November 29, 2011

Mr. Pedro Salas
Manager, Corporate Regulatory Affairs
AREVA NP, Inc.
3315 Old Forrest Road
P.O. Box 10935
Lynchburg, VA 24506-0935

SUBJECT: FINAL SAFETY EVALUATION REPORT REGARDING ANP-10278P, "U.S. EPR REALISTIC LARGE BREAK LOSS OF COOLANT ACCIDENT TOPICAL REPORT"

Dear Mr. Salas:

By letter dated March 26, 2007 (Agencywide Documents Access and Management System [ADAMS] Accession No. ML070880732), as supplemented by letters dated August 17 , 2007 (ADAMS ML072340458), June 13, 2008 (ADAMS ML081690569), December 19, 2008 (ADAMS ML083590356), March 31, 2009 (ADAMS ML090990358), April 2, 2009 (ADAMS ML091030072), April 9, 2009 (ADAMS ML091030216), and January 8, 2010 (ADAMS ML100140633), AREVA NP, Inc., (AREVA) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval Topical Report (TR) ANP-10278P, Revision 0, "U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report," ADAMS ML070880739 (proprietary), ADAMS ML070880737 (nonproprietary). In response to requests for additional information (RAIs) issued by NRC staff, AREVA submitted Revision 1 to ANP-10278P, ADAMS ML100141145 (proprietary); ADAMS ML100141095 (nonproprietary), by a letter dated January 8, 2010 (ADAMS ML100140633). On August 17, 2010, an NRC draft safety evaluation (SE) regarding our approval of ANP-10278P was provided for AREVA review and comments. By letter dated July 19, 2010, AREVA commented on the draft SE. The staff's disposition of AREVA comments on the draft SE are discussed in the attachment to the final SE enclosed in this letter.

The staff has found that ANP-10278P, Revision 1, is acceptable for referencing in licensing applications for U.S. EPR to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat a review of the acceptable material described in the TR. When the TR appears as a reference in license applications, the NRC review will ensure that the material presented applies to the specific plant involved. Regulatory applications that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that AREVA publish accepted proprietary and nonproprietary versions of this TR within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE after the title page. Also, the accepted version must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include an "-A" (designating accepted) following the TR identification symbol.

If future changes to NRC regulatory requirements affect the acceptability of this TR, AREVA will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

If you have any questions, please contact me at Getachew.Tesfaye@nrc.gov or (301) 415-3361.

Sincerely,

/RA/

Getachew Tesfaye
Senior Project Manager
EPR Projects Branch
Division of New Reactor Licensing
Office of New Reactors

Docket No.: 52-020

Enclosure:
Draft Safety Evaluation Report

cc: U.S. EPR Mailing List

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FINAL SAFETY EVALUATION BY THE OFFICE OF NEW REACTORS
TOPICAL REPORT ANP-10278P, REVISION 1
"U.S. EPR REALISTIC LARGE BREAK LOSS OF COOLANT ACCIDENT TOPICAL REPORT"
AREVA NP, INC.
DOCKET NO. 52-020

1 INTRODUCTION

By letter dated March 26, 2007, (Agencywide Documents Access and Management System [ADAMS] Accession No. ML070880732), as supplemented by letters dated August 17, 2007 (ADAMS ML072340458), June 13, 2008 (ADAMS ML081690569), December 19, 2008 (ADAMS ML083590356), March 31, 2009 (ADAMS ML090990358), April 2, 2009 (ADAMS ML091030072), April 9, 2009 (ADAMS ML091030216), and January 8, 2010 (ADAMS ML100140633), AREVA NP, Inc., (AREVA) (the applicant) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval Topical Report (TR) ANP-10278P, Revision 0, "U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report," ADAMS ML070880739 (proprietary), ADAMS ML070880737 (nonproprietary). In response to requests for additional information (RAIs) issued by NRC staff, the applicant submitted Revision 1 to TR ANP-10278P, ADAMS ML100141145 (proprietary); ADAMS ML100141095 (nonproprietary), by a letter dated January 8, 2010 (ADAMS ML100140633).

This report provides the staff's evaluation of TR ANP-10278P. The evaluation focused on differences in the design and operation of the U.S. EPR from the operating plants considered in Reference 2, and the applicability of the modeling and code assessment described in Reference 2 to the U.S. EPR.

Additional technical issues have been identified since the staff's approval of Reference 2. These issues are described in this report and are evaluated within the context of their applicability to the U.S. EPR. The staff's review resulted in the applicant revising TR ANP-10278(P). The revised report [3] is also evaluated herein. When the discussion refers to particular S-RELAP5 simulations, it is referring to the applicant's calculations associated with Reference 1. The staff's evaluation of Reference 3 focused on the revisions made to ANP-10278, changes that were made in response to the staff's evaluation of Reference 1.

2 SYSTEM DESCRIPTION

The U.S. EPR is an evolutionary pressurized water reactor (PWR) with a rated thermal power of 4590 megawatts thermal (MWt). The primary system configuration is similar to currently operating 4-loop PWRs. The core consists of 241 fuel assemblies that are 4.2 meters (m) (13.8 feet [ft]) in length. The core average linear power is 17.1 kilowatts (kW)/m (5.2 kW/ft), five to ten percent lower than operating 4-loop PWRs. Local power peaking factors in the U.S. EPR are similar to currently operating plants.

The emergency core cooling system (ECCS) in the U.S. EPR consists of four 100 percent capacity independent trains. (One hundred percent capacity means that the flow from a single system delivered to the vessel is sufficient to meet ECCS acceptance criteria during a loss of coolant accident [LOCA].) Each train contains one medium head safety injection (MHSI) pump, one low head safety injection (LHSI) pump, and one passive accumulator. Trains 1 and 2 and Trains 3 and 4 are connected just downstream of the LHSI pumps. The cross connections are normally isolated but, by procedure, must be opened if a train is out of service. Check valves located downstream of the LHSI and cross connection prevent MHSI or accumulator flows from reaching the cross connections. Thus, only LHSI may flow from one train to another. In case of loss of offsite power, each train can be powered by its own Emergency Diesel Generator (EDG). In the event of a large break loss of coolant accident (LBLOCA), one train of MHSI/LHSI pumps is assumed to fail, a second train is assumed out of service for maintenance. A third train of MHSI/LHSI pumps water into an intact cold leg, and the fourth train, which is connected to the broken cold leg, injects a portion of the LHSI into an intact loop through the corss-connect and spills the rest of the MHSI/LHSI into the containment. All four accumulators inject. They are not subject to a single failure, nor are they allowed out of service for maintenance. The accumulator attached to the broken cold leg spills to the containment.

Unique design features of the U.S. EPR relative to currently operating PWRs are core length, a heavy reflector shield surrounding the core, omission of the high head safety injection (HHSI) system, a main steam relief system on each steam generator (SG), and the use of an axial economizer in the SGs. An Emergency Feedwater (EFW) system and a Main Steam Relief Train (MSRT) are connected to each of the four SGs. These latter features are important during small break loss of coolant accident (SBLOCA) but not during LBLOCA. The reactor pressure vessel (RPV) and the pressurizer of the U.S. EPR are larger than current plants. The reactor core is positioned such that the top of the core is at approximately the same elevation as the top of the horizontal section of the SG to reactor coolant pump (RCP) crossover pipe. All of the unique features of the U.S. EPR are within the simulation capabilities of the current generation of thermal hydraulic computer programs.

3 REGULATORY BASIS

Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Section 46, paragraph (a) specifies 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 ECCS designed so that the calculated cooling performance following a postulated LOCA conforms to the criteria set forth in 10 CFR 50.46(b). 10 CFR 50.46(a) also states that the 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.

10 CFR 50.46(b) specifies that the Peak Cladding Temperature (PCT) must not be calculated to exceed 1478 degrees Kelvin (K) (2,200 degrees Fahrenheit (°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, and the core must remain in a coolable geometry. Also, 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 provided guidance on how the above regulatory criteria can be met. Regulatory Guide (RG) 1.157 [3] and NUREG/CR-5249 [4] describe acceptable approaches to determine the calculated uncertainty in the 10 CFR 50.46(b) parameters.

3.1 Methodology for Operating Reactors

In its approved realistic large break loss of coolant accident (RLBLOCA) methodology contained in EMF-2103, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," Revision 0 [2], the applicant followed the formalism of the Code Scaling, Applicability, and Uncertainty (CSAU) evaluation methodology (NUREG/CR-5249 [5]) to develop a RLBLOCA model, consistent with RG 1.157. The staff's Safety Evaluation Report (SER) for EMF-2103, Revision 0, while finding the overall approach acceptable, included conditions and limitations.

After the review and approval of EMF-2103 (P) (A) Revision 0, the applicant submitted Revision 1 for the staff's review. Review of that submittal resulted in an SER [19] with significant conditions and limitations upon the methodology. As a result, the applicant decided to withdraw EMF-2103 Revision 1 and presented plans to submit a Revision 2 that would adequately address the staff's concerns for currently operating PWRs. The applicant's submittal of ANP-10278 (P), being reviewed here, occurred just prior to its withdrawal of Revision 1. NRC approval of ANP-10278 is for the U.S. EPR only and does not resolve similar issues for currently operating PWRs.

4 TECHNICAL EVALUATION

This section provides the staff's evaluation of the issues addressed in ANP-10278P [1] and the staff's evaluation of additional issues that have arisen regarding the applicability of the RLBLOCA methodology for the U.S. EPR.

4.1 Issues Addressed in ANP-10278P

The applicant's approved RLBLOCA Evaluation Model (EM), as described in EMF-2103, Revision 0, was developed following the Code Scaling, Applicability, and Uncertainty approach. A Phenomena Identification and Ranking Table (PIRT) process was used to identify and rank key phenomena during each of the three main phases of a LBLOCA: blowdown, refill and reflood. The intent of ANP-10278P [1] was to demonstrate that the PIRT process and S-RELAP5 validation presented in EMF-2103, Revision 0 were equally applicable to the U.S. EPR. This was done by first considering all PIRT items ranked seven or higher in each transient phase and showing that the U.S. EPR design would not change the outcome of the PIRT. Secondly, the applicant reviewed the unique design features of the U.S. EPR and concluded that none of them introduced transient phenomena requiring additional S-RELAP5 benchmark calculations.

4.1.1 U.S. EPR Large Break Phenomena

The PIRT examination process covered 8 phenomena for the blowdown phase, 8 phenomena for the refill phase, and 14 phenomena for the reflood phase. The staff has reviewed the applicant's disposition of all of the 30 phenomena and agrees with the applicant's conclusions on all but 3 of them. The three exceptions are, "Fuel Rod Stored Energy," listed under blowdown phenomena, Section 4.1.1.1; "Core Post-CHF Heat Transfer," listed under blowdown, refill, and reflood phenomena, Sections 4.1.1.1, 4.1.1.2, and 4.1.1.3; and "Downcomer Liquid Level Oscillations," listed under reflood phenomena, Section 4.1.1.3. The resolutions of the staff's concerns with the treatment of these phenomena are presented in Sections 4.2.4.2, 4.2.11.3, and 4.2.14 of this report.

4.1.1.1 Blowdown Phenomena

The blowdown phenomena considered by the applicant's and the staff's evaluations are listed below:

Fuel Rod Stored Energy: The applicant's position is that the U.S. EPR fuel introduces no new methodological or phenomenological considerations with respect to fuel rod stored energy because, except for rod length, the U.S. EPR fuel is,the same as existing AREVA fuel. However, the staff has expressed concern that vendors' fuel rod computer programs may not adequately account for the effect of burnup on stored energy. The staff's position on this issue is documented in NRC Information Notice 2009-23, "Nuclear Fuel Thermal Conductivity Degradation," October 8, 2009. The staff's evaluation of the applicant's RODEX3A with respect to this issue is given in Section 4.2.14 of this report.

- Core Departure from Nucleate Boiling: Because of the similarity of the U.S. EPR fuel design to the fuel in operating plants, the staff has concluded that the Biasi and modified Zuber Critical Heat Flux (CHF) correlations are equally applicable to current operating PWRs and the U.S. EPR. Therefore, the staff finds that the RLBLOCA methodology is applicable to the U.S. EPR with respect to this phenomenon.

- Core Post-CHF Heat Transfer: The staff has determined that the U.S. EPR core introduces no new methodological or phenomenological considerations with respect to core post-CHF heat transfer. However, the staff no longer agrees [14] with the way the Forslund-Rohsenow heat transfer correlation was applied in Reference 2, believing the application there may result in unrealistically high heat transfer. Resolution of this issue for the U.S. EPR is documented in Section 4.2.11.3 of this report.

- Blowdown Quench: The U.S. EPR introduces no new methodological or phenomenological considerations with respect to rewet. However, in its approval of the Reference 2 methodology, the staff imposed the following condition: "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 run corrected." The staff finds that the applicant has satisfactorily demonstrated compliance with this condition in Section A.3.0 of Revision 1 and Revision 0 of ANP-10278P [1][3]. The applicant has identified each case for the U.S. EPR which had blowdown quench and demonstrated that it was not limiting. The staff requires that the same limitations and considerations will apply to future U.S. EPR RLBLOCA analyses unless the applicant implements a blowdown quench model in S-RELAP5.

- Top-down Quench: A limitation with regard to top-down quench was imposed by the staff in its approval of EMF-2103 [2]. The limitation reflected the applicability of the S-RELAP5 reflood model to bottom up reflood simulation only. Accordingly, Reference 2 requires that: "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."

- Core Flow Reversal and Stagnation: Reversal and stagnation of the flow in the core is determined by break size, break type, and fluid temperatures and volumes in the RPV upper and lower plena. The staff notes that the U.S. EPR design introduces nothing that would invalidate the treatment of this phenomenon by the RLBLOCA methodology. Therefore, the staff finds the methodology is applicable to the U.S. EPR.

- Critical Flow at the Break: The U.S. EPR break geometry and fluid conditions are similar to those of current PWRs for which the RLBLOCA methodology applies. Therefore, the staff finds that the methodology's calculation of critical flow and application of critical flow uncertainty parameters is applicable to the U.S. EPR.

- Flow Split between Loops: In the EMF-2103, Revision 0 methodology, the flow split between loops is determined by independently ranging the discharge coefficients at the breaks. The staff has concluded that the U.S. EPR methodology contained in ANP-10278P introduces nothing which would invalidate this feature of the methodology. Therefore, the staff finds the methodology is applicable to the U.S. EPR with respect to this phenomenon.

4.1.1.2 Refill Phenomena

The refill phenomena considered by the applicant's and the staff's evaluations are listed below:

- Core Post-CHF Heat Transfer: The staff has determined that the U.S. EPR core introduces no new methodological or phenomenological considerations with respect to core post-CHF heat transfer. However, the staff no longer agrees [14] with the way Forslund-Rohsenow heat transfer correlation was applied in Reference 2, believing that the application there may result in unrealistically high heat transfer. Resolution of this issue for the U.S. EPR is documented in Section 4.2.11.3 of this report.

- Cold Leg Condensation and Oscillations due to Accumulator Injection: The cold legs size and accumulator injection location for the U.S. EPR are similar to current operating PWRs. The EPR introduces nothing that would invalidate the RLBLOCA methodology with respect to this phenomenon. Therefore, the staff finds that the methodology's treatment of this phenomenon is acceptable for the U.S. EPR.

- Accumulator Discharge: The accumulators in the U.S. EPR are configured in a similar way to those in current plants, but they are larger. The only effect of having larger accumulators is a longer period of accumulator discharge. This alone does not invalidate the methodology's treatment of accumulator discharge. Therefore, the staff finds that the methodology's treatment of accumulator discharge is applicable to the U.S. EPR.

- Downcomer Entrainment/De-entrainment and Countercurrent, Slug and Non-equilibrium Flow: The width of the lower downcomer in the U.S. EPR is slightly larger than current 4-loop plants. The RLBLOCA methodology's ability to conservatively treat downcomer flow and entrainment of emergency core coolant (ECC) was validated using both small-scale and full-scale experiments. The staff has concluded that the difference between the U.S. EPR and current 4-loop plant downcomer geometry does not invalidate the RLBLOCA methodology's treatment of downcomer flow. Therefore, the staff finds that the methodology is applicable to the U.S. EPR with respect to downcomer flow.

- Downcomer Condensation: For the U.S. EPR, the applicant has modified the RLBLOCA methodology to increase the amount of condensation in the cold leg calculated in agreement with test data, as described in Section 4.1 of Revision 1 to ANP-10278P [3]. This change biases the downcomer liquid temperature toward the saturation temperature.

  This biasing conservatively increases the potential for downcomer boiling and is therefore acceptable to the staff.

- Downcomer 3-D Effects: The RLBLOCA methodology's ability to adequately treat downcomer 3-D effects was demonstrated (Section 4.3.1.11 of EMF-2103(P)(A) [2]) using the Upper Plenum Test Facility (UPTF), which is a full-scale facility relative to current 4-loop plants. The U.S. EPR RPV is only about 40 centimeters (cm) (16 inches [in.]) larger in diameter and its downcomer gap is about 3 cm (1.2 in.) wider than current 4-loop plants. Thus, the validation of the RLBLOCA methodology's treatment of 3-D effects is applicable to the U.S. EPR, and the staff finds that the application of the RLBLOCA methodology is acceptable with respect to 3-D effects in the downcomer. Section 4.2.4.4 of this report discusses downcomer 3-D effects further.

- Loop Flow Oscillations: In Reference 2, Section 4.4.2.2.8, the RLBLOCA methodology was shown to adequately predict the pressure and flow oscillations in the cold legs which result when ECC is injected into a steam filled full-scale system (UPTF). The cold leg geometry in the U.S. EPR is very similar to the UPTF cold leg geometry. The staff has concluded that the U.S. EPR introduces nothing which would invalidate this feature of the methodology. Therefore, the staff finds that the methodology is applicable to the U.S. EPR with respect to loop flow oscillations.

- Flow Split between Loops: In the Reference 2 methodology, the flow split between loops is determined by independently ranging the discharge coefficients at the breaks. The loop geometry of the U.S. EPR is quite similar to 4-loop operating plants; therefore, the U.S. EPR introduces nothing which would invalidate this feature of the methodology. Therefore, the staff finds that the methodology is applicable to the U.S. EPR with respect to loop flow splits.

4.1.1.3 Reflood Phenomena

The reflood phenomena considered by the applicant's and the staff's evaluations are listed below:

- Fuel Rod Oxidation: The U.S. EPR fuel design is very similar to existing designs. Therefore, the U.S. EPR core introduces no new methodological or phenomenological considerations with respect to fuel rod oxidation. The staff finds that the treatment of this phenomenon in the RLBLOCA methodology is applicable to the U.S. EPR.

- <u>Fuel Rod Decay Heat</u>: The staff has determined that the treatment of decay heat in Reference 2 is acceptable for application to the U.S. EPR. The final resolution of the decay heat issue is given in Section 4.2.2 of this report.

- <u>Core Post CHF Heat Transfer</u>: Because of the similarity of the U.S. EPR fuel to current designs, the U.S. EPR core introduces no new methodological or phenomenological considerations with respect to core post-CHF heat transfer.

  However, the staff no longer agrees [14] with the way the Forslund-Rohsenow heat transfer correlation was applied in Reference 2, believing the application there may result in unrealistically high heat transfer. Resolution of this issue for the U.S. EPR is documented in Section 4.2.11.3 of this report.

- <u>Core Reflood Heat Transfer and Quench</u>: The staff's response to this issue is covered in the previous paragraph.

- <u>Core 3-D Flow, Void Distribution and Generation</u>: These phenomena are essentially the same in current operating PWRs and the U.S. EPR and the RLBLOCA methodology has been found acceptable for operating PWRs. Therefore, the staff finds that the RLBLOCA methodology's treatment of these phenomena is also acceptable for the U.S. EPR.

- <u>Core Entrainment/De-entrainment</u>: The fuel bundles in the U.S. EPR are the same as fuel bundles in operating PWRs except that they are about 0.5 m (1.6 ft) longer. In request for additional information (RAI)-7 [7], the staff requested that the applicant assess the effect of a longer core on entrainment modeling in S-RELAP5. The applicant responded [12] that since the effects of spacer-grids are not considered in the S-RELAP5 calculation of entrainment, the degree of entrainment would not be significantly affected by the increased core length in the U.S. EPR. The amount of liquid entrainment in the core is over-predicted by S-RELAP5 for 3.6 m (12 ft) heated bundle tests (cylindrical core test facility [CCTF], FLECHT-SEASET) and for UPTF, which used a 1 m (3.3 ft) non-heated core. The applicant believes that the current RLBLOCA methodology conservatively accounts for entrainment in the U.S. EPR 14 foot core. The applicant's position is both reasonable and plausible. Therefore, the staff finds that the RLBLOCA methodology is applicable to the U.S. EPR with respect to core entrainment.

- <u>Upper Plenum Entrainment/De-entrainment</u>: The distance between the top of the core and the hot leg nozzles is greater in the U.S. EPR than in current PWRs. The RLBLOCA methodology conservatively predicts carryout (see Section 4.2.3.1 of EMF-2103(P)(A) [2]). The S-RELAP5 nodalization of the upper plenum region is the same in both the current plant model and the U.S. EPR model. This means that, for a given core steaming rate, S-RELAP5 will calculate about the same entrainment of droplets into the hot leg for both current plants and the U.S. EPR. However, the increased distance to the hot legs suggests that entrainment of droplets into the hot legs would actually be lower in the U.S. EPR. Therefore, hot leg entrainment is treated conservatively in the S-RELAP5 model of the U.S. EPR upper plenum. Based on this analysis the staff concludes that the RLBLOCA methodology is applicable to the U.S. EPR upper plenum.

- Upper Plenum Draining and Fall-Back: The core outlet geometry of the U.S. EPR is similar to operating PWRs. Consequently, it is reasonable to expect draining and fall-back in the U.S. EPR to be similar to operating plants. Therefore, the staff finds that the RLBLOCA is applicable to the U.S. EPR with respect to draining and fall-back.

- Steam Generator Steam Binding: The phenomenon of steam binding is the same in the U.S. EPR as it is operating PWRs. The RLBLOCA methodology has been shown to adequately treat this phenomenon for operating plants; therefore, the staff finds that its treatment is also adequate for the U.S. EPR.

- RCP Differential Pressure Form Loss: The modeling of the RCPs for the U.S. EPR is identical to the operating plants for which the RLBLOCA methodology is approved. Therefore, the staff finds that this aspect of the methodology is acceptable for the U.S. EPR.

- Non-condensable Gas: Except for size, the accumulators for the U.S. EPR are similar to current PWRs for which the RLBLOCA methodology was developed. Size has no effect on the behavior of the accumulators non-condensable cover gas. Therefore, the staff finds that this aspect of the methodology is applicable to the U.S. EPR.

- Accumulator Discharge: The accumulators in the U.S. EPR are configured in a similar way to those in current plants, but they are larger. This size difference only affects the length of the injection period but not the injection phenomenology. Therefore, the staff finds that the methodology's treatment of accumulator discharge is applicable to the U.S. EPR.

- Downcomer Liquid Level Oscillations: The staff's evaluation is contained in Section 4.2.4.2 of this report.

- Loop Flow Oscillations: In Reference 2, Section 4.4.2.2.8, the RLBLOCA methodology was shown to adequately predict the pressure and flow oscillations in the cold legs which result when ECC is injected into a steam filled full-scale system (UPTF). The cold leg geometry in the U.S. EPR is very similar to the UPTF cold leg geometry. The staff has concluded that the U.S. EPR introduces nothing which would invalidate this feature of the methodology. Therefore, this aspect of the RLBLOCA methodology is applicable to the U.S. EPR.

4.1.2 Applicability of S-RELAP5 to the U.S. EPR

The applicant's evaluation of the applicability of S-RELAP5 to the U.S. EPR considered 17 different features, unique to the U.S. EPR, which could potentially have a significant impact on the valid application of the RLBLOCA methodology.

The design features addressed by the applicant's and the staff's evaluation of each are given below.

- High Containment Pressure: The U.S. EPR does not have fan coolers; containment sprays are not activated until 12 hours after a LBLOCA. Consequently, containment pressures will be significantly higher for a LBLOCA in the U.S. EPR than for current PWRs. Containment pressure is a significant PIRT parameter during the refill and reflood phases of a LBLOCA. The higher containment pressure is within the modeling capability of S-RELAP5 (ICECON module); however, the staff has determined that the use of ICECON has not been sufficiently justified. The resolution of the staff's concern is addressed in Section 4.2.15 of this report.

- Containment Heat Removal System: The staff notes that no modeling or methodology changes are needed to represent the lack of fan coolers or the non-use of containment sprays. Therefore, the staff finds that the methodology is applicable to the U.S. EPR.

- In-containment Refueling Water Storage Tank: The in-containment refueling water storage tank (IRWST) is a large open pool which covers about two-thirds of the floor area at the bottom of the containment building. The staff requested additional information on the IRWST modeling in S-RELAP5 (ICECON module). The staff's concern and its resolution are addressed in Section 4.2.15 of this report.

- Medium Head Safety Injection: The simulation of MHSI and High Head Safety Injection (HHSI) are well within the modeling capability of S-RELAP5 and similar computer codes. Therefore, the staff finds that the applicant's RLBLOCA methodology is acceptable for application to the U.S. EPR with respect to the MHSI system.

- Safety Injection System/Residual Heat Removal System (SIS/RHRS): The U.S. EPR has four independent safety injection systems. Each train is capable of providing enough coolant to remove the core heat in the event of a LBLOCA. Whenever a train is out of service for maintenance, cross-connects are opened between Trains 1 and 2 and Trains 3 and 4. In the application of the RLBLOCA methodology to the U.S. EPR two SIS trains are assumed unavailable; one due to maintenance, and the other due to a single failure. Of the two remaining trains, one is assumed to inject into the broken loop and the other into one of the intact loops. Modeling the SIS in the U.S. EPR is within the capabilities of S-RELAP5; therefore, the staff finds that the approved RLBLOCA methodology is applicable for the U.S. EPR with respect to SIS modeling.

- Accumulators: In RAI-3, RAI-11, and RAI-13 [7][8] the staff requested that the applicant clarify how the accumulator lines were modeled and what assumptions were made regarding the availability of the accumulators during a LBLOCA. In an August 17, 2007, response to RAI-3 and June 13, 2008, responses to RAI-11 and RAI-13, the applicant explained the method for computing S-RELAP5 input for the accumulator lines and the method for determining the initial fluid conditions for the accumulators. The applicant also provided the reason why the accumulators are considered single failure proof. The staff finds the responses acceptable. The accumulators in the U.S. EPR are similar to current PWRs and present nothing which would invalidate the applicant's RLBLOCA methodology. Therefore, the staff finds that the methodology is applicable to the U.S. EPR with respect to accumulator modeling.

- Preventive Maintenance: The ramifications of preventative maintenance are addressed in the SIS/RHRS evaluation above.

- Large Primary System Component Sizing: The RPV of the U.S. EPR is somewhat larger than current plants. It was determined in Section 4.1.1 of this report that this did not invalidate applying the RLBLOCA methodology to the U.S. EPR. The U.S. EPR pressurizer is also approximately 50 percent larger than current plants.

Thermal hydraulic analysis codes are routinely applied to a wide range of physical systems varying greatly in size. The larger pressurizer volume is included in the S-RELAP5 model of the U.S. EPR. The larger volume will affect the timing of pressurizer emptying. Accurate representation of this is well within the modeling capability of S-RELAP5, and presents no obstacle to applying the RLBLOCA methodology to the U.S. EPR. Therefore, the staff finds that the methodology is applicable to the U.S. EPR with respect to pressurizer size.

- Large Reactor Vessel Free Volume between the Vessel Nozzles and Top of Active Core: The staff's evaluation of this issue is contained in Section 4.1.1.3 of this report, under Core Entrainment/De-entrainment.

- Heavy Reflector: The U.S. EPR differs from current PWRs in that it uses a heavy reflector – an all stainless steel structure between the periphery of the core and the core barrel. The structure is cooled by flow through axial holes that penetrate the structure. S-RELAP5 is capable of modeling both the coolant flow through the heavy reflector and the heat transfer from the structure to the coolant. Only minor modeling changes - replacement of the core baffle representation with a heavy reflector representation - are needed in the S-RELAP5 RLBLOCA model. Introduction of the heavy reflector does not invalidate any aspect of the RLBLOCA methodology. The staff finds that that S-RELAP5 is applicable to modeling this aspect of the U.S. EPR.

  Long Core: The 4.2-m (13.8 ft) core is about 17 percent longer than current PWR cores. The main effect of the longer core is the introduction of additional grid spacers in the fuel assembly. These additional spacers are modeled by adding additional frictional loss coefficients to the S-RELAP5 model. The applicant's RLBLOCA methodology has been validated against loss-of-fluid tests (LOFT) and Semiscale tests, which used 1.7-m (5.6-ft) cores, and against CCTF and slab core test facility (SCTF) tests, which used 3.6-m (11.8-ft) cores. The validation at two different core lengths indicates the methodology is scalable to a 4.2-m (13.8-ft) core. Based on the above information, the staff finds that the methodology is applicable to the U.S. EPR core.

- Fuel Rod Lower Plenum and Isolation Pellet: The U.S. EPR fuel rods have a lower plenum and a non-fuel isolation pellet which separates the plenum from the fuel pellet stack. These additional rod features can be accommodated in the RODEX3A fuel rod code simply by defining the additional geometry via input. The staff believes that RODEX3A is capable of adequately modeling the fuel rod lower plenum and the presence of the isolation pellet. Therefore, the staff finds that the RLBLOCA methodology is applicable to the U.S. EPR with respect to this fuel rod design feature.

- Partial Cooldown: The U.S. EPR has a Main Steam Relief Train (MSRT) on each SG. The system is designed to impose a controlled depressurization of the secondary side during certain events; thereby cooling the RCS and lowering the primary side pressure.

  In its application of RLBLOCA methodology to the U.S. EPR, the applicant does not credit operation of the MSRT. The staff expressed concern that, if the MSRT were to operate for the smaller break sizes considered in the RLBLOCA methodology, the physical processes could be quite different from what is currently being calculated. In RAI-25 [9] the staff requested that the applicant demonstrate that the MSRT will not operate for any of the break sizes being considered in the RLBLOCA methodology; or, demonstrate that if it did operate it would have no significant effect upon the course of the transient and the resulting PCT, fuel rod oxidation, or hydrogen generation.

In a December 19, 2008, response to RAI-25, the applicant provided re-runs of the limiting case (Case 44) and two cases with smaller break sizes (Cases 54 and 58) with the MSRT active. The results showed no change in PCT for two of the cases because PCT occurred prior to MSRT actuation. In the third case, the PCT was 23 K (41 °F) lower when MSRT operation was allowed.

The applicant stated that the results show that ignoring the actuation of the MSRT is an acceptable modeling procedure. The staff agrees that not modeling the MSRTs is a conservative approach and, therefore, approves the applicant's method of treating the MSRTs.

- Steam Generators Axial Economizer: The U.S. EPR SG employs an axial economizer which physically separates the SG downcomer into two halves. Feedwater is injected into one-half of the downcomer along with about 10 percent of the recirculation fluid. The flow in the other half of the downcomer consists of only recirculation fluid. This unique feature of the U.S. EPR is within the modeling capability of S-RELAP5. Therefore, the staff finds that the RLBLOCA methodology is applicable to the U.S. EPR with respect to SG characteristics.

- High Steam Generator Operating Pressure and Temperature: The U.S. EPR SGs operate at higher pressures and temperatures than current PWRs. This means that greater steam binding may be calculated during reflood for the U.S. EPR, particularly since operation of the MSRTs is not modeled in S-RELAP5. The U.S. EPR SG thermodynamic state and primary/secondary heat transfer are within the capability of S-RELAP5. Therefore, the staff finds that the RLBLOCA methodology is applicable to the U.S. EPR with respect to SG characteristics.

- RCP Trip - "RCP Trip on Low dP Over RCP and SIS Signal": The U.S. EPR incorporates logic to trip the RCPs if the pressure change across two of four RCPs falls below a certain value in conjunction with an SIS trip signal. Having this trip does not invalidate the applicability of the RLBLOCA methodology to the U.S. EPR; it simply changes the time at which RCP trip may occur. The presence of this trip does mean that, when applying the methodology to the U.S. EPR, there is no need to consider loss of offsite power (LOOP); see Section 4.2.3 below.

- Lack of SIS Initiation Trip on High Containment Pressure: Unlike current PWRs, the U.S. EPR does not have a high containment pressure trip to initiate SIS. This plant-specific feature has no impact upon the applicability of the RLBLOCA methodology to the U.S. EPR, because the absence of the trip does not change the phenomena which the methodology is simulating.

4.2 Resolution of Staff Concerns

The staff has reviewed the SER conditions and restrictions of EMF-2103, Revision 0, that are applicable to the U.S. EPR design and has concluded that the conditions and restrictions have been met as described in Reference 1. The rest of this section details the resolution of staff concerns regarding the applicability of the applicant's RLBLOCA methodology to the U.S. EPR.

4.2.1 Initial Power and Peaking Factors

The initial core power in the U.S. EPR RBLOCA analysis [1] is a statistically sampled parameter. In an August 17, 2007, response to RAI-3 and RAI-4 [12], the applicant explained that the core power was sampled over a ±22.0 MWt interval about the licensed power level. In RAI-10 [13], the staff expressed its concern that the plant licensing basis LOCA analysis should not be performed at less than the full licensed power level.

The staff believes that any RLBLOCA analyses should use the rated power plus the measurement uncertainty of the power instrumentation. In a June 13, 2008, response to RAI-10 [13], the applicant agreed that it would treat core power deterministically using the maximum measurement uncertainty in any future U.S. EPR RLBLOCA analyses." The applicant also presented the results of calculations that showed a heat balance measurement uncertainty of ±22 MWt resulted in less than 5.5 °K (10 °F) change in PCT.

The power peaking factors for the hot rod in the applicant's RLBLOCA methodology are computed as described in Section 5.1.3.3 of EMF-2103(P)(A) [2]. The staff finds that the procedure for selecting the power peaking factors for the hot rod yields conservative values for the peaking factors and is, therefore, acceptable for the U.S. EPR.

4.2.2 Decay Heat

Decay heat is also a statistically sampled parameter in the applicant's RBLOCA methodology. The staff questioned the use of a sampled decay heat in RAI-17 [8] and again in RAI-33 [9]. After reviewing the June 13, 2008, response to RAI-17, the staff issued an additional request for information on the use of a sampled decay heat in RAI-33. In a December 19, 2008, response to RAI-33 [14], the applicant stated:

> For the RLBLOCA analysis of the U.S. EPR, AREVA NP will model the decay heat assuming the simplified infinite operation decay heat curve presented in the ANS/ANSI 5.1-1979 standard for decay heat, plus a bias and uncertainty of +2σ. This model will be used without applying the sampling option in the decay heat calculation portion of the RLBLOCA uncertainty analysis.

In an NRC audit meeting on the RLBLOCA methodology held on September 15, 2009 [29], the applicant provided an analysis which showed that rerunning the RLBLOCA calculations using a fixed decay heat multiplier of 1.06 instead of a sampled value increased the PCT by 27.8 K (50 °F). The applicant also presented results which showed that nominal decay heat calculated by S-RELAP5 was high relative to the American Nuclear Society/American National Standards Institute (ANS/ANSI) 5.1-1979 decay heat standard. This is so because S-RELAP5 assumes energy per fission value of 200 MEV/fission, whereas the actual value is higher, particularly as fuel burnup increases. The applicant stated the decay heat calculated by S-RELAP5 was at least one percent greater than the 1979 standard at zero burnup and rose to several percent greater as fuel burnup increased. In an NRC public meeting held on October 10, 2009, the applicant retracted its December 19, 2008, response to RAI-33, and instead proposed to model decay heat using the ANS/ANSI 1979 standard, and sample it using a standard deviation of two percent. In Revision 1 of TR ANP-10278P [3], the applicant formally documented this treatment of decay heat. The staff finds that, given the large safety margin in the U.S. EPR

RLBLOCA results, this treatment of decay heat is acceptable. The staff's finding applies only to the U.S. EPR. This acceptance does not imply staff's acceptance of this decay heat treatment in the application of the RLBLOCA methodology to any other plant design.

4.2.3 Loss of Offsite Power

Loss of offsite power is a random variable in the statistical analysis of the U.S. EPR presented in Reference 1; a bi-modal distribution is used. This approach is not in compliance with General Design Criteria (GDC) 35. GDC 35 requires, in part, that:

> Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

In RAI-22 [9], the staff requested that the applicant demonstrate compliance with GDC 35. In a December 19, 2008, response [14], the applicant stated:

> By design there is no significant difference between the loss-of-offsite power (LOOP) and non-LOOP cases for the U.S. EPR. The U.S. EPR is designed with an automatic reactor coolant pump (RCP) trip on coincident safety injection (SI) signal and low RCP differential pressure. This feature causes the RCPs to trip in the event of a LOCA even if offsite power is available.

The staff finds the applicant's analysis has satisfied GDC 35 guidelines. The applicant's response also showed that, under a LOOP condition, the delays in ECCS injection are greater than those in the non-LOOP condition; therefore, LOOP results are slightly worse than non-LOOP results. The applicant has also demonstrated that the non-LOOP case is bounded by LOOP case and has further demonstrated that the system safety function can be accomplished, assuming a single failure, for the non-LOOP case.

4.2.4 Reflood Issues

The LBLOCA limiting calculation presented in Reference 1, Appendix A had a bottom skewed power shape. The PCT was calculated to occur at the onset of reflood (33.4 seconds (s)). Over the next 30 seconds the hot rod's cladding temperature dropped 70 K (126 °F). During this time the S-RELAP5 calculation exhibited large oscillations in core inlet flow. At about 65 seconds, the cladding temperature rapidly declined another 111 K (200 °F) when the nitrogen from the accumulators emptied into the primary system. At this time the system pressure exhibited an unexpectedly large short term increase of about 0.5 MegaPascal (MPa) (70 pounds per square inch (psi)).

The staff issued several RAIs to address its concerns. The RAIs and the applicant's responses are presented in the following subsections.

4.2.4.1 Axial Power Profile

While S-RELAP5 has been qualified by the applicant for reflood simulations, it has never been explicitly qualified for a situation in which the axial power is strongly bottom skewed. Indeed, there are no reflood experiments in which bottom skewed power profiles were employed. The staff noted that the applicant's RLBLOCA calculation using a 59 case set (ANP-10278P, Revision 0 [1], Appendix A) with the highest PCT has a power shape which is strongly bottom-skewed (-0.17 axial-offset) and highly peaked (F_q=2.59). The peak power location is about 0.7 m (2.3 ft) above the bottom of the core. All other things being equal, one expects a case with a top-peaked power profile to be limiting. The results from the 124 case set for the U.S. EPR RLBLOCA analysis in Reference 3 reveal that the limiting case has a top-skewed power profile.

In the U.S. EPR RLBLOCA analyses in Reference 3, the skew of the power shape, whether top peaked or bottom peaked, was sampled with equal probability for each state. The axial power distribution for each individual case was extracted from a database of axial power shapes for first-burned fuel sorted by burnup, axial peaking factor, and skew. This database was generated from physics calculations specific to the U.S. EPR design and the cycle design under consideration. The staff finds this approach acceptable for application to the U.S. EPR.

4.2.4.2 Core Inlet Flow Oscillations

In RAI-12 [13] the staff requested that the applicant provide a detailed explanation of the local core hydraulics calculated by S-RELAP5 at the time core reflood began. In RAI-19 [13] and RAI-26 [14] the staff requested that the applicant address the oscillations in core flow.

The applicant's discussion of U.S. EPR LBLOCA phenomena states that (ANP-10278P Revision 0 [1], Section 4.3, p. 4-8), "Manometer type downcomer liquid level oscillations have not been observed to any significant extent in the methodology nodalization models. The lack of these oscillations is conservative because the effect of the oscillations is to drive water up into the core and provide an additional cooling mechanism." The staff reviewed the sample problem presented in Reference 1, Appendix A and concluded that the calculation did show significant oscillations in core inlet flow and core level during reflood (see ANP-10278P Revision 0 [1], Figure A-13). Core flow oscillations arise when liquid enters the bottom of the core and encounters the hot fuel rods. The liquid is quickly heated to saturation. Bulk boiling occurs, causing a local pressure increase. The subcooled liquid is pushed back out the bottom of the core and a geyser of steam and entrained droplets flows up through the core. The core pressure then decreases, allowing liquid to once again enter the core, and the process is repeated. Downcomer/core level oscillations were observed in SCTF only when the initial ECC flow was high [23]. However, the heat transfer enhancement effect of the oscillations alone could not be quantified because they could not be suppressed in the high flow tests. The staff agrees on the existence of core flow oscillations during the reflood period of a LBLOCA, but does not agree that the magnitude of the oscillation as predicted by the S-RELAP5 code is realistic. Therefore, the staff issued RAI-19 and RAI-26.

In RAI-19 [8], the staff requested that the applicant demonstrate that the calculated oscillatory flow is supported by experiments. In a June 13, 2008, response to RAI-19 [13], the applicant presented core inlet velocity measurements from LOFT test L2-5. However, the applicant neglected to provide a comparable plot of computed results to demonstrate that S-RELAP5 oscillations were comparable in magnitude to the experimental ones. The applicant did present a plot of core inlet mass flux as computed by S-RELAP5 for L2-5, showing that S-RELAP core inlet mass flux had large oscillations. The applicant also presented a comparison of calculated and measured cladding temperatures for LOFT L2-5 and advanced the argument that, in spite of the presence of flow oscillations in the S-RELAP5 calculation, calculated PCTs conservatively envelope the data; thus demonstrating that S-RELAP5 is capable of predicting integrated core cooling for the U.S. EPR.

In RAI-26 [9], the staff requested that the applicant provide additional justification that PCTs are conservatively calculated by S-RELAP5 in spite of the core flow oscillations. In a December 19, 2008, response to RAI-26, the applicant [14] presented a comparison of computed and measured fluid velocities at the core inlet. This comparison showed that the amplitudes of the experimentally observed flow oscillations were equivalent to, or larger than, the S-RELAP5 computed oscillations for L2-5. The applicant then showed a comparison of S-RELAP5's core inlet mass flux for L2-5 to the core inlet mass flux from the U.S. EPR RLBLOCA topical report. This comparison shows that the magnitude of the calculated oscillations for L2-5 and the U.S. EPR are similar. Since the oscillations in the U.S. EPR and LOFT L2-5 simulations are similar and the calculated PCTs in LOFT are conservatively high, the applicant argued that this is an indication that the calculated PCTs for the U.S. EPR LBLOCA are conservatively high also.

In a December 19, 2008, response to RAI-26, the applicant also presented S-RELAP5 simulations of FLECHT-SEASET Tests 31701 and 31504. Test 31701 is a high reflood rate test, with a 15.2 cm/s (6 in./s) flooding rate typical of early accumulator injection. Test 31504 is a low reflood rate test with a 2.5 cm/s (1 in./s) flooding rate typical of the LHSI phase of a LOCA. Two S-RELAP5 simulations were performed for each test. The first simulation (baseline case) used the constant bundle inlet flow used in the test. For the second simulation (oscillation case), the bundle inlet flow was forced to oscillate about the mean measured inlet flow. The magnitudes and periods of the oscillations were made comparable to those seen in the U.S. EPR RLBLOCA simulation during early reflood (high flow) and late reflood (low flow). In each of the simulations, fluid conditions were set to those seen in the S-RELAP5 simulations of the limiting U.S. EPR LBLOCA, but heater rod initial temperatures and power were set to the values measured in the relevant FLECHT-SEASET test. The point of this exercise was to demonstrate that, even if the FLECT-SEASET tests were simulated with flow oscillations typical of those seen in the EPR S-RELAP5 calculation, calculated PCTs would not change significantly.

The applicant compared results from the baseline and oscillation cases and claimed that the results showed that inlet flow oscillations did not enhance core heat transfer at the peak cladding temperature location. In the high reflood rate simulations, the oscillation case shows immediate enhanced heat transfer which drops the cladding temperature about 24 K (43 °F) relative to the baseline case; however, since the PCT in both the baseline and the oscillation simulations occurred at time zero, the PCT was the same in both simulations. In the long term, however, the oscillation case did result in overall less core heat transfer, quenching the hot spot about 25 seconds later than the baseline case.

The staff notes that core inlet flow oscillations are not unique to S-RELAP5. Other codes' simulations of both SCTF and CCTF show oscillations in core inlet flow.

Of the LBLOCA cases presented in Reference 1, approximately half of the cases have their PCT time prior to 50 seconds, about 15 seconds before the accumulators empty. The staff observes that each of these early PCT cases has a large amount of ECC available for cooling the core and PCT will consequently occur shortly after lower plenum refill and the initial surge of water into the core. Therefore, core inlet flow oscillations, which are initiated by the initial insurge of water into the core, will not have a significant effect on the PCT for most of the RLBLOCA simulations, although the oscillations may affect the core quench time. Of the cases which have their PCT later than 50 seconds only two have a PCT within 120 K (216 °F) of the limiting case.

With respect to multi-dimensional effects, SCTF test results [23] showed that core water inventory is essentially constant in the lateral direction, regardless of lateral power and temperature distributions. It is reasonable to assume this will also be true for larger cores, owing to the open lattice nature of fuel rods in a PWR. SCTF also showed that a significant lateral distribution of the liquid in the upper plenum can develop late in reflood and the core quench front can also develop a distinct lateral profile. S-RELAP5, which uses a specialized two-dimensional component to model the core and upper plenum, has the capability to simulate these two multi-dimensional effects.

Based on test data, the staff believes that the magnitude and duration of the core flow inlet oscillations seen in S-RELAP5 are a characteristic of the numerical simulation rather than a characteristic of the physical system being modeled. The applicant has presented results which indicate that the existence of such oscillations in its LOFT L2-5 simulations did not result in an under prediction of PCT. An examination of the U.S. EPR RLBLOCA cases revealed that, for most cases, PCT occurred at the onset, or shortly after the onset of core flow oscillations with several seconds of accumulator flow available after the occurrence of PCT. The applicant's submittals indicate that the non-physical flow oscillations being computed by S-RELAP5 do not have a large effect upon computed PCT in the U.S. EPR RLBLOCA analysis for the case it examined. However, the staff was concerned that the core inlet flow oscillations' impact upon PCT has not been determined for all cases, particularly those with a top-peaked axial power profile. Therefore, the staff conducted independent calculations using S-RELAP5. These calculations, discussed in Section 4.3.2 of this report, indicate that the S-RELAP5 core flow oscillations during reflood have a small (~30 K) impact on core heat transfer and PCT.

After consideration of the applicant's responses to all of the staff's RAIs about core flow oscillations and the results of the staff's independent calculations, the staff finds that there is reasonable assurance that the flow oscillations computed by S-RELAP5 do not significantly impact the PCT safety margin calculated for the U.S. EPR LBLOCA. The staff believes that RLBLOCA methodology is producing acceptable results with respect to the safety parameters of interest and, therefore, finds that S-RELAP5 results are acceptable for the RLBLOCA methodology as applied to the U.S. EPR. In the present, re-analysis flow oscillations occur shortly after core reflood begins. In most cases, PCT will occur just prior to reflood; that is, the initial entry of water into the core will be sufficient to terminate the cladding temperature rise. If PCT occurs several seconds after reflood, there is a greater chance that the oscillations are strongly influencing the PCT. Therefore, the staff finds that additional evaluation is necessary for conditions in which the PCT occurs after core flow oscillations begin. The staff will require that any applicant that references this methodology must evaluate the effect of core flow oscillations if the RLBLOCA analyses exhibit core flow oscillations prior to occurrence of the maximum PCT as discussed in the conclusions of this report.

4.2.4.3 N_2 Injection

The S-RELAP calculation for the U.S. EPR limiting LBLOCA shows an apparently unrealistically large increase in system pressure shortly after the initiation of reflood (ANP-10278P, Revision 0

[1], Figure A-17). In RAI-20 [8] and RAI-27 [9], the staff requested that the applicant provide an explanation of the calculated pressure increase.

In a June 13, 2008, response to RAI-20 [13], the applicant noted that a similar pressure increase was seen in Semiscale blowdown experiments and was explained in NUREG/CR-4945, Section 4.1.8, as related to nitrogen injection into the primary system when the accumulators empty. The applicant argued that the similarity of pressure spikes in its S-RELAP5 simulation and the Semiscale test demonstrated that the S-RELAP5 pressure spike is reasonable. The staff found the applicant's explanation, "The (pressure) increase is associated with the rapid discharge of cold nitrogen from the accumulators into the RCS, which then heats and expands," unconvincing and requested that the applicant investigate the matter more thoroughly. The applicant did so and provided the results in their December 19, 2008, response to RAI-27 [14] as discussed below.

The applicant's December 19, 2008, response to RAI-27 presented the results of sensitivity studies on two RLBLOCA cases, Case 19 and Case 44. These are the cases with the two highest PCTs. Case 44 showed a large RCS pressure increase as the accumulator cover gas escaped, while Case 19 showed only a small RCS pressure increase. The applicant ran these cases with and without accumulator N_2 injection. These simulations showed that injection of N_2 had no significant effect on calculated PCT simply because the PCT occurred prior to N_2 injection. The simulations did show that N_2 injection caused an increase in core heat transfer and a decrease in cladding temperature (70 K in Case 44 and 18 K in Case 19) when it occurred. The reason for the different amount of cladding temperature reduction is probably due to Case 44 having a very bottom peaked power profile and Case 19 having a top peaked power profile. The flow surge into the core caused by N_2 injection has a larger effect on cladding temperatures in the lower part of the core.

The applicant's examination of the simulations concluded that the high pressure seen in Case 44 was due a malfunction of the S-RELAP5 break flow model when air was present at the break during N_2 injection. The air was present due to brief backflow from the containment at the end of blowdown. The applicant stated that the pressure spike seen in Case 44 was caused by an unrealistically low calculation of break flow by S-RELAP5 for the situation when air is present at the break. The applicant concluded that, while S-RELAP5 does not precisely predict the break discharge physical condition in some scenarios, the overall effect on PCT is negligible. The staff agrees with the applicant's conclusion with respect to Case 44, but is not convinced that the applicant's conclusion is valid for all cases. Evaluation of cases where the PCT occurs after, rather than before, N_2 injection should also be considered prior to drawing such a conclusion. The applicant's response to RAI-27 stated that S-RELAP5 was apparently not predicting the appropriate discharge for Case 44. This response implies that there is a potential deficiency in the S-RELAP5 break flow model. In RAI-41 the staff requested that the applicant to explain the impact of the potential code error and inform the staff on a plan to address the potential error.

In a January 8, 2010, response to RAI-41 [17], the applicant reported that it had conducted a corrective action report to evaluate possible deficiencies in the S-RELAP5 critical flow model and determined that there was no deficiency in the model, contrary to what it had reported earlier. The applicant also presented the results of an S-RELAP5 simulation of Moby Dick Experiment 3141[30], a two-component critical flow experiment. The applicant noted that S-RELAP5 agreed well with the experimental data, further indicating there was no deficiency in its critical flow model. Finally, the applicant presented the results of three S-RELAP5 simulations: Case 44 (bottom peaked power); Case 44A (chopped cosine power), and Case 44B (top peaked power). The results showed that the magnitude of the pressure peak correlated with the axial power shape: Case 44 had the highest pressure peak; Case 44B had a smaller pressure peak; and Case 44B had the lowest pressure peak. The applicant explained that the magnitude of the pressure peak was related to the amount of water in the core when the accumulators emptied. In particular, the applicant stated that the pressure increase seen in Case 44 was not artificial.

The staff conducted an independent evaluation of the S-RELAP5 critical flow model with S-RELAP5 LBLOCA simulations. The staff's simulations showed that the pressure spike seen in Case 44 was not artificial; rather, it was due to a large amount of droplets being carried over to the steam generator tubes, and being vaporized there by heat transfer from the SG secondary side. The liquid carry over was particularly large in Case 44 because of its bottom-peaked power profile. The bottom-peaked power meant that a large amount of heat was quickly transmitted to the liquid entering the core, resulting in bulk boiling and liquid carry out from the core.

Based upon the applicant's responses to RAI-41 and its own confirmatory calculations, the staff concludes that the pressure increases calculated by S-RELAP5 during N_2 injection are physically based and reasonable in magnitude.

In a December 19, 2008, response to RAI-27 [14], the applicant presented a summary of 72 S-RELAP5 sensitivity studies using 3- and 4-loop Westinghouse PWR models with and without N_2 injection and with either a cosine or top skewed axial power profile. The results show that the maximum deviation between cases with N_2 injection and those without is about 17 K (31 °F), with the N_2 injection case being higher. However, the applicability of these sensitivity studies are not validated for a design such as the U. S. EPR, because the diameter of the vessel is larger than current PWRs and because the connection sequence of the hot and cold legs to the RPV is different from current PWRs. The results do suggest, however, that the PCT in an S-RELAP5 simulation of the U.S. EPR LBLOCA is not highly affected by N_2 injection.

In RAI-28 [9], the staff requested that the applicant explain how S-RELAP5 captures the detrimental effect of nitrogen injection and associated effects seen in the Achilles test (ISP-25). In that test, the core flow increased during nitrogen injection, but this temporary flow increase resulted in an increase in carryout and a subsequent lower reflood rate and higher PCT. In a December 19, 2008, response to RAI-28 [14], the applicant provided a discussion of the S-RELAP5 simulation of ISP-25 given in Reference 22, where it is demonstrated that S-RELAP5 gave predictions of liquid carryout and steam rates that were in good agreement with the test data. Furthermore, S-RELAP5 captured the subsequent increase in cladding temperatures following N_2 passage and predicted PCTs which were higher than the measured ones. The staff has reviewed the simulation presented in Reference 24 and finds the applicant's response to RAI-28 acceptable in that it demonstrates that S-RELAP5 adequately simulated the effect of nitrogen injection in ISP-25.

4.2.4.4 <u>Development of Core Flow Prior to Lower Plenum Refill</u>

RELAP5 simulations of an U.S. EPR LBLOCA were conducted by the staff. It was noted that in some of these simulations a significant amount of flow into the core developed prior to the lower plenum refilling. In a June 13, 2008, response to RAI-12 [13], the applicant stated the beginning of core recover (BOCREC) can be calculated as the time when the void fraction in the bottom-most hot channel hydrodynamic volume drops below 0.5. This is an acceptable definition only if the lower plenum is already completely full. In RAI-38, RAI-39, and RAI-40, [11] the staff requested that the applicant determine if S-RELAP5 predicted positive core flow prior to lower plenum refill. The April 9, 2009, response to these RAIs [16] indicates that S-RELAP5 does indeed predict positive core flow prior to lower plenum refill. In RAI-42, RAI-43, and RAI-44 the staff requested that the applicant justify the acceptability of the S-RELAP5 core flow calculations. In a January 8, 2010, response to RAI-42, RAI-43, and RAI 44 [17], the applicant provided comparisons of S-RELAP5 to UPTF test data. The applicant first noted that the S-RELAP5 simulation of UPTF Test 6 shows that the S-RELAP5 prediction of the beginning of lower plenum refill is 1 to 5 seconds later than the data, and the lower plenum refill rate is under predicted. In Section 5.1 of a proprietary response to RAI-44 [17] dated January 8, 2010, the applicant presented details on the method used to calculate the time for the beginning of reflood. The staff has reviewed the applicant's calculations and finds that they provide a reasonable assurance that the beginning of reflood time calculated by S-RELAP5 is indeed conservative. Therefore, the applicant's responses to RAI-42, RAI-43, and RAI-44 are acceptable. The applicant submitted a revised response to RAI-44 [31], in which it changed the calculated reflood start times for some of the 59 cases it examined. The staff reviewed the revised RAI and determined that is still provided a reasonable assurance that S-RELAP5 calculates a conservative time for beginning of reflood. The revised response is acceptable to the staff.

4.2.5 RCP Seizure

In RAI-15 [8], the staff requested that the applicant clarify the RCP status in the broken loop and its impact on PCT. If the RCS pump in the broken loop locks and fails resulting in higher PCT, the proposed methodology needs to be justified. In a June 13, 2008, response to RAI-15 [13], the applicant stated that the RLBLOCA methodology, EMF-2103 (P) (A), models all un-powered RCPs as non-failed, free spinning rotors throughout the transient, "pump seizure is not considered part of the best-estimate LBLOCA scenario." The applicant noted that it had performed sensitivity studies of loop flow resistance in response to RAIs on EMF-2103P. These studies showed an insignificant increase in PCT (~ 2 K). The applicant also provided the results of several simulations of U.S. EPR LBLOCAs in which the RCP was assumed to lock at various times. These simulations showed that locking the rotor could increase the calculated PCT by anywhere from 10 to 20 K (18 – 35 °F). The applicant claimed that the results showed that the additional resistance associated with seizure of the pump rotor is not significant to the determination that the criteria of 10 CFR 50.46 are met for the U.S. EPR. The staff agrees with the applicant's conclusion because the PCTs calculated for the U.S. EPR are far below the safety limit. Therefore, the staff finds the applicant's treatment of the pump rotor acceptable for the U.S. EPR.

4.2.6 Radial Power Distribution

In RAI-8 [7], the staff questioned if the applicant had investigated the effects of the core radial power profile upon calculated PCT. In an August 17, 2007, response [12], to RAI-9, the applicant stated that the sensitivity studies on core radial power given in Reference 2, Appendix B were applicable to the PWR. Those studies showed that flatter core radial power profiles produce higher PCTs. The RLBLOCA methodology is, therefore, biased toward the selection of flatter core radial power profiles. The staff finds this procedure acceptable for the application of the RLBLOCA methodology to the U.S. EPR.

4.2.7 Long Term Cooling

In an August 17, 2007, response to RAI-5 [7], the applicant explained [12] that the RLBLOCA methodology does not, nor is intended to, address 10 CFR 50.46, Criterion 5 (long term cooling). Criterion 5 is addressed in Section 15.6.5 of the U.S.EPR FSAR, and evaluated by the staff in its SER to that FSAR section.

4.2.8 Zirconium Oxide Spallation

In RAI-9 [7], the staff requested that the applicant clarify how zirconium oxide spallation was included in the RLBLOCA model. In an August 17, 2007, response to RAI-9 [12], the applicant stated that the transient high temperature oxidation calculation assumes an initial oxide thickness of 0.0. Corrosion was considered in calculation of the initial clad and fuel temperatures. The applicant explained that this treatment maximizes both the cladding temperature excursion and the transient oxidation prediction. The staff agrees with this explanation. The staff notes that the low PCT and low cladding oxidation predicted during a LBLOCA of the U.S. EPR insures that zirconium spallation will be minimal.

4.2.9 Initial Temperature of Accumulator and IRWST

In RAI-24 [9], the staff requested that the applicant provide the U.S. EPR RLBLOCA analysis values of accumulator temperature, liquid volume, and initial pressure, and IRWST temperature, to provide the basis for the sampling parameter ranges, and show how these values compared with the Technical Specification values.

In a December 19, 2008, response to RAI-24 [14], the applicant explained that the RLBLOCA methodology applies the sampled containment temperature to the accumulators and the IRWST. The containment temperature is sampled uniformly from a lower bound of 288 K (59 °F) to an upper value of 323 K (122 °F). This range corresponds to the Technical Specifications (TS) Surveillance Requirements for the IRWST temperature. The TS limiting condition of operation (LCO) containment air temperature limit is 328 K (131 °F). The applicant changed and reran its limiting LBLOCA case (Case 44), with the containment temperature changed from 303 K to 328 K (86.6 °F to 131 °F), it found that the PCT increased less than 28 K (50 °F). The staff finds this change acceptable because the upper limit is now the maximum temperature permitted by the TS.

In a December 19, 2008, response to RAI-24, the applicant did not adequately address the staff's concern regarding the containment temperature sampling range. The applicant gave the basis for the containment temperature sampling range, but it did not justify that the selected range is the likely range of containment temperatures during full power operation. The staff believes the lower bound of the sampling range should be the lowest expected temperature during full power operation. A lower bound of 288 K (59 °F) seems too low for full power operation and has not been adequately justified by the applicant. In RAI-46, the staff requested that the applicant justify the present lower bound temperature or choose a lower bound temperature which can be justified.

In a January 8, 2010, response to RAI-46, the applicant proposed to use a lower bound temperature of 311 K (100 °F) for the accumulator liquid temperature sampling range. This value is based upon a review of the lower bound recorded annual temperature of operating plants with containment type similar to the U.S. EPR. The staff finds the response to RAI-46 acceptable because it provides a lower bound value based upon measured data.

It is noted that, although the IRWST temperature is set to the containment temperature, this is only done in the ICECON input. The applicant's RLBLOCA methodology requires the temperature of pumped safety injection to be set at the technical specifications maximum value for the IRWST. The applicant has conservatively set the temperature of pumped safety injection to be higher than the technical specification maximum value for the IRWST.

The applicant also provided information showing that the sampling range of the accumulator pressure and initial liquid volume were consistent with the U.S. EPR Technical Specifications Surveillance Requirements. Therefore, the staff finds the sampling approach for accumulator pressure and initial liquid volume acceptable.

4.2.10 <u>Fuel Pin Rupture</u>

The S-RELAP5 code used within the RLBLOCA model contains cladding swelling and rupture models that depend upon rod temperature and pressure history. This model was a staff concern during its safety evaluation of EMF-2103 (P) [2].

In RAI-34 [9], the staff requested that the applicant provide clarification as to how fuel pin rupture would be handled for the U.S. EPR. The staff agrees with the applicant's December 19, 2008, response to RAI-34 that, "Cycle-to-cycle burnup will impact PCT by changes in power and stored energy and that stored energy is strongly correlated to fuel rod power and, in general, they both decrease with burnup, resulting in lower PCTs." However, degradation in fuel thermal-conductivity and changes in the axial power shape create the opportunity for burned or gadolinia-bearing fuel assemblies to become limiting. In addition, per 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems," if cladding rupture is calculated to occur, the inside surfaces of the cladding shall be included in the oxidation.

4.2.11 Core Heat Transfer

4.2.11.1 <u>Critical Heat Flux Correlation</u>

In RAI-1 [6] the staff requested that the applicant clarify which CHF correlations are being used for the U.S. EPR RLBLOCA analysis. In an August 17, 2007, response to RAI-1 [12], the applicant described how the Biasi correlation has been conservatively biased so that calculated heatups occur earlier than measured. The bias on the correlation was evaluated using a set of 22 thermal hydraulic test facility (THTF) tests and validated against LOFT, Semiscale, CCTF, and SCTF tests. The staff accepts the applicant's application of the Biasi correlation because it has been shown to be conservative.

4.2.11.2 <u>Radiation Heat Transfer</u>

In its review of Reference 18, the staff expressed its concern that the lack of a rod-to-rod radiation model in S-RELAP5 validation matrix presents the potential that the uncertainty evaluation of the remaining heat transfer processes may over estimate the associated heat transfer. Thus, for conditions that do not involve significant rod-to-rod radiation, the S-RELAP5 evaluation may over estimate the net rod heat transfer. In RAI-32 [9] the staff requested that the applicant address this issue for the U.S. EPR RLBLOCA analysis.

In a December 19, 2008, response to RAI 32 [14], the applicant stated that rod-to-rod radiation in the U.S. EPR is similar to that in operating plants and presented calculations showing that rod-to-rod radiation in operating plants exceeds the radiation in the experiments used to derive the post-CHF HTC multipliers used by S-RELAP5. Therefore, the implicit inclusion of rod-to-rod radiation in the RLBLOCA methodology is conservative. Moreover, in the range of PCTs calculated for the U.S. EPR by the RLBLOCA methodology, rod-to-rod radiation is negligible. Therefore, based on its analysis, the applicant concluded that the rod heat transfer model used in the RLBLOCA methodology is acceptable for application to the U.S. EPR. The staff agrees with the analysis presented by the applicant and, therefore, finds that a rod-to-rod radiation model is not needed when applying the RLBLOCA methodology to the U.S. EPR with the current U.S. EPR fuel management scheme. However, as discussed in the limitations section of this report, the staff requires that any future analyses demonstrate that the contribution of rod-to-rod radiation is consistent with test data if the analysis shows that PCT exceeds 1255 K (1800 °F).

4.2.11.3 Dispersed Film Boiling Correlation

In RAI-30 [9], the staff stated that it believes the Forslund-Rohsenow heat transfer correlation has been applied outside of its range of application in the U.S. EPR RLBLOCA methodology and requested that the applicant quantify the impact on the RLBLOCA results. In a December 19, 2008, response to RAI-30 [14], the applicant stated that it has already modified S-RELAP5 so that it limits the amount of the Forslund-Rohsenow heat transfer correlation's contribution to no more than 15 percent of the total heat transfer rate for void fractions equal to or greater than 90 percent and committed to using the modified code for U.S. EPR RLBLOCA calculations. The staff finds that the code change and the commitment to use the code adequately address its concern and is, therefore, acceptable for U.S. EPR design only.

4.2.11.4 Fuel Rod Quench

The staff has noted [19] that the S-RELAP5 model allows rod quench to occur once the rod surface temperature drops below T_{min}, regardless of the local void fraction value. It is unlikely that quench would occur unless the local void fraction is less than 0.95. In a recent application [24] of the RLBLOCA methodology, the applicant changed the S-RELAP5 coding to require the local void fraction to be less than 0.95 before quench is allowed. The staff requires both criteria ($T_{clad} < T_{min}$; void fraction < 0.95) be met for the U.S. EPR RLBLOCA analysis. These criteria are applicable to reflood quench only.

4.2.12 Statistical Issues

Currently, the main approach in decision making with regard to compliance with 10 CFR 50.46 is via non-parametric statistics. In the context of demonstrating compliance with 10 CFR 50.46, the currently accepted safety level is defined as 95/95 with respect to the probability density function of three acceptance criteria: Peak clad temperature, maximum oxidation, and maximum hydrogen generation. In RAI-21 [9], the staff requested that the applicant justify why 59 code runs and not 124 (or more) code runs are needed for a test at the 95/95 level. It is the staff's position that the three acceptance criteria represent three independent variables. Therefore, at least 124 code runs are needed to satisfy the 95/95 acceptance criteria for all three variables.

In a December 19, 2008, response to RAI-21 [14], the applicant stated that it will revise the RLBLOCA analysis methodology for the design certification of the U.S. EPR to evaluate

124 cases instead of 59. The staff finds this to be an acceptable approach. The staff has confirmed that the Reference 3 RLBLOCA analysis used 124 cases.

4.2.13 Break Spectrum Lower Bound and Break Size

Sensitivity analyses show that the phenomena associated with LBLOCAs dominate at break sizes greater than 20 percent of the cold leg flow area, and the SBLOCA phenomena only become important at break sizes less than 10 percent of the cold leg break area. The region with break sizes between 10 and 20 percent is often referred to as the intermediate break size region. The staff's position is that the use of the probability sampling theory to satisfy the acceptance criteria for peak cladding temperature, maximum local oxidation, and core wide oxidation, should be limited to breaks falling within the appropriate phenomenological-driven region. Thus, the staff expressed concern that the lower bound on the break size in the applicant's RLBLOCA methodology was too small. In RAI-29 [9], the staff requested that the applicant provide justification for its lower bound on the break size sampling.

In a March 31, 2009, response to RAI-29 [14], the applicant reviewed the original PIRT for the RLBLOCA methodology with a focus on the phenomena relevant to smaller break sizes. The following phenomena increased in importance or were added as a result of the PIRT review:

- Fuel rod gap conductance
- Nucleate boiling in the core
- Counter-current flow limiting (CCFL) at the SG tubes
- Condensation-induced oscillations within the cold legs during reflood
- Flashing of the fluid in the downcomer during refill and reflood
- Break flow phenomena during reflood
- Loop seal clearing

The applicant considered each of the above phenomena for break sizes in the intermediate range and concluded that all but one of them was adequately treated by the current S-RELAP5 RLBLOCA model. The exception was CCFL at the SG tubes. Adequate treatment of this phenomenon would only require that the CCFL flag be activated for the appropriate junctions in S-RELAP5.

The staff has compared the S-RELAP5 RLBLOCA model to the S-RELAP5 SBLOCA model and determined that the models are very similar. Both models use two-dimensional components to represent the core and downcomer regions. The representation of the loops in the two models is identical except for the RCP. The SBLOCA model represents the volute region of the RCP explicitly, while the LBLOCA model does not. The reason this is done in the SBLOCA model is to account for the fact that the RCP impeller discharge height is above the bottom of the cold leg, thus preventing backflow through the pumps for those cases where a low level stratified flow exists in the cold legs. The SBLOCA and LBLOCA models have identical models of the SG secondary side. Their representations of the steam lines are different because the SBLOCA model simulates the MSRT while the LBLOCA model does not.

Given the considerable similarity of the SBLOCA and LBLOCA models, it is highly likely that both models would produce similar results if applied in a best estimate fashion to an intermediate break LOCA in which MSRT operation was ignored.

The results of the RLBLOCA analysis in Reference 1 for the U.S. EPR show that the average PCT of the nine cases with break sizes between 10 and 20 percent of the cold leg flow area is 816 K (1010 °F) and the maximum PCT is 953 K (1256 °F). This compares to an average PCT of 956 K (1262 °F) and a maximum of 1047 K (1425 °F) for the 19 cases with break sizes between 100 and 200 percent of the cold leg flow area. The average PCT for large breaks is 140 K (252 °F) greater than that for the intermediate breaks. In Reference 24, the applicant compared the maximum PCTs of intermediate breaks to maximum PCTs from large breaks for all the plant types which have been analyzed using the RLBLOCA methodology. The average delta PCT (large break PCT minus intermediate break PCT) ranged from 237 K to 467 K (427 °F – 840 °F), depending on the plant type.

Given the similarity of the S-RELAP5 SBLOCA and RLBLOCA models, it is unlikely that the RLBLOCA model of the U.S. EPR has misrepresented or missed any phenomena in the intermediate break region that would result in a 140 K (252 °F) increase in PCT. Therefore, the staff finds that a value of 10 percent of the cold leg flow area is an acceptable lower bound for the RLBLOCA break area spectrum for the U.S. EPR.

4.2.14 Initial Fuel Rod Stored Energy

The staff's review of ANP-10285P, "U.S. EPR Fuel Assembly Mechanical Design Topical Report" [25], revealed that the fuel pellet stored energy computed by RODEX3A may be non-conservative for higher fuel burnups. This finding impacts the RLBLOCA methodology because the methodology uses RODEX3A to compute the initial stored energy for all the fuel pin heat structures in S-RELAP5. The staff's independent calculations of stored energy using FRAPCON-3.3 [26] indicate that RODEX3A may under predict the hot rod's centerline temperature by as much as 140 K – 195 K (250 °F – 350 °F) at a burnup of 30 GWd/MTU.

In RAI-35, RAI-36, and RAI-37 [11], the staff requested that the applicant clarify the way stored energy is treated in the RLBLOCA methodology. The applicant's responses are given in Reference 15.

In RAI-35, the staff requested that the applicant provide the initial stored energy and the fuel pellet conductivity used in each of the heat structures representing fuel pins in the RLBLOCA analysis. This question was asked so that the staff could compare stored energies calculated by RODEX3A to those calculated by FRAPCON-3.3. In an April 2, 2009, response to RAI-35, the applicant explained in detail how the initial stored energy of the rods, in terms of initial transient conditions, was adjusted upward to account for the over-predicted fuel pellet thermal conductivity in RODEX3A for burnups greater than 10 MWd/kgU. The staff determined that the approach described in the proprietary response to RAI-35 was not acceptable and issued an additional question in RAI 47. The response to RAI-47 is discussed below.

In RAI-36, the staff requested that the applicant provide a calculation in which the stored energy for all fuel rods is adjusted to account for burnup. In an April 2, 2009, response to RAI-36, the applicant reran its limiting case and correcting the stored energy in the average fuel rods for a burnup of 18.3 GWd/MTU, and the outer region low power rods for a burnup of 37.5 GWd/MTU. The correction resulted in an increase of 111 K (200 °F) in the fuel centerline temperature for the average and low power rods. The RLBLOCA calculation using these increased initial temperatures resulted in an 11 K (20 °F) increase in PCT. The staff has conducted similar calculations using both RELAP5 and TRACE utilizing the UO_2 conductivity from RODEX3A for some calculations and from FRAPCON-3.3 for others. The staff's calculations showed LBLOCA

PCT increases of 33 K – 83 °K (60 °F – 150 °F) when the FRAPCON-3.3 conductivity was used instead of the RODEX3A conductivity; the difference in PCTs increased with increasing burnup.

In RAI-37, it was noted that the applicant's RLBLOCA methodology assumes that the hot rod will always be a rod in its first cycle. In RAI-37, the staff requested that the applicant discuss the process it will use to verify the assumption that the second or third cycle fuel are never limiting in terms of stored energy and PCT. In an April 2, 2009, response to RAI-37, the applicant stated that it would revise its reload check to compare the cycle design peak operating fuel enthalpy of fresh fuel to that of once-burned fuel and confirm that, at any time in the cycle, the operating enthalpy of the fresh fuel is greater than that of once-burned fuel. Should the fuel enthalpy of the second cycle fuel exceed that of fresh fuel at any point in the cycle, the conditions will be examined for the possibility that the highest PCT case in the RLBLOCA analysis could occur in the second cycle fuel. If that possibility cannot be ruled out, either the cycle design will be altered to preclude a PCT in second cycle fuel, or the RLBLOCA analysis will be expanded to include second cycle fuel.

The staff finds this process acceptable provided the process is described in detail in the RLBLOCA methodology document. The staff has confirmed that the process is described in Reference 3.

In its review of Revision 0 of the RLBLOCA Topical Report [1] the staff concluded that the applicant's use of the RODEX3A code to obtain fuel rod initial conditions may result in under prediction of fuel rod centerline temperature. The staff also concluded that the applicant's proposed method of calculating the initial stored energy for the core average assemblies and the low power periphery assemblies was inadequate and could lead to under prediction of PCT during a RLBLOCA simulation, and an under prediction of Doppler reactivity feedback as well. The applicant's responses to the staff's conclusions are documented in the following paragraphs and in Revision 1 of the RLBLOCA Topical Report [3].

The staff performed confirmatory analyses to predict fuel stored energy that will be used in both SBLOCA and RLBLOCA analyses using the FRAPCON-3.3 code and the input supplied by the applicant (RAI-29 [13]). The FRAPCON-3.3 peak fuel centerline temperature predictions were approximately 222 K (400 °F) and 172 K (310 °F) higher than the peak temperatures calculated with the S-RELAP5 code versions for SBLOCA and RLBLOCA, respectively, at the hot axial node at approximately 29 GWd/MTU burnup. In addition, the staff expects that the NRC-approved COPERNIC code [28] would show similar fuel centerline under predictions. This under prediction in initial fuel temperatures for the hot rod, hot assembly, surrounding assemblies, average core assemblies and outer core assemblies could result in up to a 111 K (200 °F) lower peak cladding temperatures (PCT) based on confirmatory calculations performed by the staff. In RAI-45 and RAI-47, the staff requested that the applicant justify its calculation of the fuel thermal conductivity and its impact on stored energy.

In a January 8, 2010, proprietary response to RAI-45, the applicant described in detail the treatment of the fuel conductivity multiplier, and expanded on information provided in the April 2, 2009, response to RAI-35. The staff finds the applicant's response to RAI-45 acceptable because it provides a consistent treatment of the fuel thermal conductivity calculation.

The January 8, 2010, response to RAI-47 stated that Section 4.1 of ANP-10278P, Revision 1 [3], was modified to address additional staff concerns on the under-prediction of fuel temperatures at certain burnup levels. The staff reviewed the modified calculation procedures for adjustment of fuel thermal conductivity and initial stored energy contained in Section 4.1 of

ANP-10278P, Revision 1 [3]. The staff finds that the version of RODEX3A and the relevant calculation procedures presented in Section 4.1 of ANP-10278P, Revision 1, are acceptable for the EPR RLBLOCA application only. Therefore, the staff finds the applicant's response to RAI-47 acceptable.

4.2.15 Containment Pressure

In the applicant's RLBLOCA methodology, the containment pressure is calculated using ICECON, a code which has been previously approved for calculating containment pressures in the current generation of PWRs. The U.S. EPR containment differs from current generation PWR containments in that it does not have containment sprays which can activate during a LBLOCA and it contains a large pool of liquid (IRWST) at the bottom of the containment.

The applicant states that, even though containment sprays are not present and higher containment pressures will be calculated using ICECON, the U.S. EPR containment is both within the ICECON modeling capability and within the RLBLOCA methodology given in Reference 2.

In RAI-16 [7], the staff requested that the applicant provide more information regarding the containment pressure calculations. In a June 13, 2008, response to RAI-16 [12], the applicant explained how containment pressure is treated statistically by ranging the containment volume and containment temperature. The applicant also stated that the ICECON model represents both the liquid pool region (IRWST) and the vapor atmosphere above it. The applicant provided a table of results of rerunning the original suite of 59 cases, each with its containment volume increased by 60 percent assuming 100 percent humidity. The resulting decrease in peak containment pressure was about 69000 Pa (10 psi) on average. The change in PCT ranged from -9 K (-16 °F) to 36 K (+65 °F) over the test suite with the limiting case having a PCT change of 14.4 K (+26 °F).

The June 13, 2008, response to RAI-16 did not address the question of whether ICECON provides a realistic simulation of the containment response. However, Appendix B of Reference 3 enumerates the following conservative assumptions that are imposed in the ICECON input to increase energy removal from the containment: 100 percent humidity in the containment atmosphere; a 10 percent increase in the best-estimate of containment surface heat transfer area; the assumption of thermal equilibrium between spilled ECC and the containment atmosphere; and the elimination of any insulating effects on exposed surfaces (e.g., paint, and the air gap between containment liner and concrete). The combination of these assumptions together with the increase in containment volume will bias the ICECON containment pressure low relative to a best-estimate calculation.

In RAI-23 [9], the staff requested that the applicant demonstrate that ICECON calculates an appropriate containment pressure response, explain how heat transfer to the IRWST water surface is treated, and explain how the best estimate containment pressure curve used in the RLBLOCA analysis is confirmed to be best estimate.

In a December 19, 2008, response to to RAI-23 [14], the applicant provided a benchmark of ICECON to an equivalent GOTHIC model of the U.S. EPR containment. The GOTHIC model is typically used to calculate a conservatively high containment pressure; therefore, for the comparison to ICECON the GOTHIC model's input was modified (primarily an increase in the surface area of heat transfer surfaces) to be comparable to the ICECON input. Both codes were driven with the mass flow and enthalpy boundary condition taken from an S-RELAP5

LBLOCA simulation. The benchmark calculation showed that ICECON and GOTHIC calculated nearly identical containment pressure responses for the first 20 seconds of the blowdown. Thereafter, the ICECON calculated pressure fell below the GOTHIC pressure by 7000 to 35000 Pa (1 – 5 psi). Therefore, the benchmark confirms that the containment pressure used in the RLBLOCA methodology is slightly conservative relative to the GOTHIC code. The staff finds the applicant's response to RAI-23 acceptable and, based on the above, finds that the use of ICECON to calculate the U.S. EPR containment pressure in the RLBLOCA methodology acceptable.

4.2.16 Downcomer Boiling

Hot downcomer walls affect PCT via two mechanisms: Reducing subcooling of the liquid entering the core and reducing the driving head for core reflood by level swell, and boil off of the liquid in the downcomer. PCT sensitivity to downcomer boiling depends upon cladding temperature and containment pressure. Sensitivity is greatest at high cladding temperatures in conjunction with low containment pressures.

During the staff review of Reference 2, the applicant provided S-RELAP5 sensitivity studies demonstrating the effect of downcomer boiling upon computed PCT for a 3-loop PWR. The base case studied had a PCT of 1285 K (1853 °F) and the containment pressure ranged between 0.14 to 0.21 MPa (20 - 30 psia). The staff expressed concern that the sensitivity shown by the applicant was considerably less than expected. It attributed the reduced sensitivity to low cladding temperatures and high containment pressures in the applicant's study.

RLBLOCA calculations for the U.S. EPR show PCTs in the 1170 K (1650 °F) range and containment pressures ranging between 0.27 and 0.35 MPa (40 - 50 psia). Therefore, PCT sensitivity to downcomer boiling is expected be less in the U.S. EPR analysis than the currently operating PWRs.

In RAI-31 [9], the staff requested that the applicant address downcomer boiling in the U.S. EPR. In a December 19, 2008, response to RAI-31 [14], consisted of presenting the results of sensitivity studies performed using the U.S. EPR S-RELAP5 model. The base case for the sensitivity studies was a modification of Case 43 of the U.S. EPR Cycle 1 RLBLOCA analysis. This case's input was modified as stated in the December 19, 2008, proprietary response to RAI-31. It should be noted that the base case for the sensitivity studies has a system pressure which is significantly lower and a downcomer liquid temperature which is significantly higher than any of the U.S. EPR RLBLOCA cases.

In the proprietary response to RAI-31 the applicant presented the results of two sensitivity studies on the U.S. EPR model which were conducted by varying the input to the base case. The applicant discussed the results of a radial mesh study and an axial nodalization sensitivity study on the downcomer boiling phenomenon. The number of nodes in the heat conduction mesh for the reactor vessel was varied. No significant differences between the two sensitivity cases and the base case were observed, indicating that the base case axial nodalization was sufficient to capture the phenomena of interest.

The sensitivity of downcomer boiling to azimuthal nodalization was previously studied by the applicant, in Reference 2 and a December 19, 2008, response to RAI 27, for a 3-loop PWR. Those studies showed that increasing the number of azimuthal nodes in the downcomer had no significant effect upon downcomer boiling. Calculated downcomer levels and core levels were essentially the same in the coarse and finely noded downcomer simulations.

Based upon its calculations, the applicant concluded that the S-RELAP5 base model of the U.S. EPR is capable of adequately representing the flow of heat into the downcomer fluid, the degree of boiling occurring in the downcomer, and the ensuing separation of steam from water. The staff finds the analysis performed and the conclusions drawn to be reasonable, and therefore acceptable. The staff also notes that that the downcomer boiling sensitivity studies were performed with the downcomer liquid near saturation temperature and a system pressure of 0.21 MPa (30 psia). The U.S. EPR RLBLOCA analyses show that, 400 seconds after the break occurrence, the downcomer liquid temperature is 5.5 K (10 °F) subcooled and its pressure is 0.28 MPa (40 psia). Therefore, downcomer boiling is not a concern in the RLBLOCA analyses for the U.S. EPR. Downcomer liquid temperatures remain well below saturation temperature during the S-RELAP5 analyses of the core recovery period of the LBLOCA transient.

4.3 Independent Analyses

Independent LBLOCA simulations for the U.S. EPR were conducted by the staff using RELAP5/MOD3.3, S-RELAP5, and TRACE. S-RELAP5 calculations were done to investigate the pressure increase due to accumulator cover gas injection, the S-RELAP5 critical flow model, and core inlet flow oscillations. The results of the confirmatory calculations were a key element guiding the staff's RAIs regarding N_2 injection, fuel rod stored energy, core flow oscillations, and lower plenum refill. These calculations also provided the staff with independent verification that analysis conservatisms being claimed by the applicant were, indeed, conservative.

4.3.1 RELAP5/MOD3.3 and TRACE Simulations

Calculations were done assuming 100 percent nominal power and nominal decay heat ANS 1979 Standard. The sensitivity of PCT to changes in the following parameters was investigated: Axial power shape, break discharge coefficient, containment pressure, and assumed safety injection (SI) train failures. TRACE calculations showed that the PCT varied between 1030 K and 1110 K (1400 °F – 1530 °F) when the break discharge coefficient was varied from 1.0 to 0.646. For these calculations, the containment pressure was specified to be the same as the applicant's limiting case, but the axial power was top-peaked (F_q=2.6 at 3.7 m elevation).

The PCT calculated by the applicant was 1046 K (1425 °F), but that case was bottom-peaked (F_q=2.6 at 0.7 m elevation). RELAP5 calculations were conducted with both bottom- and top-peaked power profiles. The RELAP5 calculations using a bottom-peaked axial all exhibited blowdown quench and PCTs near 1000 K (1341 °F). RELAP5 calculations using the top-peaked axial yielded PCT curves similar to those calculated with TRACE, both in temporal shape and maximum value.

The applicant's RLBLOCA methodology assumes that only two of the four safety injection (SI) trains are available, and one of those trains is attached to the broken loop. RELAP5 calculations were run to investigate the sensitivity of PCT to SI train availability. It was found that PCT was insensitive to which SI trains were available, as long as one of the available trains was attached to the broken loop.

A TRACE calculation was run with a top-peaked (F_q=2.6) power profile and a constant containment pressure of 0.14 MPa (20 psia) instead of a realistic containment pressure curve. The PCT for the low pressure case was 300 K (540 °F) above the base case but still well below the PCT limit. This calculation indicates that the U.S. EPR PCT would remain below 1478 K (2200 °F) even for a very conservative assumption for containment pressure.

4.3.2 S-RELAP5 Simulations

The staff conducted some simple (mini-model) S-RELAP5 and RELAP5/MOD3.3 simulations to compare the critical flow models of the two codes. It was determined that the two codes calculations of critical flow rates were in good agreement with one another. Moreover, the mini-model results were shown to compare well with S-RELAP5 EPR system calculations. Consequently, the staff independently concluded that the S-RELAP5 critical flow model did not have any deficiency, as was originally claimed and subsequently retracted by the applicant.

The staff conducted S-RELAP5 simulations to investigate the pressure increase associated with accumulator cover gas injection. It was determined that the magnitude of this pressure increase was dependent upon the axial power profile in the core. The large pressure increase for Case 44, originally thought to be nonphysical, was determined to be a result of a bottom-peaked power profile. When the accumulators empty the injection of cover gas causes a flow surge into the core. When the core power is concentrated in the lower part of the core, the flow surge results in bulk boiling and a large carryover of liquid droplets to the steam generator tubes where it is evaporated causing a spike in RCS pressure. It was shown that moving the core power upward in the core significantly reduced the amount of carry over and resulted in a much lower pressure peak.

To investigate whether the S-RELAP5 core flow oscillations during reflood caused an unrealistic increase in core heat transfer, the staff compared an S-RELAP5 system calculation with a forced reflood calculation. Both calculations used a top-peaked axial power shape. The forced reflood model was the same as the system model except that ECC was injected into the lower plenum instead of the cold legs, and the connection between the downcomer and lower plenum was severed.

The time-dependent ECC flow into the lower plenum was selected so that the average flow rate into the core was the same as the system calculation. A comparison of the system calculation and the forced reflood calculation demonstrated that the oscillations in the system calculation did not greatly increase the core heat transfer over that seen in the forced reflood calculation. The PCT for the forced reflood case was 30 K (54 °F) higher than the case with reflood oscillations.

4.4 Model Nodalization

Step 8 of the CSAU process describes how the nodalization of a plant model is determined. The plant model must be nodalized finely enough to represent both the important phenomena and design characteristics of the plant but coarsely enough to remain economical. Section 4.2 of Reference 2 describes how CSAU Step 8 is applied in the applicant's RLBLOCA methodology.

The nodalization used in the U.S. EPR RLBLOCA application closely follows the nodalization established in Reference 2. Geometrical differences between currently operating PWRs and the U.S. EPR make it necessary to deviate from the plant nodalization given in Reference 2.

The longer core in the U.S. EPR necessitates using more axial nodes in the core. The unique features, the axial economizer and the boiler partition plate, of the U.S. EPR steam generator can be accurately modeled only by revising the noding for the downcomer and boiler regions of the S-RELAP5 model. Finally, nodalization revisions are needed to properly model the RPV downcomer region and the neutron reflector coolant flow. The staff has reviewed the nodalization used for the RLBLOCA analysis of the U.S. EPR and finds it acceptable because the only difference between it and the base nodalization of Reference 2 is the necessary addition of nodes to properly describe the U.S. EPR geometry. The staff expects the nodalization described in Reference 3 to be used in all RLBLOCA analyses of the U.S. EPR. Any changes to the nodalization will have to be justified as required by the Conditions and Restrictions given in Section 5 of this report.

4.5 EPR RLBLOCA Calculation Results

Reference 3, Appendix A presents the results of a sample application of the RLBLOCA methodology to the U.S. EPR. The RLBLOCA analysis used 124 cases to obtain the highest PCT, maximum local oxidation, and maximum core wide oxidation. The highest PCT case was Case 38, with a PCT of 1158 K (1625 °F). The nominal 50/50 PCT case was 13 with a PCT of 946 K (1243 °F). Comparison of Case 13 and Case 38 shows that the relative conservatism in the limiting PCT case is 212 K (382 °F). Case 38 also had the highest maximum local oxidation, 0.92 percent. Case 2 had the highest total oxidation, 0.02 percent.

The U.S. EPR RLBLOCA sample calculation, which is for the equilibrium fuel cycle, yielded limiting parameter values that were well within regulatory limits. Specifically,

- The calculated PCT for the limiting PCT case is less than 1158 K (1625 °F).
- The maximum calculated local clad oxidation is less the 17 percent.
- The maximum amount of core-wide oxidation does not exceed one percent of the fuel cladding.

Comparison of the sample calculations in Reference 3 to those in Reference 1 shows that the highest PCT case increased by 93 K (200 °F) as a result of methodology modifications imposed by the staff in order to make the methodology acceptable for application to the U.S. EPR.

5 CONCLUSIONS

The staff concludes that the applicant's RLBLOCA methodology is acceptable for analysis of the U.S. EPR LBLOCA with the modifications delineated in Section 4.1 of Revision 1 of ANP-10278P, "U.S. EPR Realistic Large Break LOCA Topical Report" [3]:

- Rod quench requires a cladding temperature less than 755 K (900 °F) and a local void fraction less than 0.95.
- The heat transfer contribution from the Forslund-Rohsenow correlation is limited to 15 percent of total heat transfer at and above a void fraction of 0.9.
- Both split and double-ended breaks range in area from 10 percent to twice the cross-sectional area of the pipe.

- The number of sampled cases is 124. A limiting peak clad temperature case, a limiting local cladding oxidation case, and a limiting total hydrogen generation case are extracted from the 124 cases.

- Only LOOP cases are analyzed. Non-LOOP cases are bounded by LOOP cases. LOOP cases have been shown to satisfy GDC 35; therefore, so do non-LOOP cases, since they have been shown to be bounded by LOOP cases.

- Decay heat is sampled with a standard deviation of two percent.

- The initial centerline temperature for the hot rod, hot assembly, and surrounding assemblies is adjusted based upon a polynomial equation which increases the fuel centerline temperatures relative to the linear equation used in Reference 2. In addition, a temperature uncertainty is applied to the hot rod.

- The time in cycle for the average and periphery assemblies is the time of maximum densification for initial stored energy calculation. This approach is only acceptable for the U.S. EPR RLBLOCA application with the associated RODEX-3A maximum densification prediction methodology.

- The fuel conductivity multiplier is the same in corresponding steady state and transient runs.

- S-RELAP5 is modified to increase the amount of cold leg condensation relative to what is calculated using the Reference 2 methodology.

The conclusions summarized here are only applicable to the U.S. EPR design.

The staff has reviewed the SER conditions and restrictions of EMF-2103, Revision 0, that are applicable to the U.S. EPR design and has concluded that the conditions and restrictions have been met as described in Reference 3.

The conditions and limitations applicable to use of Reference 3 are:

- The model applies to bottom reflood plants only.

- 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 run 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 topdown quench occurs, the model will be justified or corrected to remove top quench. A topdown quench is characterized by the quench front moving from the top to the bottom of the hot assembly.

- Hot leg Nozzle gaps will not be included in the S-RELAP5 model.

- If the RLBLOCA methodology is applied to plants using a higher Peak Linear Heat Generation Rate 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 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. The justification is intended to ensure that the methodology has been applied to a specific plant within the conditions of this report and within the stated limitation of the topical report. The justification is expected to include

    - Nodalization: Specific guidelines used to develop the plant-specific nodalization.

    - Deviations from the reference plant must be described and defended.

    - Chosen Parameters and Conservative Nature of Input Parameters: A table that contains the plant-specific parameters and the range of the values considered for the selected parameter during the topical 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.

    - If NRC criteria or regulations change so that its conclusions about the acceptability of the report are invalidated, AREVA NP or the applicant referencing the report, or both, will be expected to revise and resubmit its respective documentation, or submit justification for the continued effective applicability of the report without revision of the respective documentation.

- An applicant that references this methodology must evaluate the effect of core flow oscillations if the RLBLOCA analyses exhibit core flow oscillations prior to occurrence of the maximum PCT.

- The staff requires that an applicant that references this methodology demonstrate that the contribution of rod-to-rod radiation is consistent with test data if the analysis shows that PCT exceeds 1255 K (1800 °F).

6 REFERENCES

1. "U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report," ANP-10278P, Revision 0, March 2007, Agency Documents Access and Management System (ADAMS) Accession No. ML070880739.

2. "Realistic Large Break LOCA Methodology for Pressurized Water Reactors, EMF-2103(NP) (A) Revision 0," Framatome ANP Richland, Inc., August, 2001, ADAMS Accession No. ML012400019.

3. "U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report," ANP-10278P, Revision 1, January 2010, ADAMS Accession No. ML100141095.

4. RG 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," May 1989, ADAMS Accession No. ML080420188.

5. NUREG/CR-5249, "Quantifying Reactor Safety Margins Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident," December 1989, ADAMS Accession No. ML082600458.

6. Letter from H.N. Berkow, NRC, to J.F. Mallay, Framatome ANP, Richland, Inc.,"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)," April 9, 2003, ADAMS Accession No. ML030760312.

7. Letter from Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Request for Additional Information Regarding ANP-10278P, 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report' (TAC No. MD4978)," July 20, 2007, ADAMS Accession No. ML071930475.

8. Letter from Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Second Request for Additional Information Regarding ANP-10278P, 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report' (TAC No. MD4978)," May 15, 2008, ADAMS Accession No. ML081330106.

9. Letter from Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Third Request for Additional Information Regarding ANP-10278P, 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report' (TAC No. MD4978)," September 5, 2008, ADAMS Accession No. ML082480447.

10. Letter from G. Tesfaye, NRC, to R. L. Gardner, "Fourth Request for Additional Information Regarding ANP-10278P, 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report' (TAC No. MD4978)," January 28, 2009, ADAMS Accession No. ML090050413.

11. Letter from G. Tesfaye, NRC, to R. L. Gardner, "Fifth Request for Additional Information Regarding ANP-10278P, 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report' (TAC No. MD4978)," March 11, 2009, ADAMS Accession No. ML090640152.

12. Letter from R. L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to an RAI on the ‘Topical Report ANP-10278P ‘U.S.EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC:07:035, August 17, 2007, ADAMS Accession No. ML072340458.

13. Letter from Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to Second Request for Additional Information ANP-10278P, ‘U.S.EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC: 08:039, June 13, 2008, ADAMS Accession No. ML081690596.

14. Letter from Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to Third Request for Additional Information Regarding ANP-10278P, ‘U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC: 08:105, December 19, 2008, ADAMS Accession No. ML083590356.

15. Letter from Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to Fourth Request for Additional Information ANP-10278P, ‘U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC: 09:036, April 2, 2009, ADAMS Accession No. ML091030087.

16. Letter from Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to Fifth Request for Additional Information Regarding ANP-10278P, ‘U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC: 09:037, April 9, 2009, ADAMS Accession No. ML091030216.

17. Letter from Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), “Response to Sixth Request for Additional Information Regarding ANP-10278P, ‘U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report’ (TAC No. MD4978),” NRC: 10:004, January 8, 2010, ADAMS Accession No. ML100140633.

18. Letter from J.F. Mallay, Framatome ANP, Inc., to Document Control Desk, NRC, “Request for Review and Approval of EMF-2103(P) Revision 1, ‘Realistic Large Break LOCA Methodology for Pressurized Water Reactors,’” August 9, 2004, ADAMS Accession No. ML052420304.

19. Letter from G. Cranston, NRC, to S. Rosenberg, NRC, “Safety Evaluation Regarding the Framatome EMF-2103(P) Revision 1, ‘Realistic Large Break LOCA Methodology for Pressurized Water Reactors’,” April 3, 2007, ADAMS Accession No. ML070940125.

20. “Compendium of ECCS Research for Realistic LOCA Analysis,” NUREG/1230, U.S. NRC, December 1988, ADAMS Accession Nos. ML053490333 and ML053620415.

21. TRACE 5.0 Developmental Assessment Manual.

22. “S-RELAP5: Code Verification and Validation,” EMF-2102(P), Revision 0, Framatome ANP, August 2001, ADAMS Accession No. ML012880267.

23. “Research Information Report on the Slab Core Test Facility (SCTF) Core-II Test Series,” MPR-1115, Vol. 1, MPR Associates, Inc., July 1989.

24. "Sequoyah Nuclear Plant Unit 1 Realistic Large Break LOCA Analysis, ANP-2695(NP)," February 2008, ADAMS Accession No. ML081080338.

25. "U.S. EPR Fuel Assembly Mechanical Design Topical Report," ANP-10285NP, Revision 0, October 2007, ADAMS Accession No. ML072840177.

26. "FRAPCON-3: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High BURNUP."

27. RODEX3A: Theory and User Manual, EMF-1557(P), Revision 4, May 2001, Framatome ANP, ADAMS Accession No. ML012880303.

28. Publication of BAW-10231(P)(A), Revision 1, 'COPERNIC Fuel Rod Design Computer Code,'" September 30, 2004, ADAMS Accession No. ML042930236.

29. Letter to AREVA NP, Inc., "Audit Report for September 15, 2009, audit to review selected areas related to U.S. EPR FSAR Chapter 15 safety evaluation," ADAMS Accession No. ML101290002.

30. C. Jeandey and G. Barriere, "Part I, Etude Experimentale d'Ecoulements Eau-Air a Grade Vitesse," DTCE/STT/SETRE Note T.T.No. 599, Janvier 1979.

31. ANP-10278Q7P, Revision 1, "Response to Sixth Request for Additional Information-ANP-10278 'U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report'," May 12, 2010, ADAMS Accession No. ML100141141.

32. Letter from Ronnie L. Gardner (AREVA) to Document Control Desk, U.S Nuclear Regulatory Commission, "Response to NRC Verbal Request for Information Regarding ANP-10278P," July 1, 2010, NRC:10:059, ADAMS Accession No. ML101830440.

Attachment
The Staffs Disposition of AREVA's comments on the Draft SE

COMMENT 1
AREVA suggested adding the phrase “delivered to the vessel” to the last paragraph on page 1.

DISPOSITION
NRC staff added the suggested phrase.

COMMENT 2
AREVA suggested language to clarify the statement “spills to the containment” in the first paragraph of page 2.

DISPOSITION
NRC staff updated language in the SER to be more specific.

COMMENT 3
AREVA suggested adding the word “approximately” to the second paragraph on page 2.

DISPOSITION
NRC staff added the suggested language.

COMMENT 4
AREVA noted that Reference 32 could be deleted.

DISPOSITION
NRC staff removed the sentence referring to Reference 32.

COMMENT 5
AREVA suggested language to clarify the number of cases that have the PCT time prior to 50 seconds on page 16 of the SER.

DISPOSITION
NRC staff made the suggested changes to improve clarity of the SER.

COMMENT 6
AREVA noted that in Section 4.2.9, the text should read “containment air” instead of “IRWST.”

DISPOSITION
NRC staff changed the text accordingly.

COMMENT 7
AREVA suggested adding a sentence to the third paragraph on page 21.

DISPOSITION
NRC staff changed the text accordingly.

COMMENT 8
AREVA commented that Section 4.2.10 contained a statement that was written like a limitation.

DISPOSITION
NRC staff removed the sentence. Limitations are contained in Section 5.0 of the report.

COMMENT 9
AREVA noted in Section 4.2.13 on page 24 that the analysis discussed was in the Reference 1 analysis.

DISPOSITION
NRC staff added a reference to Reference 1 for clarification.

COMMENT 10
AREVA noted on page 25 that the reference to RAI-29 was incorrect.

DISPOSITION
NRC staff corrected the reference.

COMMENT 11
AREVA noted that in Section 4.5 the clad oxidation limit and correlation used was incorrectly stated.

DISPOSITION
NRC staff updated the text to reference the correct limit.