Request for Additional Information (RAI)
TRACG Qualification and Application for ESBWR
ESBWR Pre-Application Review
General Electric Company

RAIs ON: (1) NEDE-32176P, Rev. 2, “TRACG Model Description,” (2) NEDE-32177P, “TRACG Qualification,” (3) NEDC-33080P, “TRACG Qualification for ESBWR,” and (4) NEDC-33083, “TRACG Application for ESBWR.”

GENERAL QUESTIONS:

26. 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.

27. 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?

28. The passive containment cooling system (PCCS) performance depends on the pressure difference between drywell (DW) and wetwell (WW) and not having any other path than the PCCS (the only path between them being through the PCCS). A GDCSLB with a single failure of the check valve can potentially create bypass between DW and WW, and compromise the PCCS performance. Please explain why this is not considered or why this is not possible.

29. What are possible single failure criteria? Should the failure of vacuum breaker (VB) be considered as a single failure? If not, please explain why not.

30. Section 3.6, NEDE-33083P, states that a bounding calculation was performed with conservative values of all parameters and initial conditions. Were there any studies performed that the combination of the worst values would generate the conservative results?

31. 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)?

32. 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.

33. Please provide a roadmap for separate effects testing used for TRACG qualification for containment analysis.

RAIs for NEDE 32176-P, Rev 2, "TRACG Model Description":

Chapter 3 (Thermal-hydraulic Model)

34. What are "k" and "B" in Eq. 3.2-8 and how are they specified?

35. Section 3.3 - When values of solution from the balance equations are restricted by critical flow or counter current flow limit (CCFL), is the time step repeated with smaller time, or are flows adjusted and calculation proceeds?

Chapter 4 (Heat Conduction Model)

36. Equation 4.1-5 - The heat transfer coefficients for different phases are multiplied by the same surface area. During the boiling regime, the surface will either have liquid or vapor in contact but not both. Please explain why this has been done or correct the equations. Same question for Eq. 4.2-1.

37. Is there guidance on when to use the implicit or explicit option for conduction calculation?

Chapter 5 (Flow Regime Map)

38. Equation 5.1-4 is used for developing criterion for transition from bubbly to annular flows. The equation implies that volume flux is much larger than 1 m/s. What happens during low flow conditions?

39. Equation 5.1-20 - How is E_1 defined?

40. Based on Fig 5.1-3, Ishii's original model is as good as the modified one. Why is there a need to modify it?

Chapter 6 (Models and Correlations)

41. Table 6.0-1 addresses the question of applicability of TRACG for a vessel. However, TRACG is also used for containment modeling. Is there a similar table for containment?

42. Why doesn't Table 6.0-1 include a steam separator?

43. Interpretation of terms for Eq. 6.1-5, provides a definition for α. The same symbol is used for more than one purpose. What is the basis that these symbols are identical?

44. Please provide a comparison between Eq. 3.1-30 and 6.1-2. Why do the gravity terms have different signs?

45. Equations 6.1-6 and 6.1-7 - Why are steady inertia terms neglected?

46. Equation6.1-10 - The ‘g’ term (gravity) is missing.

47. Equation 6.1-21- What type of averaging is implied on both sides of the equation?

48. Critical Weber number is for the upper limit on the droplet size distribution. Is the GE recommended value conservative for LOCA application?

49. Below Eq. 6.1-63, there is reference to Eq. 5.1-25. Where is this equation?

50. What is the basis of Eq. 6.1-63?

51. Section 6.2.2.3 - What void fraction is used to apportion the wall friction between the phases? Is it upstream cell or an average between the cells?

52. Section 6.4 - Is a numerically explicit approach used for implementing the level tracking model?

53. Section 6.5.3 - Are the interfacial area densities implied in interfacial momentum transfer (6.1.3) and used in mass transfer the same?

54. Section 6.5.3.2 - Bubble number density has a minimum (lower) limit of 10^7. Bubble size also has an upper and a lower limit. What is the basis of these limits? Are these limits (large bubble size and void fraction for bubbly flow) mutually consistent for bubbly flow? Similar limits were found for droplet flows in Section 6.5.5.

55. Section 6.5.4.1 (annular flow regime) - How is the noncondensible gas concentration estimated at the interface? The saturation temperature will depend on this concentration.

56. Section 6.5.4.1 (annular flow regime) - Why is the heat transfer coefficient modified on the liquid side?

57. Please check Eq. 6.5-29. When pipe is half full and α=0.5, does this expression reduce to the correct limit?

58. Section 6.6 describes the heat transfer coefficient at the wall. In section 3.1, Eqs. 3.1-19 and 3.1-20 indicate that the heat transfer coefficient accounts for the fraction of the wall in contact with one or the other phase. However, heat transfer coefficients in Section 6.6 do not indicate this. Please explain.

59. Section 6.6.10.3 - The applicability of the Tien-Gonzalez correlation was based on CORECOOL code. Was there any assessment done with TRACG?

60. Section 6.6.6 - Four critical heat flux criteria are described. What options are used and where in ESBWR? What correlation is used for flow reversal or very low flows in the channel (Modified Zuber is excluded from the channel components)?

61. Equation 6.6-64 - What is “Rem” and where is it defined?

62. Equation6.6-65 - How is “ρ_m” defined?

63. Equation 6.6-68 - What effect does “$f_{1,other}$” cover ?

64. Section 6.6.11 - Lighter than steam (helium) or heavier than steam (air) have different flow near the interface and may affect the film thickness differently. Where is this effect considered?

65. Section 6.6.11 - What condensation model is used in containment? How much is the uncertainty in the correlation? How does condensation affect the early pressure peak during steam line break LOCA?

<u>Chapter 7 (Component Models)</u>

66. Section 7.7 - The high void core region in the steam separator is assumed to have solid body rotation and the liquid film will also have swirl with tangential velocity decreasing towards the wall (no slip). Please explain the basis of liquid film tangential velocity described in Eq. 7.7-2.

67. Figures 7.7-6 and 7.7-7 show upper and lower bands for carry under. There are expressions for upper limit for carryunder. Are there similar expressions for lower limit?

68. Section 7.5.2 (p. 7.5-10 to 7.5-18) - Are there specific references for the development of the various correlations and the associated parameters, such as Eqs. 7.5-9, 7.5-13, 7.5-15, 7.5-16?

69. Section 7.5.2.2 (p. 7.5-12) - What is the physical significance of the effective hot radial thermal gap R_{eff} ?

70. Section 7.5.2.2 (p. 7.5-13) - What criteria are used to determine the gases to be considered in the calculation of the gas conductivity?

71. Section 7.5.2.2 (p. 7.5-13) - What is the basis for the gases assumed in the gap of a perforated clad?

72. Section 7.5.2.2 (p. 7.5-13) - Do the constants in Eq. 7.5-14 depend on the relative mix of steam and hydrogen?

73. Section 7.5.2.3 (p. 7.5-15) - The section on fuel pellet gap conductance has defined several “gaps.” Which ‘hot gap size’ does the model refer to in relation to the calculation of the contact pressure P_c?

74. Section 7.5.2.4 (p. 7.5-16) - What is the basis for the constant in Eq. 7.5-24?

75. Section 7.5.2.5 (p. 7.5-16) - Does R_{ref} vary with time and how?

76. Section 7.5.2.5 (p. 7.5-16) - How does the thermal expansion coefficient of the fuel take into consideration the effects of burnup, such as densification and relocation?

77. Section 7.5.2.6.1 (p. 7.5-17) - How are the inputs F_r and F_{kx} determined?

78. Section 7.5.2.6.2 (p. 7.5-18) - Does Eq. 7.5-30 still apply if P_{ci} is less than zero?

79. Section 7.5.2.7 (p. 7.5-18) - Is there any documented comparison between the gap conductance calculated by TRACG and other referenced GE models and codes?

80. Section 7.5.3.2 (p. 7.5-19) - Does the cladding perforation model apply only to the core location of maximum linear heat generation rate (LHGR)?

81. Section 7.5.3.1 (p. 7.5-19) - Why does subscript ‘f’ refers to two different variables in Eqs. 7.5-33 and 7.5-34?

82. Section 7.5.3.1 (p. 7.5-20) - How is Eq. 7.5-35 developed?

83. Section 7.5.3.1 (p. 7.5-20) - How is the factor determined for Eq. 7.5-36?

84. Section 7.5.3.2 (p. 7.5-20) - What are the subscripts ‘g’, ‘l’ and ‘v’, ‘w’, and ‘pl’ in Eqs. 7.5-37 to 7.5-39?

85. Section 7.5.3.2 (p. 7.5-20) - Is the gas temperature in the fuel the same as the plenum gas temperature?

86. Section 7.5.3.3 (p. 7.5-21) - Besides the gas conductivity, does the state of a perforated clad affect the gap conductance in other ways?

87. Sections 7.5.2 and 7.5.3 - Is it possible to summarize parameters that are axially dependent and those that are not?

88. Section 7.9 - Is a heat exchanger component used for ICS and PCCS modeling?

RAIs NEDC-32177P, "Licensing Topical Report, TRACG Qualification":

Chapter 3

89. Section 3.1.1.1 (p. 3-4) - The 8x8 rod bundle simulated a top-peaked power distribution. Was the power to the rods uniform? Are the heat fluxes noted in Table 3.1-2 axially averaged values for all 64 rods?

90. Section 3.1.1.2 (p. 3-6) - What is the uncertainty in using a single channel TRACG model to simulate a rod bundle test? Was the sub-channel effect negligible in the FRIGG test?

91. Section 3.1.1.5 (p. 3-10) - The sensitivity study investigated the effect of axial nodalization. How are sub-channel effects and the sensitivity to multiple parallel channels addressed?

92. Section 3.1.3 (p. 3-14 to 3-17) - In the Bartolomei tests void fraction was measured at different elevations. How is the void fraction shown in Figure 3.1-13 derived from the test data? A hot water coil provided heating to the test section and there should be an axial variation in the vapor volumetric flux in the heated section. Are the void fraction data shown in Figure 3.1-13 taken in the unheated section above the hot water coil?

93. Section 3.1.4 (p. 3-18) - The inlet quality for the chimney section was determined by mass and energy balance. Did the energy balance take into consideration that a fraction of the fission energy was not deposited in the core?

94. Section 3.1.5.3 (p. 3-26) - In Figure 3.1-22, the maximum level deviation is not within the measurement uncertainty as the report stated. Please explain.

95. Section 3.1.5.3 (p. 3-27) - In Figure 3.1-23, would the use of measured break flow (Fig. 3.4-12) as a boundary condition result in better agreement with pressure data?

96. Section 3.2.1 (p.3-36) - Is there any reason the negative temperature deviation is so much higher in Figure 3.2-3 than the other 3 comparisons?

97. Section 3.2.2.4 (p. 3-40) - In Figure 3.2-9, how does the rod number correspond to the position of the rods in the 8x8 bundle?

98. Section 3.3.2 (p. 3-43) - In Figure 3.3-2, the legends for the data points are missing.

99. Section 3.4.1.2 (p. 3-48) - The axial temperature profiles are shown in Figure 3.4-5 and not in Section 3.4-5.

100. Section 3.4.1.2 (p. 3-48) - What was the uncertainty of the pressure measurement?

101. Section 3.4.1.5 (p. 3-48) - Why did TRACG predict much higher break flow rate than the data for the initial 5 seconds for both Tests 15 and 24?

102. Section 3.4.1.5 (p. 3-56) - In Figure 3.4-8, what is the cause of the 20 second delay in the TRACG prediction of the transition to pure steam flow?

103. Section 3.4.2 (p. 3-59) - What is the cause of the flow spikes predicted by TRACG in Figures 3.4-11 through 3.4-13?

104. Section 3.5 (p. 3-64) - Where is the documentation for the TRACG qualification of the pressure drop for the core bypass flow paths?

105. Section 3.5.1 (p. 3-65) - How do the thermal-hydraulic characteristics of the ATLAS test bundle simulating GE9 fuel compare with the ESBWR fuel assembly?

106. Section 3.6.1.2 (p. 3-70) - For the TRACG qualification calculations, the first rod in the ATLAS test bundle to undergo burnout was known a priori from the test result. For the LOCA analysis of an ESBWR how will the first rod to burnout be identified? How is the flow distribution to the ‘hot rod’ channel and the other lumped channels determined?

107. Section 3.6.3 (p.3-72) - Are there any TRACG qualifications for burnout prediction under low pressure, low flow, and near saturation conditions that are expected in a LOCA for the ESBWR?

108. Section 5.1.1 (p. 5-1) - The boiloff test was conducted at a pressure of 2.76 MPa. Has there been assessment of low pressure boiloff that would be more representative of ESBWR post-LOCA conditions?

109. Section 5.1.1.3 (p. 5-4) - How is the uncertainty in the measured nodal void fraction related to the smoothing of the data?

110. Section 5.1.1.3 (p. 5-4) - Figures 5.1-3 to 5.1-6 showed the comparison between measured and calculated void fraction. How are the weighted average void fractions derived from the calculated nodal void fractions?

111. Section 5.1.1.4 (p. 5-4) - What is the sensitivity of the calculated results to TRACG nodalization?

112. Section 5.1.3.3 (p. 5-37) - Was TRACG able to calculate the lower plenum bulk flashing at about 16 sec. after the uncovery of the recirculation line suction inlet?

RAIs NEDC-33080P, “TRACG Qualification for ESBWR”:

Chapter 2. PANDA Transient Tests P1

113. The document reviewed does not include the information regarding the physical dimensions of the PANDA test facility. Please provide a reference that contains the relevant dimensions of the various components (vessels, tanks, heat exchangers, pressure differential to open vacuum breaker, etc.) of the facility. Please also provide the scaling ratios (vs. ESBWR) of the individual components (or any deviations from 1/45 ratio).

114. One of the main purposes of the PANDA tests was to support the use of TRACG to model the post-LOCA behavior of ESBWR containment. However, the nodalization of the PANDA test facility (Figure 2-3 of NEDC-33080P) is substantially different from that of ESBWR (presented in Figure 2-2 of NEDC-33080P and Figure 2.7-1 of NEDC-33083P, TRACG Application for ESBWR). For example, azimuthal nodalization of the VESSEL component was utilized to represents various components in PANDA, while radial nodalization was utilized to model them in ESBWR.

    1. Was there any attempt to use similar nodalizations between the ESBWR and PANDA simulations? If not, please explain why these differences should not be an issue in using the PANDA analytical results to validate the TRAC simulation of the ESBWR analysis, considering that nodalization is an important element of the validation.

    2. In view of the importance of the noncondensible gas distribution in DW and its potential impact on the PCCS performance, the nodalization of the DW is of considerable interest. Both in PANDA and ESBWR, the DW is modeled with four axial nodes. However, the DW in PANDA is represented by two radial rings and also includes two small axial nodes (to represent the connecting pipes) in the middle, while the DW in ESBWR is represented by four radial rings with relatively evenly distributed four axial nodes. It seems that these are quite dissimilar nodalizations. Please discuss the possible impact of this nodalization difference in using the PANDA analyses for the validation of TRACG code. Does this imply that the DW nodalization would not be a significant factor?

    3. The heat transfer in the poolside film may be a significant factor to determine the PCCS capability to remove heat. Please discuss the nodalization of the PCCS pool (it is not clear from the document) and its impact on the heat transfer in the outside surface of the PCCS pipes. The discussion should include the number of radial cells used and the effect of nodalization on the internal natural circulation and heat transfer in the pool (vs. using one cell radially). Were there any measurements which will help to determine the pool side heat transfer coefficients? List any tests or studies to validate this model/nodalization. Were there any sensitivity calculations regarding the pool side nodalization? Was the variation between parallel tubes accounted for? Was the changing level

elevation accounted for in calculating the heat transfer coefficients (or effective heat transfer area)? Is the same nodalization used for ESBWR?

115. The post-test results are presented in Section 2.5. Were there any attempts to do the pre-test or blind calculations? If not, why not? If there were, were any significant differences between the pre- and post-test results observed? Were any parameters adjusted during the post-test analyses? If yes, what were they? Were the same adjustment made to the ESBWR analyses?

116. The time step sizes sometimes influence the results of the calculations. Are the time step sizes of the PANDA analysis similar to those of ESBWR analysis (maximum as well as average)? What was the basis of the time step selections?

117. In almost every test (except P3), the drop in the DW pressure and decrease of the DW-WW pressure difference (sometimes negative) were observed in the initial phase of the tests. After this initial period, the Δp remained steady for most of the tests (except P2, where a repetition of this pressure drop was observed). Please clarify the discussion in Section 2.5.1.1 regarding the effect of the amount of PCCS heat removal.

    1. Should this phenomenon repeat periodically, since the excess heat removal capability still exists?

    2. If the high heat removal capacity reduces the Δp, shouldn't the PCCS heat removal and Δp balance eventually at some equilibrium? (It should be noted that the PCCS inlet flow rates in Figure P1/8-3 and the PCCS heat removal in Figure P1/8-2 did not decrease markedly during this period when the Δp decreases.)

    3. The DW pressure drops happened at considerably different times for the test and the analysis for some tests, (about 12000 and 8000 sec for P1, 7000 and 13000 seconds for P2, 22000 and 12000 sec for P6). It happens earlier for test than analysis for some tests, and later for some other tests. Please discuss how this discrepancy and inconsistency will affect the ESBWR DW calculation.

    4. Were similar drops in the DW pressure and Δp also observed in this period in the ESBWR analysis?

118. For tests P1 and P2, substantial Δp between the DW and WW (P1-1a and P2-1a) and flow to PCCS (P1-3 and P2-3) are maintained throughout the tests. This should imply either noncondensible gases or steam is flowing to WW and, therefore, the WW pressure should increase. However, the WW pressure remains constant (P2-1) or declines (P1-1). Please discuss if this observation is correct, and, if correct, please explain why. (Does this mean that there is no Δp between the PCCS and WW, and thus no flow?)

119. In general, the code does not seem to predict Δp (between DW and WW) very well for the PANDA tests, although it shows good matches for the magnitudes of the pressure and overall heat removal. In view that the Δp is the important variable in determining the performance of PCCS, please discuss how the PANDA results can be used for the validation of TRACG.

120. Editorial comments:

    1. Definitions of the TRACG variables in the figures are not provided. While some of variables are obvious, some are difficult to figure out. Some examples are D1L12C1-TR in Figure P1/8-15, or D2L12C2-TR in Figure P1/8-16, etc.

    2. It appears there is an error in Table 2-11 (Page 2-43). The elevation of instrument MTG.D1.2 is denoted as 38 m from tank bottom.

Test P1/8

121. In Figure P1/8-1a, when the VB opens, the Δp quickly increased (restored) to the level before the VB opening.

    1. Please explain why the DW pressure increases above the WW pressure. Is this due to a temporary decrease in the PCCS heat removal capability caused by the noncondensible gases in the DW?

    2. Why does the PCCS performance deteriorate so much when the noncondensible gas concentration increases very little (Figure P1/8-21 shows the concentration in DW is less than 0.3%, i.e., noncondensible gas partial pressure of 0.005 bar) after the VB opening. Is this an indication of impact of a very small amount of noncondensible gases on the PCCS performance?

    3. When the vacuum breaker (VB) opened at 12,000 seconds in P1, the noncondensible gas concentration in DW increased slightly (to 0.005 bar) (Figure P1/8-21). However, when the VB opened in P2 (Figures P2-21 and -22), it increased to 0.3 bar. Please explain why the DW noncondensible gas concentration increases are so different between these two tests.

122. Figure P1/8-2 shows a sustained deficit of the heat removal by the PCCS. Yet, the DW/WW pressures essentially remain constant during the whole test. Please explain why the cumulative effect of this heat removal deficit is not exhibited in the pressure? Wouldn’t this eventually be an issue when it continues for 72 hours (259,200 seconds)?

123. Figure P1/8-1a shows Δp is zero around 35,000 sec for the analysis, but Figure P1/8-3 shows a sustained PCCS inlet flow. Please explain what is the driving force for this flow at this time. If this is condensation driven, is this an indication that PCCS does not need Δp (DW-WW) to operate, at least when the noncondensible gas concentration is low?

124. For Test P1/8, it appears that the code does not predict the Δp very well in the period of 0-50,000 seconds (the Δp decreased to zero periodically for the analysis, while a sustained Δp was observed in the test after initial dip). In view that the Δp is the driving force of the PCCS (it also impacts on the VB opening, which influence the noncondensible gas concentration in the DW), please discuss how the results of simulation of this test can be used to validate the code.

125. Figure P1/8-5 shows that the PCCS pool level decreases to the lower header upper edge in 100,000 seconds. Is this representative of the ESBWR PCCS pool level in this time period? In view that the ESBWR containment cooling is expected to last 72 hours (259,200 seconds), please discuss why this depletion of pool water is acceptable.

126. The test and calculated gas and liquid temperatures in the WW are substantially different (Figures P1/8-17 through P1/8-20). While the calculated temperatures are constant, the test temperatures are shown to initially increase and then decrease (at around 20,000 seconds for liquid and around 40,000 seconds for the gas).

    1. Please explain this difference between the tests and analyses, discussing why this test can be used for the TRACG validation for ESBWR in spite of this difference.

    2. Please explain why the test WW liquid and gas temperatures start decreasing at about 25,000 seconds and 40,000 seconds, respectively, in the test when seemingly nothing else happens.

    3. Please also explain why the WW gas temperature continues to increase between 20,000-40,000 seconds, while the pool surface temperature starts to decrease at about 25,000 seconds.

    4. Beyond 40,000 seconds, both the WW gas and liquid temperatures continue to decrease in the test. Where does the energy go during this period (i.e., what cools the WW gas and liquid)?

Test P2

127. The purpose of this test is “to examine PCCS behavior and system interactions during the transitional period from the end of blowdown to the initiation of long-term cooling” (Section 2.3.1). However, “the comparison was adversely affected by the leaky check valve,” (Section 2.5.2.1) and consequently it appears difficult to derive any conclusions for the period when it was intended to be studied. Please explain why this test is still relevant.

128. In Section 2.5.2.1, measured and calculated DW and WW pressures and the DW-to-WW pressure difference for test P2 are compared in Figures P2-1 and 1a. It is explained that the cause for discrepancies was due to equipment malfunction and that

is was not important as calculated pressures were in line with the measurement. However, Figure P2-1a clearly shows a substantially different trend.

1. Please explain this discrepancy between the test and analysis and justify why TRACG is applicable to ESBWR LOCA calculation despite this discrepancy, in view that the Δp is the driving force of the PCCS and also affects the GDCS flow rate.

2. Why does the test Δp rise initially in the test? Since there is no steam generation during this period, it seems the Δp should be near zero.

129. Figure P2-1 shows a pressure difference between the DW pressures of the test and calculation in the initial phase (GDCS injection phase), which is substantial at this phase. Therefore, it seems that the code does not simulate this phase very well. Please explain the cause of this difference and discuss the significance of this difference in the TRACG validation.

130. Figure P2-3 shows the PCCS inlet flow and Δp between DW and WW (figure P2-1a) for the calculation. Please explain what is the driving force of this PCCS flow during the period from 5,000 to 13,000 seconds and from 15,000 to 20,000 seconds. Figure P2-3 also shows that the PCCS heat removal rates are similar for the test and calculation, while the Δp's are substantially different between the test and calculation (for example, during 15,000-20,000 seconds). Please explain why the PCCS performance is not affected by the Δp.

131. Figure P2-4 shows the calculated level difference between RPV and GDCS at a specified WW-DW pressure difference (Figure P2-1a) and corresponding water level. Since the WW pressure is lower than DW, shouldn't the GDCS tank level be higher than the RPV by at least the same amount? Please explain.

132. Figures P2-18 and p2-20 show the WW water surface temperature peaked at about 7,000 seconds and then decreased. Please explain what mechanism contributed to this cooling. On the other hand, the same figures show that the calculated liquid temperature increases steadily. Please discuss what impact this discrepancy would have in using the TRACG for ESBWR analyses.

133. Figures P2-21 and P2-22 show steady increases of the noncondensible gas in the DW for the calculation while the noncondensible gas concentration rises quickly and remains at that level for the test. Since the period in which the VB is open is much shorter for the test, it appears that the noncondensible gas flow rate is much higher during the short period when the VB was open for the test. Please compare the noncondensible gas flow rates when the VB are open for the test and calculation and explain the disparity of the flow rates, so the staff can assess how well the TRACG simulates the VB flow rates.

Test P3

134. It is stated in Section 2.5.3.1 that “TRACG’s calculation of the air purging rate from DW2 and portions of DW1 above the connecting pipe are in good agreement with the measurements (Figures P3-21 and 22).”

    1. However, Figure P3-22 shows very high degree of stratification of air partial pressure in DW2 for the calculation, while relatively uniform distribution for the test during the initial 10,000 seconds (the period when it matters most in terms of the noncondensible gases). Please discuss how GE drew the conclusion of “good agreement” from this figure.

    2. Figure P3-21 and Figure P3-15 show TRACG was unable to simulate the trapped noncondensible gas in DW2. Please explain how this TRACG shortcoming is handled in ESBWR analyses.

Tests P4 and P5

135. These tests are intended to investigate the effect on PCCS performance of the delayed release of noncondensible gas from a region of the DW not directly accessible to RPV steam flow. However, the results (test as well as analysis) show that the noncondensible gases are quickly swept to the WW once the injection stops similar to what happens earlier. Then the system repeats similar behavior observed at the beginning of the tests, at slightly higher pressure. In other words, these tests don’t seem to provide any more information than obtained in P1. To address the impact of slow seepage (bleeding) of a small amount of noncondensible gases through the PCCS and possible degradation of PCCS capability to remove heat in the presence of these gases, could a small amount of noncondensible gas (in the order of 1% or less) be continuously injected to the DW during the test? Are there any such test data available?

Test P6

136. Test P6 was performed to “consider system interaction effects associated with parallel operation of the ICS and PCCS and the effect of a direct bypass of steam from the DW to the WW air space.” Why are these effects combined in one test? Is the bypass of steam more important when the ICS and PCCS operate together? It seems these two unrelated effects make it harder to understand the results.

137. Why does the Δp decrease slower for P6 (Figure P6-1a) compared to P1 (Figure P1/8-1a), when less steam is sent to the DW in P6?

138. It appears that the Δp decreases to zero at about 20,000 seconds and again at about 40,000 sec (Figure P6-1a) for the test, because of the VB leakage bypassing steam from the DW to the WW. However, Figure P6-2 shows that the PCCS still removes most of the heat at these time periods. What is the driving force of the PCCS flow and why does the PCCS still work when DP=0?

139. What was the cause of the sudden blip of Δp for the calculation at about 42,000 seconds, when seemingly nothing else happens? The concern is whether this kind of anomaly may show up somewhere else in the TRACG calculations of ESBWR.

140. Figure P6-23 shows that TRACG substantially over-predicted the VB leakage flow rate during 15,000-25,000 seconds (the period when IC operation and VB opening overlapped), while it gave a good match after 25,000 seconds. Please discuss this inconsistency and its implication in TRACG application to ESBWR. The concern is when to trust the TRACG calculation of the VB leakage rate and when not to.

Section 2.6 Summary and Conclusions

141. In Section 2.6.2.2, it is stated that "PCC tube gas temperature comparisons indicate that, for given inlet conditions, TRACG requires a somewhat greater length of the condenser tubes to achieve complete condensation." However, this point was not discussed in any individual test. Please explain how this conclusion is derived from the tests.

142. In Section 2.6.2.3, it is stated that "a relatively large uncertainty in poolside heat transfer could be tolerated without adversely affecting the ability of TRACG to calculate the behavior of the PCCS in context of an overall systems model of the containment." Please discuss how this conclusion was determined, and provide specific data, if any, to support this conclusion.

143. In Section 2.6.2.8, it is stated that, "The modeling features described above have minimal impact on the calculation of system pressure and lead to a conservative prediction of WW gas temperature. The WW pressure is primarily set by the inventory of noncondensible gas with a minor contribution from the partial pressure of the steam in the gas space. The steam partial pressure is, in turn, set by the temperature at the surface of the SP [suppression pool]."

    1. Please explain why the modeling leads to a conservative prediction of WW gas temperature.

    2. In the long term, the containment pressure is determined by the partial pressure of the steam in the gas space in addition to the noncondensible gas mass in the WW gas space, which is determined by the liquid surface temperature, which is determined by how much of the uncondensed steam in the PCCS is deposited in the WW water. How well the PCCS performs eventually affects the WW liquid temperature and WW pressure. Please discuss why the partial pressure of the steam in the gas space is a minor contributor to the WW pressure. Please note that WW4 is ranked as high in the phenomena identification and ranking table (PIRT) for ESBWR Containment/LOCA.

RAIs for GE Report NEDC-33083P “TRACG Application for ESBWR”:

Chapter 2

144. 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?

145. 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?

146. 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?

147. Section 2.3.2 (p. 2-47) - Tables 2.3-2 through 2.3-5 did not show any test that assessed the PIRT high ranked phenomenon C23, core pressure drop. Was the assessment done as part of other PIRT phenomena?

148. Table 2.3-4 (p. 2-54) - What is the reason for introducing a new PIRT phenomenon C26 in this table? Should the interest be for the critical power for a 10-ft core and not a 9-ft one?

149. Section 2.4.4.1 (p. 2-66) - The collapsed level is a measure of liquid inventory, and is the product of mixture level and the liquid fraction. How could the sensitivity to the calculated void fraction be removed when the collapsed rather than the mixture two-phase level is used as the figure of merit to characterize water level above the core in a transient?

150. Table 2.4-1 (p. 2-69) - According to Table 2.4-1, burnout correlation, PIRT parameter C13, is a high ranked phenomenon. Why wasn’t C13 identified in Table 2.4-3 for sensitivity study? Is the modified-Zuber critical heat flux (CHF) correlation one of the options available for channel component in TRACG?

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

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

153. Section 2.4.4.2 (Figure 2.4-13) - Why is it that for some PIRT parameters, e.g. PIRT05 and PIRT84, only positive deviation is observed for both the lower and upper bound

values? What is the implication of this deviation to the selection of conservative bounding values for the PIRT parameters? Are the responses of the chimney collapsed level to the uncertainties in the PIRT parameters consistent with the expected behavior of the two-phase system?

154. Section 2.4.4.2 (Figures 2.4-13 and 2.4-14) - The sensitivity studies looked at the responses of the collapsed level and the peak cladding temperature (PCT) to the uncertainties in the PIRT parameters. Figures 2.4-13 and 2.4-14 show that in response to uncertainty in a given PIRT parameter the deviations in collapsed level and PCT do not always go in the same direction (see e.g. PIRT84M and PIRT84P). What is the correspondence between uncertainties in the collapsed level and the PCT? 10 CFR 50.46 defines 5 acceptance criteria for ECCS. How does the chimney collapsed level relate to these 5 acceptance criteria?

155. Section 2.6 (p. 2-91) - Is it possible in the TRACG calculation to predict a dryout condition in one of the core channels while a two-phase level exists in the chimney? A likely situation when this might happen is when the core flow is low. The modified-Zuber critical heat flux (CHF) correlation is inversely proportional to the void fraction and its value can be much lower than the pool boiling CHF. What is the minimum critical power ratio (CPR) in the bounding base and the sensitivity calculations?

156. Section 2.6.1 (p. 2-91) - What is the basis for determining the 2σ uncertainty level of the static head in the chimney?

157. Section 2.7.1.1 (p. 2-92) - The TRACG nodalization of the ESBWR RPV and containment for ECCS/LOCA analysis was shown in Figure 2.7-1. Where is the suction point of the GDCS? Is there any possibility of draining the GDCS pool through the broken GDCS line creating a bypass flow path between the drywell and wetwell? Was this confirmed by an qualification tests?

158. Section 2.7.2.2 (p. 2-101) - Some of the sensitivity cases have suggested that the net effect of combining uncertainties at the extreme values may not be synergistic. A case in point is the result shown in Figure 2.5-1 where the chimney collapsed level responded in opposite directions to uncertainties in plant parameters individually and when combined. Could there be compensating effects? Are the results of the ‘bounding’ case bounding? Which case has the lower minimum chimney collapsed level, the ‘bounding case’ or sensitivity case PIRT57-P shown in Figure 2.4-13?

Chapter 3: CONTAINMENT/LOCA ANALYSIS

159. NEDC-33083P states "A complete description of the ESBWR containment model can be found in Section 8.2 of Reference 24." Reference 24 is NEDC-32725P, "TRACG Qualification for SBWR," Rev. 1, Volumes 1 and 2, September 1997. In comparing Figure 3-7-1 in NEDC-33083P and Figure 8.2-5 in NEDC-32725P, any description in NEDC-32725P would not be fully representative of the ESBWR, because of the

differences in ESBWR as compared to the SBWR design. Please provide supplemental information to address this issue.

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

161. It is stated in Section 3.1.4 (Page 3-4) that "the ESBWR pressure transient does not rapidly increase to a peak value from which it must be rapidly reduced. The pressure increases slowly over several hours…"

    1. What about the peak pressure in the DW immediately after the blowdown, before and after the main horizontal vents are cleared? This peak could be higher than the long term pressure (e.g., Figure 2.7-5 vs. Figure 3.7-2.) Please provide a document discussing this initial peak pressure.

    2. Clearing of horizontal vents in the main vent lines (PIRT MV3) and chugging (partial opening of the top vent) are potentially important to affect the initial noncondensible gas flow into the WW, and the initial DW pressure peak. Please explain how this issue is handled in the analyses, and list any tests used to validate this model.

162. It is stated in Section 3.1.4 (Page 3-4) that "The containment pressure is determined by the transport of the noncondensible gases into the drywell, not by heat input to the containment." Is this statement true only if the PCCS were 100% efficient? The containment pressure is also affected by the heat not removed by the PCCS, which is deposited in the WW water by condensing steam which was not condensed by PCCS, which, in turn, raises the partial pressure of steam in the WW gas space. Is this long-term deposit of heat into WW the ultimate concern for the ESBWR containment and purpose of various tests and evaluations? Please clarify.

163. Modeling of WW gas space stratification in Section 3.3.1.1.2 referred to the PANDA modeling experience for basis of having "restricted mixing between layers," which "produced conservative results for PANDA and is expected to be conservative for ESBWR."

    (1) The PANDA report (NEDC-33080P) does not mention this particular modeling. The PANDA report says in Section 2.6.2.10 that "post-test evaluation of P-series tests demonstrated that TRACG conservatively calculates heatup of the WW gas space." However, PANDA modeling does not use the "restricted mixing between layers." Please explain.

    (2) PANDA results show substantially different trends for the WW gas temperature between the test and analyses for all tests, although the magnitudes are similar. This difference may be magnified in the long-term (PANDA usually ran about 10 hours, while the time period of interest in ESBWR is 72 hours.) Please discuss how the difference in trends is concluded to be conservative.

164. It is stated that the volumes of drywell were adjusted for “hideout volume” to maximize the effect of noncondensible gas hideout during the blowdown phase of the LOCA.

    1. In Page 3-21, it is stated that the region over the GDCS pools is included in the hideout volume. Since this region is a part of WW, not DW, this seems to be incorrect. Please clarify.

    2. Please discuss how this hideout volume would affect the initial peak of the DW pressure (adjusting volumes where a large amount of steam is released and compressed should affect the pressure change in the volume.)

    3. Immediately after the blowdown, it is possible that some of the DW noncondensible gases can move to the hideout volumes since the pressure in the open space volume is higher than these hideout volumes. Preventing these gases from moving to these volumes, the concept of hideout volumes may result in less noncondensible gases in these volumes than in reality, thus less noncondensible gas available to bleed later. Please discuss if this observation is correct.

    4. On Page 3-22, it is stated that, “This loss coefficient was representative of the loss that would be expected through the restriction area connecting the upper and lower drywell.” In view of the potential importance of impact on the PCCS of a small amount of noncondensible gas bleeding, this coefficient may be important. Please explain how this coefficient is determined. Were sensitivity studies performed varying this coefficient?

165. In Tables 3.3-3 and 3.3-4, some of the highly ranked phenomena are not cross-marked for any tests. Please discuss how these phenomena are validated or qualified for TRACG.

166. How is the nodalization accounted for in the bias calculations?

167. 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.

168. On Page 3-37 (MV1), it is stated that “In Section 5.5 of Reference 24, the short-term peak drywell pressure is shown to be always conservatively overpredicted by TRACG.” Please provide a summary discussion of that finding.

169. On page 3-40 (PC1), the bias in k/A^2 was determined “assuming the same values for ρ_{mix} and m_{mix}.” However, these values are not constants through the PCCS tubes, due to condensation, since the Δp in the equation is overall pressure drop in the PCCS, ρ_{mix} and m_{mix} should be some kind of average in the tubes, which requires some knowledge of how much steam is condensed along the tubes. Please explain how ρ_{mix} and m_{mix} are determined in the evaluation of the bias of k/A^2.

170. With respect to PC2 (Page 3-40), the potential degradation of condensation in the PCCS tubes due to continuous bleeding of a small amount of noncondensible gas in a long period may be the single most important issue in the ESBWR containment performance. Yet the documents reviewed do not provide any specific information regarding the degree of degradation. Are there any studies (tests and analyses) showing the degrees of degradation as a function of concentration (and perhaps flow rates) of noncondensible gas in the tubes? Are there any such tests available where a small amount of noncondensible gas (in the order of 1%) is continuously injected to the DW?

171. Initial DW and WW temperatures were set at their operating limit, i.e, 110°F (P. 3-49, Section 3.5.2.1). However, the higher initial temperature may results in less noncondensible gas inventory and, thus, may not be conservative. Please discuss this aspect.

172. Table 3.5-1 shows that the bounding value of the suppression pool level is higher than the nominal value. While it may be conservative in terms of the WW gas space available in the later stage of the accident, it may not be conservative in terms of the water inventory above the PCCS vent outlet, which is available to be heated by the uncondensed steam in the bounding calculations. It will also require a higher Δp (DW-WW) to clear the PCCS vent to the WW pool. Please explain.

173. Table 3.5-1 shows that the bounding value of the GDCS pool level is higher than the nominal value. While it may be conservative in terms of the WW gas space available in the later stage of the accident, it may not be conservative in terms of the total water inventory available to cool the reactor. Please explain.

174. Section 3.7.2 refers to Figure 2.7-5 for the short term response. However, Figure 2.7-5 presents the result of a GDCS line break, while Section 3.7.2 discusses main steam line break. Please clarify.

175. Figure 3.7-2 shows periodic drops of containment pressure. Please explain whether they are real or numerical and what causes them, and evaluate the impact of these phenomena on the eventual containment pressure.

176. Figures 3.7-6 and 3.7-11 show a substantial improvement of PCCS heat removal at about 8 hours. Yet, a substantial amount of noncondensible gases remain in the DW (Figure 3.7-3). Please explain what causes this improvement. The same figures show that the PCCS removes almost 100% of decay heat after 8 hours, yet the containment pressure continues to increase. What is the cause of this pressure increase?