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SIEMENS

January 26, 2001
NRC:01:007

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Additional Information – Siemens Power Corporation Topical Reports, EMF-2310(P) Revision 0, (TAC No. MA7192) and EMF-2328(P) Revision 0, (TAC No. MA8022)

Ref.: References are listed on page 2.

In Reference 1, the NRC requested additional information to facilitate the completion of its review of the SPC topical report on the PWR Non-LOCA methodology (Reference 2) and the topical report on the PWR SBLOCA evaluation model (Reference 3). Responses to this request are provided in two attachments: one proprietary and one nonproprietary.

In Reference 4, SPC provided supporting information for the review of these two topical reports. Due to NRC comments regarding typographical errors in the supporting information, SPC is providing revised copies (References 5 and 6). (NOTE: Eight copies of these reports have been provided directly to N. Kalyanam.)

Siemens Power Corporation considers some of the information contained in the attachments and enclosures to this letter to be proprietary. The affidavits provided with the original submittals of the reference reports (References 2, 3, and 4) satisfy the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

/arn

Attachments - 2/Enclosures – 2

cc: N. Kalyanam (w/Att. & Enc.)
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Ref.: 1. Letter, N. Kalyanam (NRC) to J. F. Mallay (SPC), "Request for Additional Information – Siemens Power Corporation Topical Reports, EMF-2310(P), Revision 0, 'SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors,' (TAC NO. MA7192) and EMF-2328(P), Revision 0, 'PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,' (TAC NO. MA8022)," December 11, 2000.

Ref.: 2. Letter, J. F. Mallay (SPC) to Document Control Desk (NRC), "Request for Review of EMF-2310(P) Revision 0, *SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors*," NRC:99:048, November 22, 1999.

Ref.: 3. Letter, J. F. Mallay (SPC) to Document Control Desk (NRC), "Request for Review of EMF-2328(P) Revision 0, *PWR Small Break LOCA Evaluation Model, S-RELAP5 Based*," NRC:00:002, January 10, 2000.

Ref.: 4. Letter, J. F. Mallay (SPC) to Document Control Desk (NRC), "NRC Review of Siemens Power Corporation Topical Reports," NRC:00:009, February 3, 2000.

Ref.: 5. EMF-2100(P) Revision 3, *S-RELAP5 Models and Correlations Code Manual*, Siemens Power Corporation, January 2001.

Ref.: 6. EMF-2101(P) Revision 2, *S-RELAP5 Programmers Guide*, Siemens Power Corporation, January 2001.

S-RELAP5 Request for Additional Information (RAI)

The following are in regard to EMF-2100(P) Rev. 2:

Comments/Editorials:

G.1 *In several places including the first sentence on Page 2-1, you stated that the S-RELAP5 code solves two-phase, two-fluid six equations plus one continuity equation for noncondensable gas and a boron tracking equation. S-RELAP5 actually includes a two-fluid model for a two-phase system. The sentence in your report implies that the code models two phases for two different fluids. This is not accurate.*

The S-RELAP code solves two-fluid six equations plus one continuity equation of noncondensable gas and a boron tracking equation for flow of a two-phase steam-water mixture which can contain a noncondensable in the vapor phase and a soluble in the liquid phase.

Chapter 1: Introduction

1.1 *On Page 1-2 you stated that you have applied 2-D modeling to the downcomer, core, and upper plenum. Please explain why 2-D modeling of the lower plenum and lower head has not been applied.*

The S-RELAP5 2-D component is flexible and can be applied to any selected component through input, and the 2-D modeling has been successfully applied to various RCS components, including the lower head and plenum. Use of the 2-D model adds considerably to the complexity of the system input and running time of the analysis model. Therefore, SPC methodologies will invoke the use of the 2-D model only for regions in applications where significant multi-dimensional effects are expected. Thus, the use of the S-RELAP5 2-D model will be different depending on the licensing application.

For SBLOCA applications, 2-D modeling is applied in the core and downcomer regions. Significant multi-dimensional effects which would require 2-D modeling in the lower plenum and lower head are not expected for SBLOCA. For non-LOCA transients, the 2-D capabilities are not required. The methodology topical reports for each S-RELAP5 application describe the use of the 2-D modeling for that specific application.

1.2 *On Page 1-2 you stated that the modification made to the energy equations are more appropriate for analyses involving a containment volume. In Information Notice 92-02 the staff stated that codes in the RELAP5 series are not intended to be used as containment analysis codes. Containment analysis specific codes exist for that purpose. The primary purpose of the RELAP5 codes is analysis of the response of the NSSS to accident and transient conditions. Please clarify the intent of your statement in light of the statement in the Information Notice.*

During a PWR LBLOCA, a coupling exists between reflood heat transfer and containment back pressure. Calculation of this coupling requires that accurate mass and energy release data be provided to the containment code calculation which then feeds back the appropriate back pressure for the reactor system calculation. To correct the problem associated with the Information Notice, changes were made to the S-RELAP5 code to provide energy conservation for all conditions. In addition, changes were made to incorporate the ICECON containment code into S-RELAP5, and to interface the containment code calculation so that the containment calculation is performed as part of S-RELAP5 in parallel with the NSSS transient calculation.

The energy equation changes were made to directly address the problem identified by Northeast Utilities which resulted in Information Notice 92-02. It was found that the base RELAP5 code did not conserve energy when critical flow was calculated with a large pressure drop between volumes such as from the NSSS to the containment during a LBLOCA event. This means that the mass and energy release to the containment calculated by the then existing versions of the RELAP5 code could be erroneous and results from these code versions should not be used as the source terms for containment analysis performed with either RELAP5 or a containment analysis code.

The energy equations in the base RELAP5 code are formulated in terms of thermal energy. With this formulation, P-V work terms are not calculated accurately. For the large pressure drop conditions, this results in an energy conservation error. The S-RELAP5 energy equations are formulated in terms of total energy which conserves energy over all pressure drop conditions.

In the coupled NSSS and containment calculation, the mass and energy release to a time dependent volume is calculated by S-RELAP5 for one time step. This information is then passed to the ICECON (CONTEMPT) portion of S-RELAP5 where the updated containment back pressure is calculated. Back pressure is then passed back to the time dependent volume and applied as a boundary condition on the NSSS calculation for the next time step. Since energy is conserved using the S-RELAP5 code, and this code now contains the ICECON containment module, the containment pressure can be determined using S-RELAP5.

It should be noted that the energy equation changes in the S-RELAP5 documentation have little effect on S-RELAP5 calculations for SBLOCA or non-LOCA transients, and that containment pressure is not calculated for these methodologies. The changes are necessary and important for the planned submittal of the realistic LOCA methodology, and the applications described apply only to that methodology. This change also would be important if mass and energy release are calculated for use in a containment analysis code such as GOTHIC.

1.3 *On Page 1-6 you stated that the steady-state option does not perform convergence tests and that users are required to set up the conditions for determining whether a steady-state is obtained. Please discuss the guidance provided to the users to aid them in doing this and identify where such guidance has been included.*

SPC develops user guidelines for each event analysis and a guideline for input deck generation. Those guidelines include specific requirements for developing steady- state controllers, as well as guidelines for establishing criteria for acceptable steady-state conditions. Currently, those guidelines are specific to using ANF-RELAP for the thermal hydraulic portion of the transient.

Upon acceptance of the proposed methodologies, the guidelines will be updated to reflect the differences between the use of ANF-RELAP and S-RELAP5. However, both the SBLOCA and non-LOCA analyses will use the current ANF-RELAP guidelines for establishing steady-state acceptance criteria.

The criteria for establishing steady-state calculation acceptance for any of the events are as follows:

The calculated results from the null transient using the steady-state option are examined closely to ensure that a true steady-state condition has been established. This is achieved by examining specific parameters (listed below) and comparing them against the desired steady-state plant conditions. Reasonable stability and comparison of these parameters with known steady-state values would indicate an acceptable steady-state condition has been achieved. Current guidelines recommend that plots of the key parameters be included in the calculation notebook, so the attainment of a steady-state can be visually verified.

The following are parameters are recommended for inspection to assure steady conditions have been reached:

- Reactor power
- Primary pressure
- Loop pressure drop
- Loop flow rate
- Core bypass and leakage path flow rates
- Vessel upper head temperature
- Cold leg temperature
- Hot leg temperature
- SG secondary pressure
- SG secondary mass inventory
- SG secondary void profile
- SG feedwater and steam flow rates
- SG recirculation ratio
- Mass flow rates in the SG boiler region
- Pressurizer collapsed liquid level
- Core collapsed liquid level
- Hot channel wall temperatures
- Core mass flow

Chapter 2: Fluid Field Equations and Numerical Solutions

2.1 *Please provide a description of the major differences between S-RELAP5 and RELAP5/MOD2 pertaining to the Semi-Implicit Numerical Solution Scheme.*

[

] The detailed algebraic manipulation is shown in Equations (2.131) to (2.195). The Gaussian solver without pivoting may lose significant accuracy under some circumstances (e.g., when the matrix is nearly singular); therefore, the RELAP5/MOD2 method is not used. Another difference is the more implicit treatment of the pump junction velocities, which is described on Pages 2-40 to 2-41 [Equations (2.118 to (2.124)].

2.2 *In the second paragraph on Page 2-29, Section 2.6, it is stated that RELAP5/MOD2 was extended to include a two-dimensional flow solution scheme in S-RELAP5. Was this new scheme bench-marked or validated to ensure correct implementation and correctness of the scheme? Please discuss the bench-marking.*

The S-RELAP5 two-dimensional flow scheme was verified and validated. Two types of benchmark cases were used to verify/validate the 2-D model: cases with known solutions and comparisons to multi-dimensional flow data. Calculations of cases with known solutions, such as 2-D symmetrical fill problems, validate correct implementation of the 2-D model. Comparisons with measured data show the validity of the model. A symmetric fill problem was set up for the (z,θ)-type 2-D component to check if correct velocities and flow symmetry are calculated in the 2-D model. The 2-D nodalization scheme is similar to that used for modeling the reactor vessel downcomer. The calculation shows that the liquid advances with the same velocity as the injection (time-dependent junction) velocity in all vertical directions and flow symmetry is maintained throughout the entire period, including the period after the 2-D component completely fills. This verifies that the 2-D momentum flux terms are correctly treated. A similar exercise was performed on the (z,x)-type 2-D component, producing correct results. Since the plant steady-state conditions such as flow rates, velocities, and flow patterns are known, the plant steady-state calculations can also be used to check the correctness of the 2-D model implementation.

The purpose of a comparison with test data using the 2-D component is to validate its applicability for modeling multi-dimensional flow problems. Two-dimensional flow test comparisons performed specifically to validate the S-RELAP5 2-D modeling are given in section 5.1 of the SBLOCA topical EMF-2328(P). Section 5.5.2 of EMF-2100(P) also discusses results from a UPTF simulation where the (z,θ)-type 2-D component was used to model a downcomer. The calculated results shown in Figure 5.17 on Page 5-60 of EMF-2100(P) demonstrate that a proper velocity profile was obtained in that simulation.

2.3 *On Page 2-54, the subject of time-step control is discussed. How does the time-step calculation in S-RELAP5 differ from that used in RELAP5/MOD2? In particular, discuss any differences in the way the error is measured within the two methods.*

In S-RELAP5 the time step control is performed through four criteria: (1) material Courant limit {Equation (2.211)}, (2) consistency check on the mass solution {Equation (2.213)}, (3) consistency check on the energy solution {Equation (2.214)}, and (4) Failure of equation of state. For the Courant limit, RELAP5/MOD2 implements a partial violation of the Courant limit. The partial violation scheme is present in the S-RELAP5 code, but is not used, i.e., no partial violation of Courant limit is allowed. RELAP5/MOD2 does not have item (3) and adds a measure of overall system mass differences in item (2). The criteria for the mass consistency check are 1×10^{-3} (repeat) and 1×10^{-4} (double) [see description below Equation (2.213)] in the S-RELAP5 Theory Manual, and are 2×10^{-3} and 2×10^{-4} in RELAP5/MOD2. Both S-RELAP5 and RELAP5/MOD2 check the mass conservation by computing the accumulated mass generation (or destruction) in the system, which is shown on the major edit as mass error. This system mass error is not used in time-step control in S-RELAP5 and the RELAP5 codes.

2.4 *The energy equations presented do not include energy dissipations due to wall friction and pump effects. Please derive your energy equations to show how these terms are eliminated and/or justify the exclusion of these terms. Please justify your simplifying assumption included as Equation 2.13 in your report.*

The energy equations in S-RELAP5 are expressed in the total energy form. The terms in Equations (2.4) and (2.5) plus Equation (2.13) can be identified from the following general statement of the law of conservation of energy for the fluid in a control volume:

$$\left\{\begin{array}{c}\text{rate of}\\ \text{accumulation}\\ \text{of internal}\\ \text{and kinetic}\\ \text{energy}\end{array}\right\} = \left\{\begin{array}{c}\text{rate of}\\ \text{internal and}\\ \text{kinetic energy}\\ \text{in}\\ \text{by convection}\end{array}\right\} - \left\{\begin{array}{c}\text{rate of}\\ \text{internal and}\\ \text{kinetic energy}\\ \text{out}\\ \text{by convection}\end{array}\right\}$$

$$+ \left\{\begin{array}{c}\text{net rate of}\\ \text{heat addition}\\ \text{by conduction}\end{array}\right\} - \left\{\begin{array}{c}\text{net rate of work}\\ \text{done by system}\\ \text{on surroundings}\end{array}\right\}$$

(see Page 311 of Transport Phenomena by R. B. Bird, W. E. Stewart, and E. N. Lightfoot, 1960.)

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2.5 *The energy equations presented assume that the enthalpy in the wall vaporization term ('wh) is the saturation enthalpy. Please justify this assumption.*

The product $\left(\Gamma_w\, h_k^s\right)$ represents the energy transfer for phase *k* (either addition or subtraction) associated with the mass transfer due to the "wall vapor generation" term. In subcooled boiling, Γ_w is positive and the energy transferred to the vapor within the control volume is $\left(\Gamma_w\, h_g^s\right)$ as it should be. The implication is that the generated vapor appears at the saturation temperature corresponding to the local pressure. The energy removed from the liquid phase within the control volume is then $\left(\Gamma_w\, h_f^s\right)$. As the liquid phase is subcooled, there appears to be an energy imbalance with the magnitude $\left[\Gamma_w\left(h_f^s - h_l^s\right)\right]$ corresponding to the liquid sensible heat that must be added to bring the subcooled liquid up to the saturation temperature. This energy imbalance does not exist because this sensible heat requirement has already been accounted for through the determination of the fraction of the wall heat flux that causes vapor generation (see Equation (4.27) of Section 4.3.2) as discussed below.

S-RELAP5 uses the Lahey subcooled boiling model. The wall heat flux is first divided into two parts: one for sensible heat transfer and one that is "available" for vapor generation (denoted as q''_{wv} in the manual). This heat flux that is available for vapor generation is then further partitioned into a fraction that actually causes vapor generation $\left(q''_{evap}\right)$ and that corresponding to the sensible heat transfer needed to bring the bulk liquid up to the saturation temperature based on an equal volume exchange $\left(q''_{pump}\right)$. Thus, the sensible heat transfer due to this "pumping" term accounts for the energy transfer needed to bring the mass of subcooled liquid that is being evaporated up to the saturation temperature.

2.6 *On Page 2-6 you stated that under most circumstances, assessment calculations indicate that there are essentially no differences in the results of key loss of coolant accident (LOCA) parameters between the RELAP5/MOD2 energy equations and the energy equations provided in S-RELAP5. Please provide a discussion of the assessment calculations performed including a discussion of the key LOCA parameters that were assessed. In addition, please provide a discussion of the circumstances where differences were identifies and justify your methodology in light of those differences. Also, provide similar discussions related to the other transients that you are proposing to analyze with the code.*

The referenced assessment calculations were from undocumented developmental assessment results using LOFT L2-5, LOFT L2-6, CCTF Run 54, and FLECHT-SEASET Test 31504. Those calculations were made at the time of the energy equation modification. The stated differences were from comparing the previous results without the model changes with results having the model changes implemented. The parameters compared were cladding temperatures, steam temperatures, void fractions and pressures. The model had essentially no effect on the calculated result, as expected, since the system models did not include containment modeling (e.g., a large pressure drop across a choke plane).

The non-LOCA sample problems show comparisons between ANF-RELAP, which uses the same energy equations as RELAP5/MOD2, and S-RELAP5 calculated results. Those comparisons show that S-RELAP5 is essentially equivalent to ANF-RELAP for the modeling of non-LOCA transients Page 2-1, EMF-2310(P).

The SBLOCA methodology does not include containment modeling, therefore there are no expected differences in the results.

The Realistic LBLOCA model simulates the interaction between primary system and the containment response to blowdown. In this situation, the correct energy transfer to the containment model is necessary.

A demonstration calculation can be made to show the energy error when using the S-RELAP5 energy equations compared to the RELAP5/MOD2 energy equations. Consider a closed system where potential and kinetic energies are negligible and consisting of a small diameter pipe (1 m) at high pressure (150 bar) blowing down into a large diameter pipe (10 m) at low pressure (1 bar) through an orifice. Since there is no change in total internal energy in a perfect system, a comparison of initial internal energy to the transient internal energy during the blowdown should indicate net internal energy error.

A calculation of this type was made with both S-RELAP5 and ANF-RELAP (ANF-RELAP uses RELAP5/MOD2 energy equations). The results in Figure 1 show that energy is conserved to within 0.04% by S-RELAP5 while ANF-RELAP shows an error of approximately -2%. These results imply that there will be a much smaller energy error when transferring energy out of a system (i.e., coupled primary and containment calculation) using S-RELAP5 compared to a code using the RELAP5/MOD2 energy equations.

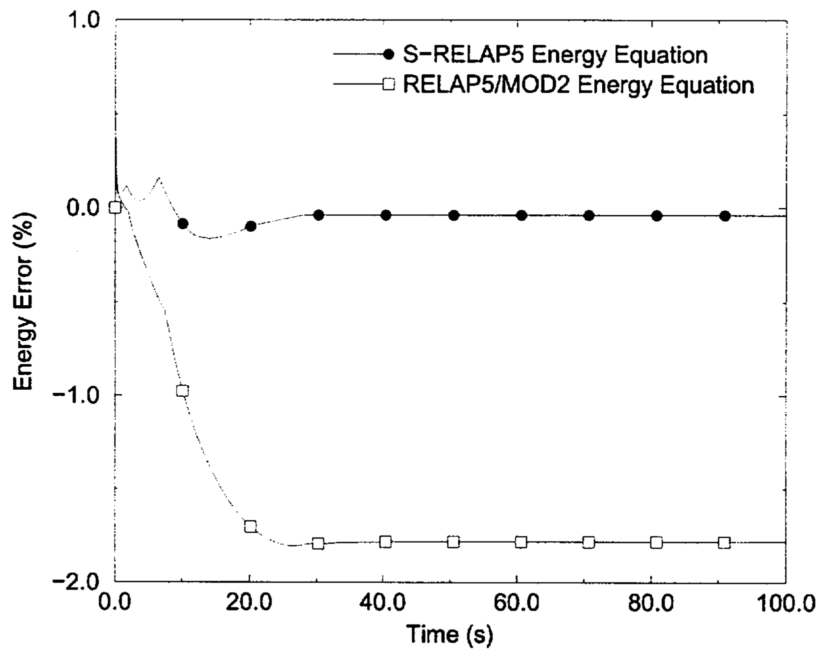

Figure 1. Comparison of energy error between S-RELAP5 and RELAP5/MOD2 energy equations

2.7 *Please provide a discussion of the heat transfer at the noncondensable gas-liquid interface and the effect of this on the energy equations. Please explain how this is modeled in your proposed methodology.*

The noncondensable interphase heat transfer is described in Section 3.4.9 {pp. 3-65 - 3-66 of EMF-2100(P)}. The effect of the model on the energy equations is handled through the interphase heat transfer terms in the energy equations (see Equations (2.5), (2.6) and the discussion on Pages 2-3 to 2-9). For SBLOCA and non-LOCA events, the noncondensable does not leave the accumulators; therefore, the noncondensable interphase heat transfer model has no effect. For LBLOCA, the entering of the noncondensable into the cold legs after the accumulators are emptied of water reduces the steam condensation rate, and thus, increases the cold leg pressures. This in turn causes a surge of ECC water into the core and provides additional cooling for a short period. It has a weak to moderate effect on the clad temperatures during the reflood phase of a LBLOCA.

2.8 *Under Section 2.4, State Relationships, you assume that the interface temperature is the saturation temperature. Please justify this assumption.*

The interface temperature is assumed to be at saturation for the modeling of the interphase heat transfer. The state relationship provides a computation of derivatives at the saturation temperature so that the interphase heat transfer terms can be linearized and treated implicitly.

It is a standard approach to use the saturation temperature as the reference temperature for formulating the interphase heat transfer model. The net effect of the interphase heat transfer model is to compute the amount of mass exchanged between the two phases. That is, the heat transfer from a phase to the saturation interface is just an intermediate step and the significant quantity is the heat transfer between the phases. At the equilibrium state, both phases are saturated. Setting the reference (interface) temperature to saturation provides a convenient measure of the deviation of a phase from equilibrium and simplifies the interphase heat transfer model.

2.9 *Please derive Equation 2.42 and justify your assumption that the extrapolated* κ *is just the saturation value for both the superheated liquid and the subcooled steam.*

Equation (2.42) has a typographical error. The corrected form, and the derivation is provided in the following text.

Equation (2.42) will be corrected in the next revision of the models and correlations document EMF-2100(P).

2.10 *Your statement that substitution of Equations 2.45 and 2.47 into Equation 2.48 yields Equation 2.50 does not appear correct. Please show how Equation 2.50 was obtained. Note that this error continues in later derivations.*

There is a typographical error in Equation (2.47): the "+" should be "=". That is, Equation (2.47) should be

$$V_g = X_n V_n = (1-X_n)V_v$$

The above equation is a direct consequence of the Gibbs-Dalton assumption that all gases (i.e., steam and noncondensables) occupy the same space. This equation will be corrected in the next revision to the models and correlations document, EMF-2100(P).

2.11 *Regarding Equations 2.101 and 2.102, why is the velocity at j+1 evaluated at time n+1 while being multiplied by the density and void fraction at j+1 from time n? Note that the velocity at j is evaluated at time n and multiplied by the density and void fraction at j from time n. Also, compare with Equations 2.103 through 2.105, wherein the velocity at j+1 is evaluated at time n+1 but multiplied by the density and void fraction at j+1 from time n. But velocity at j is evaluated at time n+1 and multiplied by density and void fraction at j from time n.*

There are typographical errors in Equations (2.101) and (2.102). The velocities at junction j should be superscripted with n+1. These changes will be made to the next revision of EMF-2100(P).

The time level difference between the velocity and mass, energy, or quality parameter is from the assumptions used in developing the semi-implicit numerical scheme. In the discussion in Section 2.6 of EMF-2100 (P), Rev 2., a reference is made to implicit terms formulated to be linear in the dependent variables at new time. The mass, energy, and noncondensable quality fluxes are those terms. Note that the momentum flux terms in Equations (2.109) and (2.110) consist of old time, or time level n, velocities. This allows the momentum equations to be reduced to Equation (2.116), the velocity at time level n+1. These new time velocities can be substituted into Equations (2.101) through (2.105) and yield expressions for mass, energy, and noncondensable quality in terms of ΔP. With appropriate substitutions, those equations can be combined into a single expression in terms of ΔP. The process is discussed in detail starting on Page 2-43.

2.12 *How are areas for the momentum flux terms in the 2-D components calculated? How is this conveyed to the user?*

The areas appear in the 2-D (and 1-D) momentum flux terms only indirectly through the volume average velocities, which are defined in Equations (2.98) - (2.100). The user usually provides the lengths and volumes of the 2-D nodes through input and the code calculates the areas by: area = volume/length. The user may also have to provide the junction areas according to the actual geometry. The S-RELAP5 Input Data Requirements section of the S-RELAP5 users' manual, EMF-CC-097(P), has a section for the 2-D component input prescription. Additional procedures will be discussed in the methodology guidelines.

2.13 *How are the variables (a_g) and (a_f) in Equation 2.116 defined?*

2.14 *Given the fact the $r\theta$ is treated as r when using the (z, θ) form of the 2-dimensional momentum equations, as opposed to the (z,r) form, how is the "r" defined?*

In the cylindrical (z,θ) 2-D system, r is measured from the origin and $r\Delta\theta$ is the length of the arc for the angle $\Delta\theta$. Since r is constant, $r\Delta\theta = \Delta(r\theta)$= arc length of an azimuthal sector. In the (z,r) system, Δr is the nodal length in the r-direction, which is the distance between two radial rings.

2.15 *Has the effect of violations of the material Courant limit been evaluated? What is the recommended value for $\Delta t_c(i)$ in Equation 2.212?*

Violation of the material Courant limit often leads to unstable solutions in the semi-implicit scheme. In the earlier years of RELAP5 development, partial violation of the Courant limit was considered to be acceptable if the solution was stable. However, its effect is difficult to quantify. Therefore, partial violation of the Courant limit is no longer used in S-RELAP5 applications. As stated in the paragraph below Equation (2.212), i=1 is used, i.e., no partial violation of the Courant limit.

Chapter 3: Hydrodynamic Constitutive Models

Editorial:

3.1 *Page 3-6, first paragraph states that Wallis asserted that $j_{g^*} \approx 0.9$. The star appears incorrectly placed. Consistent with the remainder of the text it appears that the star should be a superscript to j instead of g.*

Concur. The typo will be corrected.

Technical:

3.2 *On Page 3-1, end of the second paragraph, it is stated that code-data comparisons for the key parameters are to be used for assessing the applicability of the interphase constitutive models. Earlier in the same paragraph it was stated that the key parameters are phasic temperatures, phasic velocities, phasic densities, mass flow rates, and void fractions. Please explain how the key parameters were identified and provide the assessments that were performed to confirm the applicability of the interphase constitutive models.*

The key parameters were identified from analysis of the interphase constitutive models and their usage in the mass, energy, and momentum conservation equations. The constitutive models have an effect on mass fractions, temperatures, and slip. The parameters characterizing those phenomena are then void fraction, phasic densities, phasic temperatures, and phasic velocities. Flow rate is consequence of those preceding parameters.

Based on past experience and informal peer reviews, an informal PIRT was developed (see response to RAI 3.20). In the PIRT, processes and phenomena were ranked as having high importance, medium importance, and low importance during the five periods of a SBLOCA transient. Those processes which were ranked as having high importance established a basis for which of the S-RELAP5 models received rigorous assessment and the experimental data sets that were used for the assessment. Additionally, periods of two-phase flow could be identified in the PIRT. The experiments identified in the PIRT included the S-RELAP5 standard test set (STS), four SBLOCA specific tests, and a 2-Dimensional flow test. The STS consists of a wide range of experiments that are used to validate code performance and are exercised for each code version created for production use. The additional SBLOCA specific experiments are used primarily as phenomenological assessments in addition to model assessments. The 2-Dimensional test was used to validate the S-RELAP5 2-Dimentional capability.

The interphase constitutive models, interphase drag and interphase mass transfer, were assessed in the context of best possible performance under all conditions, as well as specific to SBLOCA transients.

In EMF-2100(P), results from several of the tests that make up the STS are presented. Listed below are those experiments with brief descriptions of the key parameters with references to their location in EMF-2100(P):

- GE Level Swell – The test assesses the level model, interphase friction, and interphase mass transfer. Key parameters are void fraction and liquid level. Discussion of results begins on Page 3-42 and void profiles are shown in Figures 3.5 and 3.6 on Page 3-43.

- THTF Tests 3.09.10j, 3.09.10m, and 3.09.10dd – The tests are steady boiling tests with level swell and are representative of the core boiling process during SBLOCA. They are used specifically for interphase friction and subcooled boiling assessments. The key parameter is void fraction. The discussion of results begins at the bottom of Page 3-43 and void profiles are shown in Figures 3.7 through 3.9 on Pages 3-44 through 3-45.

- Bennett Heated Tube Tests 5358 & 5379 – Tests used to validate transient CHF. These are not applicable to SBLOCA. The key parameter is wall temperature. The discussion of results begins on Page 4-31 and wall temperature comparisons are shown in Figures 4.2 and 4.3 on Page 4-32 in EMF-2100(P).

- FLECHT-SEASET Test 33056 – Test 33056 is used to assess the Sleicher-Rouse heat transfer coefficient to vapor. The key parameters are void fraction, mass inventory, steam temperatures, differential pressure, heat transfer coefficients, and wall temperatures. The discussion of results begins on Page 4-32 and wall temperature comparisons are shown in Figures 4.4 and 4.5 on Page 4-33.

- Marviken Tests 22 & 24 – The tests assess the S-RELAP5 critical flow model. Since Moody is used for Appendix K analysis, these tests are not applicable to SBLOCA. The key parameters are pressure, fluid temperature, and mass flow (break). The discussion of results begins in Section 5.1.3.2 and comparisons with data are shown in Figures 5.6 through 5.10 on Pages 5-28 through 5.32.

- UPTF Tests 6 & 7 – These tests were designed to quantify downcomer ECC bypass during the blowdown phase (accumulator injection phase) of a LBLOCA. The tests are also used to show 2-Dimensional effects in the downcomer inlet annulus region. The key parameters are differential pressure and mass in lower plenum. The discussion of results begin in Section 5.5.2 and gas velocity profiles are shown in Figure 5.17 on Page 5-60.

- UPTF Test 11 – The test assesses hot leg CCFL at the steam generator inlet. The test is run under SBLOCA conditions and the phenomena are applicable to SBLOCA. The key parameters are mass flow rate and CCFL. The discussion of results begin in Section 5.5.3 and comparison with data is shown in Figure 5.19 on Page 5-64.

The experiments listed below are the additional tests used specifically for SBLOCA. Included are lists of key parameters assessed. The tests are documented in EMF-2328(P):

- 2-Dimensional Flow Problems – A set of three steady state flow problems in a bundle test section. The flow was partially blocked in one of the two bundles, providing 2-Dimensional flow data for assessing 2-Dimensional codes. This problem is used to assess the S-RELAP5 2-Dimensional model. The key parameters are pressure drops and velocities. The results are discussed in Section 5.1.

- Semiscale Test S-UT-8 – This is a small scale test that investigated the effects of downcomer to upper plenum bypass on SBLOCA. The significant phenomena observed was a deep, long core level depression and subsequent heat-up prior to loop seal clearing. The portion of the transient used for assessment was the period of core heat-up prior to loop seal clearing and CCFL. The key parameters are cladding temperatures, pressure histories, mass flows, and liquid levels. The results are discussed in Section 5.2.

- LOFT LP-SB-3 – A SBLOCA test with a nuclear core. HPSI was not activated in order to instigate a core heat-up. Upon reaching designated cladding temperatures, a 'feed and bleed' process was activated in the steam generators to bring the system pressure down to accumulator injection pressure, thus terminating the experiment. The heat-up portion of this test was used to assess the dryout wall heat transfer, level model, and the 2-Dimensional model. The key parameters are cladding temperatures, pressure histories, and liquid levels. The results are discussed in Section 5.3.

- UPTF Loop Seal Clearing Test – A separate effects test to show loop seal clearing behavior under typical SBLOCA conditions. This test was used to assess loop seal clearing and horizontal stratified flow. The key parameters are pressure drops and liquid levels. Results are discussed in Section 5.4.

- BETHSY Test 9.1.b – A small scale (1/100 volume, full height) SBLOCA test with 3 loops. HPSI was not instigated to cause core heat-up. Upon reaching designated temperature, steam generators were blown down to atmospheric conditions to bring primary pressure down to accumulator injection pressure. The accumulator injection quenches the core. The experiment was continued past core quenching to show a second loop seal clearing. This test was used to assess relevant SBLOCA phenomena, including loop seal clearing (including second clearing), core heat-up, core quenching, and CCFL. The key parameters are cladding temperatures, pressure histories, pressure drops, mass flows, and liquid levels. The results are discussed in Section 5.5.

The following tests are used to assess the non-LOCA capability and are discussed in EMF-2310(P), Sections 4.2 through 4.5:

- LOFT L6-1 – Loss of load
- LOFT L6-2 – Loss of primary flow.
- LOFT L6-3 – Excessive steam load.
- LOFT L6-5 – Loss of feedwater.

Non-LOCA transients are integral tests that are event focused rather than S-RELAP5 constitutive model focused. The assessments therefore identified that the general system behavior in the simulation was physical (e.g. in a heatup transient, does the coolant expand and the pressurizer level rise? Does the power in the reactor core decrease? etc.). That being the case, the following information was considered important in the LOFT non-LOCA simulations:

- SG Level
- Pressurizer Level
- Pressurizer Pressure
- SG Pressure
- Reactor Power
- Hot Leg Temperature
- Cold Leg Temperature
- SG Steam Flow Rate
- FW Flow Rate (L6-3)
- RCS Flow Rate (L6-2)
- RCP Speed (L6-2)

At a fundamental level these few key parameters characterize the mass and energy in the system.

The additional tests listed below are part of the STS, but were not documented in EMF-2100(P). They are used for S-RELAP5 model assessment. The tests are listed with brief descriptions and the key parameters are identified:

- MIT Pressurizer – The test is used to validate the level model. The key parameters are pressure and liquid level.
- FLECHT-SEASET Tests 31504 – Test 31504 is used to assess dry-wall interphase drag and reflood wall heat transfer. The key parameters are void fraction (or differential pressure), steam temperatures, mass inventory, heat transfer coefficients and wall temperatures. Figures 2 to 8 show some examples of code-data comparisons. The results of the time-step and nodalization study depicted in Figures 6 to 8 are important for validating the flow regime transition regions and criteria. The main purpose of flow regime classification is to provide smooth transitions between different sets of correlations. The physical phenomena are mainly determined by the constitutive correlations used. Step-changes in interphase interaction terms often produce oscillations and distort the solution. Correlations are of little value if a relatively smooth solution can not be obtained. For a system code such as S-RELAP5, the applicability of the flow regime classification is primarily measured by how harmoniously different correlations work together. Therefore, the most important factors in determining the transition criteria and the extent of the transition region are appearance of smooth solutions, number of repeated time steps, time-step and nodalization sensitivities, and mass error. The interphase heat transfer correlation of Equation (3.134) is mainly responsible for the good comparison between measured and calculated steam temperatures shown in Figure 2. With respect to Figure 3, the interphase friction correlation for the inverted-slug flow sets the amount of liquid in the quench front region. The calculated differential pressure indicates that more liquid is present in neighborhood of the quench front region. This is consistent with the lower wall temperatures before quench, as shown in Figures 6 and 7. Due to numerical diffusion inherent with the donor scheme, it is difficult to spread out the liquid in a longer range, which may occur in the experiment. By keeping more liquid in the inverted slug region, a lower amount of liquid is in the upper elevations. This results in good code-data comparison of wall temperatures in the temperature-rise period. As PCT occurs in the temperature-rise period, it is significant that the code has the capability to properly calculate the thermal-hydraulic responses far above the quench front. Figure 8 shows that the calculated maximum temperature points are distributed in the outer envelope of the data points and that the spread due to time step and nodalization sensitivity is much smaller than the spread of data. The interphase friction package is responsible for the bundle mass displayed in Figure 4.

Figure 2. Steam Temperatures Calculated at 6.3 feet and Measured at 6 feet for FLECHT-SEASET Test 31504

Figure 3. FLECHT-SEASET Test 31504 Calculated and Measured Differential Pressures Between 6 and 7 feet.

Figure 4. FLECHT-SEASET Test 31504 Total Mass in the Bundle

Figure 5. FLECHT-SEASET Test 31504 Heat Transfer Coefficients

Figure 6. Calculated Rod Surface Temperatures at 6.6 feet for 20 Volume Core Cases with Various Time Step Sizes for FLECHT-SEASET Test 31504. The Solid Curve is the Data

Figure 7. Calculated Rod Surface Temperatures at 6.6 feet for 40 Volume Core Cases with Various Time Step Sizes for FLECHT-SEASET Test 31504. The Solid Curve is the Data

Figure 8. Code-Data Comparison of Maximum Clad Temperatures vs. Axial Elevation for FLECHT-SEASET Test 31504

- LOFT Tests L2-5 & L2-6 – These tests are used to assess the LBLOCA capability of S-RELAP5. Several phenomena that occur during these tests can be used to assess various models that are also used in SBLOCA. These include phenomena associated with ECC injection (subcooled water injected into superheated steam), horizontal stratification, and interphase condensation. The key parameters are cladding temperatures, pressure histories, mass flows, density, fluid temperatures, and liquid levels.

  Examples of code-data comparisons of key parameters for LOFT 2-6 and L2-5 are shown in Figures 9 to 26. The agreements are in general good. The calculated results are plotted as a solid line and the measured data are plotted as a dashed line.

Figure 9. LOFT L2-6 Broken Hot Leg Mass Flow Rate

Figure 10. LOFT L2-6 Intact Loop Cold Leg Mass Flow Rate

Figure 11. LOFT L2-6 Broken Cold Leg Density

Figure 12. LOFT L2-6 Upper Plenum Fluid Temperatures

Figure 13. LOFT L2-6 Lower Plenum Fluid Temperatures

Figure 14. LOFT L2-6 Intact Loop Hot Leg Fluid Temperatures.

Figure 15. LOFT L2-6 Pressurizer Collapsed Liquid Level

Figure 16. LOFT L2-6 Primary and Secondary Pressures

Figure 17. LOFT L2-6 Central Bundle Cladding Temperatures (Solid Pellet) at 27.5 in.

Figure 18. LOFT L2-5 Broken Loop Hot Leg Mass Flow Rate

Figure 19. LOFT L2-5 Broken Loop Cold Leg Mass Flow Rate

Figure 20. LOFT L2-5 Broken Cold Leg Density

Figure 21. LOFT L2-5 Upper Plenum Fluid Temperatures

Figure 22. LOFT L2-5 Lower Plenum Fluid Temperatures

Figure 23. LOFT L2-5 Intact Loop Hot Leg Fluid Temperatures

Figure 24. LOFT L2-5 Pressurizer Collapsed Liquid Level

Figure 25. LOFT L2-5 Primary and Secondary Pressures

Figure 26. LOFT L2-5 Central Bundle Cladding Temperatures (Solid Pellet) at 27.5 in.

- 2-D Symmetric Fill – This is a simple model with an analytic solution that can be determined visually (by inspection of printed or plotted velocities) for assessing the 2-Dimensional model (see response to Question 2.2). The key parameters are velocities and liquid levels.

- CCTF – Run 54 – This is an integral test to show the LBLOCA capability of S-RELAP5. Several phenomena that occur during these tests can be used to assess various models that are also used in SBLOCA. These include phenomena associated with ECC injection (subcooled water injected into superheated steam), horizontal stratification, interphase condensation, and core heat-up. The key parameters are cladding temperatures, pressure histories, mass flows, mass inventory, differential pressures, void fraction, and liquid levels. Examples of code-data comparisons for some key parameters are shown in Figures 27 to 32. The calculated results are generally in good agreement with the data. Note particularly that the condensation in the cold leg during the ECC injection period is well calculated, as shown in Figure 29. During the short period of accumulator injection, both calculated results and measured data indicate that the cold leg is almost full of liquid (part from ECC injection and part from condensation of steam). During the LPCI injection period, the amount of liquid is too small to be measured accurately by the instrument.

Figure 27. CCTF Test Run 54 Pump-Side Break Mass Flow Rate

Figure 28. CCTF Test Run 54 Intact Loop Hot Leg Mass Flow Rates

Figure 29. CCTF Test Run 54 Intact Loop Cold Leg Void Fraction

Figure 30. CCTF Test Run 54 Downcomer Differential Pressure

Figure 31. CCTF Test Run 54 Core Differential Pressure

Figure 32. CCTF Test Run 54 Heater Rod Surface Temperatures around the Mid-Plane for High Power Bundles

3.3 *(This question is related to large break LOCA (LBLOCA) only and may be responded to at the time of the BE LBLOCA submittal.)*

On Page 3-1, last paragraph, it is stated that the Electric Power Research Institute (EPRI) drift-flux correlations used in RELAP5/MOD3 are tuned mostly to the steady-state data with regular flow profiles and that there is little evidence that these fix-profile correlations produce good results in simulating LBLOCA transients which are highly irregular and chaotic in nature. It is also stated that the EPRI correlations do not cover the entire range of two-phase flow conditions. Based on this information, it was stated that S-RELAP5 did not adopt the same approach as used in RELAP5/MOD3 but that assessment examples are presented to show that the S-RELAP5 two-fluid formulation produces code-data comparisons that are as good as those obtained by RELAP5/MOD3 for steady-state and nearly steady-state cases. Since the concern stated with the EPRI drift-flux correlations was with the modeling of the LBLOCA transients which are highly irregular and chaotic in nature, please provide the assessments that were performed to ensure that the correlations used in S-RELAP5 are adequate for highly irregular and chaotic transient cases.

This question will be responded to as part of the NRC review of the SPC Realistic PWR LBLOCA model (to be submitted).

3.4 *In Equation 3.7, you limited α_L to a minimum value of 0.1 and used $(D^*/19)^8$. Which experiments form the basis for choosing these values? Please justify the use of these values.*

As explained in the paragraph after Equation (3.7), $(D^*/19)^8$ is a way to convert a discontinuous transition criterion of Equation (3.3) into a mathematically continuous formulation. In reactor applications, D* is either much greater than 19 or much smaller than 19; therefore, there is no practical difference between Equation (3.3) and $(D^*/19)^8$. The smaller diameter criterion of Equation (3.3) is mainly applicable to the core in the reactor systems. The core hydraulic diameter is sufficiently small to preclude the presence of the bubbly flow regime. For computational reasons, a narrow region of bubbly flow is required to provide a smooth transition between single phase liquid and slug flow. Historically, values such as 0.02, 0.05 and 0.1 have been used to define a small region of bubbly flow. There are no apparent ill effects from using any one of the values mentioned above. The value of 0.1 is chosen to provide consistency in the transformation of bubbly flow to inverted annular flow (see RAI question 3-23) since a reactor core is the only component where the dry-wall flow regimes may be of significance. Assessments of ORNL THTF Level Swell Tests, LOFT L2-5, L2-6, FLECHT-SEASET 31504 and CCTF Run 54 validate the use of these values (see data comparisons shown in response to Question 3.2).

3.5 *Please describe the tests used in the assessment and provide the assessments performed to validate the use of Equation 3.11 and the limits provided in the text that follows the equation on Page 3-6 and 3-7 in relation to the $\alpha_{S\text{-}A}$ criteria.*

Equation (3.11) is an empirical relation based on theoretical consideration and experimental observation. The justifications for using the relationship of Equation (3.11) are discussed on Pages 3-5 and 3-6. Jones and Zuber (Reference 3.12) experimentally determined that the transition between slug flow and annular flow occurs around a void fraction of 0.8. The separate-effects tests that may be sensitive to this flow regime transition criterion and, therefore, indirectly validate the criterion are: GE 1ft Level Swell Test 1004-3, UPTF Test 11, and Marviken Critical Flow Tests (co-current down flow). Assessment results of tests such as LOFT L2-5 and L2-6, Semiscale Test S-UT-8, UPTF Loop Seal Clearing Test, and Bethsy Test 9.1b also depend on the transition criterion (see data comparisons shown in response to Question 3.2).

3.6 *On Page 3-7, end of the first paragraph, it is stated that introduction of transition regions may reduce the chances of occurrence and magnitude of discontinuities in interphase interaction terms, but it can not completely eliminate the discontinuities. Please describe known discontinuities that still remain and how these are dealt with in the coding of S-RELAP5.*

By incorporating transition regions, there are no mathematical discontinuities between flow regimes. The statement was referring to the evaluation of an interphase interaction terms at successive time-steps where flow conditions are such that different flow regimes are calculated to occur. The resulting values from the interphase interaction terms may differ greatly, appearing to be computationally discontinuous. The effect of these large differences may reduce the quality of the data comparison or cause oscillations of undetermined magnitude. In general, decreasing the time-step size reduces the computational difference between successive time-step interphase interaction terms. However, reducing the time-step size does not guarantee that the computed differences will be sufficiently small so to not affect the quality of the comparison or reduce oscillations to negligible magnitudes.

The last sentence in the paragraph will be rephrased as follows to clarify its meaning:
It should be cautioned that introduction of transition regions may reduce the chances of occurrence of step-changes in magnitude of interphase interaction terms, but it cannot completely eliminate them.

3.7 *Please describe the information used to confirm the validity of the interpolation in Equation 3.15.*

The intent of Equation (3.15) is to bridge two different sets of constitutive equations. The proof of its effectiveness is mainly measured by sensitivities in time-step and nodalization sizes. The FLECHT-SEASET Test 31504, CCTF Run 54, and THTF Level Swell tests (see response to Question 3.2) were used specifically for assessing Equation (3.15). The parameters used for determination of acceptable performance were void fraction and transition to dryout.

3.8 *Under the vertical stratification section starting on Page 3-8, there appear to be no flow/velocity criteria established for when vertical stratification may occur. Please explain how vertical stratification is detected.*

The detection logic for vertical stratification is described on Pages 3-8 to 3-10. The essential point is that there is a sharp void fraction increase in a consecutive three vertical volume stack. Such a condition usually can not be established under high flow conditions. Therefore, it is redundant to include velocity/flow criteria. Nevertheless, for computational efficiency, the detection of vertical stratification is not performed for mass fluxes greater than 1500 kg/m^{2}s. This is simply a filter to exclude the circumstances where Equations (3.16) and (3.17) are nearly impossible to be satisfied.

3.9 *Please describe how the mixture level model described under the vertical stratification section was validated.*

The mixture level model is most critical for handling a condensation process. Under condensation conditions, the mixture level usually becomes a liquid level. The model is validated by 1-D and 2-D fill problems (see response to Question 2.2), the MIT pressurizer problem (qualitatively), and the LOFT non-LOCA Tests (pressurizer behavior). For flashing or boiling conditions, the mixture level provides only a small enhancement on phase separation. For flashing cases with insignificant wall-to-fluid heat transfer, the rapid decrease of interphase friction with increasing void fraction is sufficient, by itself, to produce a sharp mixture level. The assessment of the GE 1ft Level Swell Test validates the mixture level under flashing conditions. Within the PWR applications, the mixture level for the boiling cases is dominated by the transition from pre-CHF to post-CHF heat transfer. The sharp gradient in void fraction is produced by the transition from slug flow to mist (dispersed) flow. The model under such circumstances is validated by ORNL THTF Level Swell Tests, FLECHT-SEASET Test 31504, CCTF Run 54, LOFT L2-5 and LOFT L2-6 (see data comparisons shown in response to Question 3.2).

3.10 *Please describe the assessment performed to justify the method used for the transition region between the stratified and non-stratified flow (i.e., Equation 3.26 and associated restrictions and criteria).*

The primary test used for developing the transition region criteria was the UPTF Loop Seal Clearing test (see response to Question 3.2). Time-step size sensitivities were used to introduce perturbations due to apparent discontinuities between the interfacial drag for horizontal stratified and bubbly/slug flow (see response to Question 3.6). Since the vapor flow exceeded the stable flow criteria and was in the transition region, this process is an acceptable method determining transition region criteria. The acceptance criteria for determining the transition region was consistent liquid levels in the horizontal section when using time step sizes of 5 milliseconds to 100 milliseconds.

3.11 *Justify the choice of 0.9 for j_g* for the boundary between slug and annular mist flow (Equation 3.28) in light of the wide range of 0.25 to 1.0 suggested by Wallis. What are the sensitivities of the results of the analyses of interest to the value of j_g* and why is 0.9 appropriate in light of these sensitivities? What is the range of hydraulic diameters that this criterion is valid for? Please describe the assessment performed to cover the sensitivity to hydraulic diameter. Provide a comparison to applicable experimental data.*

The flow regime classification is an intermediate model necessary and convenient for providing a reasonable approximation of evaluating the interphase friction and interphase heat transfer. High precision of flow regime transition criteria is not warranted since the uncertainty of interphase friction is large. The inclusion of large region of transition before the annular flow boundary further diminishes the importance of the transition line criterion.

For the US PWR plants and their related test facilities, the main horizontal components are hot legs and cold legs. In the case of SBLOCA, the cold legs and hot legs are in bubbly flow during the early period. The flow regime then changes to and stays in the horizontal stratification flow since the vapor velocity is low. All other horizontal flow regimes play no role; therefore, the precision of the annular flow transition criterion is immaterial. For LBLOCA, the annular flow can appear in the hot legs for a short duration (about 2 sec) during the very early period of blowdown when the void fraction is higher than 0.8 and the pressure is still rather high. Under such circumstances, the limit value of 0.8 overwrites the J_g^* criterion. As soon as the pressure decreases and the density ratio of liquid to vapor increases to around 500, the flow regimes of both cold and hot legs become horizontally stratified. At liquid-vapor density ratio of 500, void fraction of about 0.8 and typical hot leg diameter of about 0.75 m, Equation (3.23) yields a critical vapor velocity of $v_{HS} \approx 40 \mathrm{m/s}$. The interpolation scheme used in the transition region [see Equation (3.65)] suggests that the horizontal stratification may be dominant at least up to half of the transition region, i.e., up to vapor velocity of about 70 m/s. Considering the vapor velocity is about 50 m/s during the refill period and about 30 m/s during the reflood period, the horizontal stratified flow is still the most important flow regime in the horizontal components for LBLOCA. Thus, for LOCA, the annular flow in the horizontal component either plays no role or is insignificant; therefore, there is no need to consider the dependency of hydraulic diameter or to determine an accurate value of J_g^*. It should be pointed out, however, that the high value of 0.9 is more appropriate for J_g^*. Since the annular flow can only be present at very high vapor velocity, a low value of J_g^* will yield a void fraction too low to be considered as annular flow.

There are no appropriate data for a direct assessment of flow regime criteria. The assessment can only be performed on the whole constitutive package, not individual pieces. The horizontal constitutive package is validated through examining mass flow rate, fluid density, fluid temperature and void fraction in cold legs and hot legs for LOFT L2-5, LOFT L2-6, CCTF Run 54, and UPTF Test 11 (see data comparisons shown in response to Question 3.2).

3.12 *Please describe how the effect of condensation at the ECCS injection point is handled in S-RELAP5.*

The effect of condensation at the ECCS injection point is generically treated by the condensation mass transfer model, including Equations such as (3.115), (3.116), (3.123), (3.142) and (3.148). There is no special ECCS component or model.

3.13 *Please show how Equation 3.23 is derived from the material in the reference. Also, it appears in Equation 3.23 that the α_g is a subscript to β. Please confirm or correct this.*

3.14 *On Page 3-48, it is stated that various assessment calculations indicate that Equations 3.98 and 3.99 function well. Please identify and discuss the tests that were used in the assessment calculations and the results of the assessment calculations.*

The purpose of Equations (3.98) and (3.99) is to bring any metastable state to as close to the saturation state as possible to prevent unforeseeable numerical difficulties caused by large departure of superheated liquid or subcooled steam state from the saturation state. The term "function well" simply means that the purpose is achieved. All metastate temperatures are close to the saturation and there are no state failures in any assessment calculation. This is a numerical necessity, as explained on Page 3-47. Except for Marviken Critical Flow Tests, there are no experimental data exhibiting effects caused by highly superheated liquid or highly subcooled vapor and the code does not calculate any of them. As for the Marviken Tests, the break flow data show an extremely short period of sudden drop and rise of break flow [see Figure 5.6 on Page 5-28 of EMF-2100(P)] due to the presence of highly superheated liquid right after the break is initiated. The code does not calculate such a sharp drop and rise in break mass flow rate, but the period is too short to be of any significance.

3.15 *Section 3.4.8 discusses the equilibrium option that exists in S-RELAP5. Please provide a table showing when (i.e., in what transient analyses) this option would be allowed and when it would not be allowed. Also, please provide a reference to the section in the user's manual that directs the user to follow these restrictions. If allowed in any of the licensing analyses, please justify the values selected.*

The equilibrium option is not and has not been used in SPC assessment and licensing analysis calculations. The need for guidelines has not been necessary since the code will not run with the option turned on.

3.16 *Section 3.4.9 discusses the effect of noncondensables on condensation rate. Please justify your use of Equations 3.169 and 3.165 in S-RELAP5 to handle the reduction of condensation rate in the presence of noncondensables. Please provide a description and results of assessment calculations that justify the use of these equations.*

The effects of noncondensables on interphase condensation appear in LBLOCA. The tests used for assessment are LOFT tests L2-5 and L2-6. In those tests, subcooled safety injection initiates in the approximate time frame as the accumulator empties of liquid and injects nitrogen into the system. Thus, subcooled liquid is injected into a two-phase mixture with noncondensables present.

The safety injection is delivered to the primary system from a constant head pump which makes the flow dependent on downstream pressure. Under the system conditions with subcooled liquid injected into superheated steam, condensation would occur, causing a slight pressure decrease which would further increase the injection rate. The reduction in condensation due to nitrogen injection from the accumulator increases the downstream pressure and thus reduces the injection rate. Therefore, LPSI flow rate is a key parameter for assessing the effects of condensation with noncondensables present.

From Figure 33, the measured LPSI flow shows a short period of decreased flow indicating that the pressure had increased during that period. The reason for the short period of increased pressure/decreased flow was the decrease in condensation due to the presence of noncondensables.

In S-RELAP5, the LOFT L2-6 LPSI is modeled with a time dependent junction specifying flow as a function of downstream pressure (simulating a constant head pump). As shown in Figure 33, the calculated and measured LPSI initially agree well. Subsequently the calculated LPSI flow rate decreases for a short period when an increasing flow is expected, following the trends measured during the experiment. This comparison shows the effects of Equations (3.165) and

(3.169). The comparison also shows the reduction in condensation is underestimated. This assessment case is used primarily for LBLOCA validation.

Figure 33. Comparison of S-RELAP5 LPSI Flow with Measured Data from LOFT Test L2-6

3.17 *For time smoothing, it is stated on Page 3-68 that the scheme implemented in S-RELAP5 is empirical and that various assessment calculations indicate that it works satisfactorily. Please describe the assessment calculations performed for confirming the time smoothing scheme. In addition, show how the assessment calculations provide a test for the scheme.*

Any test where mass transfer effects dominate the calculated results can be used to demonstrate the effectiveness of the smoothing algorithm. Upon completion of model development, the GE Level Swell Test [see Page 3-43 of EMF-2100(P)] was used to study the effects of mass transfer time smoothing, Equations (3.171) through (3.174). The criteria used for determining the constant in Equation (3.172) was the assumption that fewer repeated time-steps implies a smoother transient.

3.18 *In Section 3.4.10, in relation to mass error, it is stated that S-RELAP5 implements a strategy which forces only condensation to take place when the amount of liquid in a volume is small and subcooled and the vapor is superheated. In addition, this strategy forces only evaporation to take place when the amount of vapor in a volume is small and subcooled and the liquid is superheated. It is stated that these limits have no significant effects on physical results as one would expect from such a diminishing amount of liquid or vapor and that these limits reduce mass error substantially. Please justify your strategy for dealing with the mass error. In your justification, please discuss any assessments that were performed, the tests used in the assessments, and the results.*

3.19 *In Section 3.4.10, in relation to subcooled nucleate boiling, it is stated that S-RELAP5 implements a strategy which lowers the interphase heat transfer coefficients in order to eliminate situations where the total mass transfer rate, Γ_g, becomes negative. Please justify your strategy for dealing with this situation. In your justification, please discuss any assessments that were performed, the tests used in the assessments, and the results. In addition, the last paragraph on Page 3-70 states that there is no guarantee that the final solution at the end of each time step meets all the conditions or limits described in the section. Please explain what is meant by this statement and explain and justify what is done in S-RELAP5 when the conditions or limits are not met.*

The rationale and method for the special treatment of vapor generation under subcooled boiling conditions are discussed on Pages 3-69 to 3-70. In general, the sum of bulk mass transfer (condensing) and wall vapor generation is positive (.i.e., vaporizing) when the wall temperature is above the net-vapor-generation point and the scheme is not applied. However, mismatched conditions may be calculated at times. Mismatched conditions may be ignored or corrected. The treatment used for correcting the model inconsistency in subcooled nucleate boiling is designed to improve the quality of the numerical solutions, such as smoothness in space/time, reducing the number of repeated time steps, and reducing the mass error. The effect on the liquid temperature due to the adjustment of bulk condensation rate to be smaller than the wall vaporization rate is extremely insignificant. The scheme is intended to enhance the numerical performance of the code without affecting significantly the overall physical results. Therefore, its only validation is that the code is numerically performing well on all calculations; i.e., extremely rare code failures, no excessive number of repeated time steps, no appreciable mass error, etc. This is the case. Also, there is no code problem caused by condensation in a subcooled nucleate boiling volume, as it used to be years ago. The table shown in the response to Question 3.18 confirms that this scheme (strategy) together with other special numerical treatments for the mass transfer model produces very good mass conservation in S-RELAP5.

All special treatments discussed in this section are based on old time (i.e., at the beginning of the current time step) information. As shown in Equation (2.197), the new time (i.e., at the end of the time step) vapor generation rate is obtained from the old time vapor generation rate by including the contributions from changes of pressure, liquid energy, vapor energy, and noncondensable quality within the time step. The new time vapor generation rate (part of the final solution) may not satisfy all the conditions or limits imposed by the special treatments. As no check is made on whether any inconsistency is still present at the end of time step, there is no guarantee that the final solution meets all the conditions or limits. However, it is expected that even if some conditions are not met, the discrepancy is not significant enough to cause appreciable solution truncation error. In any case, the final solution is checked against the time-step control criteria described in Section 2.6.7 to ensure solution convergence.

3.20 *Please provide a list of the figures of merit and important phenomena in relation to each of the transients and accidents to be analyzed with S-RELAP5. Please also describe how these figures of merit and important phenomena were designated as important for the relevant analyses.*

In addition to 10.CFR 50.46 requirements of PCT and maximum cladding oxidized, the time histories of the following parameters are reported with a SBLOCA analysis:

- Primary and secondary pressure
- Reactor power
- Core level
- Core collapsed liquid level
- Total primary system mass
- Break mass flow rate
- Void fraction at the break junction
- Combined delivered SI flow
- Combined accumulator flow
- PCT node vapor temperature
- PCT node clad surface temperature
- Rupture node clad surface temperature (only if rupture occurs)
- Steam generator liquid level
- Void fraction in the last node of the loop seal (RCP side)
- Steam velocity in the loop seal
- Metal-water reaction information

A review of the behavior of the above parameters as a function of time is performed to assure that the analysis produces expected results. The choice of those parameters was confirmed by an informal PIRT that was developed to identify important phenomena with respect to SBLOCA transient period. A summary of the results of the informal PIRT for the SBLOCA event is shown in Table 2 below.

3.21 *In Sections 3.4.1 through 3.4.7 heat transfer correlations, limits on these correlations, and transition equations are presented for different flow regimes. However, no justifications are provided. Please provide justifications for the material presented in these sections and provide discussion of assessments performed to confirm the adequacy of correlations used in S-RELAP5.*

The limits on the interpolation parameters for smoothing are Equations (3.103), (3.114), (3.119), (3.124), (3.136) and (3.150). They define the transition region between two correlations of different valid ranges, for example, a subcooled correlation and a superheated correlation. In the transition region, they have the values between 0 and 1. They usually can and do take the value of either 0 or 1 to select one of the correlations. Many of the limits are simply the maximum of two correlations. They include Equations (3.101), (3.123), (3.146), (3.151), and (3.159). The approach is standard. The rest are limits placed on the phasic velocities. These are in Equations (3.125), (3.142), (3.144) and (3.148). They are numerical necessities to filter out fluctuations in code-calculated phasic velocities. They were put in to improve reliability of the code calculations.

The limits and the correlations work together as an integral package. Some of the assessments that justify/validate the mass transfer constitutive package are LOFT L2-5, LOFT L2-6, CCTF Run 54, ORNL THTF Level Swell Tests and FLECHT-SEASET 31504 (see data comparisons shown in response to Question 3.2). From LOFT L2-5 and L2-6 assessments, code data comparisons are performed on fluid temperatures at various locations, and density comparisons in cold and hot legs. In CCTF Run 54, the cold leg void fraction is a good test for the condensation model. The ORNL THTF Level Swell Tests assess the subcooled nucleate boiling model. Code-data comparisons of steam temperatures for the FLECHT-SEASET test validates the vaporization model for superheated steam. Also, the depressurization rates in blowdown calculations such as the LOFT tests and Marviken Critical Flow Tests are affected by the vaporization model of superheated liquid.

3.22 *Page 3-11, last paragraph, it is stated that "...some calculations with RELAP5/MOD2 indicated that the range of stratified flow is too small. Kukita et al suggested that the vapor velocity on the left side of Equation 3.22 be replaced by the relative velocity (v_g-v_f). This approach along with an additional constraint to exclude high mass flux conditions was implemented in the previous S-RELAP5 code versions. Recent experience with small break test cases and plant calculations indicated that the new approach might increase code variability. Therefore, the approach of replacing the vapor velocity with relative velocity is abandoned."*

Since the approach was abandoned, what was done to address the concern that the range of stratified flow was too small and how was that justified? Please provide comparisons of your approach to data to justify the adequacy of your approach.

The concern needs to be addressed because RELAP5/MOD3 uses similar approach (i.e., relative velocity and a mass flux criterion). The information is useful for the code developers so that they know the approach was tried once. Actually, the range of stratified flow defined by Equation (3.23) is not small at all for the diameter size of typical PWR hot and cold legs. This can be seen from Fig. 6 of Reference 3.3 (Taitel's paper). The region of stratified flow expands substantially with increasing diameter. The response to Question 3.11 also shows that the range of stratified flow is rather large under typical LBLOCA conditions of hot and cold legs. For PWR SBLOCA, with Equation (3.23) the flow regime in the cold/hot legs stays always in the stratified flow, but not so with the approach using relative velocity plus an additional constraint. The assessments of LOFT L2-5 and L2-6, CCTF Run 54 and UPTF Test 11 show that Equation (3.23) is applicable to both large and small diameters (see data comparisons shown in response to Question 3.2).

3.22 (This question is related to LBLOCA only and may be responded to at the time of the BE LBLOCA submittal.)

For dry-wall flow regimes, please justify your use of 0.1 for the $\alpha_{IA\text{-}IS}$ criterion in light of the information provided in the text preceding Equation 3.13 that indicates that the transformation of the three wet-wall flow regimes into inverted annular, inverted slug, and mist flow regimes should be used.

In US reactor applications, the classification of dry-wall flow regimes is really required only in the core. As discussed in response to Question 3.4, the bubbly flow boundary for the core is set at void fraction of 0.1 to be consistent with the $\alpha_{IA\text{-}IS}$ criterion.

Chapter 4: Heat Transfer Models

4.1 *In reviewing Section 4, Heat Transfer Models, it is apparent that this section is totally different to any comparable heat transfer section in RELAP5/MOD2. Contributions from various known sources constitute the basis for this heat transfer model.* Please provide qualitative (and quantitative) *justification for the formulation of this particular heat transfer model. (i.e., assumptions, mass flow rates, pressure, enthalpy, etc.).*

Most heat transfer correlations in S-RELAP5 are inherited from RELAP5/MOD2 with or without minor modifications. In the code manual, the RELAP5/MOD2 heat transfer equations are written for the heat transfer rates into hydro volumes, while the S-RELAP5 heat transfer equations are expressed in terms of the heat flux and heat transfer coefficient. The boundary conditions for the conduction solution scheme are expressed in terms of heat transfer coefficients and heat fluxes in both RELAP5/MOD2 and S-RELAP5. The selection logic for heat transfer regimes is somewhat simplified in S-RELAP5, but the regimes are essentially the same in both codes.

Equation (4.1) is a general expression for total heat in the RELAP5 series of codes, including RELAP5/MOD2 and S-RELAP5. The same is true for the heat transfer coefficients, Equation (4.2). Note that not all of the terms in Equations (4.1) and (4.2) may be present for a given heat transfer regime, as explained on Page 4-1. For example, the subcooled nucleate boiling heat transfer is described in S-RELAP5 by Equation (4.15):

$$q'' = h_{mac}(T_w - T_f) + h_{mic}(T_w - T_{sat}).$$

The heat transfer to the vapor phase is not present, i.e., h_{cg} of Equation (4.1) is zero. The same heat transfer equation is documented in RELAP5/MOD2 (RELAP5/MOD2 Code Manual Volume 1: Code Structure, Systems Models, and Solution Methods, NUREG/CR-4312, Rev. 1, March 1987, Page 109) as

$$Q_{wf} = \left[h_{mic}\,\Delta T_{sat} + h_{mac}\,(T_w - T_f)\right]A_{wf}/V$$
$$Q_{wg} = 0$$

The terms inside the square brackets of the above equation are the same as those on the right side of Equation (4.15) of S-RELAP5. Also the correlations for h_{mic} and h_{mac} are the same for both codes. In general, there are no differences between RELAP5/MOD2 and S-RELAP5 in heat transfer modeling schemes and principles.

4.2 *On Page 4-2 of the S-RELAP-5 Models and Correlations Code Manual, the last sentence of the last paragraph discusses the issue of reflood being turned off and on. Who decides when or where the option is turned on or off at the appropriate time?*

The reflood model is an input option, which can be selected by the user for some particular heat structures. If the option is selected, the user also has the option to set the time to start the model. The users' manual, RELAP5 Input Data Requirements, EMF-CC-097(P), Revision 4, describes the general recommendations for setting the starting time of the reflood model, but the specific procedures will be stated in the methodology guidelines. For SBLOCA and non-LOCA transients, the reflood model is not used. For LBLOCA applications, the user must follow the LBLOCA methodology guidelines.

4.3 *Please provide an explanation of the difference between the data and the calculational results in Figure 4.3.*

The discrepancy is explained on Page 4-31 of EMF-2100(P). It should be pointed out that this particular case is outside the range of reactor accident applications because the mass flux in the post-CHF regimes under accident conditions will never reach such a high value of 3797.4 kg/m^2-s.

4.4 *How does RELAP-5/MOD2 or MOD3 compare to the same data as that presented in RAI 4.3 above? A comparison of S-RELAP5 and RELAP5/MOD2 against the data and on the same page would help.*

Figure 34 shows measured data and the calculated results from S-RELAP5, ANF-RELAP and RELAP5/MOD3.2. "5379_Calc" is the same as shown in Figure 4.3 in EMF-2100(P) for S-RELAP5, "5379_ANFR" is from ANF-RELAP, which should yield the same result as RELAP5/MOD2, and "5379_MOD3.2" is from RELAP5/MOD3.2. The ANF-RELAP code produces the best post-CHF results because the under-prediction of vapor convective heat transfer is compensated by the use of the modified Bromley correlation at high void fraction (higher elevations). {Note: on Page 113 of the RELAP5/MOD2 manual, it indicates that Dougall-Rohsenow is used. This is incorrect. In all of the released versions of RELAP5/MOD2 and MOD3, the factor $(1-\alpha_g)v_f$ is not included in the vapor phase convective heat transfer computation.} As discussed on Pages 4-16 to 4-18 of EMF-2100(P), two correlations (Forslund-Rohsenow dispersed film boiling and modified Bromley) are used for the film boiling heat transfer in S-RELAP5. This yields much lower film boiling heat transfer than RELAP5/MOD2 at higher elevations where the void fraction is high. In RELAP5/MOD3, a multiplication factor is applied on the modified Bromley correlation to reduce the heat transfer coefficient to liquid at the high void fractions. Therefore, the temperature trend at higher elevations is very similar for S-RELAP5 and RELAP5/MOD3.2.

Figure 34. Comparison of RELAP5 Versions

Chapter 11: Point Kinetics Model

11.1 *On Page 11-16, the last equation has a term missing. The term " $-V_{01}$ " is missing. Compare with Equation 7.6-21 in NUREG/CR-5535, V1.*

Concur. The code manual EMF-2100(P) will be corrected.

The following question is in regard to Topical Report EMF-2328(P) Revision 0:

SB.1 *Please justify use of 0 percent fuel clad preoxidation in the SBLOCA analysis.*

The SPC methodology described in EMF-2328(P), "PWR Small Break LOCA Evaluation Model, S-RELAP5 Based," results in a conservative calculation of peak local oxidation for comparison to the 17% oxidation criteria of 10 CFR 50.46. The methodology assumes that the pre-accident cladding oxidation is zero in order to maximize the rate and extent of oxidation during a LOCA. This assumption results in higher peak cladding temperatures and higher peak local oxidation than assuming a non-zero pre-accident oxidation value.

Cladding oxidation from two sources is considered: (1) pre-accident or pre-transient oxidation due to corrosion at operating conditions, and (2) transient oxidation which occurs at high temperature during the LOCA. Pre-transient oxidation is determined by a fuel performance calculation and is a function of burnup. Over the burnup range that the fuel rod is at high power and can approach technical specification peaking limits, the pre-transient oxidation is small; however, at high burnups, pre-transient oxidation can become significant.

Transient oxidation is calculated as part of the LOCA analyses. By rule, this oxidation must be computed using the Baker-Just reaction rate equation. Using this equation, the calculated reaction rate decreases in direct proportion to the increase in thickness of the layer oxidized and increases exponentially with absolute temperature. Therefore, the transient oxidation is maximized by minimizing the initial oxidation layer which yields the highest reaction rate. The increased reaction rate produces higher temperatures which further increases the reaction rate, thus compounding the effect.

The reason that the assumption of zero pre-accident oxidation value results in a conservative calculation of peak cladding temperature and total peak local oxidation is that SPC's calculations show that a non-zero pre-accident oxidation assumption reduces the transient oxidation by an amount greater than the pre-accident oxidation. Therefore, the maximum oxidation; i.e., the sum of both pre-transient and transient oxidation is greatest when zero pre-transient oxidation is assumed. These results apply for conditions where the transient oxidation is the dominant contributor to the total oxidation, which is the case for calculated PCTs in excess of 2000°F and for burnups at which peaking can approach the technical specification limits. These are the most limiting cases for both LBLOCA and SBLOCA.

SPC also recognizes that conditions exist where the total oxidation is dominated by the pre-transient oxidation. This situation occurs when lower PCTs are calculated and at high burnups. For cases with low PCTs, the pre-accident oxidation becomes dominant because the transient oxidation is substantially reduced or effectively eliminated due to the low absolute temperature. For high burnups, the transient oxidation is reduced or effectively eliminated due to the inherent low power and associated low transient temperatures, and is further reduced by the presence of a significant initial oxide layer. For these cases, the maximum total oxidation is essentially equal to the initial pre-accident oxidation value. This oxidation value can exceed the value calculated using a zero initial pre–accident oxidation for these conditions; however, the total oxidation is precluded from approaching or exceeding the 17% value by the design limit on pre-accident oxidation. [

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