EMF-2103NP – Realistic Large Break LOCA Methodology for Pressurized Water Reactors Topical Report Markups

Technical Upgrade	Description & Implementation Phase	Upgrade Status
Grid Spacer Droplet Breakup Heat Transfer Enhancement	A model to increase the heat transfer downstream of a grid spacer due to droplet breakup was added. Implemented in Revision 3	See Note 1.
Interphase Heat Transfer	The interphase heat transfer for mist flow has been improved to obtain better agreement with separate effects reflood test data. Implemented in Revision 3	See Note 1.
SG Tube Inlet Interfacial Drag	Modification of the steam generator tube inlet drag as a result of an error correction to the level tracking model. Implemented in Revision 3	See Note 1.
Sampling of Core Power	The core power is treated deterministically using the nominal power plus uncertainty. Implemented in Revision 2	See Note 2.
Treatment of GDC-35	The GDC-35 requirement of off-site power is satisfied by ~~determining the most severe condition between these two configurations and then performing the RLBLOCA statistical analysis for the plant with off-site power availability set to the most severe condition. Implemented in Revision 3~~	See Note ~~1~~. 2

running two complete case sets of the RLBLOCA uncertainty analysis. The set with the most limiting 95/95 result is used to demonstrate compliance to the criteria. Implemented in Transition Program.

Notes:

1. This EM element of EMF-2103, Rev. 3 has not yet been reviewed and approved by the NRC.

2. This EM element of EMF-2103, Rev. 3 has been reviewed and approved by the NRC in several LARs, most recently in the following reference:
   Letter from T. Orf, NRC to M. Nazar, Florida Power and Light Company, “St. Lucie Plant, Unit 1 – Issuance of Amendment Regarding Extended Power Uprate (TAC No. ME5091),” July 9, 2012 (ADAMS Accession No. ML 12181A019).

1.2 *References*

1-1 EMF-2103(P)(A) Revision 0, “Realistic Large Break LOCA Methodology,” Framatome ANP Richland, Inc., April 2003.

13. Correction to the Steam Absorptivity – Revision 3

A correction to the steam absorptivity was made. In computing the vapor absorption coefficient, the pressure is conservatively truncated at ~~150~~ psi. This alteration is presented in Section 7.6.8.1 and its impact qualitatively assessed in Section 8.1.5.

[ ]

14. Core Nodalization – Revision 3

The core nodalization has been slightly changed to align the node boundaries with the bottom of the grid spacers, rather than the grid centerline. The change in the core nodalization effectively changes the hydrodynamic volume boundaries such that they are aligned with the bottom of the grid spacers, in support of the implementation of the grid droplet shattering model (item #15 below). This alteration is presented in Section 9.0 and Appendix A and its impact qualitatively assessed in Section 8.1.5.

15. Grid Spacer Droplet Breakup Heat Transfer Enhancement – Revision 3

A model to increase the heat transfer downstream of a grid spacer due to droplet breakup was added. The implementation of a model to increase the heat transfer downstream of a grid spacer is expected to have an impact during reflood above the mid-plane of the core. This alteration is presented in Section 7.5.4.10.1 and its impact verified in Sections 8.2.3 and 8.4.1.

16. Interphase Heat Transfer – Revision 3

The interphase heat transfer for mist flow was modified to raise steam and cladding temperatures and to obtain better agreement with test data from separate effects reflood tests. The details of this change are presented in Section 7.5.4.

17. Steam generator Tube Inlet Interfacial Drag – Revision 3

An error correction to the level tracking model required modification of the steam generator tube inlet drag. The model change is presented in Appendix A and its impact is qualitatively assessed in Section 8.1.5.

18. Sampling of Core Power – Revision 2

The methodology has been changed such that core power is treated deterministically using the nominal power plus uncertainty. The model change is presented in Section 3.1.3.2.2.

19. Treatment of GDC-35 – Revision 3

GDC-35 states that the plant shall be able to mitigate design basis accidents with or without offsite power available. The methodology satisfies this requirement by ~~determining the most severe condition between these two configurations and then performing the RLBLOCA statistical analysis for the plant with off-site power availability set to the most severe condition~~. The change is discussed in Section A.2.4.2.

running two complete case sets of the RLBLOCA uncertainty analysis. The set with the most limiting 95/95 result is used to demonstrate compliance to the criteria.

2.4 *References*

2-1 EMF-2103(P)(A) Revision 0, "Realistic Large Break LOCA Methodology," Framatome ANP Richland, Inc., April 2003.

2-2 Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," U.S. NRC, May 1989.

2-3 NUREG/CR-5249, "Quantifying Reactor Safety Margins, Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large Break, Loss-of-Coolant Accident," U.S. NRC, December 1989.

2-4 Regulatory Guide 1.203, "Transient and Accident Analysis Methods," U.S. NRC, December 2008.

2-5 NUREG-0800, "Standard Review Plan, Section 15.6.5 Loss-Of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary," Revision 3, U.S. NRC, March 2007.

2-6 EMF-2100(P) Revision 16, "S-RELAP5 Models and Correlations Code Manual," AREVA NP, Inc., December 2011.

Treatment of Time in Cycle

The time in cycle establishes the fuel rod properties and the lower bound for the global power peaking factor Fq. Power history calculations are performed using the methodology described in Section 9.3.1.3. Typically, fuel rod data for 20 to 40 burnup steps are explicitly written from a cycle power history calculation. The methodology examines potential limiting fuel conditions during both the first and second cycle of fuel rod operation. Fuel rod data are, therefore, provided for the first and second cycle of fuel rod operation. Third cycle fuel is sufficiently depleted that it cannot rise to the possibility of being the limiting fuel within the core and is not evaluated by the methodology.

Once the fuel rod histories for the fuel rod sub-code are found as described above, the axial and radial power shapes for the S-RELAP5 core model are selected as by the method described in Section 9.3.1.4.

Treatment of General Design Criterion-35

GDC-35 states that the plant shall be able to mitigate design basis accidents with or without off site power available. The methodology does this by ~~determining the most severe condition between these two configurations and then performing the RLBLOCA statistical analysis for the plant with off-site power availability set to the most severe condition~~. Further details are provided in Appendix A.

running two complete case sets of the RLBLOCA uncertainty analysis. The set with the most limiting 95/95 result is used to demonstrate compliance to the criteria.

The resistance terms in the above gray factors are given in terms of emissivities as

$$R_g = \frac{1-\varepsilon_g}{\varepsilon_g\left(1-\varepsilon_g\varepsilon_f\right)}$$

$$R_f = \frac{1-\varepsilon_f}{\varepsilon_f\left(1-\varepsilon_f\varepsilon_g\right)} \tag{7.538}$$

$$R_w = \frac{1}{1-\varepsilon_g\varepsilon_f} + \frac{1-\varepsilon_w}{\varepsilon_w}$$

The emissivities for vapor and droplets are computed from the following formulas:

$$\varepsilon_g = 1-\exp\left(-a\ L\ \right)$$

[

$$\varepsilon_f = 1-\exp\left(-a\ L\ \right) \tag{7.539}$$

]

where L_m is a mean path length and a_g and a_f are, respectively, the absorption coefficients of vapor and droplets. Sun et al. (Reference 7-187) used a value of $\varepsilon_w = 0.7$ in their analysis of core cooling for BWR (boiling water reactor) rod bundles. This value of wall emissivity is implemented in the code.

The mean path length is taken as $L_m = 0.85\ D_h$ for a rod bundle geometry from a FLECHT SEASET data evaluation and analysis report (Reference 7-188)~~, which appears to be based on pressure at 10 atm~~. ~~A simplified pressure relation from Siegel and Howell (Reference 7-189) indicates that the truncation at 150 psi is conservative.~~ The absorption coefficient of vapor is given by the following relation:

$$a_g = 1.814\text{x}10^{-4}\,P\left(\frac{555.56}{T_g}\right)^2\left[1-0.054\left(\frac{555.56}{T_g}\right)^2\right]\alpha_g \tag{7.540}$$

where P is pressure in Pa and T_g is the vapor phase temperature in K. The particular form of Equation (7.540), i.e., the dependency on P and T_g, and the constant are from the FLECHT SEASET report (Reference 7-188). The void fraction factor is added to account for the two-phase condition. The absorption coefficient of liquid droplets is expressed as

~~7-189. R. Siegel and J. R. Howell, "Thermal Radiation Heat Transfer," 2nd Edition, McGraw-Hill, New York, 1981.~~

7-190. E. F. Carpenter and A. P. Colburn, "The Effect of Vapor Velocity on Condensation Inside Tubes," Proceedings of General Discussion on

7-189a. D.K. Edwards, "On the Use of Total Radiation Properties of Gases," ANL/RAS 75-12, April 1975.
7-189b. S. S. Penner, "Quantitative Molecular Spectroscopy and Gas Emissivities," Addison-Wesley Publishing Company Inc., Reading, Massachusetts, USA.

7-191. RELAP5/MOD3.3 Code Manual Volume 1: Code Structure, System Models, and Solution Methods, NUREG/CR-5535/Rev 1-Vol 1, December, 2001.

7-192. L. Arrieta and G. Yadigaroglu, Analytic Model for Bottom Reflooding and Heat Transfer in Light Water Reactors, EPRI Report NP-756, 1978.

7-193. D. C. Groeneveld, S. C. Cheng, and T. Doan, "1986 AECL-UO Critical Heat Flux Lookup Table," Heat Transfer Engineering, Volume 7, pp. 46-62, 1986.

7-194. A. W. Bennett, G. F. Hewitt, H. A. Kearsey, and R. K. F. Keeys, Heat Transfer to Steam-Water Mixtures Flowing in Uniformly Heated Tubes in Which the Critical Heat Flux Has Been Exceeded, UKAEA Research Group Report, AERE-R 5373, October 1967.

7-195. EMF-2102(P) Revision 0, S-RELAP5: Code Verification and Validation, Framatome ANP, Inc., August 2001.

7-196. EMF-92-139(P), Volume 3, Supplement 3, Realistic LOCA ECCS Evaluation Model Assessment for PWR Large Break Analysis Assessment for LOFT Test L2-5, Siemens Power Corporation, June 1993.

7-197. EMF-92-139(P), Volume 3, Supplement 4, Realistic LOCA ECCS Evaluation Model Assessment for PWR Large Break Analysis Assessment for LOFT Test L2-6, Siemens Power Corporation, June 1993.

[ ]

5. There was a correction to the vapor absorptivity that caused more radiation absorption by steam.

   Radiation heat transfer to steam in S-RELAP5 is reduced at high pressures as compared to previous versions. The steam absorptivity has been revised to use a conservative, limiting value based on a pressure of ~~150~~ [ ] psi. Although this truncation of the simplified pressure relation is conservative, it will not impact reflood because the pressure during reflood is typically less than ~~150~~ [ ] psi. The overall conclusion from the Continuity of Assessment is that this change has minimal impact.

6. The Fuel Swelling Rupture and Relocation (FSRR) model has been modified in its entirety and now includes a sub-channel cooling model to more realistically model the heat transfer mechanisms that occur at the rupture location.

   The implementation of a Swell, Rupture and Relocation model is not expected to have any impact on the benchmarks since none of the benchmarks experienced swelling or rupture. The overall conclusion from the Continuity of Assessment is that this change has minimal impact. This alteration is described in Section 7.9.3.3.

7. An error correction to the Level Tracking model required modification to the input interfacial drag specified at the inlet of the steam generator tubes.

8.2.1.2 Summary and Conclusions

8.2.1.2.1 Level Swell Tests

The level swell benchmark generally shows good agreement with the test data for the three analyzed THTF level swell cases. The void fraction profiles show good agreement with the data with insignificant differences for the three cases, as shown in Section 8.2.1.6.1. The mixture level is well predicted for all three tests. These results show good agreement with the experimental data for this series of steady-state mixture level swell tests.

For Tests 3.09.10j and 3.09.10m, vapor temperature and rod surface temperatures were well predicted. Vapor and cladding temperatures for Test 3.09.10dd was not compared because in this test, the mixture level was almost near the top of the bundle.

8.2.1.2.2 Transient Boiloff Tests

This analysis investigates the transient bundle dryout response. These investigations compare the S-RELAP5 film boiling heat transfer performance at near dryout conditions with THTF test data. A range of results is shown by modeling an upper and lower bound of the film boiling heat transfer in the S-RELAP5 model and comparing the resultant cladding temperature to the measured values.

At the peak temperatures, S-RELAP5 generally conservatively overpredicts the temperature at the lower elevations. At the higher elevations, the model results trend closer to the test data yet still show a general overprediction of the temperature.

Using the criteria established in Section 8.1.4, the S-RELAP5 results also show a good prediction of the time of the temperature peak with respect to the test data for the range of elevations. From this analysis, the film boiling and dispersed flow film boiling heat transfer correlation multipliers developed in support of the RLBLOCA Revision 3 Methodology are shown to be appropriate, with transient film boiling well predicted for the RLBLOCA Revision 3 model.

For the pre-CHF region, there is good agreement between test data and the model for the level swell cases. At the mixture level, the length of this two-phase region is slightly underpredicted by the model (approximately 2-4 inches of bundle length), such that the slope of the void fraction versus elevation is higher for the model. This occurs for each of the three case comparisons. This observation is not significant for this analysis, as it does not affect the location of the mixture level, which is designated as the midpoint of the two-phase mixture.

Figure 8.2-12a and Figure 8.2-12b show S-RELAP5 calculated steam temperatures are slightly higher than the data. Figure 8.2-12c and Figure 8.2-12d show that S-RELAP5 calculated rod surface temperatures above the mixture level are well predicted.

8.2.1.6.2 Transient Boiloff

Comparisons of the transient boiloff THTF test and the S-RELAP5 prediction are shown in Figure 8.2-13 to Figure 8.2-23. Three THTF transient boiloff tests were analyzed, at different elevations for each test. For each figure, the measured THTF data are represented by two curves. Initially the uncertainty is low, due to the fact that the simulator rod is cooled by single phase coolant. Then as the fluid level boils down, a two phase mixture is present, yielding significantly higher uncertainty. These curves represent the two-sided 95% coverage limit for the measured temperature based on the mean and standard deviation extracted from the THTF data. For the S-RELAP5 prediction, upper and lower bound responses are obtained by modeling ±2σ film boiling heat transfer coefficients. For Figure 8.2-13 through Figure 8.2-22, the calculated results labeled "SR5: lower bound" apply the +2σ film boiling heat transfer coefficients and produce lower temperatures; similarly, the calculated results labeled "SR5: upper bound" apply the −2σ film boiling heat transfer coefficients and produce the higher temperatures. This also provides 95 percent coverage of the performance of the film boiling heat transfer. For all the tests analyzed, as noted in the discussion in Section 8.2.1.7.2, S-RELAP5 generally overpredicts the temperature at the lower elevations. At the higher elevations, the model results trend closer to the test data at the peak temperature yet still show a general overprediction of the temperature.

8.2.1.7 Discussion of Results

8.2.1.7.1 Level Swell

The level swell benchmark generally shows good agreement with the test data for the three analyzed THTF level swell cases. The void fraction profiles show good agreement with the data with insignificant differences for the three cases. The mixture level is well predicted for all level swell tests.

For Tests 3.09.10j and 3.09.10m, vapor temperature and rod surface temperatures were well predicted.

8.2.1.7.2 Transient Boiloff

This analysis investigated the transient dryout bundle response. A range of results is shown by modeling the upper and lower bound of both the measured (THTF) and modeled (S-RELAP5) data. This helps show the band of results that would be expected with 95 percent probability for the sheath thermocouple temperatures for the THTF test data, and 95 percent probability of the film boiling heat transfer in the S-RELAP5 calculation.

From the results at the peak temperatures, S-RELAP5 generally overpredicts the temperature at the lower elevations.

The purpose of this benchmark is to evaluate the degree of conservatism of the steam cooling correlations. These steam-cooling correlations consistently over-predict the peak cladding temperatures, indicating that when high quality steam is present, the heat transfer is conservatively underpredicted.

At the higher elevations, the model results trend closer to the test data at the peak temperature yet still show a general overprediction of the temperature. An exception is Test 3.06.6B Level G (Figure 8.2-19), where the model shows a narrower band of results, with the peak upper bound temperature being underpredicted. However, this case also overpredicts the peak temperature lower bound.

Figure 8.2-12 Void Profile for THTF Test 3.09.10dd

[ ]

Figure 8.2-13 Temperatures at Level E, Test 3.03.6AR

[ ]

Insert vapor temperature and wall temperature comparisons in PA version with [ ] prediction. Inserted here as Figures 8.2-12a through 8.2-12d.

Figure 8.2-12a Vapor Temperature for THTF Test 3.09.10j

[

]

Figure 8.2-12b Vapor Temperature for THTF Test 3.09.10m

Figure 8.2-12c Rod Surface Temperature for THTF Test 3.09.10j

Figure 8.2-12d Rod Surface Temperature for THTF Test 3.09.10m

9.3.1.5 Treatment of GDC-35 Criteria

GDC-35 states that the plant shall be able to mitigate design basis accidents, with or without offsite power available. ~~The methodology achieves this by determining the most severe condition between these two configurations, and then performing the RLBLOCA statistical analysis for the plant with offsite power availability set to the most severe condition.~~ Further details are provided in Appendix B, Section B.1.3.

9.4 *Performance of NPP Sensitivity Calculations and Determination of Combined Bias and Uncertainty (CSAU Steps 12 and 13)*

As previously discussed, the evaluation applies non-parametric statistical techniques. To accomplish this, the calculation of several individual LOCA possibilities must be conducted. Each of these possibilities must have the performance of key parameters or conditions determined randomly. This is achieved by assigning an individual PDF to each of the parameters to be varied or sampled by the methodology. The PDFs are then seeded, using standard techniques, with independent random numbers to specify the performance of each parameter for a given case. After the accumulation of the results for several possible LOCAs, the group of results is evaluated to determine the probability of compliance to LOCA criteria.

To satisfy this requirement, the RLBLOCA uncertainty analysis is performed twice: once with offsite power available, and once with offsite power unavailable.

- [ ]

- [ ]

- The Cathcart-Pawel metal-water reaction model is activated by setting the metal-water reaction flag = 1.

- [ ]

- Appropriate reference associating the COPERNIC rod number to a specific rod heat structure is necessary. This is done on heat structure card 1CCCG004. Words 1 through 4 are required for this card. Only W1 and W4 are important for LBLOCA simulation.

- An energy deposition factor or gamma smearing factor of [ ] for all modeled rods in the base input file.

A.2.3.3 Random Number Generator

The statistical nature of this RLBLOCA methodology requires the ability to randomly sample plant operational states and phenomenological conditions. For this reason, the RLBLOCA analyst must have a validated random number generator available. Random number generators are available on most computers or workstations, and provide non-negative floating point values uniformly distributed over the interval [0.0, 1.0). The symbol "[" indicates 0.0 is included in the sampled interval. The symbol ")"indicates 1.0 is not included in the interval. Automated calculations on the Linux workstation use the ~~system functions srand48() and drand48()~~ [ ] to generate pseudo-random numbers for the uncertainty analysis.

A.2.3.4 Random Number Sequence

In order to randomly vary the input data for each case, a unique series of random numbers must be generated for each case.

Using the pseudo-random number generator functions, a series of random numbers can be generated and recorded to calculate the input for each case of the uncertainty analysis. This sequence of numbers must be generated in such a way that the sequence is repeatable and is not repeated within the number of cases executed for the analysis.

[ ] A sample ~~The~~ array of ~~required~~ random numbers is shown in Table A-20, along with the variable with which each random number is associated. Note that not all of the random values are used for sampling, but generating two random numbers for each sampled parameter allows for a change in the PDF used for that parameter without a change in the random number sequence order or the total number of random numbers required.

Allowing for a change in the PDF for a parameter without necessitating a change in random number sequence will maintain the same values (given the same initial random number seed is used) for all parameters currently varied as part of the uncertainty analysis.

A.2.3.5 Random Sequence Seed

Random number generators found on most computers or workstations provide a means for supplying an initialization entry point or seed to the random number sequence. Use of a user supplied seed provides a mechanism for reproducing a series of random numbers.

[ ]

For the purposes of automating calculations it is recommended that the ~~system function srand48()~~ be used for initialization of the random number sequences. It is also recommended that the initial seed be generated from the ~~operating system time function.~~ This provides a unique seed for each application of the RLBLOCA uncertainty analysis.

hardware entropy pool of the machine where the analysis is run.

~~Due to the large number of random numbers necessary to perform the RLBLOCA uncertainty analysis, and that most random number generators are actually pseudo-random number generators, it is recommended that a new seed be provided for each case. Changing the entry point for each case will prevent random number sequences from being repeated.~~

Additionally, in order to maintain reproducibility of the sequences used, it is suggested that the ~~first random value calculated for each case be used to calculate the new seed for the subsequent case. The first random value is multiplied by a large value prior to being used because the random value is only distributed over the interval [0.0,1.0). Multiplying by a large value decreases the possibility of repeating a seed or sequence of random numbers.~~

seed for the first case be used to generate all the subsequent random numbers needed starting from one initial random seed.

~~For the purpose of automating calculations, it is recommended that the first random value for each case be multiplied by the constant large value equal to (327672+1). This ensures that a sufficient gap is provided between initial seeds so that random number sequences do not overlap.~~

A.2.3.6 Probability Distributions Functions (PDFs)

Using random numbers uniformly distributed over the interval [0.0,1.0) allows these values to be mapped to other PDFs. For the RLBLOCA uncertainty analysis, the common probability distributions to be applied to parameter uncertainty ranges are binary, uniform between two arbitrary numbers, and Gaussian (normal).

For the purpose of automating calculations, two random numbers are selected for the sampling each parameter in order to maintain reproducibility of the random number sequence because the Gaussian PDF requires two random numbers.

A.2.3.6.1 Binary PDF

The binary PDF produces a value of either 0 or 1. Using the floating point random number generator, the binary PDF is defined as:

```
int(random1 + 0.5)
```

0.5 is added to the floating point number produced by the random number generator so that, upon truncating the number to an integer, a value of 0 or 1 is produced. Random values in the interval of [0.0, 0.5) are truncated to 0 and random values in the interval of [0.5, 1.0) are truncated to 1.

A.2.3.6.2 Uniform PDF

A uniform PDF ensures an equal probability of selecting any given value over a specified range. Using the floating point random number generator, the uniform PDF ranging between the upper bound and lower bound is defined as:

```
lower_bound + random1 * ( upper_bound - lower_bound )
```

A.2.4.2 Determination of Offsite Power Limiting Condition

Reference A-17, Appendix A, GDC-35 requires that abundant emergency core cooling shall be provided both with or without the availability of off-site power. ~~For this reason, the RLBLOCA uncertainty analysis case set must be performed at the more severe condition for the plant with and without offsite power available. This is accomplished by performing a sensitivity study prior to running the full case set for the uncertainty analysis.~~

[

]

To satisfy this requirement, the RLBLOCA uncertainty analysis is performed twice: once with offsite power available, and once with offsite power unavailable. Between the two sets, the cases are identical except for the offsite power availability at the time of the break initiation. The results from both case sets are analyzed and the case set with the most limiting 95/95 result is used to demonstrate compliance to the criteria.

Table A-10 Parameter Input for Offsite Power Determination

A.2.4.3 RLBLOCA Uncertainty Analysis

~~After the availability of offsite power is determined for the uncertainty analysis, code input files are generated for each case using the appropriate offsite power input.~~

Since the RLBLOCA methodology is a statistics-based methodology, the application does not involve the evaluation of many different deterministic calculations. Instead a number of calculations are performed with the parameters defined in Table A-6 varied randomly over the specified uncertainty range. This random sampling process is repeated for a number of calculations, all of which are run to obtain key results.

A.2.4.4 Computer Codes

The COPERNIC computer code is used to predict fuel rod performance with respect to fuel rod mechanical design. The computer code S-RELAP5 is used to simulate the RLBLOCA transient. Table A-11 lists the codes used for the uncertainty analysis.

A.2.5.11.1 First Case Seed

A seed must be supplied for the first case of the uncertainty analysis. The seed must be defined by the analyst in order to reproduce the random number sequence used for the analysis. For the purpose of generating unique initial seeds for automated calculations, the seed is generated using the ~~date/time functions~~ hardware entropy pool on the computer on which the uncertainty analysis is being performed.

~~A date and time is readily available on most computer operating systems as an integer value. The time functions on a UNIX O/S can return the local time back to the Unix epoch (00:00:00 UTC on 01/01/1970) in an integer format, so that a unique seed can be provided when no value is set for the keyword first_seed in the KBI file.~~

~~The format used for the automated analysis utilizes the date/time format of "%d%H%M%S". This string returns an integer date and time. Using the date and time format provides for a large integer value and a unique seed, as desired, upon execution of the automation code.~~

~~*A.2.5.11.2 Subsequent Case Seeds*~~

~~For cases 2 through the last case, the first random number generated by the call to the random number generator is used to calculate the seed for the next case as described in Section A.2.3.5.~~

~~seed[CASE] = randnum[CASE,0] * 32767 * 32767 + 1~~

A.2.5.11.3 Random Number Sequence

Once the seed is set for the ~~subsequent~~ first case, [ ] additional random numbers are generated to randomly vary the PIRT parameters for all remaining cases. Table A-20 provides a list of the sampled parameters and the random numbers associated with each parameter. The random numbers are used to calculate fuel rod code and S-RELAP5 input for the sampled parameters.

Table A-20 Random Number Sequence

A detailed assessment of the S-RELAP5 computer code was made through comparisons to experimental data, as documented in Section 8.0. These assessments were used to develop quantitative estimates of the ability of the code to predict key physical phenomena in a PWR LBLOCA. The final step of the best-estimate methodology is to combine all the uncertainties related to the code and plant parameters and estimate the PCT at 95 percent probability and 95 percent confidence. The steps taken to derive the PCT uncertainty estimate are summarized below:

1. Base Plant Input File Development

First, base COPERNIC and S-RELAP5 input files for the plant (including the containment input file) are developed. Code input development guidelines documented in Appendix A are applied to ensure that the model nodalization is consistent with the model nodalization used in the code validation.

2. Sampled Case Development

The statistical approach requires that many “sampled” cases be created and processed. For every set of input created, each “key LOCA parameter” is randomly sampled over a range established through code uncertainty assessment or expected operating limits (provided by plant technical specifications or data). Those parameters considered "key LOCA parameters" are listed in Table A-6. This list includes both parameters related to LOCA phenomena (based on the PIRT provided in Section 5.0) and to plant operating parameters. The uncertainty ranges associated with each of the model parameters are provided in Table A-7.

3. Determination of Adequacy of ECCS

The RLBLOCA methodology uses a non-parametric statistical approach to determine that the first three criteria of 10 CFR 50.46 (PCT < 2200 °F, local oxidation < 17 %, and core-wide oxidation < 1 %) are met with a probability higher than 95 percent with 95 percent confidence.

B.1.3 GDC-35 Limiting Condition Determination

GDC-35 states that the plant shall be able to mitigate design basis accidents with or without off site power available. The methodology does this by ~~determining the most severe condition between these two configurations and then performing the RLBLOCA statistical analysis for the plant with off site power availability set to the most severe condition.~~

running two case sets of the RLBLOCA uncertainty analysis. The set with the most limiting 95/95 result is used to demonstrate compliance to the criteria. This approach is demonstrated with the W3 sample problem described in Section B.2. The approach used in the W4 sample problem (Section B.3) and the CE sample problem (Section B.4) used a deterministic evaluation prior to execution of the uncertainty analysis to establish the offsite availability condition of the case set. This approach will not used in the Revision 3 EM.

~~To determine the limiting assumption, a sensitivity study of two LBLOCA cases is performed with and without offsite power available. The plant conditions incorporated in this study are set to those expected to challenge the ECCS capability, such that the validity of the result is established for conditions expected to be representative of those that will eventually determine the LBLOCA results which will be compared to the 10 CFR 50.46 criteria. A detailed description of the sensitivity study is provided in Appendix A of this report, sub-section A.2.4.2.~~

~~The study is performed with and without off site power available. As mentioned previously, the conditions assumed will be based on those considered to be representative of the LBLOCA results that be compared to the 10 CFR 50.46 criteria. The statistical case set, set of LBLOCA sample events, is then run under the assumption that off-site power is always either available or unavailable according to the study result.~~

B.1.4 Overall Statistical Compliance to Criteria

For the RLBLOCA analyses the determination of compliance to the criteria is treated as a [ ] with all of the first three criteria of 10 CFR 50.46 using non-parametric statistics. The approach is outlined in detail in Section 9.4 of this report. [ ] Generally, the minimum margins for each of the three parameters of interest will be established by different cases. For the sample evaluations presented in this appendix, a case set size of [ ] was selected. At this size, the 95/95 metric value is provided by the [ ] for the criterion of interest.

B.2 Westinghouse 3-Loop PWR

B.2.1 Summary

The parameter specification for this analysis is provided in Table B-9. [

] The analysis addresses typical operational ranges or technical specification limits (whichever is applicable) with regard to pressurizer pressure and level; accumulator pressure, temperature (containment temperature), and level; core inlet temperature; core flow; containment pressure and temperature; and refueling water storage tank temperature. [

]

B.2.2 Plant Description and Summary of Analysis Parameters

The plant analysis presented in this section is a Westinghouse designed PWR, having three loops, each with a hot leg, a U-tube steam generator, and a cold leg with a RCP. The RCS also includes a pressurizer. The ECCS comprises three accumulators, one per loop, and one full train of LHSI and HHSI injection (after applying the single failure assumption). The HHSI and LHSI feed into common headers (cross connected) that are connected to the accumulator lines.

Two [ ] case sets were analyzed, one with offsite power available (no LOOP) and one without offsite power available (LOOP). As shown in Table B-X, the LOOP condition was more limiting with respect to the retained margin. A comparison of the two case sets with respect to PCT is also provided in Figure B-Y.

Table B-X

Figure B-Y

Table B-7 3-Loop Westinghouse Plant Operating Range Supported by the RLBLOCA Analysis (continued)

	Event	Operating Range
3.0	**Accident Boundary Conditions**	
	a) Break location	
	b) Break type	
	c) Break size (each side, relative to cold leg pipe area)	
	d) Worst single-failure	
	e) Offsite power	
	f) ECCS pumped injection temperature	
	g) HHSI pump delay	
	h) LHSI pump delay	
	i) Containment pressure	
	j) Containment temperature	
	k) Containment sprays delay	
	l) Containment spray water temperature	
	m) LHSI Flow	

~~1 This is determined prior to the execution of the set of [ ] cases.~~

B.3 Westinghouse 4-Loop PWR

B.3.1 Summary

The parameter specification for this analysis is provided in Table B-14. [

] This analysis also addresses typical operational ranges or technical specification limits (which ever is applicable) with regard to pressurizer pressure and level; accumulator pressure, temperature (containment temperature), and level; core inlet temperature; core flow; containment pressure and temperature; and refueling water storage tank temperature. The analysis explicitly analyzes fresh and once-burned fuel assemblies. [

] [

]

B.3.2 Plant Description and Summary of Analysis Parameters

The plant analysis presented in this appendix is a Westinghouse designed pressurized water reactor (PWR), which has four loops, each with a hot leg, a U-tube steam generator, and a cold leg with a RCP. The RCS also includes one pressurizer. The ECCS includes one charging and one accumulator/SI/RHR injection path per RCS loop (after applying the single failure assumption). The SI and RHR feed into common headers which are connected to the accumulator lines. The charging pumps are also cross-connected.

Table B-14 4-Loop Westinghouse Plant Operating Range Supported by the LOCA Analysis (continued)

Event		Operating Range
	f) Accumulator pressure	[
	g) Accumulator liquid volume	
	h) Accumulator temperature	
	i) Accumulator fL/D	
	j) Minimum ECCS boron	
3.0	**Accident Boundary Conditions**	
	a) Break location	
	b) Break type	
	c) Break size (each side, relative to cold leg pipe area)	
	d) Worst single-failure	
	e) Offsite power	
	f) ECCS pumped injection temperature	
	g) Charging pump delay	
	h) SI pump delay	
	i) RHR pump delay	
	j) Containment pressure	
	k) Containment upper compartment temperature	
	l) Containment lower compartment temperature	
	m) Containment sprays delay	]

[1] This is determined prior to the execution of the set of [ ] cases.

This is different than the approach described in Section A.2.4.2 but does not affect the demonstration of the overall EMF-2103 Rev. 3 methodology.

B.4 CE 2x4 PWR

B.4.1 Summary

The parameter specification for this analysis is provided in Table B-21. [

] This analysis also addresses typical operational ranges or technical specification limits (whichever is applicable) with regard to pressurizer pressure and level; SIT pressure, temperature (containment temperature), and level; core inlet temperature; core flow; containment pressure and temperature; and refueling water storage tank temperature. [

] [ ]

For the sample analysis [

]

Table B-21 CE 2x4 Plant Operating Range Supported by the LOCA Analysis (continued)

	Event	Operating Range
3.0	**Accident Boundary Conditions**	
	a) Break location	
	b) Break type	
	c) Break size (each side, relative to cold leg pipe area)	
	d) Worst single-failure	
	e) Offsite power	
	f) ECCS pumped injection temperature	
	g) HPSI pump delay	
	h) LPSI pump delay	
	i) Containment pressure	
	j) Containment temperature	
	k) Containment sprays delay	
	l) Containment spray water temperature	
	m) LPSI Flow	

1 Determined prior to the execution of the set of [ ] cases.

2 Nominal containment pressure range is -0.7 to 0.5 psig. For RLBLOCA, a reasonable value between this range is acceptable.

This is different than the approach described in Section A.2.4.2 but does not affect the demonstration of the overall EMF-2103 Rev. 3 methodology.