Request for Additional Information (RAI)
TRACG Application for ESBWR Containment Design Basis Accident (DBA) Analyses
ESBWR Pre-Application Review
General Electric Company

298. On page 3-20 of NEDC-33083P, "TRACG Application for ESBWR," General Electric (GE) states that because of the limited ability of TRACG to model condensation on horizontal surfaces, part of the diaphragm floor is included in the vent wall heat slab. Mass and heat transfer from horizontal structures differs from mass and heat transfer on vertical structures. Lumping the structures may also effect the definition of the characteristic length used to determine whether the mass and heat transfer process is laminar or turbulent. Describe how the combined heat structure was created, including a discussion of the physical properties (materials, thickness, etc.) and the Biot number (the measure of the thermal internal resistance to the surface film resistance) for each structure and the combined structure to support this model. Provide justification that this model is conservative for this purpose.

299. On page 3-21 of NEDC-33083P, GE states that certain regions with dead end connections were eliminated but their volumes were maintained in the overall model. This was done to address difficulties in TRACG to control the release of noncondensible gases from these regions. Describe these regions (general location, size, volume, flow path areas, etc.). Are the heat structures associated with these regions included in the model? The calculations are based on a uniform relative humidity in the drywell, with a lower bound value to maximize the noncondensible gases present at the start of the analysis. Are these regions large enough and isolated (by flow restrictions) such that the relative humidity in these regions could be less than the average resulting in a large inventory of noncondensible gases which could be transported to the wetwell?

300. In Table 3.4-1 of NEDC-33083P, phenomena identification and ranking table (PIRT) phenomena DW1 and DW4 are identified as "Insensitive." How were these determinations made? PIRT phenomena DW2, DW3 and WW5 are also identified as "Insensitive," based on Reference 82, NEDE-32178P, Rev. 1, "Application of TRACG to Model the SBWR Licensing Safety Analysis," January 1998. Provide a description and the results of the evaluation performed to make these determinations. If DW1 and DW4 were also addressed in NEDE-32178P, include these in the response. (NEDE-32178P is not identified as a report in support of the ESBWR pre-application review.)

301. In Table 3.4-1 of NEDC-33083P, PIRT phenomena MV1 and MV3 are identified as "Long-term response insensitive," based on Reference 24, "TRACG Qualification for SBWR," NEDC-32725P, Rev. 1 , Vol 2, Section 5.5, September 1997. Is the vent system (pipe length, submergence, flow area, etc.) similar to the SBWR design tested at the Pressure Suppression Test Facility? If not, provided a justification for the values used in the TRACG ESBWR model.

302. Question was addressed in July 9, 2003, meeting.

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304. In the PANDA tests (Section 5.7 of NEDC-32725P) it was noted that there was little or no axial stratification in the drywell. However, the TRACG models maintains stratification over the long-term, out to 48 hours (Fig. 3.7-3, NEDC-33083P).

(1) Explain the mass and heat transport processes in TRACG which sustain this axial stratification. Are there integral or separate effects test which show this sustained axial stratification? How would complete mixing effect the calculated performance on the passive containment cooling system (PCCS) and the containment response to the main steam line break (MSLB) (maintaining a high level of noncondensible gases near the PCCS inlet)?

(2) Provide a figure similar to Fig. 3.7-3 for the bounding case analysis.

305. Figure 6.6-16 in the TRACG Model Description reports uses the units "WALLS/m^2K" for the average heat transfer coefficient. Should these units be "watts/m^2-K?"

306. Equation 6.5-28 in NEDE-32176P is used for mass and heat exchange at a free surface, and is reported to be taken from "Heat Transfer," Third Edition, J.P. Holman.

(1) Provide the specific text (page) in Holman from which the equation is taken, or provide its derivation. Discuss the units as this form does not appear to be consistent with standard formulations.

(2) How was the Sparrow-Uchida degradation factor obtained? Does the correction factor include any bias based on the Sparrow or Uchida data? Is it a "best-estimate" correction? What is the uncertainty in this correction factor and is it considered in the calculations?

307. In NEDE-32176P, Rev 1, it is stated that "If the containment contains significant amounts of horizontal surface area, care should be taken to model this area with a non-horizontal equivalent area since no condensation heat transfer will be predicted using $g^*\cos(0^o) = 0.0$."

(1) For the ESBWR, is this a concern? If so, how are horizontal surfaces treated in the calculations? Provide a description of the heat structures (wall, piping, etc.) considered in the calculations in the drywell, the suppression pool and the wetwell and the mass and heat transfer correlations being used for condensation, convection and, if appropriate, radiation (based on the expected flow regime - laminar or turbulent, and orientation - vertical or horizontal). Identify the horizontal surfaces that are being treated as non-horizontal.

(2) In Section 7.11, it is stated that the Uchida correlation is available as an option for a lower bound for condensation, which would be consistent with guidance provided in Standard Review Plan. Is this option used in the calculations?

308. In NEDE-32176P, Rev. 1, it is stated that wall friction correlations are used in the same way as in other codes, like GOTHIC "which are specifically meant for containment analysis, and have been expensively qualified for these applications." Provide a

reference to the qualification of the TRACG 3-D treatment of wall friction for containment calculations.

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

309. Provide plots similar to Figures 3.7-2 through 3.7-15 in Section 3 of NEDC-33083P for the ECCS/LOCA calculations presented in Section 2 of NEDC-33083P (time frame 0 to 2000 seconds). These plots will provide a means to assess modeling differences, if they exist, between the modeling of containment for core performance versus the modeling of containment for containment performance.

310. Provide plots similar to Figures 3-7-2 through 3.7-15 in Section 3 of NEDC-33083P but for the time frame 0 to 500 seconds and for the time frame 0 to 3600 seconds. These plots will provide a means to assess the containment modeling on the short term (blowdown and early gravity driven cooling system (GDCS) injection periods).

311. Provide a table of the mass flow rate (kg/sec) and energy (J/sec) from the MSLB pipe break into the drywell for the base case (Section 3.7.2 of NEDC-33083P) and the bounding case (Section 3.7.3 of NEDC-33083P). The time between data points should be sufficiently small such that integrating the tabular data would match the integrated values at the time of GDCS injection, and to capture the timing of the suppression pool vents opening and closing and to be useful in performing a CONTAIN audit analysis of the blowdown portion of the accident (data to the onset of GDCS flow is adequate). Also provide the average reactor pressure vessel conditions at the start of GDCS injection - water inventory, steam inventory, average pressure and average temperature, and the times of each trip signal up to GDCS injection.

312. Flow Regime Maps

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

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

two-phase flow during early blowdown. The heat exchangers of the PCCS have small diameter tubes with downward film flow on the wall.

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

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

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

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

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

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

313. Wall Friction

Wall friction and momentum transfer is important in the PCCS tubes and the horizontal vents. The friction on the containment walls is also computed in the code. The single phase friction factors are calculated from the curve fit to Moody's diagram which is valid for pipe flows. The data base covers a very large Reynolds number range. However, the applicability to the drywell geometry and large diameter channels is questionable.

This model was assessed with the data base limited to small diameters, which covers the PCCS tubes, but is too small for horizontal vent. Furthermore, the two-phase multipliers were based on the data with lower steam qualities while in the drywell and in the horizontal vents, the quality could be close to 100%. Furthermore, it is not clear if the two-phase multiplier is valid for down flow as expected in the PCCS tubes and in the horizontal vents.

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

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

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

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

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

314. Wall Heat Transfer

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

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

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

(1) Provide a justification for using these correlations for the containment surfaces. It would be more appropriate to use correlations for flat plates which are based on wall length. Can it be shown that the use of an appropriately calculated hydraulic diameter to represent the structure characteristic length will result in a

conservative heat transfer calculation? Will laminar conditions exist in the containment (for example based on Gr number) for which additional correlations would be needed? In this case, or if a correlation for a flat plate were to be used to better represent the structure, the hydraulic diameter (characteristic length) would not necessarily cancel out based on a $Gr^{1/3}$ correlation.

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

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

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

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

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

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

(6) The other area of importance is heat transfer due to condensation on cold surfaces. With the accumulation of noncondensible gases, the condensation rate will degrade. TRACG models this heat transfer with the Nusselt's correlation for condensation and degradation due to noncondensible gas through use of the minimum value from the Kuhn-Schrock-Peterson (K-S-P) correlation, which was derived from vertical pipe data, and the Uchida correlation. The data base for these correlations covers pressure up to 4.5 bars which is appropriate for containment application.

In principle, the staff accepts such an approach. However, the applicability of this model to the containment analysis needs to be discussed in more detail

given the fact that the nodalization may affect the noncondensible gas concentration near the interface and therefore, the heat transfer degradation.

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

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

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

315. Interfacial Momentum Transfer

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

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

(1) Provide a discussion of the applicability of the TRACG models to address these issues for interfacial momentum transfer- void fraction, two phase multipliers for

wall friction, drop formation and the treatment of drops, and interfacial momentum - as they relate to the evaluation of containment performance.

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

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

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

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

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

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

316. Interfacial Heat and Mass Transfer

The heat and mass transfer at the interface are related and predictions of one will provide an estimate of the other. The model consists of predicting the flow regime, interfacial area density and heat transfer coefficients at the interface.

(1) It is our understanding that the liquid side interfacial heat transfer coefficient is obtained from a correlation developed for heat transfer over evaporating drops. Provide a description of the physical process being modeled and justify its use for this situation.

(2) It is our understanding that the vapor side interfacial heat transfer coefficient is obtained from the conduction heat transfer solution for a solid sphere with a correction for internal convection and the degradation due to noncondensible

gases is accounted with the a degradation factor. If this is correct, provide a description of the physical process being modeled and justify its use for this situation.

317. The TRACG containment models utilize the same conservation equations and constitutive correlations as applied to the reactor system models, i.e., the code, which was initially developed to model the BWR primary coolant system, is currently being used to model the full plant, including the containment. In addition, many of the models have identified errors and uncertainties associated with their use for the containment evaluation. Further the TRACG nodalization models are prescribed to account for additional shortcomings in TRACG to treat some important features, like mixing and stratification in the containment. Some of these prescribed models are based on expected performance (engineering judgement) or the results from small-scale experiment. Typically, containment codes are assessed against a large body of experimental tests (both separate effects and integral tests) designed to address containment performance. In addition, when a new code is proposed for use, an applicant provides a comparison to its currently acceptable code as a benchmark to aid in understanding the results and identifying important features or phenomena in the new methodology.

(1) Provide a plan and schedule to assess the ability of TRACG to model containment performance against integral tests. Integral tests that should be considered include the Marviken tests, the Carolinas Virginia Tube Reactor (CVTR) test 3 without sprays, and the Battelle-Frankfurt Model Containment (BFMC) tests C-13 and C-15 for main steam line breaks. The TRACG results should be assessed against available results from other computer program results (GOTHIC, CONTAIN, etc.).

(2) Provide a plan and schedule to assess the ability of TRACG to model containment performance against separate effect tests. Separate effects tests that should be considered include the Wisconsin Flat Plate condensation tests (Huhtiniemi, I.K. and Corradini, M.L., "Condensation in the Presence of Noncondensable Gases," Nuclear Engineering Design, 141, pp.429-446, 1993), M. Siddique, “The Effects of Noncondensable Gases on Steam Condensation Under Forced Convection Conditions,” MIT, January 1992, and K. Liang, “Experimental and Analytical Study of Direct Contact Condensation of Steam and Water,” MIT, May 1991. The TRACG results should be assessed against available results from other computer program results (GOTHIC, CONTAIN, etc.)

(3) Provide a plan and schedule to assess TRACG against the previously accepted GE codes used for containment performance evaluations, M3CPT and SHEX. These comparisons need not extend beyond the time of GDCS injection.