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Technical Evaluation Review of TRACG Applications to ESBWR Anticipated Operational Occurrences (AOOs)

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Abstract – The application of TRACG to ESBWR AOOs is reviewed in this report and discussed in terms of the thermal-hydraulic and neutronics modeling. Areas of concern were identified and RAIs were prepared. Available GEH responses to RAIs have been incorporated into this review. Unresolved RAIs have been marked as Open Items. TRACG has all of the models required to simulate ESBWR AOOs and uncertainties in the dominant models have been characterized. An uncertainty analysis for TRACG following the CSAU methodology applied to ESBWR AOOs can be performed.

Abbreviations

AOO	Anticipated Operational Occurrences
BOC	Beginning of Cycle
BWR	Boiling Water Reactor
CRD	Control Rod Drive
COBRAG	Multi-field two-phase computer code for detailed fuel assembly analysis
CPR	Critical Power Ratio
CSAU	Code Scaling, Applicability and Uncertainty
DPV	De-pressurization Valve
EOC	End of Cycle
FWCF	Feedwater Controller Failure
GEXL	GE boiling length dryout correlation
IC	Isolation Condenser
LRNB	Load Rejection Without Bypass
MCNP	Monte Carlo N-Particle
MCPR	Minimum Critical Power Ratio
MOC	Middle of Cycle
MSIV	Main Steamline Isolation Valve
PCT	Peak Clad Temperature
PIRT	Phenomena Identification Ranking Table
RAI	Request for Additional Information
RPV	Reactor Pressure Vessel
SLMCR	Safety limit Minimum Critical Power Ratio
SRP	Standard Review Plan
SRV	Safety Relief Valve
TCV	Turbine Control Valves
TGBLA	Neutron transport and diffusion coupled computer code for fuel lattice design (Toshiba)
$\Delta CPR / ICPR$	Change in CPR divided by the initial CPR

1.0. Introduction

TRACG application to ESBWR Anticipated Operational Occurrences (AOOs) (i.e. pressurization events, depressurization events, cold water events, and level transient events) was reviewed[1,2]. The main areas of review for TRACG as applied to ESBWR AOOs are: accident scenario, PIRTs, assessment, and uncertainties. The applicability and uncertainty of TRACG as applied to AOOs follows the CSAU methodology in Ref. 5.

Section 2.0 of this report identifies the scenarios in which GEH is to apply the TRACG code and associated methodology in Reference 1. Section 3.0 includes a review of GEH's PIRT. Section 4.0 discusses the TRACG thermal-hydraulic modeling. Section 5.0 discusses the TRACG 3-D transient neutronics modeling. Conclusions are in Section 6.0 and References are in Section 7.0. Appendix A summarizes all of the open items related to this review. RAIs are listed in Appendix B.

2.0. Scenario Specifications

The ESBWR design[3,4] has 1132 bundles at a reactor power of 4500 MWt. The base line analysis model is based on an equilibrium core of GE14E 10x10 fuel. A GE14E 10x10 fuel assembly has 92 fuel rods and 2 water rods. The 92 fuel rods have 78 full length rods and 14 partial length rods. The active core height is 3.048m (10 ft).

AOOs in an ESBWR can be grouped into the following

1. Pressurization events, including: turbine trip without bypass, generator load rejection without bypass, feedwater controller failure increasing flow, downscale failure of pressure regulator, main steam line isolation valve closure without position scram, loss of AC Power, and loss of condenser vacuum. This grouping includes all events in SRP[14] Section 15.2.1 - 15.2.5 which apply to ESBWRs. The feedwater controller failure increasing flow is in Section 15.1.1 - 15.1.4 but can also be considered a pressurization transient. The loss of auxiliary power is in SRP Section 15.2.6.
2. Depressurization events, including: upscale failure of pressure regulator and relief valve opening. The upscale failure of pressure regulator is in SRP Section 15.1.1 - 15.1.4. The inadvertent relief valve opening is in Section 15.6.1.
3. Cold water events, including: loss of feedwater heating and inadvertent high pressure coolant injection. The loss of feedwater heating (decrease in feedwater temperature) is in SRP Section 15.1.1 - 15.1.4. This grouping includes all events in SRP Section 15.5.1 - 15.5.2 which apply to ESBWRs.
4. Level transient events such as partial or complete loss of feedwater. This grouping includes all events in SRP Section 15.2.7 that apply to ESBWRs.

GEH selected three pressurization events to demonstrate TRACG application for AOOs (i.e. LRNB – generator load rejection without bypass, FWCF – feedwater controller failure to maximum flow - 168% of rated, and MSIV – main steam line isolation valves closure). Pressurization events tend to be the most limiting ΔCPR events for the ESBWR AOOs.

LRNB AOO assumes a generator load rejection, which results in the fast closure of the turbine control valves (TCVs) or turbine stop valves. Closure of the turbine stop valves is initiated by the turbine protection system. The fast closure of the TCVs result in a fast pressurization event. Normally, the turbine bypass valves would open to help mitigate the pressurization event. However, if turbine bypass valve failure is assumed, then at least one of the turbine bypass valves will fail to open on demand.

The pressure wave from the rapid closure of the TCVs propagates down the steamlines and into the vessel, down the chimney and downcomer and into the core. The pressure wave is attenuated by the flow area changes as it moves from the steamlines into the steam dome, down the chimney and into the core. The effect of the pressure wave in the core is to collapse the voids in the core, which results in a positive reactivity addition and a significant increase in the reactor power.

A turbine stop valve position less than approximately full open, or a low hydraulic fluid pressure in the turbine control valve solenoids that start their fast closure mode, or the sensing of any two turbine stop valves closing, initiates a scram signal. Therefore, the pressurization event and the positive reactivity added to the core are followed by a scram. Depending upon the timing of these events and the initial control rod pattern, the result can be a positive spike in the reactor power or a shutdown of the reactor.

Ref. 1 appears to indicate that for safety analysis it is assumed no control blades are partially inserted at the beginning of the transient and a slower bounding CRD scram insertion time is assumed. However, for the demonstration calculation for LRNB in Ref. 2 it appears that a rapid CRD scram insertion time was assumed. In Ref. 1, scram is initiated at 0.29 seconds for the LRNB transient, while in Ref. 2, for the same ESBWR transient, scram is initiated at 0.08 seconds. The Ref. 1 model uses a 9 ft core, while Ref. 2 model uses a 10 ft core and the Ref. 1 peak neutron flux occurs at 0.81 seconds, while the Ref. 2 peak neutron flux occurs at 0.73 seconds. RAI 21.6-57 requests that GE provide additional information on their scram insertion time. **RAI 21.6-57 is being tracked as an open item.**

Eventually, as the blades are fully inserted, the reactor is subcritical, and power drops to decay heat levels. The vessel pressure increase is terminated by the bypass valve opening. In addition, downcomer water level drops below the feedwater sparger and sprays subcooled water into the steam dome, which condenses steam and helps to terminate the pressure increase. If the bypass and feedwater systems are assumed to be unavailable, then the increase in pressure will initiate the isolation condenser (IC). If the IC is not available, then pressure will continue to increase from the decay heat power levels and results in the Safety Relief Valves (SRVs) opening.

3.0. Phenomena Identification Ranking

The critical safety parameters for ESBWR AOOs are the MCPR and reactor pressure vessel pressure. Ref. 1 and 6, presents the Phenomena Identification Ranking Table (PIRT) for ESBWR AOOs. The following phenomena were given a rank of high importance:

1) [[__________]]
2) [[__________]]
3) [[__________]]
4) [[__________]]
5) [[__________]]
6) [[__________]]
7) [[__________]]
8) [[__________]]
9) [[__________]]
10) [[__________]]
11) [[__________]]
12) [[__________]]
13) [[__________]]
14) [[__________]]
15) [[__________]]

16) [[____]]
17) [[____]]
18) [[____]]
19) [[____]]
20) [[____]]
21) [[____]]
22) [[____]]
23) [[____]]
24) [[____]]
25) [[____]]

The following phenomena where ranked as moderate importance and included in the AOO demonstration uncertainty analysis:

1) [[____]]
2) [[____]]
3) [[____]]

Not all of the moderate importance phenomena were included in the ESBWR AOO baseline demonstration calculations. This was identified as an issue in RAI 21.6-64, since GEH chose to include both high and moderate importance phenomena for ESBWR stability analysis, but only high and few moderate importance phenomena for ESBWR AOOs. **RAI 21.6-64 is being tracked as an open item.**

4.0. Thermal-Hydraulic Modeling

TRACG is a two-fluid 1D and 3D thermal-hydraulic simulation tool that also includes the capability to do coupled thermal-hydraulic/3D transient neutronics analysis[9]. TRACG solution of the conservation equations (i.e. mass, energy, and momentum) provide the code capability to address global processes. TRACG correlations and models provide code capability to model and scale dominant phenomena for ESBWR applications. TRACG numerics, structure, and nodalization provide the capability to model plant geometry and calculate specific safety parameters within a known level of accuracy.

The prediction of the important thermal-hydraulics phenomena for natural circulation (i.e. void fraction, subcooled boiling, single phase and two-phase flow losses) has been assessed against separate effects, integral effects, and plant data[8, 11]. (The qualification of TRACG in Ref. 11 is based on TRACG02 and GEH is using TRACG04 for ESBWR AOO analyses. The updated qualification using TRACG04 is requested in RAI 21.6-75. Once GEH submits the updated document, the conclusions reached in this section will be revisited to ensure they have not changed. **RAI 21.6-75 is being tracked as an open item**.) The core void fraction assessments against [[____
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[[____]]

Pressure drop comparisons against full scale bundle data and separators indicate an overall uncertainty in the TRACG pressure drop models of [[_____]]. These two capabilities are the most important phenomena for the prediction of natural circulation flows. Specifically, the void fraction distribution and the pressure drop models are the dominant phenomena for determining natural circulation flows. Comparisons of TRACG with natural circulation flow rates in the SIRIUS test facility[7] indicate a bias of [[_____]] with a standard deviation of [[__________]] Comparisons of TRACG with natural circulation flow rates in the FRIGG test facility[11] indicate a bias of [[___]] with a standard deviation of [[____]] (See Fig. 3). Additional assessments for Dodewaard, CRIEPI, and PANDA are available in Ref. 7 and 8, over a wide range of pressures, heat flux, and inlet subcoolings. The TRACG models and assessment indicates that TRACG can predict natural circulation flows and the uncertainty of these models can be propagated through statistical models to determine the uncertainty in the final safety parameter (i.e. MCPR). The dominant phenomena for natural circulation flow are modeled in TRACG and the accuracy is consistent with the available test data.

Fig. [[____
_____________________________________]]

[[____
__________________________________]]

There is a concern that the void fraction data base used to determine that TRACG void fraction uncertainty does not include any 10x10 fuel assembly data similar to the ESBWR fuel assemblies. The void fraction data base for determining the TRACG uncertainty includes single tube and 4x4 through 8x8 fuel assemblies, but does not include 10x10 fuel assemblies. In addition, it appears that the void fraction data base does not include any fuel assemblies with partial length fuel rods. The uncertainty in TRACG void fraction predictions is modeled with variations in the [[____
____
____
____]] Therefore, the uncertainty in the [[_____________________]] would be affected by going from a 8x8 to 10x10 fuel assembly with partial length rods. If void fraction data for 10x10 fuel assemblies with partial rods was available, then it could be determined if the TRACG void fraction prediction uncertainty is significantly affected. In the absence of 10x10 fuel assembly data, a 3D two-phase analysis of 8x8 and 10x10 fuel assemblies with partial length fuel rods would provide an indication of whether or not TRACG void fraction uncertainty is significantly different for 10x10 fuel assemblies with partial length fuel rods. In RAI 21.6-75, the staff requested GEH to provide a revision to Ref 11. It is expected that GEH will include the Toshiba data used for the uncertainty in void fraction in this revision. **RAI 21.6-75 is being tracked as an open item.**

The Isolation Condensers provide a mechanism to reduce the long term RPV pressure rise following a pressurization event (i.e. MSIV closure). The TRACG model of the IC has been assessed against PANTHERS data in Ref. 8 (See Fig. 4). In RAI 21.6-55, the staff requested that GEH address any differences in noding and modeling guidelines between the TRACG model used for the AOO demonstration calculations and the TRACG model used in Ref. 8. **RAI 21.6-55 is being tracked as an open item.**

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In Ref. 8, TRACG comparisons to PANTHERS data with radiolytic noncondensible gas included indicates that TRACG significantly missed the timing of the transport of these noncondensible gases through the test loop (see Fig. 5). If radiolytic noncondensible gases are present during an AOO transient, there was a concern how TRACG can be demonstrated to be conservative in terms of the transport and impact of these noncondensible gases on the condensation rates in the ICs. In RAI 21.6-55, the staff requested that GEH address this concern. **RAI 21.6-55 is being tracked as an open item.**

[[____
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GEH has indicated that the condensation heat transfer coefficients on the inside of the IC tubes and the boiling heat transfer coefficients on the outside of the IC are relatively large. When the heat transfer coefficients inside and outside are relatively large, then the heat transfer rate through the condenser tubes is controlled by the conduction through the tube walls. If the surface heat transfer coefficients are relatively large, then accurate simulation of the IC condensation rates can be accomplished by accurate simulation of the conduction through the condenser tube walls (i.e. sufficient noding and accurate thermal properties for the tube walls).

There is a concern that the GEXL correlation which is essentially a boiling length quasi-steady correlation is accurate for LRNB transient where flows, void fractions, and pressures are changing rapidly during the first few seconds of the transient. In Ref. 11, TRACG was compared to simulated LRNB transient consistent with operating jet pump BWR in the ATLAS test facility, for fuel designs GE9, GE11, and GE14 (See Fig. 6). The LRNB was simulated both with and without recirculation pump trip. The comparison indicates that TRACG transient ΔCPR predictions are within the observed boiling transition by [[____]] This data comparison indicates that the GEXL correlation is accurate for a LRNB transient. GEH's response provided in Ref. 15 closes this issue.

The data base for the GEXL correlation does not include data for the 10 ft GE14 fuel assembly. However, Ref. 1 and 8 references COBRAG calculations that indicate that the GEXL correlation uncertainty should be increased from [[_____]]

to take into account this additional uncertainty (i.e. no 10 ft ATLAS data to assess GEXL against). COBRAG is a multi-field two-phase computer code for detailed fuel assembly analysis, which predicts dryout with a mechanistic model. The applicability of the GEXL model to GE14E will be addressed in Section 4.4 of the NRC staff's ESBWR design certification safety evaluation report. The use of GEXL in the TRACG methodology will be revisited upon resolution of this issue. **This is an open item.**

Fig. 6. [[____
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Propagation of a pressure wave from the turbine control valves down the steam line into the steam dome, down the chimney and into the core is via the TRACG two-fluid numerical solution. The donor-cell differencing scheme used in TRACG is known to diffuse the propagation of the pressure wave. In addition, the fully implicit and semi-implicit numerical schemes will also tend to diffuse the propagation of a pressure wave. There was a concern about how this is incorporated into the uncertainty of an over-pressurization event with TRACG. In addition, there was a concern about the qualification and uncertainty associated with TRACG two-phase propagation of these pressure waves for rapid pressurization effects. GEH completed noding sensitivity analysis with TRACG, doubling the number of nodes in the steam line and found the impact on ΔCPR/ICPR to be on the order of [[____]] This indicates that the diffusion of the propagation of the pressure wave is not a significant contribution to the total uncertainty for TRACG for these type of pressurization events. GEH's response provided in Ref. 15 closes this issue.

Currently, the effect of any carryover droplets in the steam line is addressed in a bounding manner by assuming that the steam dryers are 100% efficient and no droplet carryover is allowed. Presence of liquid droplets in the steam line would significantly reduce the pressure wave propagation velocity down the steam line. However, two-phase propagation of the pressure wave will still be calculated in the chimney and upper plenum. The comparison of TRACG to the Peach Bottom turbine trip tests indicate that TRACG is accurately predicting the pressure rise in the core and the void collapse associated with the pressure rise in the core and the resulting increase in power (See Figs. 7 and 8). This implies that TRACG is accurately predicting the pressure wave propagation through the two-phase upper plenum and reactor core.

[[____]]

[[____]]

For cold water events the mixing and propagation of cold water entering the lower plenum and entering into the core is indicated to be a [[__________________]] phenomena. However, it is not clear how this has been addressed in terms of the accuracy of TRACG to simulate this phenomenon.

In Ref. 6, plant startup was included in the AOO PIRT analysis. During plant startup the mixing and propagation of relatively cold water entering the lower plenum and entering the core at relatively low circulation flow rates could be a significant phenomenon. For example, if cold water enters the peripheral fuel assemblies, rather than the core center fuel assemblies, then the timing and extent of flow oscillations during startup may be affected. It is not clear how this uncertainty in the radial and azimuthal core input temperatures has been included in the TRACG uncertainty analysis. In RAI 21.6-61, the staff requested that GEH address issues related to cold water mixing in the lower. **RAI 21.6-61 is being tracked as an open item.**

5.0. Transient 3D Neutronics Modeling

The important neutronics parameters for ESBWR AOOs are void coefficient reactivity feedback, Doppler reactivity feedback, scram reactivity, and 3-D kinetics. The void coefficient determines the power spike given a void collapse due to pressurization event or cold water event. The scram reactivity and Doppler reactivity feedback terminates the power spike given a void collapse. The 3D kinetics determines the transient power distribution for the ESBWR fuel assemblies. For example, if the power is peaked toward the top of the core, then the void collapse which moves from the top of the core down may result in a higher power spike than if the power is peaked toward the bottom of the core.

The void coefficient is implied in how the TRACG neutronics parameters [[_____ ____ ____ _____________________]] The dominant neutronics parameter for changes in void coefficient is the infinite multiplication factor. The uncertainty and biases for the infinite multiplication factor which is a function of [[________________ ____ ____ _______]] (Since GEH is using TGBLA06 for ESBWR AOO analyses, these comparisons need to be updated with TGBLA06. This information was requested in RAI 21.6-84. This void coefficient uncertainty discussion will be revisited when GEH submits this information. **RAI 21.6-84 is being tracked as an open item.)** The [[____ ____ _____]]. The [[___]] different lattices according to GEH include enough variability and design differences such that ESBWR fuel is well represented by this uncertainty estimate (see Ref. 13).

The [[______]] different void fractions [[_____________]] are all in-channel void fractions with the [[_______________________________________]] The neutronics parameters used by TRACG are parameterized in terms of a homogenized moderator density within the 3D neutronics node. TRACG calculates different void fractions [[__________________________________ ____ ____]] In Ref. 12, GEH investigated TGBLA and MCNP calculations with [[________________ ____ __________________]] to determine if the extrapolated uncertainty from the fits at [[________]] is conservative at higher void fractions and at interpolated void fractions. GEH found that the uncertainty fits based on [[_________]] are conservative at these higher and interpolated void fraction conditions.

Ref. 13 also attempts to address the uncertainty associated with using MCNP as the basis for determining the nuclear parameter uncertainty as compared to TGBLA, the GEH lattice physics code used to generate the neutronics parameter fits used by TRACG. The Monte Carlo method used by MCNP has an uncertainty associated with the number of histories used to calculate the infinite multiplication factor for a given fuel design and for a given set of isotopic concentrations (i.e. given burnup or exposure). GEH indicates that for 2 million histories this uncertainty is typically [[______________________________

__________________________________]] The other major uncertainty to this process is the uncertainty associated with the isotopic concentrations for a given exposure and history weighted moderator density. In Ref. 13, GEH indicates this uncertainty is [[____

__________________________]] It is not obvious that this bounds the uncertainty associated with isotopic concentrations. For example, at BOC the fresh fuel assemblies loaded into the reactor with have some uncertainty in U^{235} and burnable poison concentrations due to manufacturing tolerances. The burned fuel loaded into the equilibrium core will have some uncertainty associated with the burn/exposure calculations required to define the equilibrium core. It is not obvious how this uncertainty at BOC will be bounded by performing calculations at MOC and EOC. A range of exposures will be analyzed, but that range continues to have a set of uncertainties that do not appear to be explicitly included into the TRACG uncertainty analysis. In addition, all uncertainties are included into [[____

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___________]] Since the weighted moderator density includes uncertainty associated with the GEH void fraction correlation, there will be some uncertainty associated with these nuclear parameters, even if these parameters are not a function of exposure or isotopic concentrations. The NRC staff and its contractors (BNL) are performing independent sensitivity studies using MCNP and MONTEBURNS to evaluate GEH's methodology for calculating void coefficient uncertainty and the isotopic concentration uncertainty. This is an open item and will be resolved with Section 4.3 of the NRC staff's safety evaluation report on the ESBWR design certification. **This is an open item.**

The Doppler coefficient is incorporated via the following equation for the infinite multiplication factor[9]:

The Doppler coefficient is a function of exposure and moderator density and has an uncertainty of [[___]] (See Ref. 1). The Doppler coefficient simulates the resonance absorption in uranium and plutonium and the broadening of the resonance absorption as the fuel temperature increases. Therefore, in the equation given above, C_T is negative. It is not obvious if the Doppler coefficient is a function of fuel type or not. . RAI 21.6-60 requests GEH to justify the [[_______]] ranking of the Doppler coefficient. **RAI 21.6-60 is being tracked as an open item**

For operating reactors the GEH plant following program gives them operating data that can be used to tune and improve their models to ensure that their cross-section generation methodologies and core simulator models continue to capture accurately the plant measured power distributions and critical control rod patterns. It is not clear if any 10x10 fuel or any partial length fuel has been included into the GEH plant following program. This will be addressed in Section 4.3 of the NRC's Safety Evaluation Report on the ESBWR design certification.

The scram reactivity is simulated in TRACG by the change in neutronics parameters from uncontrolled to controlled as the control rods move into the core. The timing of the control rod movement is determined by user input and by trips relative to specified control points in the TRACG model (i.e. TCV closing, MSIV closing, etc.). The worth associated with the control movement is determined by how the neutronics parameters change from uncontrolled to controlled (i.e. control rod is present or not present in the core bypass next to the fuel assemblies simulated).

There are a number of operating plant transients that have been successfully analyzed by TRACG that indicate that TRACG neutronics models can simulate void collapse and cold water AOO transients. These include[11]:

1) Peach Bottom Turbine Trip Test – provides plant data assessment for void collapse due to an over-pressurization event and the resulting power increase.
2) Hatch MSIV Closure Test – provides plant data assessment for level and pressure response to a steam line valve closure.
3) Nine Mile Point Pump Upshift Test – provides assessment of power response to an increase in core flow.
4) Leibstadt Loss of Feedwater with HPCS Unavailable Test – provides assessment of level and pressure response to a loss of coolant inventory.

These operating BWR events are not expected to be same as AOOs in an ESBWR. However, similar phenomena must be modeled accurately to simulate these AOOs in operating plants as well as in ESBWR (i.e. power response to void collapse, pressure response to TCV closure or MSIV closure, etc.).

6.0. Conclusions

The application of TRACG to ESBWR AOOs has been reviewed. Areas of concern were identified and RAIs were prepared. Available GEH responses to RAIs have been incorporated into this review. Unresolved RAIs are documented as open items. TRACG has all of the models required to simulate ESBWR AOOs and uncertainties in the dominate models has been characterized. The dominant phenomena uncertainties in TRACG have also been characterized. These conclusions will be re-evaluated upon closure of all open items

7.0. References

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3. "ESBWR Design Description," NEDC-33084P, Class III, DRF 0000-0007-3896, August 2002.
4. Letter from D.H. Hinds (GE) to NRC, "General Electric Company – ESBWR Standard Plant Design Revision 2 to Design Control Document Tier 2, Chapters 2 through 5, 7 through 15, 17, and 18," October 31, 2006.
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8. J. R. Fitch, et. al., "TRACG Qualification for SBWR," NEDC-32725P, Class III, DRF 0000-0006-8900, August 2002.
9. J.G.M. Andersen, et.al., "TRACG Model Description," NEDE-32176P, Revision 3, Class 3, April 2006.
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12. Letter , G. Stramback (GE) to Document Control Desk (NRC), "Response to DSS-CD TRACG LTR RAIs," MFN 05-133, November 11, 2005.
13. Letter, David Hinds(GE) to Document Control Desk (NRC), "GE Response to NRC Request for Additional Information Letter No. 3 Related to NEDE-33083P, Supplement 1, TRACG Application for ESBWR Stability Analysis," MFN 05-146, December 1, 2005.
14. U.S. NRC, Standard Review Plan, NUREG 0800.

15. Letter, David Hinds (GE) to Document Control Desk (NRC), “Response to Portion of NRC Request for Additional Information Letter No. 66 Related to ESBWR Design Certification Application – TRACG Application for Pressurization Events – RAI Numbers 21.6-56, 21.6-58, and 21.6-59,” MFN 06-506, December 8, 2006.

Appendix A: Open Items

1. GE needs to provide additional information on the IC modeling used in TRACG and any noding or modeling differences between the plant model demonstration calculation and the assessment calculations for IC modeling.

2. GE needs to provide additional information on their scram insertion times assumed in the AOO analyses performed using TRACG. This is requested in RAI 21.6-57 (RAI Letter 66).

3. GE needs to provide additional information on their selection and ranking of phenomena to be included in the uncertainty analysis. This is requested in RAIs 21.6-60 and 21.6-64 (RAI Letter 66).

4. GE needs to submit the updated qualification report for TRACG. This is requested in RAI 21.6-75 (RAI Letter 66).

5. The data base for the GEXL correlation does not include data for the 10 ft GE14 fuel assembly. This will be addressed by the NRC staff in Section 4.4.XX of the ESBWR design certification safety evaluation report.

6. GE needs to address issues related to cold water mixing in the lower plenum. This is requested in RAI 21.6-61 (RAI Letter 66).

7. GE needs to update the comparisons between TGBLA and MCNP used to determine the void coefficient uncertainty to use TGBLA06, the version of the code used for ESBWR AOO licensing calculations. This is requested in RAI 21.6-84 (RAI Letter 66).

8. The NRC staff and its contractors (BNL) are performing sensitivity studies using MCNP and MONTEBURNS to evaluate GE's void coefficient uncertainty methodology and the uncertainty in their isotopic concentrations. This will be resolved in Section 4.3.XX of the NRC staff's safety evaluation on the ESBWR design certification.

9. GE needs to justify the ranking of the Doppler coefficient. This is requested in RAI 21.6.60 (RAI letter 66).

Appendix B: List of TRACG Applied to ESBWR AOOs RAIs.

21.6-55 Provide additional information regarding the modeling of the isolation condenser using the TRACG code.

a) Explain in detail how the Isolation Condenser is modeled. Provide a nodalization diagram illustrating which components are used. How is this different from the isolation condenser model used in the PANTHERS test in Section 4.2 of NEDC-32725P "TRACG Qualification for SBWR"?

b) Provide a discussion of how noncondensible gas generated by radiolytic water decomposition is treated during an event that requires the isolation condenser system (ICS). Is radiolytic noncondensible gas modeled using TRACG? If so, explain what uncertainties are included in the timing of the transport of the radiolytic noncondensible gas to the ICS. Comparison of TRACG calculations to PANTHERS data shows significant differences in the transport timing. If this is not included in the TRACG model, explain how the treatment in the TRACG modeling is conservative.

21.6.56 GEXL is a quasi-steady-state boiling length correlation, which is used in TRACG to predict the critical power ratio (CPR). Provide the basis for using a boiling length quasi-steady-state correlation for rapid pressurization transients, such as LRNB.

21.6.57 Provide additional information about the load rejection with no bypass (LRNB) event.

a) Table 4.7-1 states that the Turbine valve closure scram is initiated at 0.08 seconds into the transient. What percentage of full open are the valves when you initiate a reactor scram? What is the delay time associated with the signal? Provide justification supporting the selection of your turbine control valve closure times and signal delay times.

b) What is the amount of time from when the scram signal is initiated to when the rods actually begin to insert for the transient analyses? Justify this value.

c) Provide a version of DCD Tier 2 Figure 15.3-5e magnifying the area between 0-2 seconds.

21.6-58 A two-fluid finite difference donor cell model with a relatively coarse noding such as that implemented in the TRACG methodology tends to smear out or diffuse pressure waves. Explain how this numerical diffusion of the pressure wave has been quantified and factored into the TRACG uncertainty analysis for the rapid pressurization events.

21.6-59 Provide additional information to the staff demonstrating that TRACG is capable of calculating the propagation of a pressure wave through a two-phase mixture. Identify the assessment calculations in which this is demonstrated.

21.6.60 Provide additional information supporting why the Doppler coefficient was not included as High ranked phenomena in the PIRT for ESBWR transients.

21.6.61 Mixing in the lower plenum is not listed in the PIRT for ESBWR transients as high ranked importance phenomena for cold water transients. Provide supplemental discussion to that provided in NEDC-33079P, Supplement 1, Revision 1 justifying your ranking for this phenomena during cold water transients. Provide information such as noding studies that may have been performed with TRACG to investigate mixing for cold water transients. Discuss the radial difference in subcooling across the core for a feedwater controller failure (FWCF) event.

21.6.62 2 Regarding the CPR calculation of the FWCF event, provide the following additional information:

a) On page 4-47, you state "The CPR [change in critical power ratio] for this transient is [[ ]], higher than that for the LRNB event, because the transient initiates from a higher initial power." You state in both sections 4.7.1.1 and 4.7.1.2 on pages 4-46 and 4-47, respectively, that both transients are modeled at 100% power. Provide additional information explaining the statement that the "transient initiates from a higher initial power."

b) The power excursion for the FWCF event is much less severe than the LRNB event, yet the change in CPR is higher for the FWCF event. Provide an explanation for this behavior.

c) Explain why Figure 15.3-2g of the DCD Tier 2 does not show the same CPR for this transient. What is difference between the FWCF analysis in NEDE-33083P (MFN 04-109) and that in the DCD Tier 2 that would cause the CPR to change?

21.6-63 Provide a description of all of the differences in the analyses performed in Chapter 4 of NEDE-33083P (MFN 05-017 and MFN 04-109) and Chapter 15 of ESBWR DCD Tier 2, Revision 1.

21.6.64 In the topical reports NEDC-33083P Supplement 1 (Methodology to calculate stability margins for ESBWR using TRACG) and NEDE-32906P-A Rev. 2 (methodology to perform transient analysis for BWR/2-6 using TRACG) both high and medium importance PIRT parameters were included in the uncertainty analysis. However, for the TRACG application for ESBWR AOOs, it appears that only high importance PIRT parameters are to be included in the uncertainty analysis with the exception of a few medium ranked parameters.

a) Provide a basis explaining the exclusion of the medium ranked parameters from the uncertainty analysis.

b) Why were some medium importance parameters included in the ESBWR transient uncertainty analysis and other PIRT parameters of medium importance not included? Explain your method for selecting the parameters that you include in the uncertainty analysis.

c) On page 4-21 in Section 4.4 of NEDC-33083P-A you state "For some phenomena that have little impact on the calculated results, it is appropriate to simply use a nominal value or to conservatively estimate the bias and uncertainty." Do you use a nominal value for the medium ranked phenomena? If so, explain why bounding values were not used. Provide a discussion of how medium ranked phenomena are treated in terms of model uncertainty and bias.