REQUEST FOR ADDITIONAL INFORMATION

RELATED TO AREVA NP, INC.

TOPICAL REPORT EMF-2103, REVISION 3

"REALISTIC LARGE BREAK LOCA [LOSS-OF-COOLANT ACCIDENT]

METHODOLOGY FOR PRESSURIZED WATER REACTORS"

RAI-1 TABLE OF SAMPLED PARAMETERS

Please create a table with the following column entries for each parameter (including break size) that is treated as a random variable (or fixed/biased) in a run of the realistic large break LOCA (RLBLOCA) calculation. Include all phenomenological and plant sampled large break LOCA (LBLOCA) parameters as well.

A. The mathematical symbol used in the code for the parameter; listed in the order of its importance in the phenomena identification and ranking table.

B. The analytic expression of the correlation where the parameter appears.

C. A simple statement of the primary physical phenomenon that the parameter governs.

D. The probability density function from which random realizations of the parameter value are obtained for each code run.

E. The mean value of the parameter.

F. The variance of the parameter.

G. The limiting value

RAI-2 ASYMMETRICAL PREDICTIONS IN MODELING OF PARALLEL FLOW CONFIGURATIONS

Thermal hydraulic system codes, such as RELAP5, have been found to predict asymmetrical results when modeling parallel flow configurations, usually under low-flow conditions. Recognition of such modeling difficulties is presented by G. W. Johnsen, "RELAP5-3D Development & Application Status," Presentation at the 2002 RELAP5 International User's Seminar, September 4 - 6, 2001, Park City, Utah. In pressurized water reactor (PWR) plant analyses, such flow configurations can be related to parallel flow paths representing the cold legs in the same primary coolant loop of a Combustion Engineering (CE) PWR plant, where liquid can backflow into the steam generators from the cold leg in one of the loops. The potential flow anomaly is also associated with parallel flow channels representing different azimuthal sections of a reactor vessel downcomer including representations of steam generator secondary side volumes or other regions of the reactor system. A possible solution approach in modeling a simple flow problem between parallel pipes is discussed by D. Lucas, "Recirculating

Flow Anomaly Problem Solution Method," Proceedings of 8th International Conference on Nuclear Engineering ICONE8, Paper ID 8479, April 2 - 6, 2000, Baltimore, Maryland.

Please show that S-RELAP5 does not predict anomalous behaviors as described above for other codes when using three-dimensional (3-D) and one-dimensional (1-D) components. As part of the response, present predictions for an illustrative parallel pipe flow problem as implemented in the RELAP5 dual pipe flow input model presented below.

```
=Flow Anomaly Test Problem
*
*--------------------------------------------------------------------
*crdno             problem type        problem option
0000100                new                transnt
*--------------------------------------------------------------------
*crdno             input units              output units
0000102              british                  british
*--------------------------------------------------------------------
*crdno    time 1     time 2
0000105   10.        40.     10000.
*--------------------------------------------------------------------
0000110  nitrogen
*--------------------------------------------------------------------
*crdno end time  min dt   max dt  control  minor ed  major ed  restart
0000201   5000.   1.0e-6   2.0      3    1       250          500
********************************************************************
********************************************************************
* minor edit requests
********************************************************************
********************************************************************
*
*crdno        variable       parameter
*
301  count    0
302  dt       0
303  dtcrnt   0
304  cputime  0
305  errmax   0
306  emass    0
307  tmass    0
310  mflowj   145010000
311  mflowj   145020000
312  mflowj   716000000
313  mflowj   711000000
314  mflowj   175010000
315  mflowj   175020000
316  tempf    130010000
317  tempf    160010000
318  cntrlvar 1
319  cntrlvar 2
320  testda   2
321  testda   3
322  testda   4
20800001 testda 2
20800002 testda 3
20800003 testda 4
*
**************************************************************
**************************************************************
* hydrodynamic components
**************************************************************
**************************************************************
1300000   pmpsuca2         pipe   * loop a2 rc pump suction
1300001   1
1300101    4.2761  1
1300301        25.956   1
1300401        0.0   1
1300601            -90.   1
1300701     -25.956   1
1300801   .00030          0.    1
1301001    00     1
```

```
1301201   3   2200.0   550.0      0.0             0.0       0.0       1
*
1450000   clbrcha2        branch
1450001   2         0
1450101   10.0  5.4064       0.     0. -90.0  -5.4064  .00015      0. 00
1450200   3   2200.0    550.0
1451101   160010000 145000000   4.2761   1.0     1.0    0100
1452101   130010000 145000000   4.2761   1.0     1.0    0100
1451201   0.0       0.0        0.0
1452201   0.0       0.0        0.0
*
1600000   pmpsuca1          pipe
1600001   1
1600101    4.2761  1
1600301       25.956   1
1600401        0.0   1
1600601           -90.   1
1600701      -25.956   1
1600801   .00030          0.    1
1601001    00     1
1601201   3  2200.0   550.0   0.0                 0.0       0.0       1
*
1750000   clbrcha1        branch
1750001   2          0
*1750101   10.0  5.4064       0.     0. -90.0  -5.4064 .00015      0. 00
1750101   10.0  5.4064       0.     0. -90.0  -5.4064 .01000      0. 00
1750200   3  2200.0   550.0
1751101   175010000 160000000   4.2761   1.0     1.0    0100
1752101   175010000 130000000   4.2761   1.0     1.0    0100
1751201   0.0       0.0        0.0
1752201   0.0       0.0        0.0
*
*
7100000   lpa1hpit       tmdpvol
7100101   1.0e6    10.0 0.0     0.    -90.0  -10.0    0.      0.     00
7100200     3
7100201       0.        2200.0            90.
*
*
7110000   lpa1hpif    tmdpjun
7110101   710010000  175000000        .0246
7110200    1
7110201    0.0    0.0       0.0       0.0
7110202    10.0   96.0      0.0       0.0
*
*
7150000   lpa2hpit       tmdpvol
7150101   1.0e6   10.0  0.0     0.    -90.0  -10.0    0.      0.     00
7150200     3
7150201       0.        2200.0           550.
*
*
7160000   lpa2hpif    sngljun
7160101   145010000  715000000      10.0    1.0 1.0 0
7160201 0    0.0     0.0       0.0
*
20500100  dtempf  sum  1.0 0.0 1
20500101  0.0  1.0 tempf  160010000  -1.0  tempf  130010000
*
20500200  dtempf  sum  1.0 0.0 1
20500201  0.0  1.0 tempf  130010000  -1.0  tempf  160010000
*
.     * end of input stream
```

RAI-3 ENTHALPY FORMULATION

In Equations 7.383 and 7.385 what are the conditions at which the properties h_g, h_{fg}, and h_f are determined? What is the sensitivity of the interface heat transfer coefficient, Equation 7.383, to the value of B?

RAI-4 REFERENCE 7-81

Provide the basis for Equation 7.386, Reference 7-81.

RAI-5 MINIMUM DROPLET SIZE

Provide the basis for the minimum drop size used in S-RELAP5 and provide a sensitivity study to the droplet size.

RAI-6 ADDITIONAL DATA FROM SECTION 8.2.18

Provide a list of the FLECHT tests of Section 8.2.18 and what parameter variations they evaluated. Provide plots of (at peak cladding temperature (PCT) location and 1 node above and below and location of grid):

A. Forced convective heat transfer coefficient to vapor,
B. Grid enhancement multiplier, F_{grid},
C. Two-phase enhancement multiplier, F2Φ,
D. Radiation heat transfer coefficient to vapor,
E. Radiation heat transfer coefficient to droplets,
F. Interfacial heat transfer coefficient between the drops and the vapor,
G. Droplet number and diameter,
H. Minimum stable film boiling temperature, T_{MIN}.
I. Vapor and liquid temperatures,
J. Droplet diameter, and
K. Rod-to-rod radiation.

RAI-7 DEMONSTRATION OF STATISTICAL APPROACH: CCTF-62

Please apply the statistical analysis method to the test CCTF-62 to show the code capability for simulating a transient. Show the cladding temperatures at the 6, 8, and 10 foot elevations selected as figures of merit. Also show the cladding temperature at the PCT elevation as a figure of merit. Show the distribution for the full case runset and present histograms of the predicted vs measured peak temperatures at each elevation (zero being the PCT and plus or minus temperature difference vs frequency). Identify the parameters that are ranged. Show a plot of the PCT location for all runs against the data.

RAI-8 INTERFACIAL HEAT TRANSFER

Since SRELAP5 is 1-D, the vapor temperature and droplets are distributed evenly across the hot channel. The code computed cross-section average quantities fails to properly capture the very high temperature gradient in the vapor phase boundary layer near the wall so that the distribution of the evaporating water droplets play a fundamental role in the heat transfer process. In particular, interfacial heat transfer is over predicted. This is a major limitation for all 1-D codes. Test data shows that the channel is 3-D with accumulation of drops in the central region and a highly superheated region near the walls. The modeling of this multi-dimensional behavior leads to a substantial reduction in the interfacial heat transfer and limiting of the droplet de-superheating to the central core and not the highly superheated layer near the walls. Since SRELAP5 suffers from this deficiency, please explain what adjustments are made to the dispersed flow film boiling (DFFB) model components to overcome this major discrepancy. That is, the sink temperature is not the average channel temperature for computing single phase heat transfer, an interfacial heat transfer between the drops and the vapor is controlled by the lower vapor temperature in the central core where the drops reside. Furthermore, due to the simplified 1-D averaging of thermodynamic quantities in SRELAP5 and the limited data, it is difficult to quantify all of the component contributions to DFFB. Without the knowledge of all of the contributions to DFFB, how is the magnitude of the droplet contribution verified in the RELAP5 model. Without detailed knowledge of the magnitude of all of the components to DFFB, validation of this model against reflood data may result in including other phenomena/effects that are not pertinent to the heat transfer benefits from the droplet break up model. Lastly it is not clear if coalescence of droplets is modeled.

Please explain how coalescence of droplets is treated and modeled. As reported by Andreani in "Difficulties in Modeling Dispersed –Flow Film Boiling," Warme-und Stoffubertagung 27, 37–49 (1992), Springer-Verlag collisions continue to take place one meter above the quench front while the droplet diameter increased with elevation above the quench front by coalescence.

RAI-9 PASSIVE METAL HEAT STRUCTURE HEAT TRANSFER

It states on Page 2-3 of Topical Report (TR) EMF-2103, Revision 3, that the **[ ]** correlation is still used for passive metal heat structure heat transfer. Please identify the passive metal heat structure that the model is applied to? Also, does this include spacer grids? Please explain why this model is used for non-fuel rod structures since it is the elevated metal temperature that prevents drops from contacting or wetting the walls. Furthermore, the **[ ]** correlation is not physically based and contains several flaws that preclude it use on vertical surfaces. Please show the impact of the use of this correlation does not impact PCT following all LBLOCAs.

RAI-10 DECAY HEAT

Section 4.3.3.2.3 of TR EMF-2103 discusses the decay heat standard but does not show the calculated decay curve used in the analyses. Please compare the decay heat model with uncertainty applied to the American National Standards Institute/American Nuclear Society 5.1-1979 standard to show that the S-RELAP5 model predicts or bounds the data in the standard for 2000 seconds. Show a comparison of the integrated decay energy with uncertainty and compare to the standard. How is gamma redistribution uncertainty treated? Please explain.

RAI-11 UPDATED HEAT TRANSFER CORRELATIONS

Provide a FLECHT steam cooling test benchmark comparison using Sleicher-Rouse and Wong-Hochreiter in S-RELAP5. Include Reynolds Number plot for Wong-Hochreiter.

RAI-12 DISPERSED FLOW WEBER NUMBERS

Provide justification for the Weber numbers used for droplets in dispersed flow (Page 7-91 of TR EMF-2103, Revision 3) and the bubbles.

RAI-13 SAMPLING PLANT PROCESS PARAMETERS

A. Explain how other than a uniform distribution that exceeds upper and lower bounds of a technical specification limiting condition of operation-controlled input parameter/initial condition could be applied in an analysis. Provide justification for this treatment.

B. Explain how a licensee and AREVA NP, Inc. (AREVA) will assure that the plant parameter uncertainty treatment used in an application of TR EMF-2103P, Revision 3, is consistent with existing constraints within the facility design and licensing bases. If AREVA believes that such assurances are unnecessary, justify why not.

RAI-14 LIMIT OF FUEL PERFORMANCE MODELS TO M5™

Explain how the evaluation model (EM) will be used to model behavior for non-M5™ fuel cladding. Since this EM will be used to analyze fuel in multiple cycles of operation, consideration should be provided for co-resident, and potentially proprietary, cladding materials such as Westinghouse ZIRLO.

RAI-15 PACKING FACTOR/RUPTURE STRAIN

A. Provide additional information to justify the correlation between packing fraction and rupture strain.

B. Explain whether sufficient information exists to determine whether the packing factor is independent from other statistically treated variables, such as fuel burnup.

C. Since uncertainties associated with both rupture strain and packing factor are statistically treated, and the packing factor model is clearly dependent on the rupture strain, justify the validity of the statistical approach taken with regard to sampling both.

D. If the statistical process relied upon to combine uncertainties does not require parametric independence among sampled parameters, explain why not.

RAI-16 REWET TEMPERATURE

A. Explain whether the change described in Section 8.2 is new for Revision 3 of TR EMF-2103.

B. Provide a detailed description of the rationale discussed in the TR text.

C. Provide an assessment of the adjusted T_{MINK} value using FLECHT-SEASET tests with different flooding rates to show the general effect of changing the value. If this assessment is provided in response to another RAI question, it would be sufficient to reference that RAI response.

RAI-17 GRID SPACER ENHANCEMENT FACTOR

A. Explain how the enhancement factors applied in the reflood assessments differ from those implemented for routine S-RELAP5 emergency core cooling system evaluations.

B. Provide a basis for their development, including an assessment of the implementation within the EM.

RAI-18 GENERAL COMPARISON TO EMF-2103, REVISION 0/TRANSITION PACKAGE

Demonstrate the integral effects of the proposed model revisions by providing an updated analysis to compare alongside a recently completed analysis using a previously acceptable version of the EM. Specific comparisons should be provided for results that include a variety of PCTs and event sequences.

RAI-19 UPDATES TO CHAPTER 8

A. Provide a comprehensive set of the FLECHT benchmarking related to the updated EM.

B. For each model upgrade, or each set of upgrades that improve modeling capability with respect to a single phenomenon or process, provide an independent assessment that shows how the model upgrade performs relative to the previously approved model, and relative to its applicable assessment data set.

RAI-20 TREATMENT OF GENERAL DESIGN CRITERION-35

It is not clear that the proposed treatment of General Design Criteria (GDC)-35 will provide assurance that the sampled population reflects analyses of the limiting plant condition with respect to the availability of on- or off-site power. Provide examples to show that the current approach provides assurance of adequate plant capability in either condition stipulated by GDC-35, or propose an alternative approach to provide the requisite assurance.

RAI-21 INTERPRETATION OF STATISTICAL RESULTS

Section 9.4.1, “Statistical Approach,” of the TR explains the proposed statistical approach that would effectively collapse the three regulated parameters from Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46(b) (i.e., PCT, maximum local oxidation, and core-wide oxidation) into a single figure of merit (i.e., the ratio of the predicted value of the most limiting parameter to its regulatory limit). This single figure of merit would track with and hence indicate the intersection of the events that each of the three parameters is below its regulatory limit. Please address the following issues with this treatment:

A. The existing structure of 10 CFR 50.46 is based on an implicit understanding that licensees will calculate and maintain PCT, maximum local oxidation, and core-wide oxidation as individual figures of merit. These regulatory figures of merit may either be conservatively calculated per 10 CFR 50.46(a)(1)(ii) and Appendix K to 10 CFR Part 50, or they may be realistically calculated values that reflect applicable uncertainties. However, the staff understood from audit discussions that, while AREVA's approach is proposed as a realistic or best-estimate EM, rather than attempting to compute a realistic figure of merit for each of the criteria in paragraph (b), it would instead appear to be a unique hybrid approach that would produce conservative upper bounds for two of the three parameters. Based upon examples presented during the audit, the staff further observed that (1) the resulting upper bounds for two of the three parameters could contain unrealistic conservatism, potentially well beyond the conservatism imposed by Appendix K, and (2) the calculation of these conservative upper bounds would essentially be divorced from the physical processes governing the behavior of the two bounded parameters. Considering that these observations appear contrary to the stated intent of the 1988 revision to 10 CFR 50.46 to permit realistic EMs that reasonably account for uncertainties, please identify whether the proposed approach would provide individual, realistic figures of merit for all three criteria from paragraph (b) of 10 CFR 50.46. If physically based, realistic figures of merit that appropriately reflect uncertainty will not be provided for all criteria in 10 CFR 50.46(b), please provide justification that the proposed approach complies with the regulation.

B. Please provide justification that the proposed figure(s) of merit for PCT, maximum local oxidation, and core-wide oxidation would be sufficient to satisfy the statistical requirements of 10 CFR 50.46. Inasmuch as the proposed statistical approach asserts that **[ ]** calculations would be sufficient to develop a first-order one-sided tolerance limit for three parameters with 95 percent probability coverage at a 95 percent confidence level (see EMF-2103P, Pages 9-54 and 9-55), please justify the use of terminology such as $PCT_{95/95}$, $MLO_{95/95}$, and $CWO_{95/95}$ (e.g., see EMF-2103P, Page 9-49). Over the past 10 to 15 years, a number of authors have debated the required number of calculations to attain a target coverage and confidence level (e.g., 95/95) for multiple parameters at a given estimator grade (e.g., during the audit AREVA showed example calculations using the **[ ]** estimator). For instance, consider the debate published in Reliability Engineering and System Safety between Guba, Makai, Pal (e.g., 80 (2003) 217 - 232); Orechwa (e.g., 87 (2005) 133 - 135); Nutt and Wallis (e.g., 83 (2004) 57 - 77), etc. In light of these conflicting viewpoints, please provide conclusive evidence that it would not be necessary to perform additional calculations to provide a realistic estimate of a one-sided tolerance limit for each of the three parameters treated separately at a 95 percent probability coverage at a 95 percent confidence level (rather than what AREVA considers to be a conservative upper bound for the upper tolerance limit for two of the parameters).

C. Consider the requirements specified in 10 CFR 50.46(a)(3) concerning the estimation of the effect of changes or errors in the EM on the PCT and associated reporting requirements. As noted above, the proposed method would provide a realistic figure of merit only for the parameter with minimum margin to its regulatory limit, and conservative upper bounds for the two remaining parameters. Under existent regulations, this treatment would be of particular concern relative to the requirements of 10 CFR 50.46(a)(3) when PCT is not the parameter with the least margin to its regulatory limit. However, in light of the proposed revision to 10 CFR 50.46, this case is not the only one of concern to the present review. Based on the above discussion, please address the following items:

i. Please clarify how the effect of changes or errors in the EM would be estimated and tracked, particularly for the two parameters that would be conservatively bounded, and provide justification that the proposed method for estimating and tracking changes and errors complies with 10 CFR 50.46(a)(3). In particular, please address whether it could become necessary to re-run the entire LOCA analysis to ensure that the limits of 10 CFR 50.46(b) are satisfied each time there is a need to estimate the effect of a change or error in the EM.

ii. Please provide your interpretation as to how the reporting requirements of 10 CFR 50.46(a)(3) would apply to the two parameters for which conservative upper bounds would be computed in lieu of realistic figures of merit. In this situation, changes or errors in the calculation of the bounded parameters could be masked by the proposed statistical treatment, even in cases where the magnitude of their effect would exceed a defined threshold of regulatory significance. For example, consider a scenario in which changes or errors result in an increase in peak cladding temperature from 1700 degrees Fahrenheit (°F) to 1800 °F, while the maximum local oxidation remains constant at 0.14. In addressing this item, please recognize the substantially different weights associated with voluntary commitments, conditions and limitations in safety evaluations, and regulatory requirements.

iii. Please address how the reporting requirements in 10 CFR 50.46(a)(3) would apply when changes or errors in the EM result in a change in which of the three regulated parameters in paragraph (b) has the least margin to its regulatory criterion. In principle, changes in which parameter has the least margin could perturb the calculated figure(s) of merit for the other two parameters in a manner not directly linked to the physics in the EM, thereby triggering the aforementioned reporting requirements. For example, consider a scenario in which changes or errors result in an increase in maximum local oxidation from 0.12 to 0.14, while the PCT remains constant at 1700 °F.

<u>RAI-22</u> EXCEDENCE OF REGULATORY LIMITS

Section 9.4.1, "Statistical Approach," of the TR describes contingency actions to address the potential that the results of the statistical evaluation could exhibit evidence of exceeding regulatory limits. The TR suggests remedies including "a reduction in conservative assumptions" and indicates that the set of statistical simulations will be rerun with new random seeds supplied to the randomized parameters and with an increased number of cases to support the determination of a tolerance interval from a higher-order nonparametric estimator. Please clarify the following information:

A. Please elaborate on and provide examples of the conservative assumptions that may be relaxed by the methodology following a calculated exceedance of regulatory criteria. In particular, the NRC staff understands certain aspects of the proposed EM to be approved *in toto* and further expects the approach to be generally based on realistic or best-estimate modeling.

B. Please justify the stated procedure of generating new random seeds and rerunning calculations with a higher-grade nonparametric estimator. In particular, it is necessary that the calculational procedure contain adequate controls to minimize the potential for rejecting random outcomes demonstrating that regulatory criteria are not satisfied, making non-substantive or insufficient changes to the inputs to the analysis, rerunning statistical simulations, and passing largely on the basis of reshuffling the random numbers used to seed the key analytical parameters rather than the substance of the changes made to the input deck. As such, what process and procedural controls will exist to assure that the substantive effect of changes made to the input deck following a set of unsuccessful statistical simulations is sufficient to justify an *a priori* expectation that a subsequent set of statistical simulations will be successful?

RAI-23 INTEGRITY OF STOCHASTIC PROCESSES

The fidelity of statistical conclusions resulting from each plant-specific analysis depends, not only on the final simulation(s) traditionally used to demonstrate that the computed figures of merit comply with regulatory criteria, but also on the integrity of the process used to generate the results. In particular, for the final statistical conclusion of regulatory compliance to be valid, it would appear necessary for the analyst(s) to certify that the computed regulatory figures of merit are the result of a process that is unbiased and representative (e.g., not the result of flipping coins or rolling dice until a favorable conclusion occurs) and create auditable records capable of supporting this conclusion. Auditable records should include, not only (1) the results of the final, successful simulations, but also (2) any statistical simulations that have been performed that did not satisfy one or more acceptance criteria, (3) a description of the changes made to the input deck/EM to support the success of subsequent statistical calculations, and (4) adequate justification that the changes implemented in support of the successful simulations carried a legitimate *a priori* expectation of satisfying regulatory requirements. In light of the discussion above, please address the following requests:

A. Discuss whether calculational procedures clearly define delineation point(s) between preliminary non-statistical scoping calculations and statistical calculations of record and provide justification if not,

B. Describe procedural requirements that would be in effect for conducting, logging, and documenting all statistical calculations for a particular plant, including any statistical calculations that did not satisfy regulatory criteria,

C. Provide justification that the process for conducting, logging, and documenting statistical calculations is sufficient to demonstrate that unbiased and representative statistical conclusions can be made regarding regulatory compliance,

D. Describe and provide justification for the level of information that will be included in plant-specific applications submitted to the NRC concerning initial statistical calculations that did not satisfy regulatory criteria and the changes made to the EM to support satisfaction of regulatory criteria in subsequent statistical calculations, and

E. Discuss whether analysts will be required to certify, not only that they concur on the final plant-specific calculations applying the proposed EM, but further, that they affirm that the calculated results derive from a statistically representative calculational process that was executed in an unbiased manner.