file "Gdl-nl2.inp", the following two lines were given:

***** FA-Z
VSSLooooooFA-Zo [[ ]] E)

R1. Yes, [[

]] in this case. The baseline case (GDL-NL2.INP) simulates [[

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Section 2.4.4.3 discusses the results of sensitivity study on interactions between ECCS and containment.

Q2. Is the suppression pool spill over line explicitly modeled by both ECCS/LOCA and containment analysis TRAC-G models. If not, please provide an explanation.

R2. The suppression pool spillover pipes are not modeled in both the ECCS/LOCA and Containment/LOCA TRACG input models. The water level in the DW does not reach the spillover hole elevation in the cases presented in the application report.

Q3. Does radius distortion in the TRAC-G ECCS/LOCA model for the containment part affect the 3-D vessel numerical scheme and the overall containment response? (Both the stacked approach and large volume fraction and flow area fraction.) Please provide the explanations regarding the impact on the containment response.

R3. The radius distortion would affect the momentum exchange terms. The impact on the containment response is expected to be very small due to the relatively large radial flow area in the containment and consequently the small magnitude of the velocities and momentum fluxes. This can be seen by examining the pressure drop in the radial direction. Figure 3.1 shows the pressure difference at the top of drywell between the first cell and the fourth cell, for the ECCS/LOCA baseline case. The pressure difference is on the order of [[ ]] Hence the radius distortions are of no consequence. [[

Figure 3.1

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Q4. It was indicated that decay heat table was used to define the core total power history during the GDCS line break LOCA. Is the initial full power operating condition and the subsequent scram considered in the decay heat table? If not, please explain.

R4. The total power table used for the ECCS LOCA calculations is the sum of the fission and decay heat components. The fission power following scram is based on a representative fission power decay used in BWR LOCA analysis. This includes the effects of void reactivity feedback, which can be dominant for a large break. The decay heat table is a fit to the ANS standard. (ANSI/ANS-5.1-1994). The total power table assumes that scram and CRDs start at time 0.0 (baseline case). This assumption is expected to have very minor impact on the key calculated parameter, such as the minimum static head level inside shroud.

For GDCS line break, reactor scrams on high drywell pressure of 2 psid, which occurs at about [[ ]] (Note 1) after the break initiation. The signal response time is [[ ]] and the CRDs start to insert [[ ]] later. The total time between the break initiation and the CRDs first movement is [[ ]] A sensitivity study case was performed to show the impact of the simplified assumption used in the baseline case. In this case, the time scale in the baseline power table is shifted by adding [[ ]] and this case assumes 100% constant power from [[ ]]

Figures 4.1 and 4.2 show the static head inside shroud for the baseline case and the sensitivity study case. For the sensitivity study case, the Level 1 trip occurs at about [[ ]] earlier than the baseline case. This change in timing to L1 is the only significant effect of the delayed scram. After the Level 1 trip, which initiates the GDCS injection, the responses of the static head inside shroud for these cases are very similar. Figure 4.3 compares the results of these two cases, with a time shift corresponding to the shift of the Level 1 trip timing. This figure shows that these two curves are almost on top of each other, after the Level 1 trip. The minimum static head level for the sensitivity study case is [[ ]] lower than the baseline case. Therefore the impact on ECCS performance margin is minor.

(Note 1: The scram trip time of [[ ]] is calculated from the drywell pressure response in the first [[ ]] of the sensitivity study case.)

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Figure 4.1. Baseline case – CRDs start at 0.0 second

Figure 4.2. Sensitivity case – CRDs start at 6.05 seconds.

Figure 4.3. Comparison of Static Head Inside Shroud

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Q5. It is assumed that the PCCS condensate accumulation tank has an initial void fraction of [[ ]] (***** ALPN VSSL000129ALPN0 [[ ]] E). [[ ]] Please clarify. If not, what is the impact to the analysis results?

R5. The current configuration of the PCCS condensate drain tanks are correctly defined in the response to Q 195. The plant design had been evolving and an earlier version indeed had some water in the drain tanks to provide a loop seal. The impact of the assumed water (approximately 10 m3) in the TRACG deck are not expected to impact the analyses. For the ECCS/LOCA analysis the minimum water level is determined by the timing of the GDCS flow and not the size of the GDCS drain tank and flow. Compared to the GDCS pool capacity of [[ ]] (for all three pools), the PCCS condensate drain tank capacity is insignificant. For the Containment/LOCA analysis, the PCCS condensate drain tank has almost no impact, because the containment pressures are determined primarily by the large free air spaces in the drywell [[ ]] and wetwell [[ ]] and GDCS drain down volumes.

Q10. For the ECCS/LOCA model, how many PCCS units are lumped into one set of TRAC-G 1-D components? 3 or all 4 of them?

R10. 4 PCCS units are lumped into one set of TRACG 1-D components in the ECCS/LOCA model.

Q11. PIPE 42 and PIPE 43 are used to model GDCS air space to wetwell air space vents. However, they have identical volume and flow area. Why?

R11. For simplification, identical volume and flow area were used for PIPE 42 and PIPE 43 in the ECCS/LOCA model. The pressure difference between the GDCS air space and the wetwell is very small because flows are generally small and resistance is minor. Therefore, the results are not affected by this simplification.

Q12. The input deck "Mslb-n.inp" has the following input card: "VSSL000101DSTH0 [[ ]]" Is [[ ]] used to define the vessel wall thickness? If it is, is ESBWR reactor pressure vessel designed to have a thickness of [[ ]] Could you please clarify?

R12. The double-sided heat slab in the second ring of the VSSL component has a thickness of [[ ]] This double-sided heat slab is used to [[ ]] to model the heat transfer from the RPV inside to the DW air space.

The impact of this composite wall modeling on the long-term drywell pressure is expected to be small. A parametric study case was performed, replacing the composite wall by carbon steel with thickness of 7.25", which is typical material and thickness for the RPV outside wall. Result of this parametric case shows that the impact on peak drywell pressure is small, about [[ ]]

Q25. General Electric (GE) topical report NEDC-33080P, "TRACG Qualification for ESBWR," dated August, 2002, describes qualification studies of the TRACG computer code performed for ESBWR. This report documents two additional validation studies performed specifically in support of ESBWR. The test data used for these studies are from the P-Series containment tests performed at the PSI PANDA test facility in Switzerland and from the elevated-pressure hydrodynamic instability tests performed at the CRIEPI/SIRIUS test facility in Japan.

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52.47(b)(2) states that certification of a standard design which differs significantly from light water reactor designs or utilizes simplified, inherent, passive or other innovative means to accomplish its safety functions will be granted only if each safety feature of the design has been demonstrated either through analysis, appropriate test programs, experience, or a combination.

Part 52.48 describes that applications filed under this subpart will be reviewed for compliance with 10 CFR Part 20, Part 50 and its appendices, ... and as those standards are technically relevant to the design proposed for the facility. Part 52.48 thus invokes appropriate aspects of Part 50, including Appendix B quality assurance (QA) requirements.

For SBWR design certification qualification test program activities GE met Part 50, Appendix B by implementing their latest NRC approved "Nuclear Energy Business Operations Quality Assurance Program Description" (topical report), NEDO-11209-04A, Revision 8. Additionally, NEDG-31831, "SBWR Design and Certification Program Quality Assurance Plan," was developed by GE to fulfill the QA requirements of the SBWR reactor design and certification program. NEDG-31831 meets the requirements of ANSI/ASME NQA-1-1983 and its NQA-1a-1983 addenda, which includes specific requirements related to "Qualification Tests." NEDG-31831 provides that design and testing work performed by international technical associates will be performed to their internal QA programs acceptable to the regulatory authorities of their respective countries as evaluated by GE for compliance with the provisions of ANSI/ASME NQA-1-1983.

The staff is not clear as to what GE considers tests being "*confirmatory in nature*." Please describe what "*confirmatory in nature*" encompasses and how GE plans to use the data from the PANDA-P series tests conducted at PSI in Switzerland and the SIRIUS two-phase flow instability tests conducted in CRIEPI, Japan. It is our understanding that data from these tests is going to be used to support the ESBWR design and be part of the ESBWR design certification application. If this is the case, please describe how these tests and test data meet the GE topical report and NQA-1 quality requirements for testing related activities.

R25. [[

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## General Questions

Q26. The GE report NEDC-33083P presented main steam line break (MSLB) and gravity driven cooling system line break (GDCSLB) loss of coolant accidents (LOCAs) (Section 3.2.1, Page 3-6), but not a bottom drain line break (BDLB). Is a BDLB LOCA considered less limiting than the other two LOCAs? If yes, please explain.

R26. Yes. BDLB LOCA is considered less limiting than the other two LOCAs. The long-term peak drywell pressure depends on the effective wetwell airspace volume, which is the sum of initial wetwell airspace volume and the GDCS pool draindown volume. For both the BDLB and GDCSLB cases, the entire drainable volume of the GDCS pools will drain down and create larger draindown volume as compared to the MSLB case, resulting in lower drywell pressure. Compared to the GDCSLB, the BDLB cases have milder responses due to smaller liquid break pipe size.

Q27. The isolation condenser system (ICS) has not been considered in the LOCA calculations. Condensate return from ICS may delay opening of the depressurization valves (DPVs). Is this a conservative assumption?

R27. The IC operation has several effects when it operates. It takes some of the steam produced in the vessel and condenses it and returns it to the vessel. The steam condensation has the effect of reducing the vessel pressure faster. The faster initial depressurization reduces inventory loss following ADS operation and possibly results in earlier initiation of the GDCS. Additionally, the IC returns the condensate directly to the vessel. This later effect will have a greater impact and will result in a higher minimum water level during a LOCA.

Although IC operation may delay opening of the DPVs, the net impact of the IC operation is positive. Therefore, not considering IC operation is a conservative assumption.

General Questions

Q31. The time step sizes sometime influence the results of the calculations. What was the basis of the time step size selection for ESBWR analysis (maximum as well as average)?

R31. TRACG chooses its time step in accordance with an internal logic that continuously optimizes the accuracy and efficiency of the calculation. The only control imposed by the user is to supply maximum and minimum time step size limits. TRACG will not use a time step larger than the specified maximum and it will stop if its built-in accuracy criteria require it to use a time step smaller than the specified minimum. In addition, the user may divide the analysis time span into segments and vary the specified maximum and minimum time steps from segment to segment. The ESBWR containment calculation uses a maximum time step of [[ ]] for the first hour of the simulation and [[ ]] thereafter. The minimum time step is [[ ]] for the first hour and [[ ]] thereafter. It may also be noted that a time step sensitivity study performed in conjunction with the SBWR TRACG qualification showed no significant sensitivity to the choice of maximum time step [*TRACG Qualification for SBWR*, NEDC-32725P, V. 1, Rev. 1, August 2002, (Appendix B)].

Q32. Comparison of the TRACG Model Description report, NEDE-32176P, Revision 2, with Revision 1 indicates that significant material essential to the ESBWR review has been expunged without indication in the text. For example, Table 6.0-1 has had significant containment items removed and yet the table is not indicated as modified from Rev. 1. Section 7.11, Containment Components, has been removed in its entirety. There are also numerous missing sections related to "Wall Friction and Form Losses" which address containment modeling. Please provide appropriate revisions to the text to incorporate all material pertaining to the containment modeling that has been expunged in going from Revision 1 to Revision 2 of NEDE-32176P.

R32. Revision 2 of the TRACG Model Description report, NEDE-32176P removed discussion of the containment-related topics to simplify NRC review of the document for AOOs. The ESBWR reports reference both Revision 1 and Revision 2 of the Model Description document to provide the needed information for the containment application. The next revision of the Model Description report will integrate the removed sections with Revision 2.

Q144. Section 2.1.5 (p. 2-2) - Is it the intent of the last sentence of the section to say that TRACG analysis will not be used to demonstrate the conformance of the ESBWR to Criterion 5 (long term cooling) of 10 CFR 50.46? Has the applicability of Reference 88 to the ESBWR been demonstrated with regard to serving as the bases for compliance with Criterion 5?

R144. Long term cooling will be calculated with TRACG to demonstrate that the core is well cooled in the long term for conformance to Criterion 5. The ESBWR safety systems operate in such a way that the short term cooling is ensured by having a large vessel inventory, which is replenished by the GDCS system (GDCS pool initially and suppression pool in the long term).

Q145. Section 2.2.1.1 (p. 2-36) and Section 2.2.1.2 (p. 2-38) - What is the sensitivity of the chimney water level to the delay in GDCS flow if the IC is available? Would a delay in GDCS flow or a delay in the opening of the DPV result in significant loss of coolant from the reactor? Would the delays cause a reduction in the amount of coolant available for delivery to the reactor?

R145. The IC operation has several beneficial effects when it operates. It takes some of the steam produced in the vessel and condenses it and returns it to the vessel. The steam condensation has the effect of reducing the vessel pressure faster. The faster initial depressurization reduces inventory loss following ADS operation and possibly results in earlier initiation of the GDCS. Additionally, the IC returns the condensate directly to the vessel. This later effect will have a greater impact on the calculation and will result in a higher water level.

Q146. Section 2.2.1.4 (p. 2-39) - On p. 2-8, GE claims sensitivity to all single failures is considered and yet for the ESBWR only 2 active component failures (GDCS valve and DPV) were considered. Do these 2 single failure cases bound all other failures?

R146. Section 2.4.4.1 (NEDC-33083P) considers single failure of the following 3 active components (one GDCS injection valve, or one DPV, or one SRV). These failures are expected to bound all other failures as the GDCS capacity available to the vessel will be higher for other failures. This conclusion was also supported by analyses performed for the SBWR Standard Safety Analysis Report (Table 6.3-3).

Q151. Table 2.4-3 (p. 2-71) - What should the range of value for PIRT84 be?

R151. There is a typo in Table 2.4-3. The correct range of value for PIRT84 should be [[ ]] This will be corrected in the next revision of the report.

Q152. Section 2.4.4.2 (Figure 2.4-13) - Do "M" and "P" denote the lower and upper bound of the parameter value?

R152. Yes. "M" denotes the lower bound and "P" denotes the upper bound of the parameter value.

Q160. The ESBWR nodalizations presented in Figure 2.7-1 and Figure 3.7-1 are not the same. Please clarify.

R160. The nodalizations for ECCS and Containment analyses are different because the key parameters are different for these analyses. However, the geometries (such as volumes and elevations) are identical in these two nodalizations.

Figure 2.7-1 shows the TRACG nodalization for the ECCS/LOCA analyses. The key parameters for these analyses are the mixture level inside shroud and the peak cladding temperature. The RPV is modeled with more nodes (more levels and rings) to provide detailed responses inside the RPV.

Figure 3.7-1 shows the TRACG nodalization for the Containment/LOCA analyses. The key parameter for these analyses is the containment pressure. The containment is modeled in greater detail with more nodes while the RPV modeling is simplified with fewer nodes.

Q167. Was condensation on the containment walls included in the analysis? While the wall condensation generally helps to keep the containment pressure low, the lost water may not be available in the re-circulation through PCCS, and this may contribute to lowering of the vessel water level eventually, especially the GDCS break where the water level is relatively close to the top of core. In the GDCS break, water level is already down to the break elevation. The wall condensation will gradually lose the water in the long-term. In the period of 72 hours, this loss, in combination with loss of some steam (which was uncondensed in the PCCS) to the SP, may not be negligible. Please discuss whether this issue was assessed and its results.

R167. Condensation on the containment walls was included in the analysis. Any water condensed on the walls collects in the lower drywell and then flows through the spillover holes to the suppression pool. The water from the suppression pool then flows back to the vessel through the equalization lines.

The equalization lines (4 lines), connecting the suppression pool and the RPV, provide for long-term coolant boil-off losses to the drywell. The equalization line injection valves will open following a [[ ]] time delay initiated by a Level 1 signal and when the downcomer level reaches 1 m above the TAF. For the GDCS line break, if the downcomer level drops below 1 meter above the TAF, the equalization lines will open and refill the RPV level to 10 meters, the same elevation as the suppression pool level.

Q177. Comparison of non-dimensional parameters (similar to one presented for SBWR and CRIEPI in Table A.4-1 of NEDC-33079P), or dimension-less groups (PI-Groups) should be derived based on scaling analysis, and their numerical values should be compared for ESBWR with the test facilities in order to provide assurance that the test facility represents the ESBWR design. As indicated in Table 6.1 of NEDC-33079P, GE qualified TRACG code for its application to anticipated transient without scram (ATWS) and Stability events in ESBWR against the following facilities: 1/6 Scale Boron Mixing Test, CRIEPI and Dodewaard. GE, however, did not present comparisons of representative parameters for ESBWR design and the above facilities in the submittals. The staff, therefore, requests GE to submit scaling analyses for the above mentioned test facilities, and provide comparisons of dimension-less parameters as discussed above, between ESBWR and the test facilities in order for GE to qualify TRACG code for its application to ATWS and stability events in ESBWR against the test facilities.

R177. Comparisons of relevant dimensionless parameters between the 1/6 Scale Boron Mixing Test, CRIEPI and Dodewaard and the ESBWR are provided below.

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It can be concluded that the 1/6th scale mixing tests are reasonable for evaluating the mixing in the ESBWR bypass regions because the density difference between the borated solution and water, the core average void fraction and the leakage loss coefficients are adequately matched

CRIEPI Tests
The CRIEPI tests are natural circulation and stability tests, dominated by flashing instability at low pressure.

The relevant parameters that characterize these phenomena are shown in the table below.

Comparison of Non-Dimensional Parameters Between ESBWR and CRIEPI

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**Dodewaard Data**

The Dodewaard data have been used to qualify steady state natural circulation performance. The main parameters of interest are the geometrical configuration, flow rate and core and chimney void fractions. [[

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**Comparison of Dodewaard and ESBWR Geometry and Steady-State Parameters**

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Q262. The RPV liquid mass equation is derived in Appendix A. The derivation relies on the vapor generation formulation. No distinction is made between the short-term depressurization where the pressure in the RPV is independent of the containment conditions and the long-term transient where the containment pressure affects the vapor evolution in the vessel. Please provide the rationale for deriving equations in a generic form without considering these significant differences in the various portions of the transient.

R262. The effect of pressure on the RPV liquid mass is implemented through the last term in the liquid mass equation (Equation 3.1-11 of the report). The depressurization of the vessel results in flashing of the liquid and a reduction in liquid mass.

As pointed out in the question, the RPV is decoupled from the containment as a result of the flow being choked during the short-term depressurization (RPV pressure greater than ~90 psia). Therefore the RPV pressure (and therefore liquid mass) are not impacted by the containment pressure during this period. Subsequent to this time, the blowdown flow is no longer choked and there is some interaction between the containment pressure and RPV pressure. However, the containment time constant is orders of magnitude longer than the RPV depressurization time constant due to the thermal capacity of the suppression pool. Therefore the containment pressure is approximately constant during the later portion of RPV blowdown. [[

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For periods beyond 800 sec, the effects of pressure changes on vapor generation are negligible, as summarized below. During the period from 800 sec until approximately 1 hour after accident initiation, the liquid in the vessel is subcooled as a result of the subcooled GDCS flow into the vessel. Therefore the RPV liquid will not flash during this period and the pressurization rate is not important to the vapor generation rate. After GDCS injection finishes, the vessel is filled to a level well above the top of the core. The RPV mass is not of significant interest during these long-term periods because the water level is in the vessel is so high and changes in mass happen relatively slowly. The parameter of primary interest for safety is, instead, the containment pressure.

However, it is easy to see the potential impact of pressure changes on the RPV mass by considering the Liquid Mass Equation (Eq. 6.1-1 in the report). Losses

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of mass due to depressurization are captured by the PI group, $\Pi_{M,\dot{P}2}$. By setting this PI group equal to 1 we can see the potential change in mass for a given change in pressure,

$$\Pi_{M,\dot{P}2} = \frac{f_{4,o}\Delta P_r M_{\ell,o}}{h_{fg,o}\Delta M_{\ell,r}} = 1 \rightarrow \frac{\Delta M_{\ell,r}}{M_{\ell,o}} = \frac{f_{4,o}\Delta P_r}{h_{fg,o}} \qquad (262\text{-}1)$$

The pressure during the long-term period is 2 to 3 bar, so the maximum realistic pressure decrease is ~2 bar. [[

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[[ ]] (262-2)

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Q277. The bottom paragraph on page 5-3 states that the depressurization created representative thermal-hydraulic conditions in the RPV of GIST. What is the basis for that statement?

R277. The concern in the GIST test was that the void distribution at the beginning of the test would be similar to that which would occur if the vessel had blown down from full operating pressure. Equation B.1.4.3 of the SBWR scaling report (NEDC-32288P, Rev 1) can be used to show that the time for the voids to develop will be on the order of

$$t \approx \frac{\rho_{g,r}}{\Gamma_{g,r}}$$

where $\rho_{g,r}$ is the gas density and $\Gamma_{g,r}$ is the volumetric net vapor generation rate. [[

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Q290. The in-vessel, natural-circulation phenomena are not addressed in detail. On page 7-10, flashing is mentioned. This element of the vapor generation formulation is not clearly documented particularly in reference to the overall conditions in the RPV. The novel geometry of the RPV and its effects on the liquid inventory distribution may have a significant impact on these phenomena. How is this effect reflected in the scaling groups?

R290. The thrust of this question appears to be the scaling of the internal flows and flashing in the various regions of the RPV. The pressure differences within the RPV are much smaller than system pressure until the vessel depressurizes close to the containment pressure. Hence, the pressure rate calculated from Equation 6.1-5 is applicable to all regions of the RPV.

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Q294. Chapters 6 and 7 discuss the non-dimensionalization of the governing equations and the comparative analysis of the resulting PIs. However, the actual comparisons, in figures 7.1 through 7.7 and 8.1 to 8.7, only have one equation per transient phase. What happened to the other dynamic equations?

R294. A summary of which equations are applied in each region and transient phase is given in Table 7-1and summarized in Section 7.2 of the report. Section 7.2 of the report has been expanded to provide more detailed discussion of the rationale for application of the scaling equations to different parameters, regions and temporal phases. The revised Section 7.2 is below. This revised version will be incorporated into future revisions of the report. It should be noted that there are multiple evaluations of the equations for some phases. For example Table 7-1 shows two scaling equations being evaluated during the first two transient phases. In the revised version of Table 7-1, below, this has been increased to four equation applications during the late blowdown phase.

Dynamic equations for mass, pressure and energy (or temperature) were developed in Section 6. These equations, in the general form shown there are applicable to all of the volumes in the ESBWR. However, certain parameters are of more interest than others in different volumes and temporal phases. Therefore, the equations are applied only for those parameters, regions and temporal phases that are of interest. The specific applications of the scaling equations to different regions of the ESBWR are summarized in Table 7-1. The motivations for the selected application shown there are summarized below.

The water level in the RPV is of prime interest during the first three temporal phases – late blowdown, GDCS transition, and full GDCS. Therefore, the RPV liquid mass equation is evaluated for these phases. This is indicated by the "M"s in the RPV column of the table. Additionally, the RPV depressurization is important for the first two phases, since it controls the flashing rate and time of GDCS initiation. Thus, the RPV pressure is also considered for the late blowdown and GDCS transition phases. The liquid mass in the RPV during the long-term phase is of minimal interest for scaling since it is a simple case of decay heat boiling off inventory that is replaced by PCC return flow. The dominant parameters influencing the RPV mass are readily identifiable as boiloff due to decay heat and return flow from the PCC via the return line from the condensate tank. The scaling of the decay heat is demonstrated through the DW pressure scaling (see $\Pi_{P,mech,ADS}$ and $\Pi_{P,Wh,ADS}$ in Figure 7-6) and the PCC scaling is demonstrated through the bottom-up scaling of the PCC given in the response to RAI 259, part 1. The RPV pressure is nearly identical to the drywell pressure during the long-term phase since these volumes are connected by the large DPV pipes. Therefore, the pressure equation for the combined volume is evaluated as indicated by the "P" in the DW column for the long-term phase.

In the long-term phase, the liquid level has recovered in the RPV and the containment pressure is of primary interest. The pressure in the WW sets the containment pressure. The initial increase in containment pressure occurs during the blowdown phase when most of the noncondensibles are moved to the WW. The long-term pressure is controlled by the quantity of noncondensibles in the WW and the energy balance for the WW gas space. Therefore, the pressure equation is evaluated for the WW in the long-term PCCS phase. The DW acts primarily as a conduit for steam to flow to the PCCS and WW during all of the phases considered (this excludes the first few seconds of blowdown which is not considered as part of the ESBWR test program). To assure that this is the case and that none of the sources and sinks of energy in the DW are important, the pressure equation is evaluated for the DW during the long-term phase.

During this long-term phase the change in SP temperature is negligible. The only energy sources for the SP are heat exchange with the gas space above and the very small energy addition associated with occasional bubbling of non-condensable gas through the PCC vent. In addition, the walls provide a small energy sink. Even if all of the energy from the VB leakage flow was directly deposited into the SP region above the PCC vent for 24 hours, with no heat losses from the pool, the temperature increase in this top pool layer would only be on the order of 2 deg C. Therefore the energy equation is not evaluated for the SP during the long-term phase.

During the GDCS and GDCS transition phases, the RPV liquid is subcooled and vapor generation ceases. Without this energy source to the containment, the containment becomes quiescent. Therefore the scaling equations are not applied to the containment during this period. Most of the changes in containment parameters occur during the blowdown period. Additional evaluations of the SP energy and WW pressure have been added as part of these RAI responses (see RAI 259, part 1) to better capture this dynamic period. The updated version of Table 7-1, below, reflects these additions. The drywell pressure is interesting during the very early portion of the blowdown, during vent clearing. However, the response during that period is typical of all pressure suppression containments and has been investigated previously for the operating plants. The tests in the ESBWR program begin at later stages of a LOCA, so no scaling of the initial blowdown period is included in this report.

### Table 7-1 Application of Scaling Equations to ESBWR Phases and Regions

| | | **Plant Region** | | | |
|---|---|---|---|---|---|
| | | **RPV** [5] | **DW**[2] | **WW gas**[3] | **Suppression Pool** |
| **Transient Phase** | **Late Blowdown (7.5.1)**[1,4] | M, P | - | P | T |
| | **GDCS Transition (7.5.1)**[1,4] | M, P | - | - | - |
| | **Full GDCS (7.5.1)** [1,4] | M | - | - | - |
| | **Long Term PCCS (7.5.2)** [1,4] | - | P | P | - |

1 M = liquid mass equation, P = pressure equation, T = temperature (energy) equation.

2 DW and RPV gas act as one volume during reflood and long-term phases

3 Includes GDCS gas volume

4 Number in parenthesis is section where results are shown

5 The limiting breaks are used for each region: GDCS Line break for the RPV and MSLB for the containment

Q308. In NEDE-32176P, Rev. 1, it is stated that wall friction correlations are used in the same way as in other codes, like GOTHIC "which are specifically meant for containment analysis, and have been expensively qualified for these applications." Provide a reference to the qualification of the TRACG 3-D treatment of wall friction for containment calculations.

In addition, it appears that the modeling in TRACG is based on a presumed flow pattern (ref. Fig. 6.2-1), which is reflected in the nodalization. It is also stated that when large 3-D cells are used, the error could be larger when using the fully developed flow correlations. Only one comparison is made for two cells of approximately equal size based on an assessment of the Reynolds number. The basic data used to develop the models is based on flow in pipes with diameters in the range of a few to several millimeters, or flow in rod bundles. Based on these observations is the treatment of wall friction on containment surfaces modeled in a conservative manner? Provide a justification for applying the models to these surfaces. How does the error in the wall friction influence the integrated system response, keeping in mind that there are several models used for containment, which have errors, or uncertainties identified with them?

R308. [[

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It should be noted that wall friction in large open volumes is not a significant factor in the pressure distribution within the containment. The dominant pressure differences are <u>between</u> different regions of the containment. These pressure drops are through restrictions such as horizontal vents and the PCCS, which are typically pipes and readily amenable to the calculation of pressure drop.

Most containment codes (e.g. CONTAIN [Code Manual for CONTAIN 2.0: A Computer Code for Nuclear Reactor Containment Analysis, NUREG/CR-6533, December 1997]) treat the whole drywell as one cell, and wall friction and pressure gradients within this large cell are not even considered. This again points out the lack of importance of the wall friction correlations used in TRACG for the calculation of the overall containment pressure and temperature response.

(It should be noted that small pipes in BWRs have diameters of several centimeters rather than millimeters as stated in the question.)

## Q312. Flow Regime Maps

The flow regime maps provide the critical information about the interfacial area density and the shape for the two-fluid formulation.

The ESBWR containment consists of many regions where two-phase flow conditions exist. These regions vary in size and orientation. The drywell and suppression chamber (wetwell) consists of large volumes, which may have a condensate film on the walls and droplets in the gas phase. The suppression pool receives an inflow from a jet mixture of noncondensible gas and steam which will break-up in bubbles. There are also other liquid pools with free surfaces. The horizontal vents undergo vent clearing and two-phase flow during early blowdown. The heat exchangers of the PCCS have small diameter tubes with downward film flow on the wall.

The transition between annular flow and dispersed flow regimes is defined by entrainment inception. However, no information about entrainment inception is provided in NEDE-32176P. The entrainment rate correlation described in the report, is based on pipe data with diameters less than 0.032 meters and, therefore, the entrainment correlation does not appear to apply to any part of the containment except the PCCS tubes.

A liquid film is expected on the heat structures and liquid droplets in the drywell atmosphere. However, the droplet field can not be predicted by the entrainment criteria in the code as the mechanism is fogging and not shear at the interface. Therefore, the flow regime map does not appear to apply to the drywell and suppression chamber.

Q312.1. Justify the use of the flow regime map for calculating flows (velocities) near containment surfaces and for intercell flow between the large, 3-D cells used to model the containment volumes. It appears that the nodalization drives the determination of flow regimes and that there could be an inconsistence description of the flow regime (and cell fluid properties) at a 3-D cell boundary, which does not represent a physical structure.

R312.1. TRACG uses a relatively simple flow regime map as shown in Figure 5.1-1 of NEDE-32176P, which consists basically of two distinct patterns: (a) liquid-continuous at low void fractions, and (b) vapor-continuous at high void fractions. A transition zone separates the two primary regimes. The liquid-continuous regime applies to the single-phase liquid flow and bubbly/churn flow regimes. The vapor-continuous regime applies to the annular, dispersed droplet and vapor flow regimes. The transition regime involves churn to annular and churn to droplet regimes depending on the void fraction, flow rate and other variables.

The same flow regime map is used for vertical and horizontal flows. For horizontal flow at low velocities, a transition to stratified flow is calculated based on a critical Froude number.

These flow regimes were primarily intended for pipe geometries, but have also been successfully applied to large three-dimensional cells, e.g. in the lower plenum of the reactor vessel. The key output from the flow regime map is the choice of the interfacial shear model that determines the void fraction in these cells. Void fractions calculated in large plena of reactor vessels are reasonable and agree with data obtained from tests facilities such as PSTF and EBWR [NEDE-32177P].

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In summary, the TRACG flow regimes, while simple, should be adequate for containment calculations. This is substantiated by comparisons of TRACG calculations with Mark II and Mark III simulations in the PSTF for the short term blowdown (TRACG Qualification for SBWR, NEDC-32725P, Rev.1, Sections 5.5 and 5.6) and the PANDA test facility for the long term response (Section 5.7).

Q312.2. Describe the model for entrainment inception from films on the containment walls.

R312.2. The entrainment correlation used in TRACG is described in Section 5.1.2 of NEDE-32176P. When a cold surface with a temperature less than the saturation temperature is present in a vapor occupied cell, condensation will be initiated with a film forming on the wall. TRACG calculates the fraction entrained as droplets based on the correlation for the entrained fraction, which is a function of the vapor velocity and the liquid Reynolds number. The remaining liquid is available to form a film on the wall. The liquid film flow rate is checked against the minimum required to form a stable film over the surface. Smaller amounts of liquid will only cover the surface partially. As the liquid flow rate increases, a part of the film will be entrained as droplets, depending on the vapor velocity.

Q312.3. There is also a question about the applicability of the pipe flow regime map to the drywell, the suppression chamber (wetwell), the suppression pool and to the downward flow in the PCCS tubes and return lines and the vertical sections of the horizontal vents. The Tables 6.1-1 and 6.2-1 (NEDE-32176P, Rev 1) summarize GE's assessment of flow regime maps for different containment regions. The indirect assessment through interfacial shear and mass transfer data base covers the pressure, void fraction and mass flux range, but the diameter range is not covered for the drywell and suppression chamber and there is a large (“by about 15%”) uncertainty in applying the correlations to these volumes.

How is this uncertainty treated in the calculations? How was the uncertainty value obtained and could it be larger? How does the uncertainty in the interfacial shear and mass transfer influence the integrated system response, keeping in mind that there are several models used for containment which have errors or uncertainties identified with them?

R312.3. The applicability of the flow regime map to the large drywell, wetwell and suppression pool regions was addressed in response to (312.1) above. [[

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Q313. Wall Friction

Wall friction and momentum transfer is important in the PCCS tubes and the horizontal vents. The friction on the containment walls is also computed in the code. The single phase friction factors are calculated from the curve fit to Moody's diagram, which is valid for pipe flows. The data base covers a very large Reynolds number range. However, the applicability to the drywell geometry and large diameter channels is questionable. This model was assessed with the data base limited to small diameters, which covers the PCCS tubes, but is too small for horizontal vent. Furthermore, the two-phase multipliers were based on the data with lower steam qualities while in the drywell and in the horizontal vents, the quality could be close to 100%. Furthermore, it is not clear if the two-phase multiplier is valid for down flow as expected in the PCCS tubes and in the horizontal vents.

Q313.1. Provide justification for using this model for the PCCS tubes, the horizontal vents and the containment wall structures.

R313.1. Wall friction is not an important phenomenon in the large containment volumes. Please see the response to RAI 308 for a more detailed discussion.

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Q313.2. There is another uncertainty in the implementation of the friction factors in the 3-D component used for containment. It is not clear how the friction factor in the transverse direction are estimated from the Moody's curve, which was developed from vertical tube flows.

How is the traverse friction factor obtained for use in the large 3-D cells? How is friction handled on horizontal surfaces, for example the drywell floor or the diaphragm floor?

R313.2. Transverse friction factors are only calculated for cells that have frictional resistance in the transverse direction. An example is the flow through control rod guide tubes in the lower plenum of the reactor vessel. The loss coefficient due to contraction and expansion through the rows of guide tubes leads to a transverse friction coefficient. These are typically form losses and not Moody friction factors. In the open drywell volume there are no transverse resistances to flow. The wall friction is calculated from cell center to cell center, based on the velocity, which is calculated at the cell interface. Thus, the component of the cell velocity parallel to the wall is used in the calculation of the wall shear. Friction at a horizontal surface (such as the floor) will be calculated using the horizontal component of the velocity in the cell next to the floor. The standard wall friction correlations will be employed in this calculation based on the Reynolds number that uses the scalar value of the velocity vector. The magnitude of the velocity is very close to the component of the velocity parallel to the wall.

Q313.3. An additional uncertainty is in the partitioning of the wall friction contribution between two phases. The correlations for single phase flow along with two-phase multiplier are for mixture models and are being used for two-fluid formulations. The report does not indicate the method used to dividing wall friction between the two phases.

Describe the method (model) for dividing the wall friction between the two phases.

R313.3. [[

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Q314. Wall Heat Transfer

Wall heat transfer occurs in every component in the containment. The important areas are heat transfer to vertical and horizontal structures and inside and outside of the PCCS tubes.

The single phase heat transfer is based on Dittus-Boelter for forced flow and McAdams correlation for free convection on vertical walls. However, applicability of these correlations for large open spaces has not been shown.

The Dittus-Boelter correlation was developed from pipe data and requires the hydraulic diameter for the Reynolds (Re) number calculation. Similarly, the McAdam's correlation also requires the hydraulic diameter for computing the Grashof (Gr) number. These correlations have been implemented with hydraulic diameter based on cell size. If the cell hydraulic diameter is computed with only the wetted perimeter, the hydraulic diameter may be correct.

Q314.1. Provide a justification for using these correlations for the containment surfaces. It would be more appropriate to use correlations for flat plates, which are based on wall length. Can it be shown that the use of an appropriately calculated hydraulic diameter to represent the structure characteristic length will result in a conservative heat transfer calculation? Will laminar conditions exist in the containment (for example based on Gr number) for which additional correlations would be needed? In this case, or if a correlation for a flat plate were to be used to better represent the structure, the hydraulic diameter (characteristic length) would not necessarily cancel out based on a $Gr^{1/3}$ correlation.

R314.1. [[

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Q314.2. The correlations used to model heat transfer require an estimate of the Reynolds number, but it is not shown how it is estimated. For the 3-D formulation, there are three components of velocity and the code document does not indicate which component of the velocity is used to estimate the Reynolds number. The other uncertainty is in the use of the cell edge velocity. As the cells are large, the velocity is averaged over a large area and the effect of a no slip condition at the wall is negligible. The correlations were developed from pipe flow data where the average velocity is affected much more by the no slip condition at the wall. Furthermore, the wall heat transfer is partitioned between two phases but it is not explained how this partitioning is performed.

How is the Reynolds number obtained for use in these correlations? How does the uncertainty in obtaining the Reynolds number influence the integrated system response, keeping in mind that there are several models used for containment, which have errors, or uncertainties identified with them?

R314.2. [[

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Q314.3. Describe the method (model) for dividing the heat transfer between the two phases.

R314.3. [[

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Q314.4. For horizontal surfaces, TRACG uses the same heat transfer correlation as for vertical walls. The assessment provided indicates that for large Gr x Prandtl number (Pr), the heat transfer coefficient is significantly over predicted.

Provide an assessment of the effect of this discrepancy on the long term pressure calculation. How does the uncertainty in obtaining the heat transfer from horizontal surfaces influence the integrated system response, keeping in mind that there are several models used for containment which have errors or uncertainties identified with them?

R314.4. [[

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Q314.5. The heat transfer from a floor will be different than from a ceiling. This is not distinguished in the code. How is this difference treated in the calculations?

R314.5. TRACG uses the same heat transfer correlation for free convection from hot surfaces facing up or down. As stated in response to the previous parts of this RAI, the correlation is in good agreement with data for the former situation but overestimates the heat transfer for the latter case. See response above for further discussion of the impact of the assumption.

Q314.6. The other area of importance is heat transfer due to condensation on cold surfaces. With the accumulation of noncondensible gases, the condensation rate will degrade. TRACG models this heat transfer with the Nusselt's correlation for condensation and degradation due to noncondensible gas through use of the minimum value from the

Kuhn-Schrock-Peterson (K-S-P) correlation, which was derived from vertical pipe data, and the Uchida correlation. The data base for these correlations covers pressure up to 4.5 bars which is appropriate for containment application.

In principle, the staff accepts such an approach. However, the applicability of this model to the containment analysis needs to be discussed in more detail given the fact that the nodalization may affect the noncondensible gas concentration near the interface and therefore, the heat transfer degradation.

R314.6. [[

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Q314.7. How was the degradation factor obtained? Does the correction factor include any bias based on the data used to develop the degradation factor? Is it a "best-estimate" correction? What is the uncertainty in this correction factor and is it considered in the calculations?

R314.7. In the K-S-P correlation, the factor f2 accounts for the degradation due to noncondensibles. It is obtained by correlating the ratio of the condensation heat transfer coefficient with noncondensibles to the heat transfer coefficient without noncondensibles. The form of the correlation is given in Section 6.6 of the TRACG Model Description [NEDE-32176P]. It is intended to be a best fit to the data. The uncertainty in the K-S-P correlation was addressed in the TRACG Application Report [NEDC-33083P] and is excerpted below.

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Q314.8. The two-phase flow in the PCCS tubes is modeled with the conventional approach for a film flow regime. The critical aspect of this component is the heat transfer inside the tubes. The correlation used by TRACG for single phase flow and condensation heat transfer is appropriate as it was developed from tube data of the same diameter as the PCCS tube, and for pressures up to 5 bars.

However, implementation as described in Section 6.6.11.1 has an apparent error in Eq 6.6-60. The average heat transfer coefficient is a function of the length over which averaging was done and a derivative with respect to [z] should account for this dependency. This model should be revisited and if simplifying assumptions are being made, describe the derivation of the equation as presented.

R314.8. Equation 6.6-60 is correct. This can be readily verified by recognizing that

$$\bar{h}(z) = \frac{1}{z}\int_0^z h(x)dx$$

Combining with Equation 6.6-59 and Equation 6.6-56,

$$\mathrm{Re}_l = \frac{4}{\mu_l h_{fg}}(T_s - T_w)\int_0^z h(x)dx$$

Differentiating with respect to z,

$$\frac{d(\mathrm{Re}_l)}{dz} = \frac{4h}{\mu_l h_{fg}}(T_s - T_w)$$

Q315. Interfacial Momentum Transfer

Interfacial momentum transfer occurs at interfaces and affects the distribution of the liquid and vapor phases and therefore the void fraction. It is important to predict the void fraction accurately as it has an effect on heat transfer and the two-phase multipliers for wall friction and local pressure loss coefficients. The containment has many regions where interfacial momentum transfer needs to be modeled, such as the film on the wall (or the spillover from the vessel in the drywell), the droplet phase, the PCCS tube film flow, the flow in the horizontal vents and the flows over liquid surfaces in the GDCS tank, the suppression pool and the condensate pools that might be created in the drywell or other regions.

The general approach in TRACG is to use mixture information or a drift flux correlation and to partition it into interfacial shear for different regimes. The description lacks an assessment of the applicability of this approach to model the containment. The areas where the models may not be applicable include the drywell, the horizontal vents and the suppression pool. In the drywell area, the liquid will be in the form of films on structures and fog in the atmosphere. The flow regime maps will not predict a film flow and therefore, the code may select, for example, a dispersed flow regime. Furthermore, the fogging in the bulk due to the cooling of the steam will likely lead to a droplet flow regime. However, the size of the drops should not be determined from a Weber number equal to 12 as this critical Weber number represents the largest drop size, while a fog will consists of much smaller drops. The fogging phenomenon will produce a spectrum of drop sizes which cannot be represented by a drop size calculated from the critical Weber number, and thus resulting in a different behavior of the droplets.

Q315.1. Provide a discussion of the applicability of the TRACG models to address these issues for interfacial momentum transfer- void fraction, two phase multipliers for wall friction, drop formation and the treatment of drops, and interfacial momentum - as they relate to the evaluation of containment performance.

R315.1. [[

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Q315.2. The other area where the applicability of TRACG is not certain is in the horizontal vents as the interfacial shear was derived from vertical flow data and it may not apply to horizontal vents. No assessment has been presented for its application to the horizontal vent flows.

Provide a discussion of the applicability of the interfacial shear model in TRACG for the horizontal vents.

R315.2. [[

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Q315.3. The suppression pool receives a mixture of steam and noncondensible gases from different sources (horizontal vents, safety relief valves and PCCS). The steam condensation will depend upon the residence time of the bubble and the interfacial area. The report does recognize the difficulty of modeling the pools (see the text below Eq. 6.1-33, NEDE-32716P).

If the void fraction is over-predicted, then the interfacial shear is under predicted and bubbles will have larger residence time and larger interfacial area leading to more condensation. It is recognized that the design philosophy for the vents to the suppression pool is such that 100% of the steam is condensed in the pool (no steam escapes the pool surface into the wetwell gas space).

TRACG handles the condensation of the steam in the suppression pool based on the Bubbly/Churn flow model described in Section 6.1.3 of NEDE-32716P, but does not account for degradation due to the presence of noncondensible gases. Are the expected conditions (pressure, hydraulic diameter and mass flow rate) within the range for which the model is applicable? Is it conservative to neglect the degradation from the presence of noncondensible gases? How is the over- prediction of the void fraction addressed in the calculations?

R315.3. The reviewer apparently misunderstood the text below equation 6.1-33. The data for low vapor flow rates in a pool were used to develop a correlation for the drift velocity under these conditions. This correlation is given in Equations 6.1-34 and 6.1-35. For large hydraulic diameters and low volumetric fluxes, TRACG modifies the coefficient in the drift velocity (Equation 6.1-30) according to Equation 6.1-34. TRACG calculations are compared with the data of Wilson and Bartolomei in the report TRACG Qualification NEDE-32177P, Rev.2, Section 3.1.3. The agreement between the measured and predicted void fractions is excellent. The range of deviations is between ± 2%.

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Q315.4. Are there any data and are there any TRACG comparisons to that data where the vent submergence was not low enough to prevent steam from escaping the pool?

R315.4. There are no data where a significant amount of uncondensed steam escaped from the pool surface. The vent submergences are designed to prevent this occurrence.

Q346. Page 2-3, 3rd paragraph.

R346. This RAI is perceptive, in that the question of non-condensable content in the drywell is probably one of the largest uncertainties in overall BWR pressure suppression system performance, and has been so since the earliest test and analysis.

Prior to providing specific response to the 3 specific questions in this RAI, it will be helpful to state some general observations on BWR pressure suppression performance.

The initial response to a primary system break within the containment – independent of break size – is the same for the ESBWR design and earlier BWR designs, including the Mark I, II, III and ABWR configurations. The only significant difference between the ESBWR containment and it's predecessors is the method of decay heat removal through the passive PCCS system instead of active pool cooling modes of the Residual Heat Removal systems of current plants. No EBWR-specific testing was necessary during the early blowdown period for the ESBWR, precisely for this reason.

Prior to the ESBWR, GE calculated containment performance using the NRC approved M3CPT model described in NEDO-20533 and NEDO-20533 Supplement 1. [[

]] For main steam line and recirculation line breaks, this methodology typically calculates near-complete purge of non-condensables into the wetwell in less than 10 seconds (for example Figure 3B-10 of GESSAR II – 22A7007).
The TRACG containment model used for the ESBWR is more complex than the previous M3CPT model. [[

]] For break locations in the upper drywell, non-condensables are purged in a few tens of seconds. However, in this situation, the non-condensables in the lower drywell are first compressed, and then bleed out slowly beginning in the GDCS period.

Also, from a PCCS performance standpoint, the extent of non-condensable transport during the blowdown period is largely irrelevant, since quenching of the drywell steam contents with GDCS overflow water will open the drywell to wetwell vacuum breakers, and reintroduce non-condensables previously purged to the wetwell into the drywell.

Q346.1. It seems incorrect to say that the ESBWR LOCA analysis shows that essentially all of the initial inventory of the DW inerting gas is forced into the WW "within a matter of seconds," because the time required depends on the break size and location. Even for the MSLB, it will take more than a matter of seconds to move nitrogen gas to the WW. Please revise this statement.

R346.1. The wording will be changed to read, "during a period of time much shorter than the reactor blowdown period."

Q346.2. Please provide the TRACG-calculated time (in seconds) to move a major portion (e.g., 90% or higher) of the nitrogen gas from DW to the WW for the MSLB, GDLB, and BDLB (base cases only, no parametric studies).

R346.2. As noted earlier in the response, TRACG calculates the inventory in each drywell node, it is difficult to provide a direct answer to this question. For example, in the MSLB case, the top upper drywell calculation provided 90% transport times of 1.0, 12.0, and 13.5 seconds for the top 3 levels. Since in the MSLB there is no flow through the lower drywell, the 90% transport time for this volume is much longer on the order of 50 hours.

In the BDLB case, the bottom 4 levels are essentially cleared of nitrogen in less than 2 seconds, while 90% transport times are on the order of 100 seconds for the top 2 levels. Since there is flow through the lower drywell with a BDLB, a mechanism exists to purge the non-condensables, and this volume has a 90% transport time of about 2 hours.

GDLB information is not available at this time.

Q346.3. Please modify the following statement: "Thus, when the ESBWR PCCS is called upon to assume the decay heat load, it is expected that it will face a minimal challenge from residual noncondensable gas in the inlet mixture," to reflect the issue discussed in question 346.1 above.

R346.3. The wording is correct as written. The model does show that the vast majority of the non-condensable drywell inventory has been purged to the wetwell air space during the blowdown period. Note that this wording is in the description of the PANDA P3 test. The purpose of this test was to demonstrate that the PCC will function adequately, even if the expected conditions are not experienced in the plant.

Q360. Page 2-6, 1st paragraph. It is stated that "For design basis accidents, the peak long-term drywell pressure occurs when all the noncondensible gases are present in the wetwell and, consequently, the drywell is nearly pure saturated steam."

Q360.1. Is this statement based on TRACG analysis or test data? Let us compare this statement with the PANDA M3 test data: when the peak DW pressure occurred at around 10,000 seconds (ALPHA-613-0/Page 15), the partial air pressure in the DW was in a range of [[ ]] (ALPHA-613-0/Page 22).

R360.1. Perhaps this statement would better read, "For design basis accidents, the long term drywell pressure is maximized when all the non-condensable gasses are present in the wetwell, and, consequently, the drywell is nearly pure saturated steam." All BWR containment testing and analysis performed over the last 40 years has demonstrated that the drywell pressure may be calculated from the simple relationship:

$$P_{DW} = P_{WW} + P_{SUB} + P_{Vent} \qquad (1)$$

Where:

$P_{DW}$ is the drywell pressure
$P_{WW}$ is the wetwell air space[1] pressure
$P_{SUB}$ is the submergence head of the vent, and
$V_{vent}$ is the flow loss through the vent system

In the long term case for the ESBWR the vent system flow losses are negligible, and the submergence head is constant. The wetwell air space pressure is the sum of the partial pressure of the non-condensables and the water vapor pressure associated with the temperature of the suppression pool, i.e.

$$P_{WW} = p_{nc} + p_{vap} \qquad (2)$$

and the non-condensable partial pressure may be calculated from the classical equation of state for and ideal gas

$$p_{nc} = \frac{mRT}{V} \qquad (3)$$

where:

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[1] The terminology "wetwell air space" indicates the gas volume above the suppression pool, and does not indicate the presence of "air" – the ESBWR containment is inerted with nitrogen.

$p_{nc}$ is the wetwell non-condensable partial pressure
$m$ is appropriate gas constant
$T$ is the absolute temperature in the wetwell air space, and
$V$ is the wetwell air space volume.

Since the wetwell non-condensable partial pressure will be maximized when the wetwell non-condensable mass is maximized, the drywell pressure is maximized when all the non-condensable gasses are present in the wetwell, i.e. purged from the drywell and present in the wetwell. At a given suppression pool temperature, the drywell pressure will be maximized if all the non-condensable mass is in the wetwell.

In practice, the peak drywell pressure occurs at the time of peak suppression pool temperature, while all, or nearly all, the drywell non-condensable inventory has been purged to the wetwell. In the case in point, the drywell pressure would have been a few tenths of a psi higher if complete non-condensable carryover had occurred. In practical application, the peak drywell pressure always occurs when all or nearly all the non-condensable mass is in the wetwell. Note that in the case in question, between 98 and 99% of the non-condensables are in the wetwell.

Q360.2. Is this range of the noncondensible gas concentration deemed to be negligible (with respect to its adverse impact on the PCC heat removal) so that it would be correct to say that the DW is filled with nearly pure saturated steam?

It should be pointed out that a similar comparison to the GIRAFFE/Helium test data cannot be made for the lack of noncondensible gas concentration data, and an RAI on this issue has been included among those regarding the GIRAFFE tests.

R360.2. No level of non-condensable concentration is "deemed negligible" in the drywell performance analysis. TRACG calculates the non-condensable concentration throughout the drywell, and specifically at the location of the PCCS supply to the heat exchanger, and in the PCC heat exchanger itself. Whatever the non-condensable concentration is, it is accounted for the performance analysis.

It should also be noted that steam condensation within the PCC heat exchanger is not a function of the non-condensable content in the drywell, per-se, but of the non-condensable concentration in the PCC heat exchanger itself. When the non-condensable concentration in the PCC heat exchanger reaches the point where the decay heat can no longer be rejected, the drywell pressure will begin to rise, and this will increase the pressure within the PCC heat exchanger, lead to clearing of the PCC vent, and purge of the non-condensables from the heat exchanger. The presence of this range of non-condensables does not effect the ability of the PCCS to reject heat over a long term, only the time between purges.

There is no question in this RAI, only a statement. However, the response presented to Items (1) and (2) above are not dependant on the gas specie of the non-condensable, and would also apply to GIRAFFE.

Q363. Page 2-10, 3rd paragraph.

Q363.1. Please provide a basis for the statement that main vent clearing occurs within a few seconds of the LOCA (e.g., BDLB or GDLB).

R363.1. As was discussed in the response to RAI 346, the initial response to a primary system break within the containment – independent of break size – is the same for the ESBWR design and earlier BWR designs, including the Mark I, II, III and ABWR configurations. The only significant difference between the ESBWR containment and it's predecessors is the method of decay heat removal through the passive PCCS system instead of active pool cooling modes of the Residual Heat Removal systems of current plants. No EBWR-specific testing was necessary during the early blowdown period for the ESBWR, precisely for this reason.

Main vent clearing is dominated by the inertia of the water in the vent system and the pressurization rate in the drywell following a primary system breach, which is dependant on drywell volume and break size. BWR/2 through BWR/6 containments have Design Basis Accident (i.e. MSLB or recirculation line break) drywell pressurization rates on the order of 20 psi/sec, and main vent clearing times between about 0.5 and 1.0 sec. These designs also demonstrate a short- term drywell pressure peak associated with the vent clearing process that is near the long-term peak value for BWR/2 through BWR/5. The short-term drywell peak pressure is the maximum for BWR/6 plants.

The ABWR and ESBWR designs have break areas to drywell volume ratios some what less than these earlier designs. Hence, the drywell pressurization rate is lower, but the vent system inertia is also less due to the shortened horizontal vent in these designs. The ABWR SAR does not report vent clearing times, due to the dominance of the long term pressure response in that design.

The ESBWR containment performance is also dominated by the long-term response. There is a short-term drywell pressure peak, but it is much less than the long term pressure. The MSLB vent clearing times calculated for the ESBWR are 0.7, 1.0, and 1.4 seconds for the three levels of vents, respectively.

Q363.2. What is the duration of main vent clearing for the MSLB?

R363.2. The top main vents will remain "open" throughout the reactor blowdown and GDCS transition period, although the phenomenon main vent chugging will occur, resulting in an intermittent opening during the latter stages. The TRACG calculated duration of main vent flow is about 600seconds.

Q380. Page 2-101, next to the last paragraph. It is stated that "The core heater in the facility simulated the decay heat following a scram with 1:400 scale adjusted for stored energy effects."

Q380.1. Please explain how the GIRAFFE core power was adjusted for the stored energy effects.

R380.1. The term, "adjusted for stored energy effects" is a misnomer. Additional RPV bundle power was supplied in GIRAFFE not for stored energy per se, but to partially account for heat transfer from the GIRAFFE vessels to the environment.

GIRAFFE was an outdoor facility, and it was determined early in the program that additional energy would need to be added to the facility to account for heat losses from the various facility pressure vessels to the ambient.

The GIRAFFE SBWR Helium Series Test Report, NEDC-32608P, (previously provided to the USNRC via MFN-091-96 dated June 24, 1996) describes the processes used to ameliorate these effects. Section 3.7 of that report describes the facility characterization tests that were performed. Facility heat losses were compensated for by insulation, microheater power (trace heating elements located inside the vessel insulation), and additional RPV bundle heater power.

Q380.2. Quantify this core power adjustment in a table by dividing the initial core power in the GIRAFFE tests (listed in Table 2.5-2 on p. 2-105, Table 2.5-3 on p. 2-106, and Table 2.6-2 on p.2-119) into two parts – the equivalent decay heat power for GIRAFFE (scaled from the SBWR after the scram) and the adjustment to the core power (in kW).

R380.2. Appendix B of NEDC-32608P provides the results of the facility characterization tests. The core power was increased by a constant 27kW to account for the heat losses. Table 2.2 of NEDC-32608P states that the initial heater power was 93 kW. Table B-1 of the same report describes that 27 kW of this was added for heat loss compensation. The difference is 66 kW which is the exact results of the 2000 MW rated (SBWR), divided by a scale factor of 400, and multiplied by the one-hour shutdown power fraction of 0.0132.

Q381. Pages 2-103 (1st paragraph) and 2-111 (Fig. 2.5-5). [[

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R381. Test H2 was run with essentially no nitrogen in the D/W[1] – only helium and had no VB openings. [[

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[1] There was a very small amount (0.1%) of nitrogen measured in the D/W, due to the residual nitrogen from the previous test.

Q383. Page 2-103 (last paragraph). There are no figures in this report to compare the important parameters of the two GIRAFFE tie-back tests (T1 and T2) and the previous GIRAFFE test for which Test T1 was a tie-back test. Please provide figures to compare the important parameters (e.g., DW/WW/RPV pressures, PCC condensate flow rate, etc.)

R383. GIRAFFE testing was performed by Toshiba Corporation, a GE technical associate in Japan. The GIRAFFE/He and GIRAFFE/SIT programs were run in accordance with JEAG-4101 quality assurance guidelines. JEAG-4101 is the Japanese equivalent of ASME NQA-1 in the United States. Early GIRAFFE testing in support of the SBWR concept was not performed in full compliance with JEAG-4101.

GIRAFFE/He "tie-back" tests T1 and T2 were performed with a dual purpose. First, these tests form an integral part of the comprehensive data base for evaluation of the effects of lighter than steam non-condensables, but it was also hoped that by performing these two tests as repeats of tests not having met full quality assurance requirements, that the size of the acceptable GIRAFFE data base could be expanded. Unfortunately, this proved not to be possible. While key parameters were compared, and it was concluded that the tie-back tests provided repeatable results to the earlier tests, there was sufficient doubt caused by the quality assurance situation that the earlier GIRAFFE tests were not used in support of the SBWR.

None of the earlier GIRAFFE test data is cited in the TRACG qualification information for either the SBWR or the ESBWR.

Q384. Page 2-105, last line. Was the GDCS injection completed before the test initiation for all the GIRAFFE/Helium tests?

R384. Yes. These tests were initiated at the one-hour point in the LOCA when the GDCS tank has completely drained. The statement in the report that, "The GDCS pool level should be positioned in hydrostatic equilibrium with the RPV level…" makes this clear.

Q385. Pages 2-112 (4th and 5th paragraphs) and 2-114 (3rd paragraph).

Q385.1. Is a GIRAFFE 3-tube IC unit with two tubes plugged and only one tube operational equivalent to one IC condenser in the SBWR (which has three IC condensers)?

R385.1. No. The GIRAFFE 3-tube IC condenser with two tubes plugged is equivalent to two SBWR IC condensers.

Q385.2. [[

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R385.2. The statement in the 5th paragraph is correct.

Q389. Page 2-129, Fig. 2.6-9.

Q389.1. What was the IC condensate flow rate for Test GS2 in comparison to the PCCS condensate flow rate shown in Fig. 2.6-9?

R389.1. The IC condensate flow rate was not measured in the GIRAFFE/SIT tests. The condensate return line in the GIRAFFE Test Facility was not instrumented to measure flow rate.

Q389.2. There is a typographical error in Fig. 2.6-9 for which the unit of pressure should be in "MPa" instead of "kPa."

R389.2. GE agrees. The change will be incorporated into the next revision of the report.

The comments related to this test report are made in the context of the ESBWR Scaling Analysis._A general comment about the material presented in the report is that, even though it seems clear and easy to read and follow, there is almost no quantitative evaluation of scale or distortions. The statements "prototypical as practical" and "non-prototypical" are used often without explanation or reference of what they mean in terms of the extent of the prototypical quality or lack thereof. A number of the questions are derived from this observation.

**General Response:**

For discussion on "scale and distortion", please refer to the "ESBWR Scaling Report", NEDC-33082P, Section 5.6 which states:

> "Since the PANTHERS tests were conducted with full-scale components, there are no scaling distortions to be addressed other than the issue of PCC extrapolation. There is no expected effect from testing only one IC module except, possibly, minor distortions in pool circulation that would have minimal effect on overall heat transfer."

The purpose of isolation condenser (IC) test at SIET (known as the PANTHERS/IC test) was to test a full scale prototype heat exchanger of the same design intended for the SBWR and ESBWR. The purpose of the program was to test the heat exchanger at full pressure, temperature and flow conditions. The test facility used for this program was not intended to be representative of the SBWR/ESBWR Isolation Condenser System (ICS) of which the heat exchanger or condenser will be one part. This series was a component test and not an integral system test. The intent was to make this series a component "design qualification test" and therefore the actual test system performance was not intended nor expected to be representative of the SBWR or ESBWR system performance.

The design qualification tests were to:

- confirm the design meets thermal-hydraulic requirements
- confirm the mechanical design is adequate to assure the structural integrity of the condenser to the plant lifetime
- confirm adequacy of inservice inspection procedures
- record reference data for use in evaluation of proposed leak detection method

For practical reasons one heat exchanger of a pair was built and tested since the test facility had a limitation on steam quantity. The heat exchanger was a full-scale prototype of the same unit to be used in the SBWR/ESBWR IC System.

Q390. Page 10, Section 2.2, item (c): What constitutes a "large fluctuation" of tube-side heat transfer and flow rates?

R390. This particular objective was more for qualitative than quantitative judgment. It was recognized early in the test program that during startup and shutdown of the IC heat exchanger, transient conditions would be experienced, especially steam and condensate flows. This objective was geared more towards the steady state conditions to confirm steady, consistent (and predictable) operation of the unit. The test personnel were looking for any excessive variations in the indications for heat transfer and the various flow parameters.

Q391. On page 11, item (h): An elbow flow meter is mentioned on this page. Also, on page 17 the "elbow flow meter" is mentioned twice, indicating that there are two of these devices. Why are the instruments not mentioned in the instrumentation description or data reduction? What happened to this data?

R391. The elbow flow meters were installed in the steam supply and condensate return lines in order to see what dP transients were experienced during startup of the IC condenser. They were not intended to be used for actual flow measurement devices for the prototype test series. The actual SBWR/ESBWR system design uses such elbow flow meters to measure gross, excess flow should either line break during standby or operation. The elbow-tap flow meters measure the dP at the 90° elbow and will send a signal to the Leak Detection system in order to isolate the system in the event of a major pipe break. Startup transients are critical for this mode of leak detection since the transient could provide a spurious trip and isolation of the system.

The table of instrumentation shows the two elbow-tap dP transmitters as follows:

- steam = DP EFM1, instrument TMD 155
- condensate = DP EFM2, instrument TMD-160

Refer to Appendix A, "Instrument List", Table A.1.
Both were recorded and exist on the data tapes. For an example of the data, refer to Section 8.2.3, Page 43 and Figure 8.33.

Q392. Page 11, item (k): The vibrations measured in this test are representative of one half of the actual structure and function of the IC. How is are the measured vibrations scaled to take this into account?

R392. The acceleration measurements were made primarily for the purpose of evaluating vibration characteristics and detection of possible condensation water hammer loads. The vibration measurements were not intended to be scaled and represent the movement and vibration of one heat exchanger. The vibration instrumentation was used to monitor for gross or serious problems during the startup, operation or shutdown of the heat exchanger operation.

The first ESBWR reactor and plant will be tested per Regulatory Guide 1.68, "Preoperational and Initial Startup Test Programs for Water cooled Power Reactors". Just like any first of a kind reactor it will be instrumented and tested for various effects such as pipe expansions or contractions and unusual or unexpected vibrations. The tests during the initial startup phase will include thoroughly testing the overall isolation condenser system, during its startup, operation and shutdown. The final heat exchanger design, as installed in the ESBWR reactor will be treated as a part of this test program. The entire system will be fully tested and accepted as part of a strenuous pre-operational and startup test program.

Q393. Page 12, Section 3.1, item (e): It is noted that there are several departures from prototypical dimensions of the main steam supply line. Please, explain the nature, extent and impact of these non-typical dimensions.

R393. Item (e) of Section 3.1, is referring to the steam supply line and the point at which the steam exits the test facility pressure vessel. For the test the steam was extracted at the top of the steam vessel. The SBWR/ESBWR steam line for the IC's exit the side of the top section of the pressure vessel.

Q394. Page 12, item (g): What is meant by the phase "prototypical as is practical □" What is the condensate drain line prototypical of? Since the IC in the test a half-unit full-scale IC, is the area of the drain line one-half of the area of the actual drain line? The schematics suggest that the full IC will have a single drain line. The underlying assumption is that doubling the size of the tested IC would double the drain line flow. Please provide the basis for this assumption. In addition, the dynamic response of a half drain line, or even a full drain line with half-unit IC would be different from the prototype. How are these differences accounted for in the test and the analysis?

R394. "Prototypical as is practical" means that within reason, good engineering judgment and economics, an effort was made to simulate the actual heat exchanger design.

The drain line is prototypical of the actual heat exchangers drain line and was tested with exactly the same size piping as the double heat exchanger design. The drain lines from two heat exchangers join and are routed back to the ESBWR reactor pressure vessel. The drain line flow for the test was about 50% of the flow to be experienced in the actual design since only one module or heat exchanger unit was tested. Total drain line flow is just a matter of basic design, considering the maximum velocity and therefore pressure drop of the drain line as part of the whole IC system. Again, there was no attempt to simulate a prototypical IC system only test the heat exchanger component.

Q395. Page 13, Section 3.2: It is stated that since the facility includes a half-unit full-scale IC, scaling analysis is not necessary. Please explain how the dynamic response of the flow and the system vibration aspects were accounted for in the scaling analysis.

R395. Please refer to RAI 392 through 394 above and the general response above.

Q396. Page 16, Section 3.5.1: The last paragraph in this sections suggests that there may be a steam flow into the system that is not being measured. Is this statement correct? Please provide additional details regarding this steam flow and any impact it may have on the test results.

R396. Steam flow to the test specimen (heat exchanger) is measured. The superheated steam is supplied through two lines to the test (pressure vessel), one a 5" line and one a 3" line. Both lines of superheated steam are reduced in pressure through pressure control valves and desuperheated with water sprays. The total steam is mixed at a mixing tee and then passes to the vessel. The saturated steam leaves the vessel after first passing though a separator unit and dryer unit. The total steam flow to the IC heat exchanger is measured for test purposes at the exit of the vessel. The 3" superheated steam flow into the mixing tee is not measured but is desuperheated and mixed. The total steam flow is measured once it leaves the pressure vessel. The detailed P&ID of the test facility shows this arrangement.

Q397. Bottom of page 16: There is a typographical error, it should read "steam" instead of "staam."

R397. The word "steam" is misspelled as "staam".

Q398. On page 17, Section 3.6: It is stated that the IC returns to the vessel [[ ]] below the water level. Is this the collapsed water level or the two-phase water level? If it is the two-phase water level, how is this level detected or measured?

R398. Please refer to the description of the reactor pressure vessel in Section 3.5.2 of the report and Figure 1.2. The test vessel is designed to simulate the presence of the RPV. The ICS is designed strictly as a natural circulation driven steam condenser, relying upon the difference in densities between the steam leg versus the cooler condensate leg. The pressure vessel acts as a return vessel for the condensate and input source for the steam similar to a BWR. There is a level of saturated water that sits in the lower part of the vessel with steam being first desuperheated and then injected into the vessel and to the steam space above the normal water level. The normal water level is fixed at about 7 meters from the vessel bottom. The condensate is allowed to return to the vessel at about 4.12 meter below the normal water level (~2.88 m above bottom). Section 6.3 describes how the vessel water level is measured.

Q399. Section 3.6, bottom of page 17: [[

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R399. The actual design of the ICS for the SBWR and ESBWR has a requirement for minimum slope of the drain line at 1/25 or 4%. Therefore the test facility requirement meets the design requirement.

Q400. The top paragraph of page 18 discusses the characteristic time of valves, specifically to simulate the prototypic valve opening of the IC return. It is not clear in this report or in the NEDC-33082P, "ESBWR Scaling Report," how the characteristic time of the IC system compares to the other dynamic (and simultaneous) aspects of the system response. It is also not clear whether the dynamic response characteristic of the IC return line was considered in the design of the test or in the analysis of the data. Please explain if and how these dynamic features of the test were analyzed in the context of scaling and data sufficiency.

R400. Again, this was <u>not</u> an attempt to prototypically test an IC system only the heat exchanger component. The test condensate return valves were used to simulate the opening of the actual design condensate valve. The two test valves were actually a 4" ball valve and a 2" valve in parallel. The small valve was opened first followed by the quick opening of the 4" valve. The initial time for opening the 4" valve was selected at two seconds. During the shakedown testing, two seconds was found to be too rapid, causing some water hammer in the test loop. After some shakedown testing it was discovered that by opening the 2" for about 25 seconds followed by opening the 4" valve, the water level drop in the heat exchanger could be better controlled and no water hammer was experienced. The actual opening time of the current design is about 30 seconds.

Q401. Section 3.7 on page 18: The vent lines are described in detail. Are the vent lines prototypical?

R401. The vent lines in the actual design are at the same locations as the single unit used for testing. The ESBWR design has both a top header vent and a lower header vent. In the design the vent lines are ¾" Schedule 80 pipe, the same size as those in the tested vent lines.

Q402. Section 4.9 on page 23: The scribe marks used to measure permanent strains are described. It is stated in the report that the results are not yet available. Are these results now available? Were there any permanent deformations of the system? Please provide the detailed results from the measurement of the scribe marks.

R402. These scribe marks were not measured at the conclusion of the test program. There was no known permanent deformations of the heat exchanger.

Q403. Were the data acquisition systems discussed on page 24 synchronized?

R403. Yes, the data acquisition systems were monitored and synchronized by the common supervisory computer per the detailed procedures of the test facility (SIET).

Q404. Page 35, Section 7.1: It is suggested that tests to examine the effect of inlet pressure could be conducted consecutively. If a test has already been performed, the water in the IC return line would be warmer than it was during the initial test, thus varying the head available in the IC line. How was this effect addressed in the experiments?

R404. The procedure for this test sequence required the heat exchanger pool be brought to saturation temperature (~100°C) before collecting the steady state data. This provided somewhat of a fixed pool temperature for the condensate as it exited the pool. In addition the procedure called for holding at the new inlet pressure to stabilize for at least 10 minutes and to verify steady-state conditions per their test procedure. Once steady-state was confirmed the data was recorded for 30 minutes. Primarily there is stabilization of conditions between tests.

Q405. The test matrix for the startup demonstration of the IC consisted of a single test. How is it demonstrated that this test encompasses the expected phenomena, given that the IC return line is not entirely prototypical, even assuming that the half-unit IC and the return pipe behave in a prototypical fashion? What basis, analytical or experimental, supports the sufficiency if the test data for this component? According to the conclusions in Section 9, this test was not conducted. Was the test conducted after the test report was written?

R405. [[

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During the initial startup test program for the ESBWR (refer to RAI 392) the startup of the IC system will be demonstrated during a full closure of the main steam isolation valves (i.e,. transient conditions).