April 9, 2003

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP, Richland, Inc.
2101 Horn Rapids Road
Richland, WA 99352

SUBJECT: SAFETY EVALUATION ON FRAMATOME ANP TOPICAL REPORT EMF-2103(P), REVISION 0, "REALISTIC LARGE BREAK LOSS-OF-COOLANT ACCIDENT METHODOLOGY FOR PRESSURIZED WATER REACTORS" (TAC NO. MB7554)

Dear Mr. Mallay:

By letter dated August 20, 2001, Framatome ANP submitted Topical Report EMF-2103(P), Revision 0, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," for NRC staff review and approval.

The NRC staff has completed its review of the topical report and Framatome ANP's response to the staff's request for additional information (RAI) with regard to the analysis of large break loss-of-coolant accident (LOCA) events in pressurized water reactors of the Westinghouse 3- and 4-loop and Combustion Engineering 2x4 designs. The NRC staff's safety evaluation describes the S-RELAP5 analysis code and the assessment of the code's capabilities based on application of the Code Scaling, Applicability, and Uncertainty (CSAU) evaluation methodology. The report is acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the report and in the associated NRC staff's safety evaluation, which is enclosed. The safety evaluation defines the basis for acceptance of the topical report.

The subject topical report and supporting documentation has been reviewed by the Advisory Committee on Reactor Safeguards which has agreed with the staff's recommendation for approval by its letter of December 20, 2002.

If the NRC staff's criteria or regulations change so that its conclusion in this letter, that the topical report is acceptable, is invalidated, Framatome ANP and/or the applicant or licensee referencing the topical report will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the topical report without revision of the respective documentation.

Accordingly, use of the subject Framatome ANP methodology is acceptable for referencing in licensing submittals subject to the following conditions and limitations as discussed in the safety evaluation:

- The model applies to 3 and 4 loop Westinghouse- and CE-designed nuclear steam systems.
- The model applies to bottom reflood plants only (cold side injection into the cold legs at the reactor coolant discharge piping).

- The model is valid as long as blowdown quench does not occur. If blowdown quench occurs, additional justification for the blowdown heat transfer model and uncertainty are needed if the calculation is corrected. A blowdown quench is characterized by a temperature reduction of the peak cladding temperature (PCT) node to saturation temperature during the blowdown period.

- The reflood model applies to bottom-up quench behavior. If a top-down quench occurs, the model is to be justified or corrected to remove top quench. A top-down quench is characterized by the quench front moving from the top to the bottom of the hot assembly.

- The model does not determine whether Criterion 5 of 10 CFR 50.46, long term cooling, has been satisfied. This will be determined by each applicant or licensee as part of its application of this methodology.

- Specific guidelines must be used to develop the plant-specific nodalization. Deviations from the reference plant must be addressed.

- A table that contains the plant-specific parameters and the range of the values considered for the selected parameter during the topical report approval process must be provided. When plant-specific parameters are outside the range used in demonstrating acceptable code performance, the licensee or applicant will submit sensitivity studies to show the effects of that deviation.

- The licensee or applicant using the approved methodology must submit the results of the plant-specific analyses, including the calculated worst break size, PCT, and local and total oxidation.

- Applicants or licensees wishing to apply the Framatome ANP realistic large break loss-of-coolant accident (RLBLOCA) methodology to M5 clad fuel must request an exemption for its use until the planned rulemaking to modify 10 CFR 50.46(a)(i) to include M5 cladding material has been completed.

The review of the models and benchmarks noted concerns and deficiencies resulting in conditions of use of S-RELAP5 as follow, which have been committed to in a letter from Framatome ANP to NRC dated December 20, 2002:

- A CCFL violation warning will be added to alert the analyst to CCFL violation in the downcomer should such occur.

- Framatome ANP has agreed that it is not to use nodalization with hot leg to downcomer nozzle gaps.

- If Framatome ANP applies the RLBLOCA methodology to plants using a higher planar linear heat generation rate (PLHGR) than used in the current analysis, or if the methodology is to be applied to an end-of-life analysis for which the pin pressure is significantly higher, then the need for a blowdown clad rupture model will be

reevaluated. The evaluation may be based on relevant engineering experience and should be documented in either the RLBLOCA guideline or plant specific calculation file.

- Slot breaks on the top of the pipe have not been evaluated. These breaks could cause the loop seals to refill during late reflood and the core to uncover again. These break locations are an oxidation concern as opposed to a PCT concern, since the top of the core can remain uncovered for extended periods of time. Should an analysis be performed for a plant with loop seals with bottom elevations that are below the top elevation of the core, Framatome ANP will evaluate the effect of the deep loop seal on the slot breaks. The evaluation may be based on relevant engineering experience and should be documented in either the RLBLOCA guideline or plant-specific calculation file.

In accordance with the guidance provided on the NRC's website, we request that Framatome ANP publish an accepted version within 3 months of receipt of this letter. The accepted version shall incorporate (1) this letter and the enclosed SE between the title page and the abstract, (2) all RAIs from the NRC staff and all associated responses, and (3) a "-A" (designating accepted") following the report identification symbol.

We have determined that the enclosed safety evaluation does not contain proprietary information as defined in 10 CFR 2.790. However, we will delay placing the safety evaluation in the public document room for a period of ten working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis for such claim pursuant to 10 CFR 2.790.

Our acceptance applies only to matters approved in the report. On the basis of our review of the topical report and our finding as to its acceptability, we will review license applications that reference the report to ensure that the material presented applies to the specific plant involved.

In the event that any comments or questions arise, please contact Drew Holland at (301) 415-1436.

Sincerely,

/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 693

Enclosure: Safety Evaluation

methodology is to be applied to an end-of-life analysis for which the pin pressure is significantly higher, then the need for a blowdown clad rupture model will be reevaluated. The evaluation may be based on relevant engineering experience and should be documented in either the RLBLOCA guideline or plant specific calculation file.

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Enclosure: Safety Evaluation

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See attached ORC

Table 1-Charts: ML 030730436 **PKG: ML030760337**
ACCESSION NO. ML030760312 **NRR-043**

OFFICE	PDIV-2/PM	PDIV-2/LA	SRXB/BC*	OGC*	PDIV-2/SC	PDIV/D
NAME	DHolland	EPeyton	JWermiel	SETurk	SDembek	HBerkow
DATE	4-9-03	4/9/03	2/25/03	4/3/03	4/9/03	4/9/03

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT EMF-2103(P), REVISION 0

"REALISTIC LARGE BREAK LOCA METHODOLOGY FOR

PRESSURIZED WATER REACTORS"

PROJECT NO. 693

1.0 INTRODUCTION

On August 20, 2001, Framatome ANP submitted EMF-2103(P), Revision 0 (Reference 1), for NRC staff review and approval for application of the S-RELAP5 thermal-hydraulic analysis computer code to the realistic large break loss-of-coolant accident (RLBLOCA) in Westinghouse and Combustion Engineering (CE) pressurized water reactors (PWRs) as detailed in References 3 through 7.

Framatome ANP stated that its goal is to apply a single computer code to the analysis of both LOCA and non-LOCA transient events. The NRC staff has previously reviewed and approved application of the S-RELAP5 code to Title 10, *Code of Federal Regulations* (10 CFR) Part 50, Appendix K, small break LOCA (SBLOCA) events (Reference 8), as well as certain non-LOCA Standard Review Plan (SRP) Chapter 15 events (Reference 9).

This safety evaluation (SE) addresses application of the S-RELAP5 code in a realistic manner in which the uncertainties in estimating the necessary parameters to satisfy the requirements of 10 CFR 50.46(b) are determined for the large break LOCA (LBLOCA).

2.0 REGULATORY BASIS

The requirements of 10 CFR 50.46 specify that each boiling or pressurized light-water nuclear power reactor fueled with uranium oxide pellets within cylindrical zircaloy or ZIRLO cladding must be provided with an emergency core cooling system (ECCS) that must be designed so that the calculated cooling performance following a postulated LOCA conforms to the criteria contained within the paragraph.

The stated requirement can be met through an evaluation model for which an uncertainty analysis has been performed as follows:

> *...the evaluation model must include sufficient supporting justification to show that the analytical technique realistically describes the behavior of the reactor system during a loss-of-coolant accident. Comparisons to applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be*

accounted for, so that, when the calculated ECCS cooling performance is compared to the criteria set forth in paragraph (b) of this section, there is a high level of probability that the criteria would not be exceeded.

Paragraph (b) specifies that the peak cladding temperature (PCT) must not be calculated to exceed 2,200°F, the maximum cladding oxidation must not exceed 0.17 times the total cladding thickness before oxidation, the maximum hydrogen generation must not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding surrounding the fuel pellets were to react, the core must remain in a coolable geometry, and the core temperature shall be maintained at an acceptably low level and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

The NRC has suggested certain means by which the above regulatory criteria can be met. References 10 and 11 describe acceptable approaches to determine the calculated uncertainty in the 10 CFR 50.46(b) parameters.

3.0 REGULATORY EVALUATION

The Framatome ANP S-RELAP5 code is based on the RELAP5/MOD2 (References 14 and 15), RODEX3A fuel models (References 16 through 18), ICECON containment code (References 19 and 20), and RELAP5/MOD3 code (Reference 21). The NRC staff became familiar with many of the modifications made to the RELAP5/MOD2 and RELAP5/MOD3 codes during its S-RELAP5 SBLOCA review. That review focused on the conservative nature of the models necessary to satisfy the requirements of 10 CFR Part 50, Appendix K. The requirements of a realistic code are somewhat different in that many of the prescriptive conservative models can be replaced by more realistic models. Doing so necessitates evaluation of the uncertainty in the calculated results. Various means of achieving an estimate of uncertainty are available in the realm of statistical analysis. Framatome ANP has chosen to follow the basic Code Scaling, Applicability and Uncertainty (CSAU) evaluation methodology outlined in NUREG/CR-5249 (Reference 11). While the CSAU approach defines the process by which an uncertainty analysis is performed, it leaves room for the applicant to determine the specific statistical methodology to be applied. Framatome ANP has chosen the non-parametric order statistics methodology. An expanded explanation of the statistics involved is presented throughout this SE.

The following chronology describes the milestones in the NRC staff's review:

- Request for review of S-RELAP5 for RLBLOCA: August 20, 2001. Receipt of code and documentation: August 2001 (Reference 1).

- Acceptance of code for review by the NRC staff: October 3, 2001 (Reference 2).

- Presentation to the staff describing code material and approach to uncertainty analysis: October 30, 2001 (Reference 12).

- Presentation to the Advisory Committee on Reactor Safeguards (ACRS) Thermal-Hydraulic Subcommittee regarding code methodology and uncertainty analysis methodology: January 17/18, 2002 (Reference 13).

- NRC requests for additional information (RAIs): July 2002 (Reference 22).
- Framatome ANP response to the staff's RAIs: August 2002 (Reference 23).
- ACRS Thermal-Hydraulic Subcommittee meeting: November 2002.
- ACRS Full Committee meeting: December 2002.

Sections 3.1 through 3.14 of this SE describe a comparison of the Framatome ANP methodology with the CSAU methodology.

3.1 Step 1 - Scenario Selection

The processes and phenomena that can occur during an accident or transient vary considerably depending upon the specific event being analyzed. Framatome ANP has identified the LBLOCA as the event to which the methodology under review will be applied.

Framatome ANP is consistent with this step in the CSAU approach.

3.2 Step 2 - Nuclear Power Plant (NPP) Selection

The dominant phenomenon and timing for an event can vary significantly from one nuclear power plant design to another. Framatome ANP has specified the nuclear power plant applicability for the methodology under review to be the Westinghouse 3- and 4-loop designs and the CE 2-loop (4 pumps) design.

Framatome ANP is consistent with this step in the CSAU approach.

3.3 Step 3 - Phenomena Identification and Ranking

The behavior of a nuclear power plant undergoing an accident or transient is not influenced in an equal manner by all phenomena that occur during the event. A determination must be made to establish those phenomena that are important for each event and various phases within an event. Development of a Phenomena Identification and Ranking Table (PIRT) establishes those phases and phenomena that are significant to the progress of the event being evaluated.

The Framatome ANP PIRT differs from that in NUREG/CR-5249 (Reference 11) in describing the CSAU approach. NUREG/CR-5249 omitted the following items from the PIRT:

- There was no hot bundle region. Consequently, the calculated sink temperatures were too low, lowering the PCT. The hot rod was incorrectly contained in the average core region.
- The plant calculations were not performed at realistic peak linear heat rates (PLHR). A PLHR of 9.5 kilowatts per foot (kw/ft) was used whereas a more realistic upper bound to the PLHRs fall in the range 12.0 to 13.0 kw/ft. This low PLHR lowers the PCT.

- The effects of containment pressure were not evaluated, so the impact of steam binding and the potential for downcomer boiling were missed. These effects will also tend to increase the PCT.

The PIRT developed in support of the Framatome ANP RLBLOCA methodology addresses each of these areas in addition to identifying the phases of the LBLOCA and the phenomena occurring in each phase. All phenomena ranking high and medium are addressed in the code assessment process.

The specific phases described in the Framatome ANP PIRT are:

- Blowdown - The phase of the LOCA defined as the time period from initiation of the break until flow from the accumulators or safety injection tanks begins.

- Refill - The phase of the LOCA from the time accumulators or flooding tanks begin injecting until the mixture level in the vessel refills the lower plenum and begins to flow into the core.

- Reflood - The phase of the LOCA from the lower plenum filling and emergency core cooling (ECC) flow into the bottom of the core until the temperature transient throughout the core has been terminated.

- Post-Critical Heat Flux (CHF) Heat Transfer - Defined according to the transient phase. During blowdown, high pressure, high mass flux, low vapor superheat film boiling. During refill, a combination of dispersed flow film boiling and natural convection to single-phase vapor. During reflood, dispersed flow film boiling.

- Reflood Heat Transfer - Defined for the reflood period as convection to single-phase steam, wall-to-fluid radiation, film boiling, and transition boiling.

- Rewet - Defined according to transient phase. During blowdown, quench associated with high heat transfer rates near the quench front during high liquid flow. During refill and reflood, limited to top-down quenching due to falling liquid films.

The Framatome ANP methodology incorporates a hot bundle in addition to the hot rod, and plant calculations are performed at realistic, representative peak linear heat generation rates. The ability to address containment back pressure has been addressed through interfacing the S-RELAP5 capability with the ICECON containment analysis code previously approved by the NRC.

Framatome ANP is consistent with the PIRT guidelines and the specifications of this step in the CSAU approach.

3.4 Step 4 - Frozen Code Version Selection

The version of a code, or codes, reviewed for acceptance must be "frozen" to ensure that after an evaluation has been completed, changes to the code do not impact the conclusions and that changes occur in an auditable and traceable manner. Framatome ANP has specified that the

S-RELAP5 version UJUL00 code, and the UMAR01 version of the code incorporating the corrected RODEX3A code, which are frozen, were used for the uncertainty analysis.

Framatome ANP is consistent with this step in the CSAU approach.

3.5 Step 5 - Provision of Complete Code Documentation

This step is to provide documentation on the frozen code version such that evaluation of the code's applicability to postulated transient or accident scenarios for a specific plant design can be performed through a traceable record. Framatome ANP has provided the necessary documentation in References 3 through 7 and 16 through 20.

Framatome ANP is consistent with this step in the CSAU approach.

3.6 Step 6 - Determination of Code Applicability

The applicability of the Framatome ANP methodology is addressed in the following evaluation of the technical content of the documentation.

3.6.1 Heat Transfer Models

In its review of the heat transfer models within the RLBLOCA model (Reference 4), the NRC staff proceeded by first identifying the differences (modifications) in the heat transfer models and CHF correlations between the previously reviewed SBLOCA models in S-RELAP5 (Reference 8), and the RLBLOCA model. For example, Framatome ANP pointed out that in the heatup/dry-out period of the SBLOCA, the core can essentially be characterized by a single-phase steam region above a two-phase mixture region. Therefore, its PCT is mainly determined by the single-phase vapor heat transfer and will not be significantly impacted by small changes in other heat transfer models.

Due to the large number of different heat transfer correlations used in analyzing a particular transient, and in order to obtain a better understanding of such subtle differences and other differences between the two models, the NRC staff chose to investigate one particular transient from its initiation to its termination, carefully analyzing the various heat transfer correlations (Biasi, modified Zuber, etc.) used in the methodology. The review consisted of carefully reviewing the applicability of each particular correlation as the transient unfolded.

The NRC staff requested additional information from the vendor in Reference 22 and asked Framatome ANP to choose a transient and identify all the different correlations that are used from the beginning of the transient to the end. The NRC staff asked Framatome ANP to state the particular correlation used, its applicable range (in terms of the Reynolds Number, flow rates, etc.), and validation of its use in the applicable range.

3.6.1.1 Transient Simulation

The transient chosen for simulation is a limiting transient in terms of PCT for a 3- and 4-loop Westinghouse plant. To demonstrate the capability of S-RELAP5 to simulate a LBLOCA transient, Framatome ANP constructed a test-matrix composed of key correlation dependent

parameters (such as pressure, mass flow, temperature, range of applicability, etc.) based on validation studies (benchmarks such as those from the Thermal-Hydraulic Test Facility [THTF] tests and the FLECHT-SEASET tests) and published correlation reports. The key parameters that were identified are those parameters that are typically used to define the thermal-hydraulic behavior and correlation development. The test-matrix defined the space in which the selected transient is expected to exist. Ideally, the test-matrix should span the simulation-space; however, realistically, there may be holes in the test-matrix which Framatome ANP does not expect to fill in because of the lack of available data and test facilities.

Consequently, Framatome ANP constructed a PIRT for the LBLOCA to demonstrate adequate coverage of the test-space (Reference 23). The PIRT identified and ranked the relevant phenomena identified as being important for LBLOCA. Table 1 of Reference 1 highlights the core heat transfer phenomena identified as being important for the LBLOCA. Table 1 of Reference 1 does not explicitly identify all the important heat transfer regimes or correlations. However, this information is provided in Reference 3. Table 1 of Reference 1 does provide a tabulation of the ranking of important heat transfer regimes, such as the nucleate boiling, CHF, departure from nucleate boiling (DNB), transition boiling and the film boiling regimes. The Framatome ANP PIRT team concluded, and the NRC staff agrees, that other heat transfer regimes were either not present or had negligible impact on the peak clad temperatures. Data (Figures 1, 2, 3 and 4 provided in Reference 23 for the 3- and 4-loop sample plants), indicates that the core heat transfer around the hot rod is limited to the heat transfer regimes stated above.

In Reference 23, Framatome ANP provided a time-line of the chosen PCT event as it unfolded, including clad temperature plots from the 3- and 4-loop sample problems, as well as the respective LBLOCA phases (see Table 3 in Reference 23). The complexity of the PCT scenarios are evident as multiple heat transfer correlations are called upon at the various stages, based upon appropriate applicable ranges of the respective heat transfer correlation. Results of the analyses indicate that with the exception of the period from the onset of quenching to the end of the calculation, the dominant heat transfer mode is the Sleicher-Rouse correlation, representative of single phase convection. In addition, the results of the analyses also show that for the majority of the transient, the hot rod is in film boiling, which is consistent with the PIRT results of Table 1 of Reference 1.

Reference 23 also included a chronological presentation of each of the heat transfer correlations in terms of the range of applicability and validation as applied to the hot rod.

The system of heat transfer correlations in S-RELAP5 includes the range of applicability of the individual correlations, as well as the expanded ranges of applicability of correlations beyond their published ranges. The expanded range of applicability is provided by the uncertainty analysis using the THTF and the FLECHT-SEASET data sets and the RLBLOCA analysis methodology, resulting in a bias calculation used to validate the calculated uncertainty bias.

Tables comparing pressure and heat flux (the heat flux was translated into linear heat generation rate [LHGR]) are provided and compared to published ranges for each of the correlations in the simulated space. Where gaps existed between the range of applicability in matrix space and simulated space, a statistical uncertainty was applied to the data for the range of applicability. To bridge the gap in the void fractions for application of the Forslund-Rohsenow

and the modified Bromley correlations, linear interpolation was utilized to extend the applicability of these correlations. The NRC staff would have preferred a more physical solution to this situation; however, the NRC staff also recognizes the fact that large uncertainties do exist in thermal-hydraulic formulation and there is a shortage of relevant data in this subject. Given the limited availability of data to fill in these gaps, and the acceptable predictions of the most important phenomena in the assessment cases described below, the staff finds this linear interpolation to be acceptable.

3.6.1.2 Reflood Heat Transfer

In computing the heat transfer to the liquid, Framatome ANP uses the Bromley correlation and the Forslund-Rohsenow correlation to cover parts of the anticipated range of void fraction. Linear interpolation between the two correlations is used to obtain the heat transfer coefficient between applicable ranges of void fraction. Framatome ANP is, in effect, interpolating between two correlations to determine the heat transfer along a major portion of the fuel rod for a sustained period of time during reflood. The NRC staff and Framatome ANP do not agree on understanding the nature of the Forslund-Rohsenow model with regard to wall-droplet contact heat transfer when the wall temperature is above the minimum film boiling temperature, that is, Tw>Tmin, the Leidenfrost temperature. The NRC staff understands the Forslund-Rosenow correlation to be primarily a vapor de-superheating effect and secondarily a combination of a wet contact model and a dry contact model that should only be applied above the quench region where the wall is below the minimum film boiling temperature. Reference 26 states, "...heat is transferred from the wall to a possibly superheated vapor to liquid droplets. Superimposed on this two-step process is an additional amount of heat that is transferred from the tube wall directly to the liquid droplets, a kind of Leidenfrost effect." The NRC staff believes that References 24 through 32 further support this position. Framatome ANP, on the other hand, believes the Forslund-Rohsenow model is a dry contact model which can be applied when the wall temperature is greater than the minimum film boiling temperature. In addition, the NRC staff notes that the Forslund-Rohsenow model was developed from data taken for mass fluxes 10 to 100 times the mass flux typical of low flooding rate reflood conditions.

The NRC staff and Framatome ANP studied the Forslund-Rohsenow correlation's effect further through several assessment calculations using the S-RELAP5 code. Assessment cases were recalculated with a multiplier set to multiply the Forslund-Rohsenow equation by a factor of zero (0) when Tw>Tmin. When this was done, the assessments showed that this limitation on Forslund-Rohsenow had no effect on the peak cladding temperature or its time of occurrence. This is to be expected since the void fraction in the period leading up to the PCT is predominantly above 0.995. When the void fraction is above 0.995, the dominant heat transfer is single-phase vapor determined by the Sleicher-Rouse correlation.

Beyond the time of PCT, the void fraction is lower than 0.995 so that either the modified Bromley, Forslund-Rohsenow, or an interpolation between the two is used. This results in temperature response beyond the point of PCT that was slightly higher and the quench time delayed. The overall effect on temperature beyond the PCT point and the quench point was a change in temperature ranging from -24°F to +20°F. Since this temperature variation is within the experimental uncertainty for temperature measurements, the NRC staff concludes that while the staff disagrees with Framatome ANP on the applicability of the Forslund-Rohsenow model for wall temperatures above the minimum film boiling temperature, its use does not play

a significant role in the temperature response of the transient. The NRC staff, therefore, accepts the modeling included in the Framatome ANP RLBLOCA methodology.

An overall comparison of the performance of the steam cooling model can be seen in Figure 1 (attached to this SE); the steam temperature at the time of PCT for FLECHT-SEASET Test 31302. The steam temperature predicted by S-RELAP5 is conservative relative to the measured steam temperature. The higher predicted steam temperature results in lower, conservative, heat transfer from the fuel rod simulators.

3.6.1.3 Minimum Film Boiling Temperature

S-RELAP5 employs a conservatively low minimum film boiling temperature and uses this temperature limit for both blowdown and reflood. This temperature does not bound the lower range of Tmin for blowdown suggested in NUREG/CR-5249 (i.e., 600°K). However, since the NUREG/CR-5249 report was prepared, experience with various vendor analyses, and staff analyses using its own suite of codes show that Tmin in the range 600 to 750°F is not expected to have a strong sensitivity to PCT. Therefore, the model is adequate since it does not impact the PCT.

3.6.1.4 Heat Transfer Models Summary

The NRC staff agrees with the Framatome ANP conclusion that the post-CHF heat transfer is the dominant influence on the clad temperatures of the fuel rod. The submitted analysis demonstrated that although multiple CHF correlations are employed (programmed into S-RELAP5) simultaneously during a LBLOCA calculation, a single phase vapor provides the primary heat transfer sink for the hot fuel rods. It is the interplay between these different correlations (superpositioning, overlapping of correlations, etc.) that actually forms the overall post-CHF heat transfer correlation in S-RELAP5.

The NRC staff also reviewed the range of applicability and the expanded range, based on the statistical treatment and code to data comparisons. The NRC staff agrees with Framatome ANP that in general, the FLECHT-SEASET and the THTF data sets used to expand the range of applicability encompass the original derived range of applicability. However, there remained regions in the test-matrix (assessment-space) where the range of applicability of certain correlations and associated uncertainty analysis still contained some gaps. To account for these gaps, Framatome ANP assessed the code against a series of integral tests, including LOFT, CCTF, and Semiscale (References 3 and 5). The analyses showed good agreement with the test data and the uncertainty analysis thereby enabling Framatome ANP to complete the test-matrix (assessment space) and cover the simulation space.

The NRC staff notes that there is disagreement regarding the application of the Forslund-Rohsenow model when the wall temperature exceeds the minimum film boiling temperature. Since the effect of the correlation when used within the overall heat transfer model has been shown to be negligible under the conditions existing in both experimental comparisons and in predicted full plant conditions, the NRC staff accepts the overall reflood heat transfer modeling in the S-RELAP5 code.

3.6.2 Decay Heat Model

Framatome ANP employs conservative assumptions to compute the decay heat using the ANSI/ANS-5.1-1979 standard (Reference 34). The ANSI/ANS-5.1-1979 standard is applicable where U235 is the principal fissile material, but does consider fission contributions from Pu239 and U238. Framatome ANP has assumed infinite reactor operating time, all fissions are from U235, a fission energy of 200 MeV/fission, and one standard deviation total decay heat uncertainty. Actinide capture decay power is also computed using the ANSI/ANS-5.1-1979 standard equations, along with the addition of decay heat from neutron capture in fission products. The NRC staff concludes that the decay heat model used in the Framatome ANP RLBLOCA methodology is conservative and acceptable.

3.6.3 Counter-current Flow (CCFL) Model

The S-RELAP5 Code employs a CCFL model to limit the flow of liquid into the core through the fuel alignment plate. Since the CCFL model is not used in the downcomer, there are no controls to assure that future plant calculations will not result in violations of the CCFL or unrealistic co-current downflow in this region. Furthermore, the drag and entrainment models in the original RELAP5 code were not developed specifically to accommodate countercurrent flow. In response to the staff's RAIs, Framatome ANP calculations of the Wallis parameters from the 3-loop sample problem show that there is not a violation of the CCFL in the downcomer. The 4-loop sample problem, however, shows a CCFL violation three times during the transient simulation. The staff agrees with Framatome ANP that this is a minor effect and does not affect the overall success of the calculation. To preclude excessive CCFL violation in future applications, Framatome ANP has agreed to have the code provide a warning message to the analyst if a CCFL violation in the downcomer occurs. The code user will then determine if the transient is being influenced by the CCFL violation or whether the violation is insignificant. The NRC staff accepts this code addition in lieu of the addition of a CCFL model to the downcomer.

3.6.4 Break Type and Size

The requirements of 10 CFR 50.46(a)(1)(i) state, in part:

> ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated.

Framatome ANP has interpreted the above requirements to mean that the break size can be sampled as one of the variable parameters treated statistically by random sampling. The NRC staff has studied the position proposed by Framatome ANP and accepts its approach on the basis of the break type and size distributions assumed in its analysis. Specifically, the methodology applies a binomial distribution to the break type sampling, that is, the two break types, Double Ended Guillotine and Slot, are treated as equally probable. In addition, the entire break size distribution is uniform from the largest to the smallest size. Thus, the break type and size selection is of uniform probability for the entire spectrum.

In response to an NRC staff request for additional information, Framatome ANP performed a complete set of analyses while fixing the break size at the worst calculated size. That is, for the 0.66 DEG CL break in a 3-loop Westinghouse plant (the case that resulted in the worst PCT calculated at 1853°F), the remaining parameters treated statistically were chosen by Monte Carlo sampling to establish the 59 sample cases. The calculations resulted in two (2) PCTs calculated above the base worst case and 57 PCTs below the base case. The two PCTs above the base case were 20°F and 76°F above the base case. The NRC staff finds the break spectrum as calculated by Framatome ANP in support of its RLBLOCA methodology acceptable.

Should Framatome ANP elect to alter this distribution specification to one with a bias on size or type, the NRC staff will require further review of that approach.

3.6.5 Critical Flow Model

The critical flow model in S-RELAP5 utilizes the Trapp-Ransom model for subcooled flow and homogeneous equilibrium model (HEM) for two-phase flow. The model does not model non-equilibrium critical flow through the break and therefore does not address the guidance in items b and c in Section 3.4.1.1 of Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," which states that the critical flow model should (b) provide thermal non-equilibrium conditions when the fluid is subcooled, and (c) provide a means of transition from non-equilibrium to equilibrium conditions.

Framatome ANP responded to an NRC staff question on the subject of the transition region between subcooled and saturated fluid conditions lasting 5 – 15 seconds in the Marviken tests and less than 5 seconds in plant calculations. The Marviken test comparisons showed good agreement with the data except in the transition region. Since the transition region is of short duration, this calculation discrepancy has an insignificant effect on the calculation and is considered acceptable.

3.6.6 Multi-Dimensional Downcomer Model

To demonstrate momentum conservation and to assist in understanding the behavior of the 2-D downcomer model, the NRC staff requested that Framatome ANP present the results of several simple test models. The RELAP5 code, as well as other similar codes such as TRAC and RETRAN, can produce anomalous flow circulations, for example, between parallel pipes. These anomalies are of a numerical nature and cannot easily be corrected without the use of additional artificial form losses (Reference 33). Framatome ANP provided the results of a calculation of the sample flow problem presented in Reference 33 and described how the S-RELAP5 code resolves this anomalous flow behavior. The NRC staff finds Framatome ANP's response to this concern is acceptable because it demonstrates that the Framatome ANP multidimensional downcomer model addition does not exhibit anomalous circulatory flow.

3.6.7 Downcomer Boiling

Framatome ANP presented the results of a downcomer boiling study performed for the three-loop plant, including eight variations of the nodalization, cross-flow form loss, and containment pressure.

Since the sensitivity studies performed include containment back pressure as low as 10 psia, along with the effect of single failure, the methodology has been shown to be applicable to subatmospheric containment, including ice condenser plants.

The sensitivity studies were compared to the base case PCT and the variations resulted in an increase of less than 100°F. The NRC staff concludes that the effect of downcomer boiling has been properly accounted for in the analysis.

The sensitivity studies performed demonstrate applicability of the methodology to containment pressures as low as 10 psia. Thus, the methodology is applicable to subatmospheric containment designs, including ice condenser containments, to a containment back pressure of 10 psia. Application to containments with a back pressure lower than that value will require further justification.

3.6.8 ECC Bypass

ECC bypass is calculated by the interaction of the interfacial friction, wall drag, and condensation models. Framatome ANP confirmed that no credit is taken for the bypass conservatism in the uncertainty analysis. That is, there is no direct, negative bias in the uncertainty methods simulating ECC bypass. This is conservative and acceptable to the NRC staff.

Framatome ANP is consistent with this step in the CSAU approach since the models used in the methodology adequately represent physical phenomena identified in the PIRT, or are conservative relative to available data.

3.6.9 Two-Phase Pump Degradation Model

An evaluation of the use of either the Semiscale or EPRI-CE two-phase pump degradation model in the RLBLOCA methodology is presented in Appendix B of Reference 3. Sensitivity studies show an 18°F higher PCT using the Semiscale model than the PCT using the EPRI-CE model. Since the expected variability in an S-RELAP5 calculation is 30°F, this level of variation indicates that either model will produce essentially the same result in a RLBLOCA analysis. Framatome ANP uses the EPRI-CE two-phase pump degradation model in its SEM/PWR-98 10 CFR Part 50, Appendix K model, as well as the other applications of the S-RELAP5 model (References 8 and 9). The NRC staff finds the change to consistently use the EPRI-CE two-phase pump degradation model in the RLBLOCA methodology to be acceptable.

3.6.10 Gadolinia Bearing Fuel Rod Modeling

In the performance of sensitivity studies required to respond to an RAI on the RLBLOCA methodology, Framatome ANP discovered that the modeling of Gadolinia bearing fuel rods had

been performed incorrectly. The modeling of Gadolinia bearing fuel rods was corrected and the results showed about a 63°F reduction in the 95/95 PCT for the three-loop sample problem and a 66°F reduction in the four-loop sample problem.

The correction to the Gadolinia bearing fuel rod modeling was to consider a set of Uranium Oxide (UO_2) and Gadolinia bearing fuel rods for each of the 59 cases analyzed. In the sample problems, this meant analyzing a UO_2 rod and a 2 weight percent (w%), 4 w%, 6 w%, and 8 w% Gadolinia bearing fuel rod for each case. The power in the Gadolinia bearing fuel rod is reduced relative to the UO_2 rod at the statistically selected point in time for each case. The PCT established for each case is the highest of the PCTs for all of the rods modeled.

Framatome ANP is consistent with this step in the CSAU approach. The NRC staff finds the sensitivity studies performed acceptable.

3.7 Step 7 - Establish Assessment Matrix

Framatome ANP established an assessment matrix of separate effects tests and integral system tests, summarized in Table 1 attached to this SE, to address the important phenomena identified in the PIRT. The NRC staff review of several of the tests used in the assessment matrix follows, along with some specific staff experience and observations while using the S-RELAP5 code on NRC's computers.

While the staff reviewed all of the assessments performed in support of the RLBLOCA methodology, the following discussion will emphasize those assessments performed against the 2D/3D test program data. The most recent generic PWR test program in the public domain was sponsored by the NRC Office of Nuclear Regulatory Research during the 1980-90 timeframe. Much of the work done at those test facilities used full-scale, or nearly full-scale, reactor component simulation components. In addition, the data are considered to be of high quality. For this reason they are considered to be highly appropriate for code assessment.

Before discussing the results of the review of the 2D/3D assessments, two examples are given of the assessments presented by Framatome ANP. Figure 2, Framatome ANP RLBLOCA Figure 4.35 taken from Reference 3, attached to this SE, shows the comparison of the S-RELAP5 maximum cladding temperature calculation versus the measured temperature for FLECHT-SEASET Test 31504. The figure shows that the code is conservative with respect to the measured cladding temperature throughout the length of the test assembly. Figure 3, Framatome ANP RLBLOCA Figure 4.194 taken from Reference 3, attached to this SE, shows the comparison between the S-RELAP5 predicted cladding temperature and the measured cladding temperature for LOFT test LP-LB-1. Two S-RELAP5 predictions are shown, one made without accounting for the code biases determined from the separate effects test assessments, and one made with the biases taken into account. Again, the code predicted cladding temperature is conservative relative to the measured temperature throughout the test assembly except at the very top of the fuel assembly. At that point, the temperature is significantly below the PCT. It is also noted in the LOFT assessment that the effect of considering the biases is to bring the code predicted temperature into close agreement with the measured temperature with the attendant data error bands.

3.7.1 Upper Plenum Test Faciltiy (UPTF)

Framatome ANP compared RLBLOCA S-RELAP5 calculational results to seven UPTF tests. The UPTF tests were performed to provide full-scale simulation of the primary system phenomena occurring during three phases of a PWR LBLOCA. The phases investigated were end-of-blowdown, refill and reflood. The phenomena that the code calculations must realistically represent in this assessment include countercurrent flow in the downcomer, upper tie plate, upper plenum and hot leg, CCFL, refill behavior, condensation induced pressure and fluid oscillations, entrainment/de-entrainment, steam binding, and carryout. Discussion of the specific tests follows.

3.7.1.1 UPTF Tests 6 and 7

Five calculations of UPTF Test 6 and one calculation of UPTF Test 7 were designed to examine downcomer countercurrent flow during blowdown, ECC bypass, and lower plenum refill with cold leg injection. The RLBLOCA S-RELAP5 calculations were assessed against the data to determine the code's ability to predict them.

The tests simulated late blowdown and refill phases of a PWR cold leg LBLOCA. The Test series 6 calculations were initiated with very little or no lower plenum water inventory, and nitrogen injection with ECCS injection. The Test series 7 calculation was initiated with the lower plenum partially filled. A lower plenum drain valve operated by a level-controller allowed the observation of lower steam injection rates to further extend the Test 6 series. Nitrogen was not injected with the ECCS flow in Test 7.

A constant steam flow rate was injected into the core and steam generator simulators for each test calculation, but the injection rate varied by test. The lowest steam injection rate data was gathered from Test 7. A constant ECCS injection was delivered into the three intact cold legs in all the tests.

Steam injected into the core traveled downward to the lower plenum, up the downcomer and out the broken cold leg. Depending on the downcomer steam flow rate, the ECCS water entering the downcomer either bypassed to the broken cold leg, or penetrated downward to fill the lower plenum. The lower plenum water level determined the amount of ECCS water reaching the lower plenum.

Framatome ANP noted that there was very little water delivery to the downcomer until the cold legs were completely filled with water. Further, the rate of penetration varied inversely with the steam flow rate. The ECC water penetrated the downcomer opposite the broken cold leg, but the water from the intact cold leg adjacent to the broken leg was bypassed to the break, as expected. However, the calculated end of bypass occurred later than it did in the experiment. It is not clear whether this was due to the calculation missing the initial high flowrate, or whether it results from the delay due to filling the cold legs before penetration.

The downcomer pressure increased with increasing steam flowrate. Pressure drop due to condensation was captured by the code in most cases. The code predicts a pressure increase due to ECC water entrainment to the broken cold leg, producing two-phase critical flow at the break. However, it was not clear how the mixture level tracking influenced the flow at the break.

Framatome ANP stated that S-RELAP5 overpredicts lower plenum sweep-out. It concluded that the steam velocity increased through the downcomer and that the overprediction of liquid sweep-out reduces the lower plenum refill rate and will conservatively delay core recovery and quench.

The positive slope of the lower plenum mass inventory curve indicates ECC water penetration into the downcomer. Underprediction of the initial high refill rate results in a lower ECC penetration rate.

Two sensitivity studies, lower plenum oscillations and a 2D lower plenum model, were performed. These studies were performed to investigate the large oscillations of pressure, lower plenum level and lower plenum mass.

As a result of the studies, Framatome ANP suggested that the large oscillations were due to the level tracking in the bottom node of the lower plenum model. When the level tracking model was turned off, the large oscillations dampened, and the mass and level remained significantly lower than the data. To investigate this, the 2D lower plenum model was implemented. Results were improved by implementing the 2D model.

3.7.1.2 UPTF Test 8

The purpose of Test 8 was to investigate condensation-induced pressure and fluid oscillations in the cold legs due to ECCS injection. Overall, the code closely predicted the flow regime transition between slug flow and stratified flow. However the downcomer temperature plots when S-RELAP5 changes from slug to stratified flow, were not in good agreement with the data.

3.7.1.3 UPTF Tests 10 and 29

The purpose of Tests 10 and 29 was to verify the ability of a code to properly predict entrainment/de-entrainment and to limit countercurrent flow at the upper tie plate and upper plenum regions for a LBLOCA during reflood. The downcomer and lower vessel were filled with water to prevent steam flow between the core and the downcomer.

When using the CCFL inputs recommended by the RLBLOCA methodology, Framatome ANP observed that overall predictions of total water carryover to the steam generator simulators indicated that the code overpredicts the liquid carryover to the steam generators. It concluded that this would result in an overprediction of the steam binding effect which would reduce the reflood rate. Related to the overprediction of the liquid carryover, Framatome ANP further suggested that the fallback to the core was underpredicted. The results improved when using the CCFL input parameters suggested by KWU for UPTF tests, rather than the CCFL model values specified in the RLBLOCA methodology.

3.7.1.4 UPTF Tests 10 and 12

These tests were similar to the previous set, except flow was allowed between the core and the downcomer and nitrogen was included in Test 12. Similar results were obtained for these tests as the previous set. Nitrogen did not appear to have a significant impact on CCFL.

3.7.1.5 UPTF Test 11

Test 11 was composed of a series of quasi-steady-state separate effects tests to investigate countercurrent flow in the hot leg. Flow conditions were changed to develop a set of countercurrent flow curves at low and high pressure. Further, the models for these tests were built with and without CCFL models at the junction between the hot leg and inlet plenum.

The results of these tests show that the interfacial friction package alone cannot properly calculate the countercurrent flow at the steam generator inlet plenum. Therefore, as concluded by Framatome ANP, the CCFL model must be applied at the junction between the hot leg and the steam generator inlet plenum. The CCFL coefficients for the Wallis form result in good agreement with the data.

3.7.2 Cylindrical Core Facility (CCF) Test

Framatome ANP compared the S-RELAP5 calculational results to 4 CCF tests. The CCF tests were intended to provide full-scale simulation of the primary system phenomena occurring during reflood after a PWR LBLOCA. The phenomena that the code calculations realistically represented in these assessment cases include ECC flow behavior in the downcomer, and reactor core responses during reflood. The NRC staff concludes that the code performed acceptably in the CCF assessment test cases.

3.7.3 Code Internals and Experience

The NRC staff compared a few selections from the RLBLOCA coding to the documentation provided. Five subroutines were reviewed. They were CHFCAL, DITTSG, DITTUS, FILMBL, and PREDNB. The purpose of the comparison was to determine consistency, soundness of approach and completeness between the documentation and the code. The results of this review follow.

3.7.3.1 Subroutine CHFCAL

Subroutine CHFCAL calculates the CHF using the Zuber and Biasi CHF correlations. Many of the NRC staff's questions involved only minor clarification in the documentation. In some cases, correlation descriptions which appeared in the code did not appear in the documentation. For example, the description of the "Extended Biasi" was not included in Reference 4. However, Framatome ANP stated, and the NRC staff confirmed, that the Extended Biasi is not applied to RLBLOCA, SBLOCA and other Chapter 15 non-LOCA methodologies. In another case, the interpolation scheme found in the coding used to smooth the transition between two correlations for mass flux from 100 to 200 kg/m2s had not been updated in Reference 4. Framatome ANP is aware of this, and correction will be made in a documentation revision. The NRC staff also checked for unit consistency and found that units had been accounted for correctly.

3.7.3.2 Subroutine DITTSG

Subroutine DITTSG codes the implementation of either the Dittus Boelter or Sleicher Rouse convective heat transfer correlations. Again, many of the staff's questions involved only minor

clarifications. Some terms in the correlations needed to be completely accounted for in the text, and an equation reference error was corrected. Framatome ANP will correct inconsistencies in the documentation in a subsequent version of the document.

3.7.3.3 Subroutine DITTUS

Subroutine DITTUS calculates the forced convection heat transfer correlation only for liquid. One line of code in the natural convection correlation within DITTUS did not appear in the documentation. Framatome ANP stated that this coding was added to smooth the transition between the forced convection correlation and the natural convection correlation. This oversight will be corrected in the approved documentation.

3.7.3.4 Subroutine FILMBL

The FILMBL routine computes the heat transfer coefficients for film boiling. Framatome ANP provided the NRC staff with some minor clarification about the continuity between the documentation and the coding. As a result, the NRC staff found the subroutine to be correctly coded.

3.7.3.5 Subroutine PREDNB

This subroutine calculates the pre-DNB forced convection heat transfer correlations. As with the other subroutines, Framatome ANP provided the NRC staff with some minor clarification. The NRC staff concludes that the subroutine is correctly coded.

Framatome ANP provided the NRC staff with the necessary clarification leading to establishing consistency between the code and documentation and an understanding of the soundness of its approach. The NRC staff concludes from its review of the selected subroutines that the coding is correct.

3.7.4 NRC Staff Studies of Effects on PCT

The NRC staff investigated PCT changes for the Framatome ANP 3-loop PWR model due to code changes to 3 subroutines and 6 variations in the reflood rate. The three modifications investigated by the staff included an increase in the post-DNB forced convection heat transfer correlation (PSTDNB) by a factor of two, an increase in the liquid water viscosity (VISCOL) by a factor of five, and multiplication of the wall drag (FWDRAG), for both liquid and vapor phases, by factors of 0.1, 2, and 10. The unmodified calculation predicted a PCT of 1663°F at 232 seconds, with quench at 199 seconds.

Neither the change in post-DNB forced convection heat transfer nor the change in the liquid viscosity had a significant effect on the predicted PCT. The increase in the forced convection heat transfer correlation, alone, lowered the PCT to 1582°F, and the increase in liquid viscosity, alone, lowered the PCT to 1564°F. In both cases the quench time changed less than 40 seconds.

The variations in the wall drag had a much more significant effect on the PCT, as would be expected since changing the wall drag alters the reflood rate. The base case used for the wall

drag study had a PCT of 1577°F with a quench time of 232 seconds. Increasing the wall drag by a factor of 2 increased the PCT to 1617° and delayed quench by 50 seconds. Increasing the wall drag by a factor of 10 resulted in an entirely different transient. In this case, there was a blowdown quench on the order of 400°F along with a delay in the PCT, now occurring at 150 seconds versus 30 seconds in the original calculation. In this case, the PCT reached 1686°F with a steadily decreasing clad temperature, but no quench at the time of problem termination at 370 seconds.

Figure 4 (attached to this SE), illustrates the effects of multiplying the liquid viscosity by a factor of 10, multiplying the post-DNB forced convection heat transfer by a factor of 10, and multiplying the wall drag by a factor of 10 for a PWR model. A comparison of the results obtained by ranging the multiplier on the wall drag from 1 to 2 to 10 is shown in Figure 5 (attached to this SE), for the PWR model.

An additional study was performed based on the model for the FLECHT-SEASET Test 31504. FLECHT-SEASET Test 31504 was a low flooding rate test, fixed as a boundary condition at 0.972 in/sec. Thus, the test assembly was controlled in reflooding by a prescribed liquid and vapor velocity which was then influenced by the fuel simulator power profile. The test assembly model consists of a lower plenum, heated core volume, unheated core volume, and an upper plenum. The 12-foot heated core is divided into 20 equal length axial nodes with a cosine power shape.

Since the forced convection heat transfer and liquid viscosity were determined to be less important than the wall drag, only the wall drag was modified for this study. Three cases were calculated: wall drag unmodified, and wall drag multiplied by 0.1, 2, and 10, as can be noted in Figure 6 (attached to this SE), with the base case calculated with a multiplier of 10 on the liquid viscosity for comparison. The first three cases had little effect on the overall progress of the transient. The calculated PCTs were 2168°F, 2132°F, and 2096°F, for the multipliers of 0.1, 1, and 2, respectively. The multiplier of 10, however, again altered the shape of the temperature plot significantly. The PCT in this case was reduced to 1969°F with a later quench.

Close examination of the cases indicates that when the wall drag is increased, with a fixed coolant boundary condition, more water mass is retained in the lower portion of the core allowing the quench front to progress, combined with an increase in the steam flow rate. Thus the heat transfer is improved under these conditions. When the reduced wall drag is used, there is a higher mass flow out of the core, a higher carryout fraction, but less liquid in the core to allow advancement of the quench front. In addition, the flow regime map indicates that the flow is inverted annular flow, a less efficient mode for heat removal.

These analyses performed by the NRC staff with the Framatome ANP S-RELAP5 code confirm the importance of reflood heat transfer in the analysis of the large break LOCA.

The NRC staff concludes that for the parametric studies it performed, the relative importance of the phenomena are consistent with the identified PIRT rankings.

3.7.5 Cladding Material Applicability

Framatome ANP incorporated the NRC-approved M5 cladding material properties into the S-RELAP5 methodology (References 35 and 36). Sensitivity studies were performed to investigate the sensitivity of PCT and oxidation with the substitution of M5 for Zircaloy cladding. The studies show that no unique phenomenological differences are introduced with the M5 cladding.

Differences in the cladding material properties do cause differences in the fuel pellet behavior due to differences in the gap width, thus affecting pellet temperature and pellet-cladding interaction. The resulting increase in fuel centerline temperature, increased gap heat transfer resistance, and removal of stored energy produced a PCT that is 40°F higher for M5 clad fuel, and a maximum change in oxidation of +0.04%. The M5 cladding material properties approved by the NRC have been properly incorporated in the Framatome ANP RLBLOCA methodology.

Under existing NRC regulations, applicants wishing to apply the Framatome ANP RLBLOCA methodology to M5 clad fuel must request an exemption for its use (prior to a rulemaking to modify 10 CFR 50.46(a)(1)(i) to include M5 cladding material).

The staff concludes that Framatome ANP is consistent with this step in the CSAU approach based on a broad assessment of the code against accepted separate effects tests and integral systems tests, with the addition of the most recent test facility results that were performed at full- and nearly full-scale models.

3.8 Step 8 - NPP Nodalization Definition

Reference 11 discusses the tradeoffs in determining an adequate NPP nodalization. Framatome ANP developed guidelines for its RLBLOCA methodology that are as explicit as possible to remove nodalization as a contributor to calculational uncertainty. The guidelines provide rules for deriving the appropriate nodalization, thus defining a method for automating the generation of input for a RLBLOCA analysis that maintains consistency in approach from one analysis to another. Development of the guidelines has relied heavily on past experience with the S-RELAP5 code and its predecessor code versions.

The NRC staff has noted that NPP nodalization should not consider gaps between the hot leg nozzles and the downcomer in the plant model. The leakage from these nozzle gaps relieves the steam pressure/steam binding effect during reflood and is, therefore, beneficial to reflooding the core and reducing the PCT. There is no evidence to support the view that the nozzle gaps would remain open under the high temperatures present due to the steam exiting the core under transient conditions. Framatome ANP has agreed that it is not to use nodalization with hot leg to downcomer nozzle gaps.

Framatome ANP is consistent with this step in the CSAU approach by specifying a nodalization approach that maintains consistency between the application of the methodology and the assessment of the methodology.

3.9 Step 9 - Definition of Code and Experimental Accuracy

Simulation of the experiments developed from Step 7 using the NPP nodalization from Step 8 provides checks to determine code accuracy. The differences between the code calculated results and the test data provide bias and deviation information. Code scale-up capability can also be evaluated from separate effects data through full-scale data when they are available. Overall code capabilities are assessed from integral systems test data. In addition to these assessment tools, the code uncertainty determination must also use additional techniques to determine the uncertainty in the individual contributions arising from both code and experiment, along with a range of uncertainty for each of the individual contributors.

Framatome ANP used comparisons of code predictions to test data for 15 different separate effects test facilities to determine code biases in correlations and models, which were then applied to the assessments performed for the integral systems test facilities.

Framatome ANP is consistent with this step in the CSAU approach since the uncertainties in experimental data have been accounted for in determining the biases identified for use with the methodology.

3.10 Step 10 - Determination of Effect of Scale

Various physical processes may give different results as components or facilities vary in scale from small to full size. The effect of scale must be included in the quantification of bias and deviation to determine the potential for scale-up effects. The effect of scale was addressed by Framatome ANP with regard to each of the phases of the transient described in the PIRT along with the discussion of test scaling, code scaling and specific phenomena scaling. In a departure from the discussion in Reference 11, Framatome ANP has included in the scale determination for S-RELAP5, the full-scale UPTF test data, which became available after the preparation of Reference 11. This is an enhancement to the methodology identified in Reference 11.

Framatome ANP is consistent with this step in the CSAU approach since the recommendation provided in Reference 11 has been used and enhanced by inclusion of full-scale facility test data where available.

3.11 Step 11 - Determination of the Effect of Reactor Input Parameters and State

The purpose of this step is to determine the effect that variations in the plant operating parameters have on the uncertainty analysis. Plant process parameters characterize the state of operation and are controllable by the plant operators to a certain degree. Framatome ANP performed a review to identify the NPP parameters that are to be addressed when performing a LBLOCA analysis. The parameters identified come from the PIRT, plant-specific technical specifications, and utility input. Components, or operating parameters, and the associated parameters and ranges were addressed by Framatome ANP.

Sensitivity studies were performed to establish a requirement on the level of importance an analyst might give when quantifying process parameter uncertainties. The results from a set of sensitivity studies performed for process parameters for the 3- and 4-loop PWRs were given.

Sensitivity studies are also useful in determining if certain parameters need not be treated statistically, can be treated conservatively instead, or can be treated as insignificant.

Framatome ANP is consistent with this step in the CSAU approach since the effect of reactor input parameters has been considered in the sensitivity studies performed in support of the methodology.

3.12 Step 12 - Performance of NPP Sensitivity Calculations

Sensitivity calculations are performed to evaluate methodology sensitivity to parameters such as PCT or metal-water reaction, and to various plant operating conditions that arise from uncertainties in the reactor state at the initiation of the transient, in addition to sensitivity to plant configuration.

Framatome ANP is consistent with this step in the CSAU approach since adequate sensitivity studies have been performed.

3.13 Step 13 - Determination of Combined Bias and Uncertainty

The individual uncertainties resulting from code models of important phenomena, scale effects, and NPP input parameter variations must be combined to obtain an overall bias and uncertainty.

Framatome ANP provided sample RLBLOCA analyses for 3- and 4-loop PWRs following the framework described in Reference 3. Base input models were developed to describe the NPP and fuel behavior based upon information obtained from several different 3- and 4-loop plants. Consequently, the analyses are considered representative of typical 3- and 4-loop PWR designs, rather than specific representations of specific plants. The models used, in general, are taken as demonstrations of the applicability of the RLBLOCA methodology to the 3- and 4-loop PWR designs.

Framatome ANP is consistent with this step in the CSAU approach.

3.14 Step 14 - Determination of Total Uncertainty

The first few steps in the CSAU methodology identify and rank the physical phenomena important to judging the performance of the safety systems and margins in the design. The phenomena are compared to the modeling capability of the code to assess whether the code has the necessary models to simulate the phenomena. Most important, the range of the identified phenomena covered in experiments is compared to the corresponding range of the intended application to assure that the code has been qualified for the most significant phenomena, as reflected in the ranking process, over the appropriate range. The result is then provided in a PIRT. The NRC staff has reviewed the PIRT provided for S-RELAP5 in Reference 3, and finds it acceptable and consistent with the NRC staff's experience in judging the important phenomena associated with the LBLOCA.

The discussion of the uncertainty analysis approach presented in NUREG/CR-5249 and in Regulatory Guide 1.157 envisioned the use of response surfaces for quantifying uncertainty in

the calculated PCT. The NRC staff recognizes that there are other valid and acceptable means by which the uncertainty can be assessed. Framatome ANP has chosen to use a method based on non-parametric order statistics which follows the development by Wilks (Reference 37) and others.

The Framatome ANP methodology as described in Reference 3, applies a statistical method based on order statistics to demonstrate that S-RELAP5 meets the acceptance criteria for RLBLOCA analyses of pressurized water reactors. These are

1. High probability that the calculated maximum PCT value is less than 2200°F.

2. High probability that the calculated maximum nodal oxidation is less than 17 percent.

3. High probability that the calculated maximum total core oxidation is less than 1 percent.

The methodology adopted by Framatome ANP is based on combining the individual biases and uncertainties in the S-RELAP5 model and plant parameters to infer the uncertainty associated with the parameters in the above acceptance criteria via Monte Carlo sampling. That is, the distributions of the model parameters and plant parameters are sampled at random; and for each sample of parameters, a RLBLOCA calculation is performed. The three parameters in the acceptance criterion are scored. The Framatome ANP methodology claims that 59 cases are sufficient to show that the value of the 59th order statistic associated with the peak cladding temperature can be used to show that the acceptance criteria for all three parameters are met.

A 95% probability at 95% confidence (95/95) inference with regard to a random variable based on a sample size of 59 is valid in the case of a univariate distribution. Satisfaction of the above acceptance criteria at a uniform probability and confidence level of 95/95 implies a trivariate distribution is necessary. A trivariate distribution requires performing additional calculations. This has not been done by Framatome ANP.

Instead, Framatome ANP has referred to Regulatory Guide 1.157 for clarification of the acceptance criterion. Specifically:

> *The revised paragraph 50.46(a)(1) (i) requires that it be shown with a high probability that none of the criteria of paragraph 50.46(b) will be exceeded, and is not limited to the peak cladding temperature criterion. However, since the other criteria are strongly dependent on peak cladding temperature, explicit consideration of the probability of exceeding the other criteria may not be required if it can be demonstrated that meeting the temperature criterion at the 95% probability level ensures with an equal or greater probability that the other criteria will not be exceeded.*

Rather than performing the number of calculations needed to support a trivariate analysis, Framatome ANP has used a mixture of classical statistics in support of a univariate analysis combined with engineering knowledge in support of the remaining two criteria. That is, the 59 cases performed provide the PCT at the 95/95 level. Since the PCT is below the criterion of 2,200°F, and the cladding oxidation is a strong function of temperature, there is a high probability that the cladding oxidation will be below the acceptance criteria. Information provided by Framatome ANP indicates that the local and total oxidation level at the calculated

PCT are 0.8 percent and 0.02 percent, respectively, for the 4-loop plant, and 1.3 percent and 0.04 percent, respectively, for the 3-loop plant. These oxidation levels are significantly below the acceptance criteria cited above. Thus, combining classical statistics with engineering knowledge provides reasonable assurance at a high probability that the acceptance criteria will not be exceeded.

The NRC staff has studied the position proposed by Framatome ANP that break type and size be treated statistically, and accepts its approach on the basis of the break type and size distributions assumed in its analysis. Specifically, the methodology applies a binomial distribution to the break type sampling, that is, the two break types (double-ended guillotine and slot breaks) are equally probable. In addition, a uniform distribution is applied to the entire break size spectrum from the largest to the smallest size. Thus, the break type and size selection is of uniform probability for the entire spectrum.

The NRC staff finds that the Framatome ANP methodology for the statistical results of an analysis of a RLBLOCA of a PWR meets the acceptance criteria stated in 10 CFR 50.46 and Regulatory Guide 1.157.

Framatome ANP is consistent with this step in the CSAU approach.

4.0 CONCLUSIONS

The NRC staff concludes from its review of the documentation, code and input models submitted that the S-RELAP5 RLBLOCA methodology is structured consistent with the CSAU methodological process, and satisfactorily reflects the intended use of the methodology to address licensing requirements for a variety of similarly designed nuclear power plants.

The NRC staff concludes that the approach proposed by Framatome ANP for selection of break type and size is acceptable since it assumes a binomial distribution of break type and uniform distribution of break size. Should Framatome ANP choose to change from this approach, the NRC staff will review the proposed changes.

The review of the models and benchmarks noted concerns and deficiencies resulting in conditions of use of S-RELAP5 as follows, which have been committed to in Reference 38:

- A CCFL violation warning will be added to alert the analyst to CCFL violation in the downcomer should such occur.

- Framatome ANP has agreed that it is not to use nodalization with hot leg to downcomer nozzle gaps.

- If Framatome ANP applies the RLBLOCA methodology to plants using a higher planar linear heat generation rate (PLHGR) than used in the current analysis, or if the methodology is to be applied to an end-of-life analysis for which the pin pressure is significantly higher, then the need for a blowdown clad rupture model will be reevaluated. The evaluation may be based on relevant engineering experience and should be documented in either the RLBLOCA guideline or plant specific calculation file.

- Slot breaks on the top of the pipe have not been evaluated. These breaks could cause the loop seals to refill during late reflood and the core to uncover again. These break locations are an oxidation concern as opposed to a PCT concern, since the top of the core can remain uncovered for extended periods of time. Should an analysis be performed for a plant with loop seals with bottom elevations that are below the top elevation of the core, Framatome ANP will evaluate the effect of the deep loop seal on the slot breaks. The evaluation may be based on relevant engineering experience and should be documented in either the RLBLOCA guideline or plant-specific calculation file.

The following restrictions apply when the Framatome ANP methodology is used for analysis of RLBLOCA.

- The model applies to 3 and 4 loop Westinghouse and CE-designed nuclear steam systems.

- The model applies to bottom reflood plants only (cold side injection into the cold legs at the reactor coolant discharge piping).

- The model is valid as long as blowdown quench does not occur. If blowdown quench occurs, additional justification for the blowdown heat transfer model and uncertainty are needed or the calculation is corrected. A blowdown quench is characterized by a temperature reduction of the PCT node to saturation temperature during the blowdown period.

- The reflood model applies to bottom up quench behavior. If a top-down quench occurs, the model is to be justified or corrected to remove top quench. A top-down quench is characterized by the quench front moving from the top to the bottom of the hot assembly.

- The model does not determine whether Criterion 5 of 10 CFR 50.46, long term cooling, has been satisfied. This will be determined by each applicant or licensee as part of the application of this methodology.

The NRC staff also notes that a generic topical report describing a code such as S-RELAP5 cannot provide full justification for each specific individual plant application. When a license amendment is necessary in order to use the S-RELAP5-based RLBLOCA methodology, the individual licensee or applicant must provide justification for the specific application of the code which is expected to include:

- <u>Nodalization</u>: Specific guidelines used to develop the plant-specific nodalization. Deviations from the reference plant must be addressed.

- <u>Chosen Parameters and Conservative Nature of Input Parameters</u>: A table that contains the plant-specific parameters and the range of the values considered for the selected parameter during the topical report approval process. When plant-specific parameters are outside the range used in demonstrating acceptable code performance, the licensee or applicant will submit sensitivity studies to show the effects of that deviation.

- Calculated Results: The licensee or applicant using the approved methodology must submit the results of the plant-specific analyses, including the calculated worst break size, PCT, and local and total oxidation.

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Attachments:
1. Table 1 - S-RELAP5 Assessment Matrix
2. Figure 1 - FLECHT-SEASET Test 31302
3. Figure 2 - FLECHT-SEASET Test 31504
4. Figure 3 - LOFT LP-LB-1 S-RELAP5 Analysis
5. Figure 4 - PCT Independent of Location - PWR
6. Figure 5 - PCT Independent of Location - PWR
7. Figure 6 - Peak Clad Temperature - FS 31504

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