GE Nuclear Energy

James E. Quinn
Projects Manager, LMR and SBWR Programs

Advanced Reactor Programs
General Electric Company
175 Curtner Ave., M/C 165
San Jose, CA 95125-1088
*408 925-1005, Dial Comm: 8*425-1005*
Fx: 408 925-3991, Email: QuinnJ@sjcpo2.ne.ge.com

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Attention: Theodore E. Quay, Director
Standardization Project Directorate

Subject: SBWR - Non-Proprietary Version of RAI Responses Submitted September 20, 1994

Reference:

1. Letter from Dino C. Scaletti (NRC) to Mr. James E.Quinn (GE), Request for Withholding Information From Public Disclosure, General Electric (GE) Responses to Request for Additional Information (RAI) Dated September 20, 1994, dated August 10, 1995.
2. Letter MFN 096-94 from R.H. Buchholz (GE) to Richard W. Borchardt, Submittal of Additional Information on Licensing Topical Reports (NEDE-32176P, NEDE-32177P and NEDE-32178P), dated September 20, 1994.

In response to the NRC's Reference 1 request, GE is providing the enclosed non-proprietary version of Reference 2.

Sincerely,

J.R.B.

James E. Quinn

cc:

P. A. Boehnert	(NRC/ACRS)	(2 paper copies plus E-Mail)
I. Catton	(ACRS)	(1 paper copy plus E-Mail)
A. Drozd	(NRC)	(1 paper copy plus E-Mail)
S. Q. Ninh	(NRC)	(2 paper copies plus E-Mail)
D. C. Scaletti	(NRC)	(1 paper copy plus E-Mail)
J. H. Wilson	(NRC)	(1 paper copy plus E-Mail)

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D040 1/1

RAI Number: 901.1

Question:

Critical flow: The design for the flow restrictors on the steam line and Gravity-Driven Cooling System (GDCS) injection lines may make them efficient diffusers, which may allow critical flow to occur at a higher downstream-to-upstream pressure ratio than usually encountered. Is this taken into account in GE Nuclear Energy's (GE's) modeling in TRACG?

GE Response:

The user specifies where TRACG will check for critical flow. For a straight pipe this is done at the end of the pipe, for an orifice at the orifice location, and for a convergent/divergent nozzle at the minimum flow area. This procedure was used for the Pressure Suppression Test Facility (PSTF) tests where the critical flow was controlled by a converging diverging nozzle in the blowdown pipe. Very good results were obtained for these comparisons justifying the procedure for calculating critical flow at the minimum area.

RAI Number: 901.2

Question:

Two-Phase Level Tracking: The original level tracking model developed under the refill-reflood had errors in the hydraulic head term and interfacial friction treatments. This caused significant errors in pressure calculations. What changes have been made to correct the original implementation?

GE Response:

The original TRAC level tracking model limited its impact on the governing thermal-hydraulic equations to the modification of the donor-celled void fraction. The coupling of the level model in TRACG has been improved. The interaction of the level model with the governing equation is described in the response to question 901.11bb.

RAI Number: 901.3

Question:

Mixing Models: The turbulent mixing model is totally unmechanistic using a c=0.1 constant value. GE plant model nodalizations do not come close to resolving profiles to the degree of accuracy needed to use a mixing model of the form chosen by GE. Explain the use of this model.

GE Response:

PROPRIETARY - Provided by Reference 2*

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*Refers to Reference 2 of the transmittal letter to this non-proprietary version of the RAI response.

RAI Number: 901.4

Question:

Steam Separator: The GE steam separator model seems to be a steady state model. How slow do transients have to be for this model to be valid?

GE Response:

The steam separator model is a transient model, where the separated flow is determined from the local instantaneous conditions at the separator barrel inlet. The key parameters in the separator model, however, were determined from full scale steady-state separator test data. This model has been tested under transient conditions using full scale plant data including Hatch MSIV closure and two pump trip tests, and Peach Bottom Turbine trip tests. The turbine trip tests were very fast transients, where significant flow changes over a short time occur for the separator. Good results were obtained for all these tests demonstrating the adequacy of the TRACG steam separator model under transient conditions.

RAI Number: 901.5

Question:

Numerical Methods: J.H. Mahaffy (see the paper in Enclosure 2, "Numerics of Codes: Stability, Diffusion, and Convergence") has shown that the GE implicit hydraulic solution method is inconsistent with the original differential equations at large Courant numbers and has the effect of adding a time step size-dependent inertia. This can affect things like flow coastdowns after a pump trip. What is the significance of this?

GE Response:

The numerical method in TRACG is described in NEDE-32176P Section 6, and the discretization of the momentum equation is given in Section 6.3.1.1. TRACG uses a mixture of old and new velocities for the convective term in the momentum equation. This is done in order to give sufficient numerical stability to allow the use of large time step sizes for slow or quasi steady-state transients. For fast transients the time step control in TRACG will automatically reduce the time step size to obtain an accurate calculation. In order to demonstrate the sensitivity of TRACG to the discretization of the convective term in the momentum equation, an experimental version of TRACG was generated allowing a fully explicit formulation using old time step values in addition to the standard formulation as described in NEDE-32176P Section 6. The Hatch pump trip test has been simulated using both formulations (see Figure 901.5.1*), and it is seen that the sensitivity to the discretization is insignificant.

* PROPRIETARY - Provided by Reference 2

RAI Number: 901.6

Question:

Control Blocks: The existence of feedback loops does not make implicit solutions impossible. TRAC-BF1 has an implicit control system solution. How can you ensure that the GE solution is not sensitive to the order chosen to evaluate the control blocks?

GE Response:

The TRACG control system is solved sequentially based on the order of the control block specification. Given this scheme, the implicit solution of feedback loops is impossible. The control system must be evaluated at a time step size sufficiently small to guarantee that the control system will be stable. The user must define a maximum control system time step size (can be smaller than the thermal-hydraulic time step) that produces an accurate control system response.

RAI Number: 901.7

Question:

Why there is no qualification data provided for the following phenomena?

a. Accumulator behavior for the Standby Liquid Control System (SLCS)

b. Boron transport and mixing

c. Gas mixing in containment

d. Containment pressurization from beginning of high pressure blowdown.

a. Accumulator behavior for the Standby Liquid Control System (SLCS)

GE Response: (901.7a)

The accumulator behavior for the SLCS is controlled by the decompression of the gas in the accumulator tank and the flow from the accumulator as a function of the pressure difference between the accumulator and the reactor pressure vessel. The flow from the accumulator is controlled by frictional pressure drop and/or critical flow, which has been assessed extensively in the TRACG qualification repot [NEDE-32177P]. GE will qualify TRACG against alternative methods for the adiabatic decompression of the accumulator tank.

b. Boron transport and mixing

GE Response: (901.7b)

In the TRACG model, the boron is transported at the same velocity as the liquid in the cell. The boron solution is assumed to be perfectly mixed with the liquid in the cell. In a three dimensional simulation, these models allow for the stratification of the colder and denser boron solution due to density variations and mixing between cells. However, because of the assumption of perfect mixing in a cell, the cell size can have an influence on the calculated results and must be appropriately chosen. The current SBWR nodalization should produce reasonable results.

GE intends to complete qualification of the boron mixing process through comparisons with tests in the 1/6 scale boron mixing facility at Vallecitos. The tests with boron injection in the upper plenum and subsequent transport through the bypass into the core provide a good simulation of the SBWR.

c. Gas mixing in containment

GE Response: (901.7c)

The mixing model in TRACG is not being used currently. Comparisons against the asymmetric injection PANDA tests will be used to determine whether the mixing model is needed.

d. Containment pressurization from beginning of high pressure blowdown.

GE Response: (901.7d)

TRACG has been compared to containment response for the early blowdown phase from the PSTF test facility. Figure 901.7d.1* shows a comparison of the measured and calculated drywell pressures for a liquid blowdown simulating a recirculation line break and Figure 901.7d.2* shows comparison of the measured and calculated drywell pressures for a steam blowdown simulating a steam line break. It is seen that TRACG calculates the early containment response during the blowdown phase well.

* PROPRIETARY - Provided by Reference 2

RAI Number: 901.8

Question:

Why there is no code qualification provided for separate effects condensation against any data?

GE Response:

The condensation heat transfer model which is used for the passive containment cooling system (PCCS) was correlated from the University of California Berkeley data. It is not meaningful to compare the correlation against the same data from which it was derived since this was done in [K. M. Vierow and V. E. Schrock, "Condensation in Natural Circulation Loop with Non-condensable Gases, Part 1 – Heat Transfer", Proc. Intl. Conf. on Multi-phase Flow, Tsukuba, Japan, pp183–186, September 1991]. Instead the condensation heat transfer model was compared against tests from the GIRAFFE facility, where prescribed steam and non-condensable flows were injected in the PCC unit. Comparison of the measured and calculated condensation heat transfer rates are contained in NEDE–311177P Section 4.4. In addition TRACG was also compared to system effects tests from the GIRAFFE facility (NEDE-311177P Section 5.5).

RAI Number: 901.9

Question:

Why there is no code qualification provided for horizontal stratified flow (hydraulic and thermal)?

GE Response:

Stratified flow in horizontal pipes is not significant for BWRs during transients and LOCAs, and has not been identified as a significant phenomenon in the PIRT. The model is physically reasonable and is based on correlations from the literature. No further qualification is planned.

RAI Number 901.10

Question:

Vierow-Shrock natural circulation condensation oscillation may occur with a stuck-open vacuum breaker in containment. Can TRACG predict such a phenomenon?

GE Response:

There has been no attempt to predict the observed oscillatory behavior in the earliest UCB facility using TRACG. This was not thought to be a productive activity because the integral system behavior of the UCB facility would bear no relationship to the integral system behavior of the SBWR. It is believed, however, that TRACG contains all of the necessary thermal-hydraulic models to predict oscillatory behavior in the SBWR.

RAI Number 901.11

Question:

Respond to the following questions on the thermal-hydraulic model described in NEDE-32176P, "TRACG Model Description - Licensing Topical Report".

a. The conservation equations in Section 3.1 including mixing terms of mass, momentum, and energy, but there are no expressions defining them. Provide definitions.

b. What is the typical value of α_{tran} for the flow regime map? Why is it related to the stratified flow when the flow in the BWR vessel is predominantly vertical? Does GE use the same flow regime map for both vertical and horizontal flow?

c. Subflow regimes are used in the global flow regime of liquid continuous flow and vapor continuous flow. What are the criteria for these subflow regime transitions?

d. Should not the factor 2 be in the denominator in Eq. (3.2-12) for the wall friction? Is G^2 used instead of $G|G|$?

e. Is x in Eq. (3.2-15) a flow quality or an equilibrium quality?

f. Is the same loss coefficient C in Eq. (3.2-17) used for both the forward and reverse flows?

g. Section 3.2.2 states that the wall friction is distributed between the phases proportional to the void fraction. What is the basis of this statement. Is this statement valid for all flow regimes? Is it in agreement with the wall heat transfer distribution between the phases?

h. The modified Chisholm correlation used for wall friction is a departure from the design method used in the past. Has any assessment been done to compare the two?

i. The homogeneous two-phase multiplier Eq. (3.2-18) is used for form losses. In view of its significant impact on thermal-hydraulic stability, has its adequacy been assessed? See the discussion on the subject in Electric Power Research Institute's (EPRI's) report NP-1924-CCM, July 1981.

j. The equivalence between the two-fluid and drift flux models established for steady-state conditions are used for transient interfacial shear calculations. Has any assessment been done to show that this is still valid under severe transient conditions such as large amplitude oscillations induced by thermal-hydraulic instability (e.g., LaSalle-2 event)?

k. How good is the approximation used for the velocity of dispersed phase in Eq. (3.2-59)?

l. Section 3.2.3.1 states that a value for k of 1.53 in Eq. (3.2-26) allows for fits with wide range of the data. Identify the reference for this.

m. What is the basis of selecting Weber number of 6.5 in Eq. (3.2-27)?

n. Why is maximum of Eqs. (3.2-26) and (3.2-30) used for drift velocity?

o. Why is k = 1.41 in Eq. (3.2-43) and k = 1.53 in Eq. (3.2-26)?

p. What is the basis of interfacial density expression Eq. (3.2-46)?

q. In Section 3.2.7.2, why is Eq. (3.2-73) needed if the position of the level is known from Eq. (3.2-64)? What is the basis of Eqs. (3.2-65) and (3.2-66)? What happened to the vapor generator rate above and below the level in the cell? The level velocity is generally derived from the jump conditions at the level. How is this formulation consistent with the vapor mass balance equation?

r. What is the basis of Eq. (3.2-84)?

s. What is the basis of Eq. (3.2-87) (Ref., range, and validity)?

t. In Section 3.2.5.2, the liquid side heat transfer coefficient is given by Eq. (3.2-90) and the reference is an older version of TRAC-PWR. The TRAC-PF1/MOD2 is now using a different expression. Are the data bases for these correlations valid for SBWR conditions?

u. Provide the range and validity of Eqs. (3.2-91) and (3.2-92).

v. Eq. (3.2-95) describes the vapor side heat transfer coefficient and is based on TRAC-P1A (Ref. 3-4). However, the later version of TRAC (TRAC-PF1, NUREG/CR-5069) states that this expression is very approximate and is based on the flow over a jet. What is the justification of Eq. (3.2-95)? Where does it apply in a BWR?

w. What is the experimental basis for Eq. (3.2-98)? Is the degradation factor flow-regime dependent? How does Eq. (3.2-98) match with the analysis of Sparrow, et al. in Figure 3.2-4?

x. In Section 3.2.10.3, how is the wall heat transfer divided between the liquid and vapor phases in the transition boiling mode?

y. How applicable is the correlation for condensation (Section 3.2.10.5) based on low pressure tests for the isolation condensers (ICs)?

z. Various pool boiling and forced flow correlations are described in Section 3.2.10.9. How valid are they for a natural circulation system with parallel channels? Are these correlations based on soft inlet or hard inlet conditions?

aa. In Eq. (3.2-142), H_{Chen} is not defined. What is it?

bb. On page 3-15, reference is made to Subsection 3.3.7.3. Where is the subsection?

cc. What is the value of α_{cut} used for level detection in Eq. (3.2-63)? Why is it used?

dd. What is the basis of using 0.999 for α^+ in Eq. (3.2-74)?

ee. What are j_g^- and j^- in Eq. (3.2-75)?

ff. How is flow reversal handled in the level tracking?

gg. What is the expression for q_{evap}'' in Eq. (3.2-113)?

hh. Why is Eq. (3.2-120) squared?

ii. What is α_{min} in Eq. (3.2-130)? What is its typical value? How is it obtained?

jj. What is the expression for ε_i in Eq. (3.2-147)?

kk. What are F_{ji} in Eq. (3.2-151) and F_{ij} in Eq. (3.2-152)?

ll. What are the definition and unit of P and T in Eq. (3.2-167)?

mm. What is the basis for using Eq. (3.2-181) for the Leidenfrost temperature?

nn. What is T in Eq. (3.2-185)? What is its units? Should not 10^5 in this equation be 10^4?

oo. Why is the boron transport model not presented? How is boron mixing treated?

a. The conservation equations in Section 3.1 including mixing terms of mass, momentum, and energy, but there are no e· perssions defining them. Provide definitions.

GE Response: 901.11 (a)

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b. What is the typical value of α_{tran} for the flow regime map? Why is it related to the stratified flow when the flow in the BWR vessel is predominantly vertical? Does GE use the same flow regime map for both vertical and horizontal flow?

GE Response 901.11(b):

Stratified flow is only used for horizontal flow. For vertical flow $g_T = 0$ in Equation 3.2-6 and α_{tran} is given by Equation 3.2-5.

$$\alpha_{annular} = \left(1 + 4\frac{\rho_v}{\rho_\ell}\right)\frac{1}{C_o} - 4\frac{\rho_v}{\rho_\ell}$$

$$C_o = C_\infty - (C_\infty - 1)\sqrt{\frac{\rho_v}{\rho_\ell}}\ ;\ C_\infty = 1.393 - 0.015\ \ln(Re)$$

A typical value for α_{tran} is 0.8. For $\alpha_{tran} = 0.8$ the transition to annular flow will occur for a void fraction interval of 0.7 – 0.8.

For horizontal flow the transition to separated flow occurs if the condition for stratified flow given by the critical Froude number (Equation 3.2-6) is exceeded, or if the transition to annular flow given by the above correlation is exceeded.

c. Subflow regimes are used in the global flow regime of liquid continuous flow and vapor continuous flow. What are the criteria for these subflow regime transitions?

GE Response 901.11(c):

The subflow regimes and the criteria for their selection are given by Figure 3.2-5.

Flow Regime	Wall condition			
	Boiling transition			
	No		Yes	
	$T_W < T_{sat}$	$T_{sat} < T_W < T_{CHF}$	$T_{CHF} < T_W < T_{min}$	$T_{min} < T_W$
Liquid continuous	Liquid convection	Subcooled/ Nucleate Boiling	Transition boiling	Film boiling
Vapor continuous	Condensation	Forced convection vaporization	Transition boiling	Steam convection

Figure 3.2-5. Selection Logic for Wall Heat Transfer Coefficient

The subflow regimes are given by void fraction and the wall condition. For the liquid continuous flow regime single phase liquid occurs for $\alpha = 0$, and inverted annular flow occurs when the wall has exceeded boiling transition. For the vapor continuous flow regime single phase vapor flow occurs for $\alpha = 1$, and the entrainment correlation (Equation 3.2-7) determines the entrainment rate, except if the wall has exceeded boiling transition 100% entrainment is assumed.

d. Should not the factor 2 be in the denominator in Eq. (3.2-12) for the wall friction? Is G^2 used instead of $G|G|$?

GE Response: 901.11(d)

Equation 3.2-12 should read:

$$F_w = \frac{1}{2} \frac{f_\ell}{D} \frac{|G|G}{\rho_\ell} \phi_{\ell o}^2$$

The above equation is implemented correctly into the TRACG program.

e. Is x in Eq. (3.2-15) a flow quality or an equilibrium quality?

GE Response: 901.11(e):

In Equation 3.2-15 x is the flow quality.

f. Is the same loss coefficient C in Eq. (3.2-17) used for both the forward and reverse flows?

GE Response: 901.11(f)

TRACG has two loss coefficients, one for forward flow and one for reverse flow.

g. Section 3.2.2 states that the wall friction is distributed between the phases proportional to the void fraction. What is the basis of this statement. Is this statement valid for all flow regimes? Is it in agreement with the wall heat transfer distribution between the phases?

GE Response: 901.11(g)

It can be shown for dispersed flow, that the variation of the shear across a flow channel will generate a force on the dispersed phase [J. G. M. Andersen, K. H. Chu, and J. C. Shaug, "BWR REFILL/REFLOOD Program TASK 4.7 – Model Development, Basic Models for the BWR Version of TRAC," GEAP-22051.

NUREG CR-2573, EPRI NP-2375. April 1983]. If the liquid is the continuous phase the total wall shear on the liquid per unit area is:

$$F_{w\ell,\mathrm{total}} = \frac{4}{D} \tau_w$$

The interfacial force per unit area due to the shear distribution is given by:

$$f_{w\ell v} = \alpha \frac{4}{D} \tau_w$$

Combining these equations gives a net force on the gas of:

$$F_{wv} = \alpha \frac{4}{D} \tau_w ,$$

and a net force on the liquid of:

$$F_{w\ell} = \frac{4}{D} \tau_w - \alpha \frac{4}{D} \tau_w = (1 - \alpha) \frac{4}{D} \tau_w$$

Details on this derivation is given in the above reference. This partitioning is only applied to the wall shear. The wall heat transfer is partitioned between the phases based on the wetted fraction, e.g., if the wall is wetted all the heat transfer goes to the liquid.

h. The modified Chisholm correlation used for wall friction is a departure from the design method used in the past. Has any assessment been done to compare the two?

GE Response: 901.11(h)

The modified Chisholm correlation and the two-phase friction factor given by Equations 3.2-13–3.2-16 is consistent with current GE design methods.

i. The homogeneous two-phase multiplier (3.2-18) is used for form losses. In view of its significant impact on thermal-hydraulic stability, has its adequacy been assessed? See the discussion on the subject in Electric Power Research Institute's (EPRI's) report NP-1924-CCM, July 1981.

GE Response: 901.11(i)

PROPRIETARY - Provided by Reference 2

j. The equivalence between the two-fluid and drift flux models established for steady-state conditions are used for transient interfacial shear calculations. Has any assessment been done to show that this is still valid under severe transient conditions such as large amplitude oscillations induced by thermal-hydraulic instability (e.g., LaSalle-2 event)?

GE Response: 901.11(j)

It is an assumption that the interfacial shear e.g., for bubbly flow is given by the drag coefficient for the bubbles and the average relative velocity between the phases, and that this correlation is valid under transient conditions. Under steady state conditions a balance between buoyancy and interfacial drag will control the relative velocity, for transient conditions however a balance between the buoyancy, interfacial drag and pressure gradient will exist. Assuming that the relative velocity would remain constant under such transient conditions, as would be predicted by the drift flux correlation, is not reasonable, but the assumption of constant drag coefficient is reasonable provided that a significant distortion of the bubble shape does not occur.

The interfacial shear model derived based on this assumption has been extensively tested (See NEDE-32177P Section 3.1). The OF-64 and the Christensen tests were heated tests, and consequently a substantial spatial acceleration would exist in the test section. As the bubbles move up through the test section they will undergo a substantial acceleration, and thus these tests validate the interfacial shear model under transient conditions. Other tests such as Wilsons and Bartolomeis test were adiabatic test and validate the void fraction model under true steady state conditions i.e., with neither temporal or spatial acceleration.

TRACG has been tested for severe transient conditions such as large amplitude oscillations by comparison to the FRIGG thermal-hydraulic stability tests (See NEDE-32177P Section 3.7). These test results are well predicted by TRACG giving an overall validation of the TRACG models including the interfacial shear model.

k. How good is the approximation used for the velocity of dispersed phase in Eq. (3.2-59)?

GE Response: 901.11(k)

Equation 3.2-59 is an approximation. For low void fractions the vapor is the dispersed phase, and the velocity of the vapor phase will be the dispersed phase velocity, as predicted by Equation 3.2-59. Similarly, for high void fractions the liquid is the dispersed phase, and the velocity of the liquid phase will be the dispersed phase velocity, as predicted by Equation 3.2-59. For intermediate void fractions, e.g. for churn flow the velocity of the dispersed phase is not well defined. Equation 3.2-59 was chosen as it has the right limits and avoids a discontinuity at the flow regime transition between churn flow and dispersed annular flow.

l. Section 3.2.3.1 states that a value for k of 1.53 in Eq. (3.2-26) allows for fits with wide range of the data. Identify the reference for this.

GE Response: 901.11(l)

The value of 1.53 is recommended by Zuber and Findlay [N. Zuber and J. A. Findlay, Trans. ASME J. Heat Transfer vol. 87, ser. C, p. 453, 1965].

m. What is the basis of selecting Weber number of 6.5 in Eq. (3.2-27)?

GE Response: 901.11(m)

The Weber number is not selected for Equation 3.2-27. The ratio of the drag coefficient and the Weber number is derived from the equivalence to the drift flux model and is given by Equation 3.2-27. For interfacial heat transfer (NEDE-32176P Section 3.2.9.2), however the particle size is needed to determine the interfacial area and heat transfer coefficients. A maximum stable particle size corresponds to a Weber number of 12—13 [G. B. Wallis, "One Dimensional Two-Phase Flow," McGraw-Hill Book Co., Inc., New York, 1969]. Using a Weber number of 13 as the upper bound for stable particle sizes, a value of half of the upper bound 13/2 = 6.5 was chosen to represent the average particle size.

n. Why is maximum of Eqs. (3.2-26) and (3.2-30) used for drift velocity?

GE Response: 901.11(n)

For low flow rates in large geometrics such as bubbles rising in a large pool, a value of k in Equation 3.2-26 of 1.53 leads to an overprediction of the void fraction. By using Wilsons bubble rise model [J. F. Wilson, R. J. Grenda and J. E. Patterson. "The Velocity of Rising Steam in a Bubbling Two-Phase Mixture," ANS Trans. 5(1). p. 151-152 1962]. Equation 3.2-30 was derived. Equation 3.2-30 gives k values greater than 1.53 for low flow and large hydraulic diameters.

o. Why is k = 1.41 in Eq. (3.2-43) and k = 1.53 in Eq. (3.2-26)?

GE Response 901.11(o)

k = 1.53 is used for bubbly flow. This value is consistent with the recommendations of Zuber and Findlay [N. Zuber and J. A. Findlay, Trans. ASME J. Heat Transfer vol. 87, ser. C, p. 453, 1965]. Other authors have recommended slightly different values. Ishii [M. Ishii, "One Dimensional Drift-Flux Model and Constitutive Equations for Relative Motion Between Phases in Various Two-Phase Flow Regimes," ANL-77-47, October 1977] suggests a value of $\sqrt{2}$, however Ishii also states that the difference between the values is insignificant. This value, k = 1.41, is used for droplet flow.

p. What is the basis of interfacial density expression Eq. (3.2-46)?

GE Response: 901.11(p)

For dispersed annular flow with large flow rates the droplets are generated by entrainment from the film. The initial velocity difference is thus the gas velocity minus the film velocity, and as the film velocity is much smaller than the gas velocity, this velocity difference can be approximated by the volumetric flux. For these conditions the entrainment fraction is generally high, the droplets are very small having a velocity close to the gas velocity, and therefore the gas velocity is close to the volumetric flux. Using the gas velocity and a critical Weber number of 12 leads to Equation 3.2-46. This model for high velocity dispersed annular flow is recommended by Ishii [M. Ishii, "One Dimensional Drift-Flux Model and Constitutive Equations for Relative Motion Between Phases in Various Two-Phase Flow Regimes," ANL-77-47, October 1977].

q. In Section 3.2.7.2, why is Eq. (3.2-73) needed if the position of the level is known from Eq. (3.2-64)? What is the basis of Eqs. (3.2-65) and (3.2-66)? What happened to the vapor generator rate above and below the level in the cell? The level velocity is generally derived from the jump conditions at the level. How is this formulation consistent with the vapor mass balance equation?

GE Response: 901.11(q)

The level velocity is used to predict when a two-phase level will leave a cell. In the event the level does exit a cell, the level velocity is used to predict the new velocity conditions at the boundary the level has crossed. Vapor generation within the cell will affect the cell average void fraction as defined by the vapor mass balance equation. The level position will be impacted by the cell average void fraction as shown in Equation (3.2-64). Equations (3.2-65, 66) define the above and below level void fractions assuming there is no change in above and below level void fraction across cell boundaries.

r. What is the basis of Eq. (3.2-84)?

GE Response: 901.11(r)

For low velocities the droplet size is determined by a critical Weber number based on the relative velocity. For dispersed annular flow with high velocities, however, the droplets are created by entrainment from the film, and in that case the droplet size is determined by a critical velocity based on the difference between the gas and film velocities. This velocity is approximated by the volumetric flux (See Question 901.11p). In order to avoid discontinuities the transition is made where Equation 3.2-46 will generate a smaller droplet size than the droplet size basing the Weber number on the relative velocity.

s. What is the basis of Eq. (3.2-87) (Ref., range, and validity)?

GE Response: 901.11(s)

The minimum film thickness as given by Equation 3.2-87 is determined for a film using Nusselt's falling film model and minimizing the total energy (surface tension and kinetic energy). Such an analysis gives:

$$d_{f,\min} = \left(18 \frac{\sigma\ \mu_\ell^2}{g^2\ \rho_\ell^3}\right)^{0.2}$$

The factor of 0.5 which is applied to this expression (See Equation 3.2-87) is empirical and was applied to avoid having film thickness less than the minimum film thickness for conditions where no boiling was predicted from the GEXL correlation (Section 3.2.10.9). This correlation has been used for all the qualification which has been performed for TRACG. The qualification include separate effects tests, component performance tests, integral system effects tests and plant data, and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG including the above model adequately simulates a BWR.

t. In Section 3.2.5.2, the liquid side heat transfer coefficient is given by Eq. (3.2-90) and the reference is an older version of TRAC-PWR. The TRAC-PF1/MOD2 is now using a different expression. Are the data bases for these correlations valid for SBWR conditions?

GE Response: 901.11(t)

The development of the BWR version had its origin in TRAC-P1A which contained the above correlation for the liquid side heat transfer coefficient as given by Equation 3.2-90. This correlation has been used for all the qualification which has been performed for TRACG and previous BWR versions of TRAC. The qualifications include separate effects tests, component performance tests and integral system effects tests and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG, including the above model, adequately simulates a BWR.

u. Provide the range and validity of Eqs. (3.2-91) and (3.2–92).

GE Response: 901.11(u)

The correlations for interfactial heat transfer given by Equations 3.2-91 and 3.2-92 are based on an analytical solution to the conduction in a spherical particle. The factors of 2.7 and μ_ℓ/μ_v are empirical and intended to account for internal circulation in the droplets [Minutes of the Condensation Workshop, NRC Silver Spring Building, Maryland, May 24-25, 1979]. These correlations have been used for all the qualification which has been performed for TRACG. The qualification include separate effects tests, component performance tests, integral system effects tests and plant data, and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG including the above model adequately simulates a BWR.

There is a typographical error in Equation 3.2-91, it should read:

$$H_{iv} = \frac{2}{3} \pi^2 \frac{k_v}{d_B} \left\{ 2.7 \frac{\mu_\ell}{\mu_v} \right\}$$

v. Eq. (3.2-95) describes the vapor side heat transfer coefficient and is based on TRAC-P1A (Ref. 3-4). However, the later version of TRAC (TRAC-PF1, NUREG/CR-5069) states that this expression is very approximate and is based on the flow over a jet. What is the justification of Eq. (3.2-95)? Where does it apply in a BWR?

GE Response: 901.11(v)

The development of the BWR version had its origin in TRAC-P1A which contained the above correlation for the liquid side heat transfer coefficient as given by Equation 3.2-95. This correlation has been used for all the qualification which has been performed for TRACG and previous BWR versions of TRAC. The qualification include separate effects tests, component performance tests and integral system effects tests and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG including the above model adequately simulates a BWR.

w. What is the experimental basis for Eq. (3.2-98)? Is the degradation factor flow-regime dependent? How does Eq. (3.2-98) match with the analysis of Sparrow, et al. in Figure 3.2-4?

GE Response: 901.11(w)

Equation 3.2-98 applies to the degradation of condensation heat transfer for dispersed annular flow. It was recommended by Zuber for condensation on droplets based on review of Russian literature [Minutes of the Condensation Workshop, NRC Silver Spring Building, Maryland, May 24-25, 1979]. The Sparrow-Uchida degradation factor given by Figure 3.2-4 is applied for free surfaces and not for dispersed annular flow as incorrectly stated in NEDE-32176P.

It is not straight forward to compare the two correlations for the degradation factors since they are applied for different flow regimes and have different functional forms. The degradation for droplets as given by Equation 3.2-98 is a function of the void fraction, which is not the case for the Sparrow-Uchida degradation factor for free surfaces. A typical value for the degradation factor for droplets as given by Equation 3.2-98 is 0.08 – 0.15.

x. In Section 3.2.10.3, how is the wall heat transfer divided between the liquid and vapor phases in the transition boiling mode?

GE Response: 901.11(x)

At T_{min} it is assumed that the wall is completely dry i.e. that the wetted fraction is 0.0. At T_{CHF} the wetted fraction is calculated based on the minimum film thickness given by Equation 3.2-87. This wetted fraction is then used to divide the heat transfer between the liquid and the vapor.

y. How applicable is the correlation for condensation (Section 3.2.10.5) based on low pressure tests for the isolation condensers (ICs)?

GE Response 901.11(y)

Isolation condenser performance during reactor transients is characterized by essentially pure steam condensation at high vapor Reynolds number with a turbulent condensate film. Under these conditions, the TRACG correlation reduces to a classical correlation for condensation from a stagnant vapor to a turbulent film (albeit, at low pressure). It is reasonable to believe that the predicted condensation rate from this correlation is conservative. It should also be noted that for IC high pressure performance the resistance to condensation heat transfer does not dominate the overall thermal resistance from the flowing vapor stream to the IC pool. The largest component of the overall thermal resistance is associated with conduction through the Inconel 600 tube wall. The planned IC tests in PANTHERS will provide data for confirmation.

z. Various pool boiling and forced flow correlations are described in Section 3.2.10.9. How valid are they for a natural circulation system with parallel channels? Are these correlations based on soft inlet or hard inlet conditions?

GE Response: 901.11(z)

The boiling transition criteria in Section 3.2.10.9 are based on 'hard' or stable inlet conditions. The issue here is whether channel instability is expected to occur before a critical heat flux condition based on stable inlet conditions. It is recognized that the lower of the two thresholds could be taken as the limiting condition.

At rated conditions, the channel critical power is approximately 5.7 MW, depending on local peaking. At this power, the channel decay ratio is in the range of 0.16 to 0.36 depending on whether nominal or design basis axial peaking is used for the calculation. The core decay remains below 0.5 at the scram power level. Thus there is sufficient margin to instability (channel, core and regional) at the critical power level. Critical power correlations with 'hard' inlet conditions are therefore justified.

aa. In Eq. (3.2-142), H_{Chen} is not defined. What is it?

GE Response: 901.11(aa)

H_{Chen} is Chen's correlation given by Equation 3.2-106.

bb. On page 3-15, reference is made to Subsection 3.3.7.3. Where is the subsection?

GE Response: 901.11(bb)

The section describing the modifications to the governing equations in the presence of a two-phase level was inadvertently omitted. The discretized equations described in Section 6.2.1 are impacted by the presence of a level through the void fraction axial donor-celling as follows:

$$\phi^{d}_{i+1/2} = \begin{cases} \phi_i & \text{if } v_{i+1/2} \geq 0 \text{ and no level exists in cell } i \\ \phi_{i^+} & \text{if } v_{i+1/2} \geq 0 \text{ and a level exists in cell } i \\ \phi_{i-1} & \text{if } v_{i+1/2} < 0 \text{ and no level exists in cell } i+1 \\ \phi_{i+1} & \text{if } v_{i+1/2} < 0 \text{ and a level exists in cell } i+1 \end{cases}$$

The donor-celling for source connections to the vessel for flow from vessel cell i is impacted in a similar fashion as follows:

$$\phi^{d}{}_{s} = \begin{cases} \phi_i & \text{if no level exists in cell } i \\ \phi_{i^+} & \text{if level position is below connection} \\ \phi_{i^-} & \text{if level position is above connection} \end{cases}$$

The donor-celled property is interpolated between the above and below values as a level crosses the source connection area. The pressure drop from cell center to cell center in the momentum equation is also adjusted to account for a level in the cell. The pressure gradient is modified to reflect the fluid conditions that exist at the cell boundary.

The interfacial heat transfer and shear are also impacted by a two-phase level. Above and below level heat transfer coefficients are calculated and volume weighted using the level position. A free surface convection component is added to account for free surface heat transfer. The interfacial shear is evaluated at the conditions present at the cell boundary when a level exists.

cc. What is the value of α_{cut} used for level detection in Eq. (3.2-63)? Why is it used?

GE Response: 901.11(cc)

The value of α_{cut} used is 0.2. This value is used to indicate the existence of a well defined two-phase level. If a level has been established within a cell, the α_{cut} criteria is no longer used.

dd. What is the basis of using 0.999 for α^+ in Eq. (3.2-74)?

GE Response: 901.11(dd)

The value of 0.999 for the above level void fraction given in equation (3.2-74) is used if there is no entrainment from below the level. If there is sufficient vapor flow to entrain liquid, then equation (3.2-72) will be used to determine the above level void fraction.

ee. What are j_g^- and j^- in Eq. (3.2-75)?

GE Response: 901.11(ee)

In equation (3.2-75), j_g^- and j^- are the vapor and mixture volumetric flux below the level, respectively.

ff. How is flow reversal handled in the level tracking?

GE Response: 901.11(ff)

Flow reversal will impact the donor-celling performed for the conservation equations (see Question 901.11bb). Changes in the calculated cell average void fractions and boundary velocities will impact the level model calculations of ΔZ_L, α^+, α^-, and v_L.

gg. What is the expression for q_{evap}'' in Eq. (3.2-113)?

GE Response: 901.11(gg)

In equation 3.2-113, q_{evap}'' is given by:

$$q_{evap}'' = q_w'' - q_\ell''$$

where q_ℓ'' is given by Equation 3.2-114.

q_ℓ'' is the fraction of the wall heat flux for subcooled boiling that goes to heat up the liquid.

q_{evap}'' is the fraction of the wall heat flux for subcooled boiling that goes to evaporation.

hh. Why is Eq. (3.2-120) squared?

GE Response: 901.11(hh)

Equation 3.2-120 is the same as the model incorporated in TRAC-BF1/MOD1 [J.A. Borkowski et. al., "TRAC-BF1/MOD1 An Advanced Best-Estimate Program for BWR Accident Analysis," NUREG/CR-4356, July 1992]. This correlation has been used for all the qualification which has been performed for TRACG and previous BWR versions of TRAC. The qualification includes separate effects tests, component performance tests and integral system effects tests and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG including he above model adequately simulates a BWR.

ii. What is α_{min} in Eq. (3.2-130)? What is its typical value? How is it obtained?

GE Response: 901.11(ii)

Equation 3.2-130 describes the calculation of the wetted fraction, which is used to partition the heat transfer between the liquid and the vapor. α_{min} in this equation is determined from the minimum film thickness given by Equation 3.2-87, and is given by:

$$d_{f,min} = (1 - \alpha_{min}) \frac{D_H}{4}$$

jj. What is the expression for ε_i in Eq. (3.2-147)?

GE Response: 901.11(jj)

In equation 3.2-147 ε_i is the surface emissivity.

kk. What are F_{ji} in Eq. (3.2-151) and F_{ij} in Eq. (3.2-152)?

GE Response: 901.11(kk)

F_{ij} is the view-factor from surface i to surface j, defined as the fraction of thermal radiation that leaves surface i that will reach surface j. F_{ji} is the view-factor from surface j to surface i.

ll. What are the definition and unit of P and T in Eq. (3.2-167)?

GE Response: 901.11(ll)

In equation 3.2-167, P is the pressure in bar and T is the temperature in Kelvin.

mm. What is the basis for using Eq. (3.2-181) for the Leidenfrost temperature?

GE Response: 901.11(mm)

The Leidenfrost temperature given by Equation 3.2-181 is determined by matching data for falling film quenching rates. It is simply an empirical constant tuned to give the best fit to data for conduction controlled rewetting using Equation 3.2-176. This model was developed for TRAC-P1A [R.J. Pryor et. al, "TRAC-P1A, An Advanced Best Estimate Computer Program for PWR LOCA Analysis," NUREG/CRA-0665, May 1979].

nn. What is T in Eq. (3.2-185)? What is its units? Should not 10^5 in this equation be 10^4?

GE Response: 901.11(nn)

In equation 3.2-187 T is the wall surface temperature in Kelvin. There is a typographical error in Equation 3.2-185, it should read:

$$\frac{ds}{dt} = \frac{3.217 \cdot 10^{-6}}{s} \exp\left(- \frac{2.007 \cdot 10^{4}}{T} \right)$$

In Equation 3.2-186 the heat generation rate should be:

$$Q = 6.45 \text{ MJ/kg}_{Zr}$$

oo. Why is the boron transport model not presented? How is boron mixing treated?

GE Response: 901.11(oo)

The boron is assumed to perfectly mixed with the liquid in a given computational cell, and is assumed to be transported with the liquid velocity. The conservation equation for boron mass is given by:

$$\frac{\partial}{\partial t}(c_b) = - \nabla \cdot (c_b \bar{v}_\ell) + M_{mix,b}$$

Mixing between nodes is included through the mixing term (See question 901.11a).

RAI Number 901.12

Question:

Respond to the following questions on the heat conduction model described in NEDE-32176P:

a. Should the negative sign in Eqs. (4.1-2) and (4.1-3) be there?

b. What is the basis for using 0.96 in Eq. (4.2-7) for uncertainty?

c. What is R on the right-hand side of Eq. (4.2-18)?

d. Is the temperature ratio on the right-hand side of Eq. (4.2-29) consistent with the volume-to-temperature ratios of the other two terms?

a. Should the negative sign in Eqs. (4.1-2) and (4.1-3) be there?

GE Response: 901.12(a)

There is a typographical error in Equation 4.1-2 and 4.1-3. They should read:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) + q''' \qquad (4.1\text{-}2)$$

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r}\left(rk \frac{\partial T}{\partial r}\right) + q''' \qquad (4.1\text{-}3)$$

b. What is the basis for using 0.96 in Eq. (4.2-7) for uncertainty?

GE Response: 901.12(b)

PROPRIETARY - Provided by Reference 2

c. What is R on the right-hand side of Eq. (4.2-18)?

GE Response: 901.12(c)

PROPRIETARY - Provided by Reference 2

d. Is the temperature ratio on the right-hand side of Eq. (4.2-29) consistent with the volume-to-temperature ratios of the other two terms?

GE Response: 901.12(d)

PROPRIETARY - Provided by Reference 2

RAI Number 901.13

Question:

Respond to the following questions on the component models described in NEDE-32176P:

a. A turbine model is not among the component models presented. How is a turbine modeled in TRACG?

b. Why is the mixture density ρ_m used in Eq. (5.2-1) instead of liquid density ρ_ℓ ?

c. Where is the assumption $v_v = v_\ell$ in Eq. (5.2-3) used in the pump model? How is this assumption justified?

d. Safety valves are of spring action type which has hysteresis effect. How is this handled by the valve model?

e. Is x in Eq. (5.5-8) a dynamic flow quality? How is it calculated?

f. Should not the negative sign associated with R in Eq. (5.5-10) be positive? (Consequently, the numerator of Eq. (5.5-11) for R should have a negative sign.)

g. In view of question 901.f, is Eq. (5.5-12) correct?

h. What is the rationale for using Eq. (5.5-12) for transient critical power ratio (CPR) if TM(t) < TM(0) and using Eq. (5.5-13) if otherwise? Why is the linear relationship valid?

i. Which test data were used to obtain the α^h curve in Figure 5.5-4?

j. Is Eq. (5.6-5) correct or is area ratio missing in the first term on the right-hand side of Eq. (5.6-2)? Eq. (5.6-5) cannot be derived from Eqs. (5.6-2) and (5.6-4).

k. Is the final expression for Eq. (5.7-5) correct? [r_w is missing in the last term in the bracket. It should be a $r_w(r_w-r_f)$.]

l. Why are the bypass fluid properties, instead of hydraulic in-channel properties, used in the kinetics calculations as stated on page 5-52?

m. What is the experimental basis for the steam dryer efficiency curves shown in Figure 5.9-1? What are typical values of $v_{vd,1}$, $v_{vd,u}$, and Δx_d?

n. The transition from the spray regime to the submerged jet regime for the case of nonexistent two-phase level in the upper plenum is not clear. How is the void fraction used for this transition?

o. Quasi-static momentum balance is used for the submerged jet model. How important is the temporal effect? Has any assessment been done?

p. What are ρ_∞ and h_∞ in the submerged jet model? What profiles are used for density η, velocity f, and enthalphy ϕ?

q. What is the basis for Eq. (5.11-1)? Provide justification.

r. Why is it necessary to have only one cell for the steam shell in the heat exchanger model? What is the impact of this simplification?

s. Is the heat exchanger model adequate to represent the isolation condenser in the SBWR? How is the non-uniform temperature distribution in the tube bundle and IC pool taken into account?

a. A turbine model is not among the component models presented. How is a turbine modeled in TRACG?

GE Response: 901.13(a)

There is no turbine model in the current version of TRACG.

b. Why is the mixture density ρ_m used in Eq. (5.2-1) instead of liquid density ρ_ℓ?

GE Response: 901.13(b)

In the pump model it is assumed that the two-phase flow is homogeneous. Equation 5.2-1 thus represents the mixture momentum equation for the pump, and hence the mixture density is used instead of liquid density.

c. Where is the assumption $v_v = v_\ell$ in Eq. (5.2-3) used in the pump model? How is this assumption justified?

GE Response: 901.13(c)

See question 901.13b.

The pump model in TRACG is similar to the pump model in the PWR version of TRAC. This model has been used for all the qualification which has been performed for TRACG and previous BWR versions of TRAC. The qualification include component performance tests, integral system effects tests and plant data, and cover a wide range of conditions typical of BWRs. Based on this qualification it is concluded that the combined set of models in TRACG including the above model adequately simulates a BWR.

d. Safety valves are of spring action type which has hysteresis effect. How is this handled by the valve model?

GE Response: 901.13(d)

The valve model has the capability to model valves with different opening and closing pressure setpoints but does not have the capability to model the opening and closing characteristics of spring action safety valves. The opening and closing characteristics of safety valves can be modeled by the control system which provides the appropriate valve area to the valve component.

e. Is x in Eq. (5.5-8) a dynamic flow quality? How is it calculated?

GE Response: 901.13(e)

Equation (5.5-8) defining the thermal margin (TM) for each node should read as follows:

$$\mathrm{TM} = \frac{x_c + \dfrac{\Delta h_s}{h_{fg}}}{x_e + \dfrac{\Delta h_s}{h_{fg}}} \qquad (5.5\text{-}8)$$

where

x_c = Node instantaneous critical quality

Δh_s = Subcooling at channel inlet

x_e = Node instantaneous equilibrium quality

= $(h-h_f)/h_{fg}$

h = $h_\ell + x(h_v - h_\ell)$

x = $G_V/(G_V + G_\ell$

f. Should not the negative sign associated with R in Eq. (5.5-10) be positive? (Consequently, the numerator of Eq. (5.5-11) for R should have a negative sign.)

GE Response: 901.13(f)

PROPRIETARY - Provided by Reference 2

g. In view of question 901.f, is Eq. (5.5-12) correct?

GE Response: 901.13(g)

See question 901.13f.

h. What is the rationale for using Eq. (5.5-12) for transient critical power ratio (CPR) if TM(t) < TM(0) and using Eq. (5.5-13) if otherwise? Why is the linear relationship valid?

GE Response: 901.13(h)

PROPRIETARY - Provided by Reference 2

i. Which test data were used to obtain the α^H curve in Figure 5.5-4?

GE Respponse: 901.13(i)

PROPRIETARY - Provided by Reference 2

j. Is Eq. (5.6-5) correct or is area ratio missing in the first term on the right-hand side of Eq. (5.6-2)? Eq. (5.6-5) cannot be derived from Eqs. (5.6-2) and (5.6-4).

GE Response: 901.13(j)

There is an error in the jet pump equations. Equation 5.6-4 should read:

$$\frac{P_2 - P_1}{\rho_\ell} = -v_2\left(v_2 - v_1\frac{A_1}{A_2}\right) + B \qquad (5.6\text{-}4)$$

By combining Equations 5.6-2 and 5.6-4, the momentum source term is calculated to be:

$$B = \frac{A_3}{A_2}\,v_3\,(v_3 + v_1) + \frac{A_3}{A_2}v_1v_2 \qquad (5.6\text{-}5)$$

k. Is the final expression for Eq. (5.7-5) correct? [r_w is missing in the last term in the bracket. It should be a $r_w(r_w\text{-}r_f)$.]

GE Response: 901.13(k)

The correct expression for Equation 5.7-5, should include r_w in the last term in the bracket as follows:

$$\begin{aligned}(1 - x_i)\,W_i &= \int_o^{r_w} \rho_f v_a\,(1 - \alpha)\,2\pi r dr\\ &= 2\pi\rho_f v_{ag}\left(\frac{1}{3}\,\frac{r_f}{r_w}b\right) r_f^2\\ &\quad + 2\pi\rho_f v_{af}\left[\left(\frac{1 + a}{2}\right)\left(r_w^2 - r_f^2\right) - a r_w\left(r_w - r_f\right)\right]\end{aligned}$$

l. Why are the bypass fluid properties, instead of hydraulic in-channel properties, used in the kinetics calculations as stated on page 5-52?

GE Response: 901.13(l)

The vessel component provides the bypass density which is volume weighted with the in-channel density to provide an overall water density for each kinetics node. The overall water density is used to evaluate the kinetics parameters.

m. What is the experimental basis for the steam dryer efficiency curves shown in Figure 5.9-1? What are typical values of $v_{vd,1}$, $v_{vd,u}$, and Δx_d?

GE Response: 901.13(m)

PROPRIETARY - Provided by Reference 2

n. The transition from the spray regime to the submerged jet regime for the case of nonexistent two-phase level in the upper plenum is not clear. How is the void fraction used for this transition?

GE Response: 901.13(n)

If there is no two-phase level in the upper plenum, the void fraction is compared α_{tran} given by Equation 3.2-4. If $\alpha > \alpha_{tran}$, the spray mode is assumed, and if $\alpha < \alpha_{tran} - 0.1$, the submerged jet mode is assumed. In between a linear interpolation based on the void fraction between the two modes is applied.

o. Quasi-static momentum balance is used for the submerged jet model. How important is the temporal effect? Has any assessment been done?

GE Response: 901.13(o)

The assumption of a quasi-static momentum balance for the submerged jet model is justified since the velocity of the liquid coming out of the spray nozzles are much larger than the two-phase flow velocities in the upper plenum, and the transit time of the liquid from the spray nozzles to the upper tie plate is small.

The upper plenum model has been compared to test data from the SSTF test facility under transient conditions (See Section 5.4). The observed agreement with the data for this test is good justifying the quasi-static assumption in the model.

p. What are ρ_∞ and h_∞ in the submerged jet model? What profiles are used for density η, velocity f, and enthalphy ϕ?

GE Response: 901.13(p)

ρ_∞ and h_∞ are the ambient values for the density and enthalpy in the upper plenum. Linear profiles are used for the density and enthalpy, and a cosine profile is used for the velocity.

q. What is the basis for Eq. (5.11-1)? Provide justification.

GE Response: 901.13(q)

For the heat exchanger component, the user must specify a table of shell liquid level (SLL) versus shell void fraction and the elevation of the drain cooler inlet elevation relative to the bottom of the shell (EDC). The assumption is made that only liquid is present below the position of the liquid level and only vapor is present above the level. With this assumption the donor cell void fraction α_{DC} for flow from the shell to the drain cooler is:

$$\alpha_{DC} = \begin{cases} 0.0 & \text{if } SLL \geq EDC \\ 1.0 & \text{if } SLL \leq ECD - 0.05m \\ (EDC - SLL)/0.05 & \text{If } (ECD - 0.05m) < SLL < EDC \end{cases}$$

The 5 cm for linear interpolation of the donor-celled void fraction provides a gradual change in α_{DC} as the drain cooler inlet is uncovered.

The validity of the α_{DC} modeling is dependent on an accurate user specification of the shell liquid level versus void fraction and the applicability of the above and below void fraction assumptions. If the assumptions or input requirements are not appropriate for a particular application, the user has the option to use other components to model the shell side of the heat exchanger in more detail. The generalized component-to-component heat transfer is then used to model the heat transfer between the tubes and shell.

r. Why is it necessary to have only one cell for the steam shell in the heat exchanger model? What is the impact of this simplification?

GE Response: 901.13(r)

The heat exchanger component allows the user to simulate typical heat exchangers with a minimum number of cells. To accomplish this, the model requires that the details of the shell side geometry be provided as a function of shell average void fraction. The user supplied tables of shell liquid level versus void fraction and fraction of tubes covered by liquid versus liquid level provide the basis for determining the detailed shell internal conditions. If the assumptions or input requirements of the heat exchanger component are not appropriate for a particular application, the user has the option to use other components to model the shell side of the heat exchanger in more detail. The generalized component-to-component heat transfer is then used to model the heat transfer between the tubes and shell.

s. Is the heat exchanger model adequate to represent the isolation condenser in the SBWR? How is the non-uniform temperature distribution in the tube bundle and IC pool taken into account?

GE Response: 901.13(s)

The IC is simulated in a similar fashion as the PCC using the component to component heat transfer option, and using the UCB correlation for the condensation heat transfer. The IC behavior is characterized by condensation from a uniform pressure vapor stream to the IC pool. The pool is assumed to be saturated. This assumption will give a conservative result for the overall heat removal, which is adequate for integrated system analysis. The need for more detailed modeling will be determined based on comparisons with the PANTHERS data.

RAI Number 901.14

Question:

Respond to the following questions on the numerical method described in NEDE-32176P:

a. In the lumped heat slab model, the source term is neglected as in Eq. (6.1-5). How can the direct energy deposition (say, due to gamma ray) be accounted for in such a model? Where are Eqs. (6.1-1) through (6.1-4)?

b. The transition from Eq. (6.1-11) to Eq. (6.1-12) is not obvious. What is $\tilde{T}_w^{n+1}$ on the right-hand side of Eq. (6.1-12)? How are $\frac{\partial T_w}{\partial T_\ell}$ and $\frac{\partial T_w}{\partial T_v}$ evaluated?

c. Is Eq. (6.1-12) correct? Using it, one cannot get Eqs. (6.1-13) and (6.1-14).

d. Are Eqs. (6.1-15) and (6.1-17) correct? Δs should be associated with the first two terms on the right-hand side of these equations.

e. Why is Δt in Eq. (6.1-20)?

f. What has happened to $\Delta\tilde{T}_w^{n+1}$ term of Eq. (6.1-19) in Eqs. (6.1-21) through (6.1-25)?

g. What is Δs in the last term of Eq. (6.1-26)? Should not the first two terms on the right-hand side of this equation have Δz with them?

h. What is Δs in the last term of Eq. (6.1-29)? Is it Δr_{N-1}? Should not the first two terms on the right-hand side of this equation have Δz associated with them? Also the Δ_{N-1} in the first term associated with q" should be Δr_{N-1}.

i. Why is Δt in Eq. (6.1-34)?

j. What has happened to $\Delta\tilde{T}_w^{n+1}$ term of Eq. (6.1-33) in Eqs. (6.1-35) through (6.1-39)?

k. In the predicator-corrector method, the corrector step attempts to conserve precisely only the mixture mass. Is not the precise energy conservation equally important? How can one be sure that energy is adequately conserved?

l. The boron conservation equations in Section 6.3.3.2 appear to have made the assumption that the boron solution is perfectly mixed with the liquid.

This being the case, how can it model the imperfect mixing at low flow conditions and the potential boron stratification in the lower plenum?

a. In the lumped heat slab model, the source term is neglected as in Eq. (6.1-5). How can the direct energy deposition (say, due to gamma ray) be accounted for in such a model? Where are Eqs. (6.1-1) through (6.1-4)?

GE Response: 901.14(a)

There is no source term in the neither the lumped slab model nor the 1-dimensional slab model in the vessel component and any direct deposition in these slabs are neglected. In a BWR approximately 4% of the energy is deposited outside the fuel, and most of that is deposited in the liquid and is due to the slowing down of the neutrons. Any direct depositions in structural materials outside the channels is insignificant.

The numbering of the equations in this section was inadvertently started at number 5 instead of number 1.

b. The transition from Eq. (6.1-11) to Eq. (6.1-12) is not obvious. What is $\tilde{T}_w^{n+1}$ on the right-hand side of Eq. (6.1-12)? How are $\frac{\partial T_w}{\partial T_\ell}$ and $\frac{\partial T_w}{\partial T_v}$ evaluated?

GE Response: 901.14(b)

PROPRIETARY - Provided by Reference 2

c. Is Eq. (6.1-12) correct? Using it, one cannot get Eqs. (6.1-13) and (6.1-14).

GE Response: 201.14(c)

When equation 6.1-12 is substituted into Equation 6.1-9, one gets:

$$\begin{aligned} q_{w\ell}^{n+1} = q_{w\ell}^{n} - \theta\frac{\partial q_{w\ell}}{\partial T_\ell}\Bigg[\Delta\tilde{T}_w^{n+1} &+ \left(\frac{\partial T_w}{\partial T_\ell} - 1\right)\Delta T_\ell^{n+1} \\ &+ \left(\frac{\partial T_w}{\partial T_v}\right)\Delta T_v^{n+1}\Bigg] \end{aligned} \qquad (6.1\text{-}13)$$

$$\Delta\tilde{T}_w^{n+1} = \frac{-\Delta t\left(q_{w\ell}^{n} + q_{wv}^{n}\right)}{MC_{pw}^{n} - \Delta t\theta\left(\frac{\partial q_{w\ell}}{\partial T_\ell} + \frac{\partial q_{wv}}{\partial T_v}\right)}$$

$$\frac{\partial T_w}{\partial T_\ell} = \frac{-\Delta t\theta\,\frac{\partial q_{w\ell}}{\partial T_\ell}}{MC_{pw}^{n} - \Delta t\theta\left(\frac{\partial q_{w\ell}}{\partial T_\ell} + \frac{\partial q_{wv}}{\partial T_v}\right)}$$

$$\frac{\partial T_w}{\partial T_v} = \frac{-\Delta t\theta\,\frac{\partial q_{wv}}{\partial T_v}}{MC_{pw}^{n} - \Delta t\theta\left(\frac{\partial q_{w\ell}}{\partial T_\ell} + \frac{\partial q_{wv}}{\partial T_v}\right)}$$

Similar equations can be obtained for the vapor phase:

$$\begin{aligned} q_{wv}^{n+1} = q_{wv}^{n} - \theta\frac{\partial q_{wv}}{\partial T_v}\Bigg[\Delta\tilde{T}_w^{n+1} &+ \left(\frac{\partial T_w}{\partial T_\ell}\right)\Delta T_\ell^{n+1} \\ &+ \left(\frac{\partial T_w}{\partial T_v} - 1\right)\Delta T_v^{n+1}\Bigg] \end{aligned} \qquad (6.1\text{-}14)$$

In the TRACG implementation the first two terms which are constant in these equations have been combined into the first term.

d. Are Eqs. (6.1-15) and (6.1-17) correct? Δs should be associated with the first two terms on the right-hand side of these equations.

GE Response: 901.14(d)

Equations 6.1-15 and 6.1-17 are the energy balance for the first and last node in the slab per unit surface area. The left hand side is the change in stored energy. On the right hand side, the first two terms are the heat flux to the fluid, which are functions of the surface and fluid temperatures, but independent of the node thickness. The last two terms on the right hand side represent heat conduction in the slab and energy generation, both of which are associated with the node thickness Δs.

e. Why is Δt in Eq. (6.1-20)?

GE Response: 901.14(e)

PROPRIETARY - Provided by Reference 2

f. What has happened to $\Delta \tilde{T}_w^{n+1}$ term of Eq. (6.1-19) in Eqs. (6.1-21) through (6.1-25)?

GE Response: 901.14(f)

PROPRIETARY - Provided by Reference 2

g. What is Δs in the last term of Eq. (6.1-26)? Should not the first two terms on the right-hand side of this equation have Δz with them?

GE Response: 901.14(g)

Equations 6.1-26 is the energy balance for the first node in the cylinder per unit length. The left hand side is the change in stored energy. On the right hand side, the first two terms are the heat flux to the fluid, which are functions of the surface and fluid temperatures, but independent of the node thickness. The last two terms on the right hand side represent heat conduction in the cylinder and energy generation.

$$\left(r_1\Delta r_1 + \frac{\Delta r_1^2}{4}\right) \rho_1 C_{p1}^n \ \Delta T_{w,1}^{n+1} =$$

$$\begin{aligned}
&-2r_1\Delta t H_{w\ell i}^n \left[T_{w,1}^n - T_{\ell i}^n + \theta\left(\Delta T_{w,1}^{n+1} - \Delta T_{\ell i}^{n+1}\right)\right] \\
&-2r_1\Delta t H_{wvi}^n \left[T_{w,1}^n - T_{vi}^n + \theta\left(\Delta T_{w,1}^{n+1} - \Delta T_{vi}^{n+1}\right)\right] \qquad (6.1\text{-}26) \\
&+2r_{1+\frac{1}{2}}\Delta t k_{1+\frac{1}{2}}^n \ \frac{T_{w,2}^n - T_{w,1}^n + \zeta\left(\Delta T_{w,2}^{n+1} - \Delta T_{w,1}^{n+1}\right)}{\Delta r_1} \\
&+\left(r_1\Delta r_1 + \frac{\Delta r_1^2}{4}\right) \Delta t \ q'''
\end{aligned}$$

h. What is Δs in the last term of Eq. (6.1-29)? Is it Δr_{N-1}? Should not the first two terms on the right-hand side of this equation have Δz associated with them? Also the Δ_{N-1} in the first term associated with q" should be Δr_{N-1}.

GE Response: 901.14(h)

Equations 6.1-29 is the energy balance for the last node in the cylinder per unit length. The left hand side is the change in stored energy. On the right hand side, the first two terms are the heat flux to the fluid, which are functions of the surface and fluid temperatures, but independent of the node thickness. The last two terms on the right hand side represent heat conduction in the cylinder and energy generation, both of which are associated with the node thickness Δr.

$$\left(r_N\Delta r_{N-1} - \frac{\Delta r_{N-1}^2}{4}\right) \rho_N C_{pN}^n \ \Delta T_{w,N}^{n+1} =$$

$$\begin{aligned}
&-2r_N\Delta t H_{w\ell o}^n \left[T_{w,N}^n - T_{\ell o}^n + \theta\left(\Delta T_{w,N}^{n+1} - \Delta T_{\ell o}^{n+1}\right)\right] \\
&-2r_N\Delta t H_{wvo}^n \left[T_{w,N}^n - T_{vo}^n + \theta\left(\Delta T_{w,N}^{n+1} - \Delta T_{vo}^{n+1}\right)\right] \qquad (6.1\text{-}29) \\
&+2r_{N-\frac{1}{2}}\Delta t k_{N-\frac{1}{2}}^n \ \frac{T_{w,N-1}^n - T_{w,N}^n + \zeta\left(\Delta T_{w,N-1}^{n+1} - \Delta T_{w,N}^{n+1}\right)}{\Delta r_{n-1}} \\
&+ \Delta t q''' \left(r_N\Delta r_{N-1} - \frac{\Delta r_{N-1}^2}{4}\right)
\end{aligned}$$

i. Why is Δt in Eq. (6.1-34)?

GE Response: 901.14(i)

PROPRIETARY - Provided by Reference 2

j. What has happened to $\Delta \tilde{T}_w^{n+1}$ term of Eq. (6.1-33) in Eqs. (6.1-35) through (6.1-39)?

GE Response: 901.14(j)

PROPRIETARY - Provided by Reference 2

k. In the predictor-corrector method, the corrector step attemps to conserve precisely only the mixture mass. Is not the precise energy conservation equally important? How can one be sure that energy is adequately conserved?

GE Response: 901.14(k)

PROPRIETARY - Provided by Reference 2

1. The boron conservation equations in Section 6.3.3.2 appear to have made the assumption that the boron solution is perfectly mixed with the liquid. This being the case, how can it model the imperfect mixing at low flow conditions and the potential boron stratification in the lower plenum?

GE Response: 901.14(l)

The boron is assumed to be perfectly mixed with the liquid in a given computational cell, and is assumed to be transported with the liquid velocity. Stratification of the boron is primarily due to the increased density of the cold water with which the boron is injected, the added density due to the dissolved boron is a second order effect.

TRACG has a multi-dimensional solution in the vessel component where boron is injected. When cold borated water is injected into a cell, the density of that cell will be higher than the density of the neighboring cells. As a consequence the higher static head of the liquid in the cell where boron is injected will cause a downflow of fluid from that cell compared to the neighboring cells. The multi-dimensional solution automatically has the capability to calculate stratification and no special model is needed as is the case for one-dimensional models.

RAI Number 901.15

Question:

Respond to the following questions on the three-dimensional kinetics model described in NEDE-32176P:

a. Has any assessment been done of the acceptability of assumptions (7.1-2) and (7.1-3)? (Note that the spatial distributions of the fast and thermal neutrons are indeed very different and that the neutron spectrum does change a lot during a large amplitude power oscillation when the void fraction in the core changes between 0.1 and 0.99.)

b. Is Eq. (7.1-7) correct? The product of $(1+M_2^2 B_2 + \tau/\Sigma_2 v_2)$ and $(1+M_2^2 B_2 + \tau/\Sigma_3 v_3)$, which can be approximated to $[1+(M_2^2 + M_2^2)\cdot B_2 + (1/\Sigma_2 v_2 + 1/\Sigma_3 v_3)\tau]$, is missing in the last term of the equation. What is the impact of neglecting this?

c. What is the justification for neglecting the term involving τ in Eq. (7.1-11)?

d. The choice of neutron flux as the weighting function instead of the adjoint flux leads to a residual reactivity [see Trans. Am. Nucl. Soc., 24, 470 (1979)]. What is the impact of using self adjoint?

e. Is the expression for $\overline{\beta}_n$ correct? $\overline{\beta}_n$ is missing in the integrand and $\frac{K_\infty}{\mu_0} - 1$ should be $\frac{K_\infty}{\mu_0}$.

f. Is Eq. (7.1-20) correct? There seems to be an extra term and a dot is missing in the leakage term.

g. How is the factor 8 derived in Eq. (7.1-23)?

h. An average v_i is used in Eq. (7.1-26) with the assumption $v_1 = v_2 = v_3 = v$. How is the average v determined? What is the error on the nodal power from this assumption?

i. How is the spectral mismatch correction ΔK_i calculated?

j. Why are M^2, D_1, Σ_1, and A_∞ treated as a function of U only?

k. Does the Doppler coefficient depend on exposure?

l. What is f in Eq. (7.3-2)? It is not defined.

m. Which experimental data were used to determine the decay heat parameters f_k and λ_k? What are their values?

n. Is the exponent 36 in Eq. (7.4-15) correct?

o. Is it sufficiently accurate to use the thermal-hydraulic time step for point kinetics calculations? (Note that the thermal- hydraulic time step can take 250 msec or more.)

p. How often is the shape function recalculated in a typical transient? Is the update of the shape function automatically controlled?

a. Has any assessment been done of the acceptability of assumptions (7.1-2) and (7.1-3)? (Note that the spatial distributions of the fast and thermal neutrons are indeed very different and that the neutron spectrum does change a lot during a large amplitude power oscillation when the void fraction in the core changes between 0.1 and 0.99.)

GE Response: 901.15(a)

The assumptions implicit in Equations (7.1-2) and (7.1-3) are in the one and one-half group method. Equation (7.1-2) has been tested numerous times over a wide range of void fractions from zero to 70%. Equation (7.1-3), on the other hand, is tested in the context of the qualification tests simulating the SPERT and the Peach Bottom turbine trips.

b. Is Eq. (7.1-7) correct? The product of $(1+M_2^2B_2 + \tau/\Sigma_2 v_2)$ and $(1+M_2^2B_2 + \tau/\Sigma_3 v_3)$, which can be approximated to $[1+(M_2^2 + M_2^2)\bullet B_2 + (1/\Sigma_2 v_2 + 1/\Sigma_3 v_3)\tau]$, is missing in the last term of the equation. What is the impact of neglecting this?

GE Response: 901.15(b)

Equation (7.1-7) is derived assuming terms involving power and cross products of B^2, τ, and $\dot{C}_n$ are small and may be neglected. With this assumption,

$$\frac{\sum_{n=1}^{N} \dot{C}_n}{\Sigma_1 \ \phi_1}\left[1 + \left(M_2^2 + M_3^2\right) B^2 + \left(1/\Sigma_2 v_2 + 1/\Sigma_3 v_3\right)\tau\right] = \frac{\sum_{n=1}^{N} \dot{C}_n}{\Sigma_1 \phi_1}$$

Equation (7.1-7) is therefore as intended and only cross products have been neglected.

c. What is the justification for neglecting the term involving τ in Eq. (7.1-11)?

GE Response: 901.15(c)

Substituting the effective velocity v^* and assuming $\mu_o \approx 1$, the term involving τ in the precursor equation can be written as:

$$\frac{\tau}{\Sigma_1}\left(\frac{1}{v_1} - \frac{1}{v^*}\right) \approx \frac{\tau}{\Sigma_1 v^*} \ (\text{for } v_1 >> v^*)$$

For typical BWR conditions, $\Sigma_i \approx 0.03 \text{ cm}^{-1}$ and $v^* \approx 10^6$ cm/sec. The value of τ for BWR transients is in the range of 10 – 20 sec^{-1}. Therefore,

$$\frac{\tau}{\Sigma_1}\left(\frac{1}{v_1} - \frac{1}{v^*}\right) < 0.001$$

This term is much less than the value of K_∞ and may be neglected.

d. The choice of neutron flux as the weighting function instead of the adjoint flux leads to a residual reactivity [see Trans. Am. Nucl. Soc., 24, 470 (1979)]. What is the impact of using self adjoint?

GE Response: 901.15(d)

TRACG utilizes a one-group transient diffusion equation. For a one-group model, the adjoint flux ϕ^* is equal to the flux ϕ. The reference article dealing with multi-group methods recommends the use of the initial adjoint flux as the weighting function in the derivation of point kinetics reactivity. TRACG is consistent with this recommendation in the factorization of the flux and derivation of the amplitude parameters. The residual reactivity noted in the article is a result of the approximation $(W, M\phi) \approx (W, \Delta M\phi)$. TRACG does not make this approximation by maintaining the reactivity in the form $(W, M\phi)$.

e. Is the expression for $\overline{\beta}_n$ correct? $\overline{\beta}_n$ is missing in the integrand and $\frac{K_\infty}{\mu_0} - 1$ should be $\frac{K_\infty}{\mu_0}$.

GE Response: 901.15(e)

PROPRIETARY - Provided by Reference 2

f. Is Eq. (7.1-20) correct? There seems to be an extra term and a dot is missing in the leakage term.

GE Response: 901.15(f)

PROPRIETARY - Provided by Reference 2

g. How is the factor 8 derived in Eq. (7.1-23)?

GE Response: 901.15(g)

PROPRIETARY - Provided by Reference 2

h. An average ν_i is used in Eq. (7.1-26) with the assumption $\nu_1 = \nu_2 = \nu_3 = \nu$. How is the average ν determined? What is the error on the nodal power from this assumption?

GE Response: 901.15(h)

PROPRIETARY - Provided by Reference 2

i. How is the spectral mismatch correction ΔK_i calculated?

GE Response: 901.15(i)

PROPRIETARY - Provided by Reference 2

j. Why are M^2, D_1, Σ_1, and A_∞ treated as a function of U only?

GE Response: 901.15(j)

D_1 and Σ_1 are fast neutron parameters which are very weak functions of the fuel exposure. They are however, strong functions of the amount of water in the lattice and therefore are treated as functions of the relative water density. Likewise, M^2 is principally a fast neutron parameter. It has a component which is the thermal neutron migration area (which does depend on fuel exposure) but this component is small relative to the total migration area. Therefore to a good approximation, the effect of fuel exposure on the total may be neglected. A_∞ is a very small adjustment to the migration area and therefore, using the same reasoning, the exposure dependence may be neglected.

k. Does the Doppler coefficient depend on exposure?

GE Response: 901.15(k)

Section 7.2 should have indicated that the Doppler coefficient C_T is a function of exposure and relative water density.

l. What is f in Eq. (7.3-2)? It is not defined.

GE Response: 901.15(l)

PROPRIETARY - Provided by Reference 2

m. Which experimental data were used to determine the decay heat parameters f_k and λ_k? What are their values?

GE Response: 901.15(m)

PROPRIETARY - Provided by Reference 2

n. Is the exponent 36 in Eq. (7.4-15) correct?

GE Response: 901.15(n)

PROPRIETARY - Provided by Reference 2

o. Is it sufficiently accurate to use the thermal-hydraulic time step for point kinetics calculations? (Note that the thermal- hydraulic time step can take 250 msec or more.)

GE Response: 901.15(o)

PROPRIETARY - Provided by Reference 2

p. How often is the shape function recalculated in a typical transient? Is the update of the shape function automatically controlled?

GE Response: 901.15(p)

PROPRIETARY - Provided by Reference 2

RAI Number 901.16

Question:

Response to the following questions on Appendices B and C of NEDE-32176P:

a. What are the uncertainties on the thermodynamic properties? Has any comprehensive assessment been done to determine the accuracy of these property fits or correlations, especially at low pressure near the atmospheric pressure?

b. What are the uncertainties on the material properties? Has any comprehensive assessment been done on these material property correlations or data?

a. What are the uncertainties on the thermodynamic properties? Has any comprehensive assessment been done to determine the accuracy of these property fits or correlations, especially at low pressure near the atmospheric pressure?

GE Response: 901.16(a)

The thermodynamic properties used in TRACG are consistent with the properties used in TRAC-BF1 and TRAC-PF1. The properties have been assessed (TRAC-PF1/Mod 1, Correlations and Models, Appendix A) and found to provide good agreement with steam table data over a wide range of conditions. Additional assessment by GE has confirmed the performance of the property fits over the expected range of application including low pressure.

b. What are the uncertainties on the material properties? Has any comprehensive assessment been done on these material property correlations or data?

GE Response: 901.16(b)

The material properties in TRACG for BWR simulation are consistent with the properties found in the GE BWR Materials Properties Handbooks. The properties contained in these handbooks are verified and controlled and must be used for all design applications. The application of these material properties in TRACG is consistent with all other licensed GE computer codes.

RAI Number 901.17

Question:

Respond to the following miscellaneous questions on NEDE-32176P:

a. In Section 3.1, the liquid energy balance Eq. (3.1-7) is given. However, in Section 6.2, the mixture energy Eq. (6.2-9) is used. Which one is actually used in the code?

b. Should not the hydraulic diameter D_h be in the numerator in Eq. (3.2-14) for the Reynolds number?

c. Should not ρ_ℓ in Eq. (3.2-40) be ρ_v?

d. Should not $<j>$ in Eq. (3.2-52) be $<j_v>$? What are m and K in Eq. (3.2-54)?

e. Is D_B in Eq. (3.2-91) d_b?

f. What is the correlation used for T_{min} in Eq. (3.2-120)?

g. Should not H be Hi and the summation be over j in Eq. (3.2-148)?

h. What are α_d and d_d in Eq. (3.2-166)?

i. What is t_{ij} in Eqs. (3.2-171), (3.2-174), and (3.2-175)? Is it τ_{ij}?

j. Should not the summation over J be j in Eqs. (3.2-171) and (3.2-172)?

k. Should not R_{c0} in Eq. (4.2-17) be R_{fo}?

l. The motor torque T_m in Eq. (5.2-14) is stated to be defined via the control system. How is this done, automatically by TRACG or by the user?

m. Is H_d on page 5-40 the same as H_D?

n. Why is the steam line not connected to the steam dome in Figure 5.8-3? As such, the wet steam will flow to the steam line.

o. What is the variable s in Eqs. (5.10-2) through (5.10-5)? It appears that s is the spatial variable of the trajectory and that the time dependency is neglected. How important is the temporal effect?

p. Is $V - \nabla V$ on page 5-69 correct? Should it be $V \bullet \nabla V$?

q. Should not the minus sign for the convective term in Eq. (6.1-15) be a plus sign?

r. Should not $\Delta r_M^2 / 4$ on the left-hand side of Eq. (6.1-31) be $\Delta r_{M+1}^2 / 4$?

s. Should not the minus sign associated with the virtual mass term in Eqs. (6.2-6), (6.2-15), (6.2-17), and (6.3-13) be a plus sign?

t Should not v_{dR} in the virtual mass term in Eq. (6.2.12) be v_{dZ}?

u. Should not ρ_g associated with Fw in Eq. (6.2-17) be ρ_ℓ?

v. Should not the subscript j of the last term in Eq. (6.3-9) be j-1?

w. Should not $\partial v_{gz} / \partial R$ in Eq. (6.3-13) be $\partial v_{\ell z} / \partial R$?

x. Should not $\Delta^2 P_{IJK}$ in Eq. (6.3-52) be ΔP_{IJK}?

y. Shou'd not the minus sign associated with $\tau / \Sigma_2 v_2$ in the third term on the right-hand side of Eq. (7.1-6) be a plus sign?

z. Should not ϕ at left-hand side of Eq. (7.1-13) be ϕ_1?

aa. Should not v_1 in Eqs. (7.1-16) and (7.1-18) be v^*?

bb. Should not λ_n in Eq. (7.1-19) be $\overline{\lambda}_n$.?

cc. Is the expression for total $\overline{\beta}$ correct? (The subscript n on the left-hand side should not be there.)

dd. Should not β in the expression for M^{*2} be $\overline{\beta}$?

ee. Should not S' and C_n in the expression for S_t on page 7-13 be $\overline{S}'$ and $\overline{C}_n$, the spatial average over a cell?

ff. Should not Δ^2 in Eq. (7.1-24) be Δ_{ij}^2?

a. In Section 3.1, the liquid energy balance Eq. (3.1-7) is given. However, in Section 6.2, the mixture energy Eq. (6.2-9) is used. Which one is actually used in the code?

GE Response: 901.17(a)

In the TRACG solution the vapor and mixture energy equations are used. It does not matter which equation is used, since the mixture energy is the sum of the vapor and liquid energy.

b. Should not the hydraulic diameter D_h be in the numerator in Eq. (3.2-14) for the Reynolds number?

GE Response: 901.17(b)

Equation 3.2-14 should read:

$$Re_k = \frac{G\ D_h}{\mu_k} \qquad (3.2\text{-}14)$$

c. Should not ρ_ℓ in Eq. (3.2-40) be ρ_v?

GE Response: 901.17(c)

Equation 3.2-40 should read:

$$\rho_c = \rho_v \qquad (3.2\text{-}40)$$

d. Should not $<j>$ in Eq.(3.2-52) be $<j_v>$? What are m and K in Eq. (3.2-54)?

GE Response: 901.17(d)

Equation 3.2-52 should read:

$$\sqrt{\frac{< j_v >}{j_{vo}}} + \sqrt{\frac{< j_\ell >}{j_{\ell o}}} = 1 \qquad (3.2\text{-}1)$$

m and K are constants in the CCFL correlation, typical values are m=1 and K=3.2–4.2.

e. Is D_B in Eq. (3.2-91) d_b?

GE Response: 901.17(e)

Equation 3.2-91 should read:

$$H_{iv} = \frac{2}{3} \pi^2 \frac{k_v}{d_b} \left\{ 2.7 \frac{\mu_\ell}{\mu_v} \right\} \tag{3.2-91}$$

f. What is the correlation used for T_{min} in Eq. (3.2-120)?

GE Response: 901.17(f)

T_{min} is described in Section 3.2.10.10 and is given by Equations 3.2-144 and 3.2-146.

g. Should not H be Hi and the summation be over j in Eq. (3.2-148)?

GE Response: 901.17(g)

Equation 3.2-148 should read:

$$H_i = \sum_j H_{ji} \tag{3.2-148}$$

h. What are α_d and d_d in Eq. (3.2-166)?

GE Response: 901.17(h)

Equation 3.2-166 should read:

$$a_\ell = 1.11 \frac{\alpha_d}{d_d} \tag{3.2-166}$$

α_d is the droplet volume fraction and d_d is the droplet diameter.

i. What is t_{ij} in Eqs. (3.2-171), (3.2-174), and (3.2-175)? Is it τ_{ij}?

GE Response: 901.17(i)

Yes. Equation 3.2-171, 3.2-174 and 3.2-175 should read:

$$Q_{abs,v} = \sum_i \sum_j A_i \left(F_{ij} \; B_i^I + B_{ij}^A \right) \left(1 - \tau_{ij} \right) \frac{a_{vij}}{a_{vij} + a_{\ell ij}} \tag{3.2-171}$$

$$q_{i,v} = \sum_{j} \left\{ \left(F_{ij}\ B_i^I + B_{ij}^A \right) \left(1 - \tau_{ij} \right) \frac{a_{vij}}{a_{vij} + a_{\ell ij}} - F_{ij}\ \varepsilon_{vij}\ S_v \right\} \qquad (3.2\text{-}174)$$

$$q_{i,\ell} = \sum_{j} \left\{ \left(F_{ij}\ B_i^I + B_{ij}^A \right) \left(1 - \tau_{ij} \right) \frac{a_{\ell ij}}{a_{vij} + a_{\ell ij}} - F_{ij}\ \varepsilon_{\ell ij}\ S_\ell \right\} \qquad (3.2\text{-}175)$$

j. Should not the summation over J be j in Eqs. (3.2-171) and (3.2-172)?

GE Response: 901.17(j)

Yes. Equations 3.2-171 and 3.2-172 should read:

$$Q_{abs,v} = \sum_{i} \sum_{j} A_i \left(F_{ij}\ B_i^I + B_{ij}^A \right) \left(1 - \tau_{ij} \right) \frac{a_{vij}}{a_{vij} + a_{\ell ij}} \qquad (3.2\text{-}171)$$

$$Q_{emit,v} = \sum_{i} \sum_{j} A_i\ \varepsilon_{mij}\ \frac{\varepsilon_{vij} S_v}{\varepsilon_{vij} + \varepsilon_{\ell ij}}\ F_{ij} \qquad (3.2\text{-}172)$$

k. Should not R_{c0} in Eq. (4.2-17) be R_{fo}?

GE Response: 901.17(k)

PROPRIETARY - Provided by Reference 2

l. The motor torque T_m in Eq. (5.2-14) is stated to be defined via the control system. How is this done, automatically by TRACG or by the user?

GE Response: 901.17(l)

The control system to define the pump motor torque is user specified to model the dynamics of the pump motor. For MG set plants, the recirculation control system describes the relationship between load demand and recirculation pump motor dynamics including the dynamics of the drive motor, generator, and coupler.

m. Is H_d on page 5-40 the same as H_D?

GE Response: 901.17(m)

Yes.

n. Why is the steam line not connected to the steam dome in Figure 5.8-3? As such, the wet steam will flow to the steam line.

GE Response: 901.17(n)

In Figure 5.8-3, the steam line is connected to the steam dome. The outer edge of the dryer region (ring 3) is a solid boundary simulating the dryer skirt. The water level normally covers this skirt sealing off this passage to the steam line. Steam must pass vertically through the dryer region before entering the dome and steam line. Passing through the dryer prevents wet steam from entering the steam line.

o. What is the variable s in Eqs. (5.10-2) through (5.10-5)? It appears that s is the spatial variable of the trajectory and that the time dependency is neglected. How important is the temporal effect?

GE Response: 901.17(o)

s is the spatial variable along the trajectory. The trajectory is calculated using a quasi-static approximation. See question 901.13o for a discussion of the quasi-static approximation.

p. Is $V - \nabla V$ on page 5-69 correct? Should it be $V \bullet \nabla V$?

GE Response: 901.17(p)

Yes. On page 5-69, the terms $V - \nabla V$ should be $V \bullet \nabla V$.

q. Should not the minus sign for the convective term in Eq. (6.1-15) be a plus sign?

GE Response: 901.17(q)

Equation 6.1-15 should be:

$$\begin{aligned}\Delta s \rho_1 C^n_{p1}\ \Delta T^{n+1}_{w,1} = &-\Delta t H^n_{w\ell i}\left[T^n_{w,1} - T^n_{\ell,i} + \theta\left(\Delta T^{n+1}_{w,1} - \Delta T^{n+1}_{\ell,i}\right)\right]\\ &-\Delta t H^n_{wvi}\left[T^n_{w,1} - T^n_{vi} + \theta\left(\Delta T^{n+1}_{w,1} - \Delta T^{n+1}_{vi}\right)\right]\end{aligned} \qquad (6.1\text{-}15)$$

$$+\ \Delta t k^n_{1+\frac{1}{2}}\ \frac{T^n_{w,2} - T^n_{w,1} + \zeta\left(\Delta T^{n+1}_{w,2} - \Delta T^{n+1}_{w,1}\right)}{\Delta s} + \Delta t\ q'''\ \Delta s$$

r. Should not $\Delta r^2_M / 4$ on the left-hand side of Eq. (6.1-31) be $\Delta r^2_{M+1} / 4$?

GE Response: 901.17(r)

Equation 6.1-31 should be:

$$\left(r_{M+1}\Delta r_{M+1} + \frac{\Delta r^2_{M+1}}{4}\right)\rho_{M+1}C^n_{pM+1}\ \Delta T^{n+1}_{w,M} =$$

$$\begin{aligned}&+\ 2r_{M+\frac{3}{2}}\Delta t\, k^n_{M+\frac{3}{2}}\ \frac{T^n_{w,M+2} - T^n_{w,M+1} + \zeta\left(\Delta T^{n+1}_{w,M+2} - \Delta T^{n+1}_{w,M+1}\right)}{\Delta r_{M+1}}\\ &+\ 2r_{M+\frac{1}{2}}\Delta t\, H^n_{gap}\left[T^n_{w,M} - T^n_{w,M+1} + \zeta\left(\Delta T^{n+1}_{w,M} - \Delta T^{n+1}_{w,M+1}\right)\right]\\ &+\ \Delta t q'''\left(r_{M+1}\Delta r_{M+1} + \frac{\Delta r^2_{M+1}}{4}\right)\end{aligned} \qquad (6.1\text{-}31)$$

s. Should not the minus sign associated with the virtual mass term in Eqs. (6.2-6), (6.2-15), (6.2-17), and (6.3-13) be a plus sign?

GE Response: 901.17(s)

The term should be equal and of opposite sign to the corresponding term in the vapor equations. The relative velocity is defined as the vapor velocity minus the liquid velocity.

t. Should not v_{dR} in the virtual mass term in Eq. (6.2.12) be v_{dZ}?

GE Response: 901.17(t)

Equation 6.2-12 should be:

$$\frac{\partial}{\partial t} v_{vZ,I+1/2,J,K} + \left[v_{vZ} \left(\frac{\partial v_{vZ}}{\partial Z} \right)^{d} + v_{vR} \left(\frac{\partial v_{vZ}}{\partial R} \right)^{d} + \frac{v_{v\Theta}}{R} \left(\frac{\partial v_{vZ}}{\partial \Theta} \right)^{d} \right]_{I+1/2,J,K}$$

$$+ \left(\frac{k\rho_c}{\alpha\rho_v} \right)_{I+1/2,J,K} \left[\frac{\partial}{\partial t} v_{RZ} + v_{dZ} \left(\frac{\partial v_{RZ}}{\partial Z} \right)^{d} \right]_{I+1/2,J,K} =$$

$$- \frac{1}{\rho_{v,I+1/2,J,K}} \frac{P_{I+1,J,K} - P_{I,J,K}}{\Delta z_{I+1/2}} \qquad (6.2\text{-}12)$$

$$- \left[\bar{g} + \frac{1}{\alpha\rho_v} \bar{f}_{\ell v} + \frac{1}{\rho_v} \bar{\bar{F}}_w \right]_{Z,I+1/2,J,K} + B_{vZ,I+1/2,J,K}$$

u. Should not ρ_g associated with Fw in Eq. (6.2-17) be ρ_ℓ?

GE Response: 901.17(u)

Equation 6.2-17 should be:

$$\frac{\partial}{\partial t} v_{\ell\Theta,I,J,K+1/2}$$

$$+ \left[v_{\ell Z} \left(\frac{\partial v_{\ell\Theta}}{\partial Z} \right)^{d} + v_{\ell R} \left(\frac{\partial v_{\ell\Theta}}{\partial R} \right)^{d} + \frac{v_{\ell\Theta}}{R} \left(\frac{\partial v_{\ell\Theta}}{\partial \Theta} \right)^{d} + \frac{v_{\ell\Theta} v_{\ell R}}{R} \right]_{I,J,K+1/2}$$

$$- \left[\frac{k\rho_c}{(1-\alpha)\rho_\ell} \right]_{I,J,K+1/2} \left[\frac{\partial}{\partial t} v_{R\Theta} + \frac{v_{d\Theta}}{R} \left(\frac{\partial v_{R\Theta}}{\partial \Theta} \right)^{d} \right]_{I,J,K+1/2} \qquad (6.2\text{-}17)$$

$$= - \frac{1}{\rho_{\ell,I,J,K+1/2}} \frac{P_{I,J,K+1} - P_{I,J,K}}{R_{J+1/2}\ \Delta\Theta_{K+1/2}}$$

$$- \left[\frac{-1}{(1-\alpha)\rho_\ell} \bar{f}_{\ell v} + \frac{1}{\rho_\ell} \bar{\bar{F}}_w \right]_{\Theta,I,J,K+1/2} + B_{\ell\Theta,I,J,K+1/2}$$

v. Should not the subscript j of the last term in Eq. (6.3-9) be j-1?

GE Response: 901.17(v)

Equation 6.3-9 should be:

$$\phi_j^{n+1,m} - \phi_j^n = -C\left(\phi_j^{n+1,m} - \phi_{j-1}^{n+1,m-1}\right) \qquad (6.3\text{-}9)$$

w. Should not $\partial v_{gz}/\partial R$ in Eq. (6.3-13) be $\partial v_{\ell z}/\partial R$?

GE Response: 901.17(w)

Equation 6.3-13 should be:

$$v_{\ell Z,I+1/2,J,K}^{n+1} - v_{\ell Z,I+1/2,J,K}^{n} + \Delta t\, v_{\ell Z,I+1/2,J,K}^{n} \left\{ \begin{array}{c} \dfrac{v_{\ell Z,I+1/2,J,K}^{n+1} - v_{\ell Z,I-1/2,J,K}^{n}}{\Delta z_I} \\ \text{if } v_{\ell z,I+1/2,J,K}^{n} \geq 0 \\ \dfrac{v_{\ell Z,I+3/2,J,K}^{n} - v_{\ell Z,I+1/2,J,K}^{n+1}}{\Delta z_{I+1}} \\ \text{if } v_{\ell z,I+1/2,J,K}^{n} < 0 \end{array} \right.$$

$$+ \Delta t \left[v_{\ell R} \left(\frac{\partial v_{\ell Z}}{\partial R} \right)^d + \frac{v_{\ell \Theta}}{R} \left(\frac{\partial v_{\ell Z}}{\partial \Theta} \right)^d \right]_{I+1/2,J,K}^{n}$$

$$- \left[\frac{k \rho_c}{(1-\alpha)\rho_\ell} \right]_{I+1/2,J,K}^{n} \left[v_{RZ}^{n+1} - v_{RZ}^{n} + \Delta t v_{dZ}^{n} \left\{ \begin{array}{c} \dfrac{v_{RZ,I+1/2,J,K}^{n+1} - v_{RZ,I-1/2,J,K}^{n}}{\Delta z_I} \\ \text{if } v_{dZ}^{n} \geq 0 \\ \dfrac{v_{RZ,I+3/2,J,K}^{n} - v_{RZ,I+1/2,J,K}^{n+1}}{\Delta z_{I+1}} \\ \text{if } v_{dZ}^{n} < 0 \end{array} \right. \right]_{I+1/2,J,K} =$$

$$- \frac{\Delta t}{\rho_{\ell,I+1/2,J,K}} \frac{P_{I+1,J,K}^{n+1} - P_{I,J,K}^{n+1}}{\Delta z_{I+1/2}} - g\Delta t + B_{\ell Z,I+1/2,J,K}^{n} \Delta t \qquad (6.3\text{-}13)$$

$$+ \frac{\Delta t}{[(1-\alpha)\rho_\ell]_{I+1/2,J,K}} \left[f_{\ell v}^n + \frac{\partial f_{\ell v}^n}{\partial v_{vZ}}\left(v_{vZ}^{n+1} - v_{vZ}^n\right) + \frac{\partial f_{\ell v}^n}{\partial v_{\ell Z}}\left(v_{\ell Z}^{n+1} - v_{\ell Z}^n\right)\right]_{Z,I+1/2,J,K}$$

$$- \frac{\Delta t}{\rho_{\ell,I+1/2,J,K}} \left[F_w^n + \frac{\partial F_w^n}{\partial v_{vZ}}\left(v_{vZ}^{n+1} - v_{vZ}^n\right) + \frac{\partial F_w^n}{\partial v_{\ell Z}}\left(v_{\ell Z}^{n+1} - v_{\ell Z}^n\right)\right]_{Z,I+1/2,J,K}$$

x. Should not $\Delta^2 P_{IJK}$ in Eq. (6.3-52) be ΔP_{IJK}?

GE Response: 901.17(x)

Equation 6.3-52 should be:

$$\Delta^2 P_{j_{i3}} = d_{i_1} + \vec{e}_{i_1} \overrightarrow{\Delta^2 P_j} - \Delta P_{IJK} \tag{6.3-52}$$

y. Should not the minus sign associated with $\tau/\Sigma_2 v_2$ in the third term on the right-hand side of Eq. (7.1-6) be a plus sign?

GE Response: 901.17(y)

The third term on the right hand side of the equation (7.1-6) should have a plus sign associated with the term $\tau/\Sigma_2 v_2$.

z. Should not ϕ at left-hand side of Eq. (7.1-13) be ϕ_1?

GE Response: 901.17(

The ϕ on the left-hand side of equation (7.1-13) should be ϕ_1.

aa. Should not v_1 in Eqs. (7.1-16) and (7.1-18) be v^*?

GE Response: 901.17(aa)

The v_1 in equations (7.1-16, 18) should be v^*.

bb. Should not λ_n in Eq. (7.1-19) be $\overline{\lambda}_n$?

GE Response: 901.17(bb)

The λ_n in equation (7.1-19) should be $\overline{\lambda}_n$.

cc. Is the expression for total $\overline{\beta}$ correct? (The subscript n on the left-hand side should not be there.)

GE Response: 901.17(cc)

The expression for the total β should be

$$\overline{\beta} = \sum_{n=1}^{N} \overline{\beta}_n .$$

dd. Should not β in the expression for M^{*2} be $\overline{\beta}$?

GE Response: 901.17(dd)

PROPRIETARY - Provided by Reference 2

ee. Should not S' and C_n in the expression for S_t on page 7-13 be $\overline{S}'$ and $\overline{C}_n$, the spatial average over a cell?

GE Response: 901.17(ee)

The terms in the expression for the source term S_t should be the average over a cell.

ff. Should not Δ^2 in Eq. (7.1-24) be Δ^2_{ij}?

GE Response: 901.17(ff)

The Δ^2 in equation (7.1-24) should be Δ^2_{ij}.

RAI Number 901.18

Question:

What is the adder for nodalization uncertainty?

GE Response:

No explicit adder is included for nodalization uncertainty. However the uncertainties of candidate parameters were developed considering separate effects and integral tests, and therefore the uncertainties applied implicitly contain nodalization uncertainties in many cases. For example the channel void correlation uncertainty is derived from TRACG separate effect test comparisons, and the SBWR nodalization is based on that nodalization. The application of a void uncertainty derived from separate effect comparisons includes channel nodalization uncertainty.

This rationale applies to the parts of the SBWR model which are nodalized per the standard BWR nodalization, which is shown in NEDE 32177P to be adequate. The differences from the standard nodalization described in section, 3.3.1 do not involve significant additional uncertainties. The additional chimney axial levels 3.3.1 (1) showed the axial void to be fairly constant. This increase in detail does not incur additional uncertainty. The elimination of axial levels at the recirculation suction nozzle and steam separator mid-plane, 3.3.1 (2) have no effect due to the absence of a recirculation system or steam separator area changes in SBWR. The radial nodalization in the chimney, 3.3.1 (3) is considered through the sensitivity study on the upper plenum interfacial shear multiplier (F1) in which the 2 sigma uncertainty is taken as a 10% change in core flow. Steam dryer volume, 3.3.1 (4) and loss coefficients for internal flow changes (5) are not nodalization differences, but rather features which accurately model the SBWR reactor.

RAI Number 901.19

Question:

The uncertainty of using 2-D instead of 3-D hydraulics has not been discussed. How are second-order effects taken into account?

GE Response:

The 3-D hydraulics option in TRACG is not applied in SBWR transient analysis. A 2-D axi-symetric model is applied. Because none of the SAR Chapter 15 transients cause a non-uniform azimuthal temperature, pressure or flow profile, the 2D approximation is valid and incurs no additional uncertainties.

RAI Number 901.20

Question:

Table 3-2 in NEDE-32178P lists the core inlet temperature as 511°C. What is the correct core inlet temperature?

GE Response:

The correct temperature is 278 deg. C.

RAI Number 901.21

Question:

Sensitivity studies for the axial nodalization and for the fuel channel grouping are mentioned in Section 3.3, but no references are given. Please provide references, or include the results of these studies in NEDE-32178P. Some of the other nodalization decisions are justified in a qualitative way. These should be quantified, as appropriate.

GE Response:

A more complete treatment is provided in the attached presentation entitled "TRACG Nodalization for SBWR".

RAI Number 901.22

Question:

The report states that the SBWR is expected to operate generally more than 15 percent above the operating limit minimum critical power ratio (OLMCPR), but could theoretically reach its value, in particular, under end-of-cycle conditions. However, with SSAR data of an OLMCPR value of 1.32 and with possible DCPR values of 0.25, it would appear that no uncertainty or bias adders were used in the SSAR, suggesting either a reevaluation or a redefinition of the OLMCPR. Comment on this observation. (Reference Section 3.6)

GE Response:

PROPRIETARY - Provided by Reference _

RAI Number 901.23

Question:

There are apparently differences between the phenomena identification and ranking tables (PIRTs) of Ref. 8 and Table 3.3 of NEDE-32178P, as shown in Table 3.1 of Section 3.7.2. Explain. (For a more consistent report, the underlying PIRTs should be included in the report, maybe as an appendix.)

GE Response:

The PIRT has been updated and is presented as Tables 2.3-1, 2.3-2, and 2.3-3 of the SBWR Test and Analysis Program Description, NEDC-32391P.

RAI Number 901.24

Question:

One sigma (1s) uncertainties of the candidate parameters are included in Table 3.3. How have these been obtained? For some this may be straight forward (for safety-relief valve set point, manufacturers data would be expected to be the source). How are, for instance, the reactivity coefficients and decay heat parameters and the gap conductance values determined? Four percent on Doppler coefficient and 4.4 percent on decay heat would appear to be very small uncertainties. (Reference Section 3.7.4)

GE Response:

The uncertainties listed in Table 3-3 were obtained from TRACG comparisons to tests, design specifications for equipment, dimensional tolerances for manufactured components, and model uncertainties previously derived for related models. The Doppler uncertainty is of the last category. The same uncertainties were applied as are used in the ODYN transient application methodology, from Table 12-1 in NEDE-21156. The uncertainty in decay heat is taken from ANSI/ANS 5.1.

RAI Number 901.25

Question:

From the description of the parameter variation, it appears that each parameter was varied separately from a base best-estimate case; that is, joint variations were not conducted. Explain this. If variations were done separately, justify this approach. (Reference Section 3.7.4)

GE Response:

Separate variations from a base best-estimate case are conservatively provided:
1) The response of each parameter is linear within its 95% confidence band.
2) Relevant parameters do not combine non-linearly to produce an effect which is greater than their summed individual contributions.

To establish the linearity required by 1), sensitivities were conducted at both the plus and minus 2 sigma value. No significant non-linearities were found.

To establish that relevant parameters do not combine non-linearly, the relevant parameters which contribute most of the uncertainty will be combined 2 at a time at the 1 sigma level, and the results compared to individual perturbations at the 1 sigma level. (The 1 sigma level is used since the probability of 2 different parameters being simultaneously at their 1 sigma values is approximately the same as any one being at its 2 sigma value, the search is then for linearities at a probability level consistent with the other sensitivity studies.) If significant non-linear combinations are found, an additional adder to address this effect will be included.

RAI Number 901.26

Question:

The method used to establish the cumulative uncertainty is not clear from the description given in Sections 3.7 and 3.8. Provide further detail and, preferably, reference to where it is described and where else it has been used. (This question is connected also to Question 901.25 above.)

GE Response:

PROPRIETARY - Provided by Reference 2

RAI Number 901.27

Question:

In Table 3.3, PIRT # C1DX, to what does "code qualification against plant integral test" refer? Does it refer to future prototype experiments? Was the implied current lack of knowledge considered in additional bias?

GE Response:

"Code qualification against plant integral test" refers to the comparisons against BWR plant data in NEDE-32177P. It does not refer to a future prototype test. Rather than an "implied current lack of knowledge" those comparisons showed TRACG to be very accurate in predicting the measured power response, such that no additional uncertainty to account for the kinetics solution is necessary.

RAI Number 901.28

Question:

In Section 4, the simple statement that results are satisfactory, as given, is not sufficient. While the statement is believed to be correct, the results of the anticipated transient without scram simulations should at least be summarized here in quantitative form, with reference to report(s) containing more complete results. The acceptance criteria should be explicitly stated, and compared to the results of that accident simulations.

GE Response:

The detailed ATWS results are given in section 15.8 of the SBWR SAR.

RAI Number 901.29

Question:

The second paragraph of Section 4.2.1 presents a qualitative argument for use of an analytical limit of the safety-relief valve setpoint, stating that the higher set point is of negligible effect on the long-term suppression pool temperature. This point should be supported by presenting quantitative results.

GE Response:

A sensitivity study was performed varying the SRV setpoints from their lower bound ("operational limit") to the upper bound ("analytical limit", which was used in the SBWR SAR section 15.8 analysis). This confirmed that the use of upper bound setpoints results in a conservatively higher peak vessel pressure. The mass flow from the SRV to the suppression pool and consequent suppression pool heat-up is approximately 4% less when the lower bound setpoints are used. However, because more margin is available to the suppression temperature limit, the sensitivity to the SRV setpoint is relatively less, as shown in the table.* In a consistent analysis higher SRV setpoints are conservative relative to the most limiting parameter (peak vessel pressure). For this reason upper bound setpoints were applied in the SBWR SAR analysis.

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* PROPRIETARY - Provided by Reference 2

RAI Number 901.30

Question:

The model description in Section 5.2.2 gives a brief qualitative reference to the nodalization used. As requested for Section 3 (Question 901.21), justification with reference to any available nodalization studies should be supplied.

GE Response:

A more complete treatment is included in the attached discussion entitled "TRACG Nodalization for SBWR".

RAI Number 901.31

Question:

Conformance to 10 CFR 50.46 Acceptance Criteria 1, 2, and 3 is stated to follow directly from the "results." It is assumed that this means TRACG code predications. No reference to clad oxidation and metal-water chemical reactions in either of the three reports (NEDE-32176P, NEDE-32177P, and NEDE-32178P) can be found. If this is a simple and possibly well-justified model, like "no oxidation at clad temperatures below xxx," then this should be stated here. (Reference Section 5.4)

GE Response:

TRACG does model heat generated by metal water reaction as described in section 3.2.13 of NEDE-322176 P. The model is not important to SBWR application because the heat of reaction is not significant until the clad temperature rises above 1000 deg C, and the SBWR clad never heats up above its initial temperature which is less than 310 deg. C. The "results" referred to are the TRACG calculations.

RAI Number 901.32

Question:

There is no reference to any PIRTs for emergency core cooling system/loss-of-coolant accident (ECCS/LOCA) scenarios, considering the in-vessel segment of the transients. The PIRTs referenced in Section 3 (as Reference 8 of NEDE-32178P) do include LOCA scenarios. Confirm that these are to be applied here and, if not, provide an alternate reference or provide a justification as to why PIRTs are not required here. As requested for Section 3 (Question 901.23), the PIRTs should be reproduced here, possibly as an appendix. (Reference Section 5)

GE Response:

The PIRTs for the SBWR are presented in Tables 2.3-1 (LOCA/ECCS), 2.3-2 (LOCA/Containment) and 2.3-3 (Transients) of the SBWR TAPD NEDC-32391P.

RAI Number 901.33

Question:

Comment on whether the decay heat of actinides is included in the analysis, as required by Regulatory Guide 1.57 (Position C.3.2.3). (Reference Section 5.4)

GE Response:

The actinides which contribute most to shutdown power in low-enriched light water reactors are U^{239} and Np^{239}. All other actinides have such long half lives or exist in such low concentrations that their contributions are insignificant. The total power of actinides is a function of exposure. The average energy per decay of each actinide is taken from ANSI/ANS-5.1, "American National Standard for Decay Heat Power in Light Water Reactors".

RAI Number 901.34

Question:

For a self-consistent report, the results of the LOCA analyses should be referenced and there should be at least a table, summarizing the runs made, their break sizes, and the most important output parameters, including peak clad temperature, with time of occurrence. (Reference Section 5.4)

GE Response:

In cases where results were previously reported in an available source, the report contains only a cross reference to insure consistency between the two sources. The results of the LOCA analyses are referenced in section 6.2 of the SBWR SAR.

RAI Number 901.35

Question:

By comparing Tables 5.1 and 5.2 in Section 5.4.1, it appears that many parameters were not included in the uncertainty analysis, which remains incomplete. Expand or provide a justification.

GE Response:

A more complete discussion of important parameters is presented in Section 4.0 of the SBWR TAPD, NEDC-32391P. A more detailed uncertainty analysis for LOCA will per performed.

RAI Number 901.36

Question:

The restriction of considering only a single scenario that is, a steam line break, should be justified. (Reference Section 6.1)

GE Response:

At the time of issue of NEDE-32178P, the conclusion that the main steamline break was limiting was based on results of "short-term" analyses performed with M3CPT over the full break spectrum. Subsequently, the full break spectrum was addressed for "long-term" response using TRACG. The results of these analyses supported the earlier conclusion that the main steamline break was limiting.

RAI Number 901.37

Question:

Since the containment design basis accident simulations mentioned here have not been reported in the SBWR standard safety analysis report (SSAR), it would be strongly desirable to include the results in Section 6.2.2 at least through summary tables and with reference to the complete results.

GE Response:

A containment design basis accident simulation was reported in the SBWR SSAR (see SSAR paragraph 6.2.1.1.3).

RAI Number 901.38

Question:

PIRTs for the containment analysis of ECCS/LOCA scenarios are mentioned in Section 6.3.2, but without any reference or details. Confirm that the PIRTs referenced in Section 3 (as Reference 8 of NEDE-32178P) were used here, and if not, provide an alternate reference. As stated before (Questions 901.23 and 901.32), the PIRTs should be made a part of NEDE-32178P.

GE Response:

The PIRTs are presented as Table 2.3-1 (LOCA/ECCS), 2.3-2 (LOCA/ Containment) and 2.3-3 (Transients) of the SBWR TAPD, NEDC-32391P.

RAI Number 901.39

Question:

The variation of three parameters and comparison to a previous model cannot be considered to be full uncertainty evaluation corresponding to the CSAU process. For a complete uncertainty evaluation, at least all of the points of Section N of Table 5.1 should be addressed in full. (Reference Section 6.3.2)

GE Response:

It is recognized that the sensitivity studies performed do not constitute a full CSAU uncertainty analysis. The intention was to consider the sensitivity of the analysis results to uncertainties in what was judged to be a key subset of the model parameters. A more detailed CSAU analysis will be performed.

RAI Number 901.40

Question:

Section 1 at the end of the third paragraph states "so it can perform <u>any</u> [emphasis added] transient or accident analyses." It would appear preferable to be more specific here, for instance it might better read "most transient or accident analyses for current BWRs, with exceptions as noted in the report."

GE Response:

Section 1 should be more correctly understood to mean "so it can perform a broad range of transient and accident analyses".

RAI Number 901.41

Question:

In Section 2.4, it is not correct to state that TRACG is used for all LOCA analyses. (Note the "nearly all," at the beginning of Section 2.1.)

GE Response:

Section 2.4 states that "TRACG is used for evaluation of containment response during LOCA. The analysis determines the most limiting LOCA for containment (or Design Basis Accident (DBA)) in terms of containment pressure and temperature response."

RAI Number 901.42

Question:

Include reference to GETAB (NEDO-10958) in the report. (Reference Section 3.5)

GE Response:

The GETAB licensing topical report, NEDE-10958-A, "General Electric BWR Thermal Analysis Basis (GETAB) Data, Correlation and Design Application", January 1997, is an appropriate reference in Section 3.5.

RAI Number 901.43

Question:

Considering overpressure protection, Section 3.7.2 of the report refers to "the analysis submitted." Should it be assumed this means the analysis in Section 5.2 of the SSAR. Confirm and clarify the wording of the report. If "submitted" always refers to the SSAR and not to this submittal, this could be clarified in one general statement.

GE Response:

Section 3.7.2 should be understood to mean "the analysis submitted in section 5.2 of the SBWR SAR".

RAI Number 901.44

Question:

It is assumed that PIRT parameters ranked 7 and higher were included with the candidate parameters in Table 3.3. Clarify. (Reference Section 3.7.2)

GE Response:

Those PIRT parameters ranked 7 or higher are classified as candidate parameters (i.e. by definition a candidate parameter is 7 or higher.) Table 3-3 lists the candidate parameters. The PIRT tables are presented as Tables 2.3-1 (LOCA/ECCS), 2.3-2 (LOCA/Containment), and 2.3-3 (Transients) of the SBWR TAPD, NEDC-32391P.

RAI Number 901.45

Question:

Provide the correct reference for "Reference 7-9." (Reference Section 4.2.1)

GE Response:

GE will revise section 4.2.1 to read "as documented in Reference [9]". (Reference to "Assessment of BWR Mitigation of ATWS", NED 24222, September 1979.)

RAI Number 901.46

Question:

In Section 5.4, second paragraph, confirm whether Section 5.3.1 is meant instead of "5.1.5," which does not exist. Provide correction for "Reference 7-10," which also does not exist.

GE Response:

GE will revise section 5.4 to read: " conformance criteria given in 5.3.1" and "demonstrated generically for GE BWRs in Reference [10], section III.A."

RAI Number 901.47

Question:

Table 5-1 for Section B.2, four flow rate entries are missing exponent on "10".

GE Response:

GE will revise Table 5-1 to add the missing exponents, per the table provided in Reference 2.

RAI Number 901.48

Question:

The scale of Figure 5-2 makes it useless for any scaling of actual values used. A table, giving the power <u>ratio</u> (correct ordinate label), for instance at 1, 10, 100, 100 s, etc., would be significantly more useful.

GE Response:

The ordinate of the figure will be changed to "Power (fraction of initial)". A figure is used rather than a table to graphically illustrate the reduction in power following the scram.

RAI Number 901.49

Question:

For the last sentence of Section 6.2.2, provide a description or reference for the "special procedure" to account for thermal stratification in the suppression pool.

GE Response:

PROPRIETARY - Provided by Reference 2

RAI Number 901.50

Question:

The second sentence of Section 6.3.1, "containment will maintain structural integrity. . . (excluding the blowdown peak)," appears to be phrased misleadingly. Clarify and/or revise the wording. (Blowdown peak determined by M3CPT?)

GE Response:

In the final paragraph of Section 6.2.2, it was stated that M3CPT is used for determination of "vent clearing and dynamic loads". One of the vent clearing loads is the peak blowdown pressure.

RAI Number 901.51

Question:

For Table 6.1, Entry (4), what does "internals stored energy added to decay heat" mean? The one is an initial condition, generally in units "work," the other is a heat generation rate, generally in units "work/time."

GE Response:

The wording of the Table 6.1 entry should be changed to say "Rate of release of fuel, vessel, and vessel internals stored energy added to decay heat."

TRACG Nodalization for SBWR

The TRACG nodalization used for SBWR analysis is dependent upon the type of analysis being performed. Each analysis type requires a different level of modeling detail for the SBWR reactor system. From a nodalization perspective, the SBWR analyses can be divided into three categories. For transient analysis, the focus is on the core and reactor pressure vessel response. The nodalization for transient analysis is provided in Section 1. For containment analysis, the focus is on the containment response during a design basis accident and thus requires less detail in the core and reactor vessel nodalization. The containment nodalization is described in Section 3. The nodalization used for LOCA evaluation must combine reactor vessel nodalization of the transient model with sufficient containment detail to capture the impact on ECCS performance. The LOCA nodalization is described in Section 2.

1. Transient Analysis Nodalization

A standard TRACG nodalization is used for SBWR reactor transient simulation. The reactor pressure vessel nodalization is consistent with the BWR nodalization described in Section 6 of the TRACG Qualification Document NEDE-32177P. Differences between the SBWR and BWR nodalizations are the result of unique SBWR design features that are reflected in the nodalization. The reactor system is represented by a standard set of TRACG components as follows:

- Reactor vessel
- Fuel channels
- Guide tubes
- Steam separators
- Steamlines (up to the turbine bypass and stop valves)
- Isolation Condenser
- Feedwater lines
- Piping associated GDCS injection (described in containment section)
- Control system

For transient analysis, the containment structure is not modeled explicitly. The containment pressure, temperature and heat transfer coefficients used as boundary conditions for the reactor pressure vessel thermal/hydraulic calculations.

1.1 Reactor Vessel

The reactor vessel is represented by a TRACG three-dimensional vessel component. The specification of each axial level is associated with some reactor hardware. The level of detail in the vessel nodalization is consistent with that used in Section 5.1 for the TLTA simulation [NEDE-32177P]. The definition of each level boundary is described in Reference 2.

Reference 2 describes the rationale for modeling the SBWR chimney, steam separator and core regions.

Heat transfer to the vessel structure is modeled using vessel heat slabs. Heat slabs that are located on node boundaries such as the core shroud, core support plate or vessel outer wall are modeled as double-sided heat slabs. Structures such as in-core monitor equipment that are contained within a cell are modeled as lumped heat slabs. The heat transfer between the vessel fluid and other component structures is provided by the TRACG component-to-component heat transfer capability.

1.2 Fuel Channels

The fuel channels are represented by the TRACG one-dimensional channel component. At least one channel component is used to represent the fuel channels within each core ring of the reactor vessel. Additional channels are utilized to reflect different channel geometry and channel power level. Three "average" channel groups per chimney partition are simulated.

Additional fuel channel information is provided by Reference 2.

The channel power distribution is specified by the 3-D kinetics model. The fuel rods are grouped into different rod groups according to their fuel properties and power levels. Each fuel rod (representing a rod group) is modeled using six temperature nodes in the fuel region and three in the clad. The gap conductance is calculated using the dynamic gap conductance model.

1.3 Control Rod Guide Tubes

The control rod guide tubes are represented by TRACG one-dimensional tee components. One guide tube component is specified for each core ring. The number of actual tubes represented by each TRACG component is dependent on the diameter of each core ring. High pressure injection is provided in the SBWR by CRD flow, which is modeled using a fill component attached to each guide tube.

1.4 Steam Separators

The steam separators are represented by TRACG tee components and the mechanistic separator model. One separator component is specified for each core ring. The number of separators represented by each TRACG component is dependent on the diameter of each core ring. The nodalization of the separators is consistent with the qualification discussed in Section 4.2 of NEDE-32177P.

1.5 Steamlines

Two sets of TRACG components are used to represent the steamlines from the vessel outlet to the manifold. A single line then connects the manifold to the turbine bypass and stop valves. This nodalization allows the simulation of a steamline break. If no break is required, a single line from the vessel to the manifold may be used. The comparison to the Peach Bottom turbine trip pressure data (Section 7.1) and Hatch MSIV closure pressure data (Section 7.3) in NEDE-32177P provides the qualification for the steamline nodalization.

Additional steamline information is provided by Reference 2.

1.6 Isolation Condenser

The Isolation Condenser (IC) is modeled by a tee component transferring heat to a fill/tee/break combination, drained by a valve. The nodalization is described in the containment section below. The transient response is insensitive to IC performance, since the IC capacity far exceeds that required to prevent safety valve actuation. The ICs themselves are redundant to the high pressure CRD injection.

1.7 Feedwater Piping

The feedwater line is represented by a pipe component connecting the vessel with a fill. The fill provides the boundary conditions which prescribe the feedwater flow rate and feedwater enthalpy. The fill boundary conditions are specified by the control system.

1.8 Control Systems

The following control systems are modeled using the TRACG control system capability:

- Pressure Controller
- Feedwater and Level Controller
- Isolation Condenser and Main Steam Isolation
- SRV Actuation
- Turbine Bypass Control
- Reactor Protection System
- CRD Injection Control

As described in Section 6.8 of the code qualification [2], the control system is basically the same as that used in the ODYN series of computer codes. The majority of the control components modeled are not safety related. The safety of the design is shown by the worst single failure of each control in either direction.

1.9 Standby Liquid Control System

For ATWS evaluation, the SLCS is added to the model. The boron injection system in the SBWR consists of an accumulator and piping connecting it to the core bypass region.

Additional standby liquid control system information is provided by Reference 2.

2 LOCA Evaluation Nodalization

The TRACG SBWR loss of coolant accident (LOCA) evaluation model includes the ECCS and both vessel and containment components, as well as the piping and pathways that connect them. This evaluation model is provided by Reference 2.

2.1 Reactor Vessel

Additional reactor vessel information is provided by Reference 2.

The TRACG SBWR LOCA evaluation model also includes the main steamlines (MSLs) and the Main Steamline Isolation Valves (MSIVs). Eight Safety/Relief Valves (SRVs) and two depressurization valves (DPVs) are mounted on the main steamlines. Four more DPVs are mounted on stub lines attached to the vessel. The feedwater lines (FWLs), GDCS injection lines, SRV discharge lines to the suppression pool, DPV discharge lines to the drywell and the main containment vents from the drywell to the suppression pool are all represented in the TRACG SBWR LOCA evaluation model.

2.2 Containment

Since the drywell pressure impacts the performance of the Gravity-Driven Cooling System, a containment model is also required for LOCA evaluations. However, because the containment response after the initial vessel blowdown is relatively slow, the containment does not require detailed nodalization.

Additional containment information is provided by Reference 2.

3 Containment Analysis Nodalization

The SBWR containment model includes all major containment systems and, specifically, the passive heat removal systems unique to the SBWR design. The use of TRACG for containment performance evaluations is unique to the SBWR. Containment response calculations for other BWRs rely on codes developed specifically for that purpose. Because of the number of systems and components which must be represented, the TRACG SBWR containment model is relatively large. A nodalization diagram for the model is shown in Figure 3-1. The radial coordinates shown in Figure 3-1 are relative to the reactor pressure vessel (RPV) centerline. The axial coordinates are relative to the RPV bottom dead center.

3.1 RPV and Containment Volumes

PROPRIETARY - Provided by Reference 2

3.2 One-Dimensional Components

In addition to the VSSL component, the SBWR TRACG containment model includes a large number (approximately 50) of one-dimensional PIPE, TEE, and VLVE components. The one-dimensional components are used to model the Passive Containment Cooling System (PCCS), Isolation Condenser System (ICS), RPV fuel bundles, Safety/Relief Valves (SRVs), depressurization valves (DPVs), LOCA vents, vacuum breakers, and various other connections between the regions of the two-dimensional VSSL component. In general, the number of components associated with a particular function in the TRACG model is significantly less than the corresponding number of components in the SBWR. In the interest of practicality and efficiency, the model lumps several SBWR components into a single TRACG component.

Additional one-dimensional components information is provided by Reference 2.

3.2.1 Lower Drywell

PROPRIETARY - Provided by Reference 2

3.2.2 Fuel Bundles

PROPRIETARY - Provided by Reference 2

3.2.3 PCCS

PROPRIETARY - Provided by Reference 2

3.2.4 SRVs and DPVs

PROPRIETARY - Provided by Reference 2

3.2.5 LOCS Vent, Vacuum Breakers, and Equalizations Lines

PROPRIETARY - Provided by Reference 2

3.2.6 Other One-Dimensional Components

The balance of the model is made up of an assortment of one-dimensional components which model broken pipes from various locations on the RPV, the supply of feedwater and control rod drive flow to the RPV, radiolytic gas production within the RPV, RPV pressure taps, DW-to-WW bypass leakage, the RPV bottom drain line and the Reactor Water Cleanup System suction line.