U.S. NUCLEAR REGULATORY COMMISSION

FINAL SAFETY EVALUATION (REVISED) FOR

TOPICAL REPORT WCAP-16996-P/WCAP-16996-NP, VOLUMES I, II, AND III, REVISION 1,

"REALISTIC LOSS-OF-COOLANT ACCIDENT EVALUATION METHODOLOGY

APPLIED TO THE FULL SPECTRUM OF BREAK SIZES" (TAC NO. ME5244)

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

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Enclosure 1

1.0 INTRODUCTION AND BACKGROUND

1.1 Background

By letter LTR-NRC-10-73 dated November 23, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML103610186), Westinghouse submitted for the U.S. Nuclear Regulatory Commission (NRC) staff review and approval TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)." The NRC staff performed an acceptance review and found the material presented in the TR submittal sufficient to complete a comprehensive review. By letter dated March 28, 2011 (ADAMS Accession No. ML110740373), the NRC informed WEC regarding its acceptance of TR WCAP-16996-P/ WCAP-16996-NP Volumes I, II, and III, Revision 0, for a comprehensive review.

1.2 Purpose, Scope, and Applicability of the Review

The FULL SPECTRUM™ LOCA (FSLOCA™) methodology, as the previous Westinghouse Best-Estimate (BE) Evaluation Models (EMs), was patterned after the Code Scaling, Applicability, and Uncertainty (CSAU) methodology published by NRC in 1989. At the same time, the development roadmap for the FSLOCA™ EM followed NRC Regulatory Guide (RG) 1.203, which was released in 2005. For the purpose of NRC staff's review and approval, Westinghouse documented the new EM in TR WCAP-16996-P/WCAP-16996-NP, Revision 0, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," where the initial submittal included three volumes: Volume I, "WCOBRA/TRAC-TF2 Models and Correlations," Volume II, "WCOBRA/TRAC-TF2 Assessment," and Volume III, "Full Spectrum LOCA Uncertainty Methodology and Demonstration Plant Analysis." The purpose, scope, and applicability of the review are provided in the following sections.

1.2.1 Purpose of the Review

This safety evaluation (SE) documents the results of an in-depth technical evaluation of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)." The review was performed to determine the technical applicability of the thermal hydraulic methods and modeling techniques as described in TR WCAP-16996-P/ WCAP-16996-NP, Revisions 0, for application to BE simulations of the full spectrum of LOCA sizes in pressurized water reactors (PWRs) of certain designs. As a result of the in-depth technical evaluation by NRC staff of Revision 0, and issued requests for additional information (RAIs), Westinghouse revised original TR and submitted to NRC Revision 1 of WCAP-16996-P/ WCAP-16996-NP that supersedes Revision 0.

1.2.2 Scope of the Review

The FSLOCA™ BE EM was built on the previous WEC BE EM described in TR WCAP-16009-P-A, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)," dated January 2005. The ASTRUM EM was based on the system code WCOBRA/TRAC and addressed only large break (LB) LOCA (LBLOCA) scenarios with a minimum break size of 0.09 m^2 (1.0 ft^2). Basically, the FSLOCA™ BE EM replaces the 1-D portion of the WCOBRA/TRAC code and extends the applicability of the code to include the treatment of small break (SB) LOCA (SBLOCA), intermediate break (IB) LOCA (IBLOCA), and LBLOCA scenarios. Thus, the new BE EM FSLOCA™ was developed to perform analyses for break sizes down to and including the SB range of break sizes less than 0.09 m^2 (1.0 ft^2). Given the pedigree of the FSLOCA™ BE EM, the review was primarily focused on those portions of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, which have been revised since the approval and publication of the previous WEC BE EM ASTRUM in TR WCAP-16009-P-A.

Basically, the FSLOCA™ BE methodology extends the applicability of a BE methodology to cover SBLOCA analyses. Currently, analyses of SBLOCAs are performed using the WEC conservative Appendix K based, NOTRUMP SBLOCA EM previously approved by the NRC staff and described in TR WCAP-10079-P-A, "NOTRUMP - A Nodal Transient Small-Break and General Network Code," dated August 1985. Table 1 below identifies the currently approved WEC EMs for LOCA analyses that will be covered by the submitted FSLOCA™ EM.

Table 1: WEC EMs for LOCA Analyses with Their Areas of Applicability

	LBLOCA Applications			**SBLOCA Applications**		
	EM	**WEC TR**	**System Code**	**EM**	**WEC TR**	**System Code**
Current WEC EMs	**1981 EM (Appendix K EM)**	**WCAP-10266-P-A, Revision 2**	**BASH**			
	CQD (BE EM)	**WCAP-12945-P-A**	**WCOBRA/TRAC MOD7A, Rev.1**			
	ASTRUM (BE EM)	WCAP-16009-P-A Rev. 0	WCOBRA/TRAC MOD7A Rev. 6	NOTRUMP SBLOCA (Conservative Appendix K based EM)	Overall EM: WCAP-10054-P-A/ WCAP-10081-A (Non-proprietary) Code Proper: WCAP-10079-P-A/ WCAP-10080-A (Non-proprietary)	NOTRUMP
FSLOCA™	FSLOCA™ BE EM based on WCOBRA/TRAC-TF2 Rev. 1.1 (WCAP-16996-P Rev. 0) The frozen FULL SPECTRUM™ LOCA evaluation model is WCOBRA/TRAC-TF2 Version 1.3 as noted in WCAP-16996-P, Vol. 1, Rev. 1 (page 2-52). Note Version 1.1 was the as-submitted version.					

Since the inclusion of the SBLOCA break sizes into the applicability scope of the FSLOCA™ BE represents a major extension of the spectrum for the proposed EM, special attention was given in reviewing the suitability of the submitted FSLOCA™ EM for analyzing the SBLOCA spectrum for the intended class of PWR designs. As such, the focus of the review was directed toward those models that were modified and added to the WCOBRA/TRAC code to properly characterize SBLOCA phenomenological behavior needed to evaluate and show acceptable emergency core cooling system (ECCS) performance.

1.2.3 Applicability of the Review

The ASTRUM LBLOCA EM has been approved by the staff for Westinghouse designed three- and four-loop plants with ECCS injection into the Cold Legs (CLs) as well as for Westinghouse designed two-loop plants with upper plenum injection (UPI) and CE designs. In addition, the ASTRUM EM was also submitted for the AP1000 design as part of the AP1000 Design Control

Document. The NOTRUMP EM met the requirements provided in Section 50.46 of Title 10 of the *Code of Federal Regulations* (10 CFR) and Appendix K, and was found by the NRC staff to be acceptable for the analysis of SBLOCA events for WEC reactor designs caused by a rupture in the reactor coolant system (RCS) pressure boundary with a total cross sectional area less than 0.09 m^2 (1.0 ft^2), for which the normal charging system flow is not sufficient to maintain pressurizer level and pressure. The NRC staff has also approved the use of NOTRUMP for SBLOCA evaluation for CE designed plants.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, "Executive Summary" states that "the FULL SPECTRUM^{TM} LOCA EM is intended to be applicable to all PWR fuel designs with Zirconium alloy cladding" and that "the code models, their assessment, and conclusions on model biases and uncertainties are aimed to be generic and applicable to the same class of plants covered by the ASTRUM EM." During the review process, Westinghouse clarified that an initial approval for the application of the FSLOCA^{TM} EM to Westinghouse designed three- and four-loop plants with CL ECCS injection, only, was sought. The applicant indicated that after such an initial approval, a follow up approval of the FSLOCA^{TM} EM for analyzing Westinghouse designed two-loop plants with UPI and CE designs would be pursued in a future revision. This clarification was made at the August 12-15, 2013, NRC audit of the FSLOCA^{TM} EM and documented in the audit summary document submitted to NRC with letter LTR-NRC-13-70.

This review determines the applicability of the FSLOCA^{TM} EM for performing BE analyses for the entire spectrum of LOCAs including SBLOCA, IBLOCA, and LBLOCA scenarios in Westinghouse designed three- and four-loop PWR plants. In addition, such applications of the Westinghouse FSLOCA^{TM} BE EM are subject to the limitations and conditions as described in the corresponding section of this SE.

2.0 REGULATORY BASIS EVALUATION

2.1 Regulatory Requirements

The NRC amended the requirements of the ECCS Rule in 10 CFR 50.46 and Appendix K, "ECCS Evaluation Models," to 10 CFR Part 50. These changes in the regulations reflected the improved understanding of ECCS performance during reactor transients, which was obtained through extensive research performed since the NRC published the original requirements in January 1974. The amendment to 10 CFR Part 50 added the option of using realistic EMs (commonly referred to as BE plus uncertainty analysis methods or simply BE) in addition to employing the more conservative analysis methods, defined in Appendix K. Accordingly, the uncertainty in the BE analysis must be quantified and considered when comparing the results of the calculations with the applicable limits in 10 CFR 50.46(b), so that there is a high probability that the criteria will not be exceeded.

The Westinghouse FSLOCA™ EM is a BE methodology based on satisfying the requirements set forth in 10 CFR Part 50 as outlined below.

2.1.1 10 CFR 50.46 Emergency Core Cooling System Rule Requirements

The ECCS Rule in 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," requires in 10 CFR 50.46(a)(1)(i) that each PWR, fueled with uranium oxide pellets within cylindrical zircaloy or ZIRLO cladding, must be equipped with an ECCS. The ECCS must be designed in compliance with certain requirements pertaining to the following areas:

(1) ECCS analysis method,
(2) ECCS analysis scope, and
(3) ECCS performance criteria.

2.1.1.1 ECCS Analysis Method

The regulation at 10 CFR 50.46(a)(1)(i) requires that "ECCS cooling performance must be calculated in accordance with an acceptable evaluation model" and provides for two alternative options for acceptable EMs (analytical techniques):

(1) realistic, and
(2) conservative.

Accordingly, 10 CFR 50.46(a)(1)(i) describes an EM of the first category as a method that "realistically describes the behavior of the reactor system during a loss-of-coolant accident." With regard to an EM of the second category, 10 CFR 50.46(a)(1)(i) refers to 10 CFR 50.46(a)(1)(ii) where it is stated that such an EM "may be developed in conformance with the required and acceptable features" of Appendix K, "ECCS Evaluation Models," to 10 CFR Part 50.

The regulation at 10 CFR 50.46(a)(1)(i) requires that a realistic EM must include sufficient supporting justification to show that the model describes realistically the behavior of the reactor system during a LOCA. Specifically, the paragraph identifies the following realistic EM requirements.

(1) Comparisons to applicable experimental data must be made.
(2) Uncertainties in the analysis method and inputs must be identified and assessed.
(3) Item (2) above is done so that the uncertainty in the calculated results can be estimated.
(4) This uncertainty must be accounted for so that when the calculated ECCS cooling performance is compared to the acceptance criteria in 10 CFR 50.46(b) there is a high level of probability that the acceptance criteria would not be exceeded.
(5) Refers to Part II, "Required Documentation," of Appendix K, "ECCS Evaluation Models," to 10 CFR Part 50, which sets forth the EM documentation requirements.

Furthermore, 10 CFR 50.46(c)(2) defines an EM as the calculational framework for evaluating the behavior of the reactor system during a postulated LOCA. An evaluation model includes one or more computer programs and all other information necessary for applying the calculational framework to a specific LOCA (the mathematical models used, the assumptions included in the programs, the procedure for treating the program input and output information, the parts of the analysis not included in the computer programs, values of parameters, and all other information necessary to specify the calculational procedure).

2.1.1.2 <u>ECCS Analysis Scope</u>

The regulation at 10 CFR 50.46(a)(1)(i) requires that "ECCS cooling performance must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated."

2.1.1.3 <u>ECCS Performance Criteria</u>

10 CFR 50.46(a)(1)(i) requires that ECCS calculated cooling performance following postulated LOCAs conforms to the criteria set forth in 10 CFR 50.46(b). This paragraph defines the criteria for calculated ECCS cooling performance during postulated LOCAs in 10 CFR 50.46(b)(1) through 10 CFR 50.46(b)(5) as follows:

(1) Peak Cladding Temperature.
The calculated maximum fuel element cladding temperature shall not exceed 2,200 ºF (1,477.59 K or 1,204.44 ºC).
(2) Maximum Cladding Oxidation.
The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation. This is based on the Baker-Just equation.
(3) Maximum Hydrogen Generation.
The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.
(4) Coolable Geometry.
Calculated changes in core geometry shall be such that the core remains amenable to cooling.
(5) Long-Term Cooling.
After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

2.1.2 Appendix K to 10 CFR Part 50

Appendix K, "ECCS Evaluation Models," to 10 CFR Part 50, in its Part II, "Required Documentation," sets forth the following EM documentation requirements:

(1)(a) "A description of each evaluation model shall be furnished. The description shall be sufficiently complete to permit technical review of the analytical approach including the equations used, their approximations in difference form, the assumptions made, and the values of all parameters or the procedure for their selection, as for example, in accordance with a specified physical law or empirical correlation."

(1)(b) "A complete listing of each computer program, in the same form as used in the evaluation model, must be furnished to the Nuclear Regulatory Commission upon request."

(2) "For each computer program, solution convergence shall be demonstrated by studies of system modeling or noding and calculational time steps."

(3) "Appropriate sensitivity studies shall be performed for each evaluation model, to evaluate the effect on the calculated results of variations in noding, phenomena assumed in the calculation to predominate, including pump operation or locking, and values of parameters over their applicable ranges. For items to which results are shown to be sensitive, the choices made shall be justified."

(4) "To the extent practicable, predictions of the evaluation model, or portions thereof, shall be compared with applicable experimental information."

(5) "General Standards for Acceptability -- Elements of evaluation models reviewed will include technical adequacy of the calculational methods, including: For models covered by § 50.46(a)(1)(ii), compliance with required features of section I of this Appendix K; and, for models covered by § 50.46(a)(1)(i), assurance of a high level of probability that the performance criteria of § 50.46(b) would not be exceeded."

2.1.3 Appendix A to 10 CFR Part 50

The requirements of 10 CFR 50.46 are in addition to the requirements provided in General Design Criterion (GDC) 35, "Emergency Core Cooling," in Part IV, "Fluid Systems," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50.

The GDC 35 states requirements regarding the RCS heat transfer rate capabilities during a LOCA and provides for requirements regarding electric power and equipment redundancy for ECCS systems. Specifically, GDC 35 requires that the ECCS is capable of transferring heat from the reactor core following any loss of reactor coolant at a rate so that the following two requirements are met:

(1) Fuel and clad damage that could interfere with continued effective core cooling is prevented.
(2) Clad metal-water reaction is limited to negligible amounts.

In addition, GDC 35 imposes redundancy requirements with regard to components and features so that the ECCS safety function can be accomplished assuming a single failure for both onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available).

2.2 Regulatory Guides

2.2.1 Regulatory Guide 1.157

Following the amendment of the ECCS Rule in September 1988, the NRC provided further guidance to applicants in May 1989 by publishing RG 1.157, “Best-Estimate Calculations of Emergency Core Cooling System Performance.” RG 1.157 describes acceptable models, correlations, data, model evaluation procedures, and methods for meeting the realistic (best-estimate) EM requirements for calculating ECCS performance during a LOCA as set forth in 10 CFR 50.46.

2.2.2 Regulatory Guide 1.203

The NRC published RG 1.203, “Transient and Accident Analysis Methods,” in December 2005 with the intent to provide guidance for use in developing and assessing EMs for accident and transient analyses. It was expected that an additional benefit of publishing RG 1.203 would be that EMs developed using these guidelines will provide a more reliable framework for risk-informed regulation and a basis for estimating the uncertainty in understanding transient and accident behavior. RG 1.203, Part A, “Introduction,” refers to the NRC NUREG-0800, “Standard Review Plan,” (SRP) stating that the guide and SRP Section 15.0.2 cover the same subject material and are intended to be complementary, with Section 15.0.2 providing guidance to reviewers and this guide providing practices and principles for the benefit of method developers. Regulatory Guide 1.203, Section D, “Implementation,” states that the guide is approved for use as an acceptable means of complying with the NRC regulations and for evaluating submittals of “new or modified EMs proposed by vendors or operating reactor licensees that, in accordance with 10 CFR 50.59, require NRC staff review and approval.”

Regulatory Guide 1.203 outlines the two fundamental features of transient and accident analysis methods:

(1) the EM concept and
(2) the basic principles important for the EM development, assessment, and review.

2.2.2.1 Evaluation Model Concept

In accordance with 10 CFR 50.46(c)(2), RG 1.203 states that the EM constitutes the calculational framework for evaluating the behavior of the reactor system during a postulated transient or a design-basis accident. As such, the EM may include one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event, such as procedures for treating the input and output information, specification of those portions of the analysis not included in the computer programs for which alternative approaches are used, or all other information needed to specify the calculational procedure. It is the entirety of an EM that ultimately determines whether the results are in compliance with applicable regulations and therefore the development, assessment, and review processes must consider the entire EM. Most EMs used to analyze the events in SRP Chapter 15 rely on a systems code that describes the transport of fluid mass, momentum, and energy throughout the RCSs.

2.2.2.2 Evaluation Model Development and Assessment Principles

Regulatory Guide 1.203 defines the following six basic principles as important to follow in the Evaluation Model Development and Assessment Process (EMDAP).

(1) Determine requirements for the evaluation model.
(2) Develop an assessment base consistent with the determined requirements.
(3) Develop the EM.
(4) Assess the adequacy of the evaluation model.
(5) Follow an appropriate quality assurance protocol during the EMDAP.
(6) Provide comprehensive, accurate, up-to-date documentation.

Part C, "Regulatory Position," in RG 1.203 discusses the NRC staff's regulatory position and provides guidance concerning methods for calculating transient and accident behavior. Part C of RG 1.203 provides Regulatory Positions on five aspects of an EMDAP that address the basic principles identified above and offer additional guidance. Regulatory Positions 1 through 5 are identified below.

Regulatory Position 1: "Evaluation Model Development and Assessment Process (EMDAP)"
Regulatory Position 2: "Quality Assurance"
Regulatory Position 3: "Documentation"
Regulatory Position 4: "General Purpose Computer Programs"
Regulatory Position 5: "Graded Approach to Applying the EMDAP Process"

Regulatory Position 1, "Evaluation Model Development and Assessment Process (EMDAP)," in RG 1.203 identifies four basic elements developed to describe an EMDAP. The elements address directly the first four EMDAP basic principles and provide guidance in twenty individual steps, Steps 1 through 20. In addition, Regulatory Position 1 includes requirements for reaching an adequacy decision. The basic elements of Regulatory Position 1 are identified below.

Element 1: Establish Requirements for Evaluation Model Capability
Element 2: Develop Assessment Base
Element 3: Develop Evaluation Model
Element 4: Assess Evaluation Model Adequacy
Adequacy Decision

Regulatory Position 2, "Quality Assurance," in RG 1.203 addresses the fifth of the basic principles. It discusses the need for quality assurance protocol as the development, assessment, and application of an EM are three activities that relate to the requirements of Appendix B to 10 CFR Part 50. Regulatory Position 3, "Documentation," in RG 1.203 addresses the sixth basic principle. Regulatory Position 4, "General Purpose Computer Programs," in RG 1.203 addresses aspects related to general purpose transient analysis computer programs developed to analyze a number of different events for a wide variety of plants. Specifically, Regulatory Position 4 states that "application of the EMDAP should be considered as a prerequisite before submitting a general purpose transient analysis computer program for review as the basis for EMs that may be used for a variety of plant and accident types." Finally, Regulatory Position 5, "Graded Approach to Applying the EMDAP Process," provides guidance on the extent to which the full EMDAP should be applied for a specific application based on the following four EM attributes: (1) novelty of the revised EM compared to the currently acceptable model, (2) complexity of the event being analyzed, (3) degree of conservatism in the EM, and (4) extent of any plant design or operational changes that would require reanalysis.

Appendix A of RG 1.203, “Additional Considerations in the Use of this Regulatory Guide for ECCS Analysis,” describes uncertainty determination and provides guidance for best-estimate LOCA analyses. Appendix A of RG 1.203 refers to SRP Sections 15.6.5 and 15.0.2 that are outlined in the following.

2.3 NUREG Report Guidance

2.3.1 NUREG-0800, “Standard Review Plan”

NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” (SRP), Section 15.0.2, “Review of Transient and Accident Analysis Methods,” was first published by NRC in March of 2007. NUREG-0800, Section 15.0.2, is the companion SRP section to RG 1.203.

SRP Section 15.6.5, “Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary,” was revised by the NRC in March 2007 with the publication of its Revision 3. It describes for reviewers the review scope, acceptance criteria, review procedures, and findings relevant to ECCS analyses.

2.3.2 NUREG/CR-5249 Code Scaling, Applicability, and Uncertainty (CSAU)

The NRC has developed the CSAU methodology for code uncertainty evaluation. The CSAU process has been demonstrated for LBLOCA and boiling water reactor (BWR) ATWS. Other methods of uncertainty evaluation may be acceptable.

Following the revision of the ECCS Rule in 10 CFR Part 50 in September of 1988 and the publication of RG 1.157 in May of 1989, the NRC developed and applied the principles of an EMDAP in a study on quantifying reactor safety margins. In this study, published in December 1989 as NUREG/CR-5249, the NRC developed the CSAU methodology for code uncertainty evaluation. In NUREG/CR-5249, the CSAU evaluation methodology was applied to a LBLOCA to demonstrate a method that could be used to quantify uncertainties as required by the realistic option provided in the 1988 revision of the ECCS Rule in 10 CFR 50.46. Since its publication, the CSAU has been applied in several instances, with modifications to adjust to each particular circumstance. In particular, the CSAU process has been demonstrated for PWR LBLOCA applications.

3.0 FULL SPECTRUM™ LOCA METHODOLOGY SUMMARY

3.1 FULL SPECTRUM™ LOCA Methodology Overview

The previously approved WEC BE methodologies are described in TR WCAP-12945-P-A, “Code Qualification Document for Best Estimate LOCA Analysis,” dated March 1998, and in TR WCAP-16009-P-A, “Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM),” dated January 2005. Both the Code Qualification Document (CQD) and the ASTRUM methodologies followed NRC RG 1.157 and were developed for simulation of LBLOCAs.

The development and documentation of the FSLOCA™ methodology followed the EMDAP documented in RG 1.203, which was issued by the NRC in December 2005. In practice, the applicant used both RGs during the development and documentation of the FSLOCA™ EM as certain aspects in RG 1.157 were found as more detailed than RG 1.203. Table 2 below identifies and describes major characteristics of the previously approved WEC BE methodologies for LOCA analyses that represent the background for the proposed FSLOCA™ EM, which is also included in the table.

Table 2: WEC Approved and Proposed Best-Estimate Methodologies for PWR LOCA Analyses

WEC EM	Submitted/ Approved	WEC TR	System Code	Methodology Foundation	NRC Guidance	Plant Application	Uncertainty Treatment	LOCA Spectrum
CQD	9-1992/ 6-1996	WCAP-12945-P-A Rev. 2 and WCAP-14747 (Non-proprietary)	WCOBRA/ TRAC MOD7A Rev. 1	CSAU (1989)	RG 1.157 (1989)	WEC three- and four-loop plants with CL ECCS injection	Monte Carlo process with sample response surfaces	Single LBLOCA spectrum
	8-1995/ 5-1999	WCAP-14449-P-A Rev. 1	WCOBRA/ TRAC MOD7A Revision 1	CSAU (1989)	RG 1.157 (1989)	WEC two-loop plants with UPI	Monte Carlo process with sample response surfaces	Single LBLOCA spectrum
ASTRUM	6-2003/ 11-2004	WCAP-16009-P-A, Revision 0	WCOBRA/ TRAC MOD7A Rev. 6	CSAU (1989) (except uncertainty treatment)	RG 1.157 (1989)	WEC three- and four - loop plants with CL ECCS injection and two-loop plants with UPI, CE designs, AP1000	Use of non-parametric order statistics to combine uncertainties	Single LBLOCA spectrum
FSLOCA™	11-2010/	WCAP-16996-P/WCAP-16996-NP, Revision 0	WCOBRA/ TRAC-TF2, Revision 1.1	EMDAP (2005) (except uncertainty treatment)	RG 1.203 (2005)	WEC three- and four-loop plants with CL ECCS injection	Use of non-parametric order statistics to combine uncertainties	Two separate SBLOCA/ LBLOCA spectra

Major characteristics of the systems codes used in the proposed FSLOCA™ EM and in a subset of the currently approved WEC methodologies for LBLOCA and SBLOCA analyses are presented in Table 3 below.

Table 3: Major System Code Features in WEC EMs for SBLOCA and LBLOCA Analyses

<table>
<tr><th colspan="2">EM</th><th rowspan="2">Approved or Submitted</th><th rowspan="2">3D Module (VESSEL) Code</th><th rowspan="2">1D Module Code</th></tr>
<tr><th>Name and TR</th><th>System Code</th></tr>
<tr><td rowspan="2">NOTRUMP WCAP-10079-P-A/ WCAP-10080-A (Non-proprietary)</td><td rowspan="2">NOTRUMP</td><td rowspan="2">8-1985</td><td rowspan="2">None</td><td>NOTRUMP</td></tr>
<tr><td>General 1D flow network (max 200 nodes) with two-phase drift flux model and mixture level tracking in stacked nodes</td></tr>
<tr><td rowspan="3">ASTRUM WCAP-16009-P-A, Revision 0</td><td rowspan="2">WCOBRA/TRAC MOD7A, Revision 6</td><td rowspan="2">11-2004</td><td>COBRA-TF</td><td>TRAC-PD2</td></tr>
<tr><td>Based on WEC modified COBRA-TF (three-field (TF) formulation for vapor, continuous liquid, and entrained liquid droplet fields with separate sets of continuity, momentum, and energy equations for each field except a common energy equation for continuous liquid and entrained liquid droplet fields)</td><td>Two-phase five-equation drift flux model (mixture velocity plus a drift flux model)</td></tr>
<tr><td>WCOBRA/TRAC MOD7A, Revision 7</td><td>Changes under 10 CFR 50.46</td><td colspan="2">Revision 7 released to reflect error corrections and minor improvements including some additional features for special applications</td></tr>
<tr><td rowspan="2">FSLOCA™ WCAP-16996-P/WCAP-16996-NP, Revision 0</td><td rowspan="2">WCOBRA/TRAC-TF2, Revision 1.1</td><td rowspan="2">11-2010</td><td>COBRA-TF</td><td>TRAC-PF1/MOD2</td></tr>
<tr><td>Based on modified WEC COBRA-TF (three-field (TF) formulation for vapor, continuous liquid, and entrained liquid droplet fields, addition of non-condensable gas transport equation in COBRA-TF, separate sets of continuity, momentum, and energy equations for each field except common energy equation for the continuous liquid and entrained liquid droplet fields)</td><td>Two-fluid (TF) six-equation formulation (non-condensable transport already implemented)</td></tr>
</table>

3.2 FULL SPECTRUM™ LOCA Methodology Mapping to EMDAP Elements

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, Section 1.2, "Mapping of FSLOCA EM Development to Regulatory Guidance, Regulatory Guide 1.203 (EMDAP)," states that "to the extent possible the EMDAP process (RG 1.203) was followed as a roadmap in the development and documentation of the FSLOCA EM." This section summarizes the mapping of the FSLOCA™ EM to the four basic elements with their twenty steps identified in Regulatory Position 1, "Evaluation Model Development and Assessment Process (EMDAP)," in RG 1.203 for describing an EMDAP. In particular, Table 4, "FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 1 and 2," which is shown below, summarizes Steps 1 through 4 for Element 1 as well as Steps 5 through 9 for Element 2. The following Table 5, "FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 3 and 4," summarizes Steps 10 through 12 for Element 3 along with Steps 13 through 20 for Element 4. These tables also provide references, where appropriate, to sections in the TR that describe pertinent EM areas in more detail.

Table 4: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 1 and 2

EMDAP Elements and Steps		FSLOCA™ EM WCAP-16996-P/WCAP-16996-NP, Revision 0		Major Modifications/ Clarifications/Notes
Element	**Step**	**Summary**	**TR Section**	
1. Establish Requirements for Evaluation Model Capability	1. Specify Analysis Purpose, Transient Class, Power Plant Class	DEG/split break LOCAs for WEC 3/4 loop plants with CL ECCS injection, 2 loop plants with UPI, CE designs to demonstrate meeting with a high degree of probability 10 CFR 50.46 criteria: 10 CFR 50.46(b)(1) "Peak cladding temperature," 10 CFR 50.46(b)(2) "Maximum cladding oxidation," 10 CFR 50.46(b)(3) "Maximum hydrogen generation," 10 CFR 50.46(b)(4) "Coolable geometry," and 10 CFR 50.46(b)(5) "Long-term cooling."	Section 1.2.1 Section 2.3.1 Section 32.1 Section 32.3.1	WEC 3 loop plants with CL ECCS injection (follow up approval will be sought for other designs). FSLOCA™ EM is not applicable for demonstrating compliance with CFR 50.46(b)(5) "Long-term cooling."

Table 4: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 1 and 2, continued

	2. Specify Figures of Merit	Peak Clad Temperature (PCT). Maximum Local Oxidation (MLO). Core-Wide Oxidation (CWO). Additional code performance measures used in code assessments as physical tracking points and proof of accuracy.	Section 1.2.1 Section 1.2.2 Section 2.2	10 CFR 50.46(b)(4) "Coolable geometry" criterion is not tracked explicitly in the FSLOCA™ EM.
	3. Identify Systems, Components, Phases, Geometries, Fields, and Processes that Must Be Modeled	Defined though the Phenomena Identification and Ranking Table (PIRT) process.	Section 2.3	n/a
	4. Identify and Rank Key Phenomena and Processes	FSLOCA™ PIRT identifies phenomena for each LOCA transient period (phase) and ranks them as of high (H), medium (M), low (L) importance.	Section 2.3	LBLOCA PIRT based on PIRT previously reviewed by NRC. SBLOCA PIRT was a subject to independent peer review.

Table 4: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 1 and 2, continued

2. Develop Assessment Base	5. Specify Objectives for Assessment Base	Assess EM and develop new models (correlations) when needed through selection of a database (Separate Effects Tests (SETs) and Integral Effects Tests (IETs)) and through definition of simple test problems.	Section 1.2.4 Section 2.6.1	Plant transient data not included in the FSLOCA™ database.
	6. Perform Scaling Analysis and Identify Similarity Criteria	Full scale or prototypical data is used when possible while scaling considerations are provided otherwise for each model in Sections 3 through 11 in Volume I and for assessments in Volume II.	Section 1.2.5 Section 2.6.2 Section 32.2.3	Sufficiency in SBLOCA database diversity to demonstrate bounding of expected plant-specific responses not evident.
	7. Identify Existing Data and/or Perform Integral Effects Tests (IETs) and Separate Effects Tests (SETs) To Complete the Database	Most of the CQD (WCAP-12945-P-A) LBLOCA database used for FSLOCA™. The LBLOCA validation basis extended to cover SBLOCA. Two independent datasets used to support EM development in Volume I and assessment in Volume II.	Section 2.6.2 Section 2.6.3 Section 2.6.4	Limitations proposed to address insufficient SBLOCA database.

Table 4: FSLOCA^{TM} EM Mapping to RG 1.203 EMDAP Elements 1 and 2, continued

	8. Evaluate Effects of IET Distortions and SET Scaleup Capability	Considered on a case-by-case basis in applications in Volume I and Volume II.	Section 2.6.2 Section 2.6.3	Additional scaling considerations in response to review findings resulted in database changes.
	9. Determine Experimental Uncertainties as Appropriate	Uncertainties in the test measurements and in the data reduction process are considered in comparisons with code predictions when possible. Experimental uncertainties also considered in the uncertainty analysis.	Section 1.2.6 Section 1.3 Section 29.6	Consideration of uncertainties in databases requested for individual assessments.

Table 5: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 3 and 4

EMDAP Elements and Steps		FSLOCA™ EM WCAP-16996-P/WCAP-16996-NP, Revision 0		Major Modifications/ Clarifications/Notes
Element	**Step**	**Summary**	**TR Section**	
3. Develop Evaluation Model	10. Establish an Evaluation Model Development Plan	FSLOCA™ EM is an evolution of the current BE ASTRUM EM. Whereas the WC/T-TF2 Software Development Plan was designed to suit an incremental development process, extent of changes and novelty of including SBLOCAs led to the application of the full EMDAP process by the applicant.	Section 1.2.7 Section 2.5 Section 32.2.5	No prior validation of WCOBRA/TRAC for SBLOCA led to EM application changes for the SBLOCA spectrum.
	11. Establish Evaluation Model Structure	WC/T-TF2 Rev. 1.1 was developed based on the structure of the approved ASTRUM EM and its system code WCOBRA/TRAC MOD7A Rev. 6.	Section 1.2.7 Section 2.5	
	12. Develop or Incorporate Closure Models	Specific model developments and/or improvements identified and implemented.	Section 2.5.1 Section 2.5.2 Section 2.5.3	

Table 5: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 3 and 4, continued

4. Assess Evaluation Model Adequacy	13. Determine Model Pedigree and Applicability To Simulate Physical Processes	Available closure relationships were used or new specialized models were developed in some instances using SET data. Models were based on local thermal hydraulic parameters and evaluated for applicability over the full spectrum of LOCAs.	Section 1.2.8 Sections 4 through 11 (Volume I)	
	14. Prepare Input and Perform Calculations To Assess Model Fidelity or Accuracy	Models assessed using experiments from a set of SET facilities.	Sections 4 through 11 (Volume I)	Proposed uncertainty ranges for specific models revised based on review findings.
	15. Assess Scalability of Models	Bottom-up scalability considerations of closure relations presented on a case-specific basis in Sections 4 through 11 of Volume I.	Sections 4 through 11 (Volume I)	
	16. Determine Capability of Field Equations To Represent Processes and Phenomena and the Ability of Numeric Solutions To Approximate Equation Set	Top-down description of the governing equations and numerical algorithm provided. Numerical benchmarks against thought or first principle problems performed.	Section 3 Section 12.5.4.2 Section 23 (numerical tests) Section 28.1.3 Section 29.3.3	

Table 5: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 3 and 4, continued

	17. Determine Applicability of Evaluation Model To Simulate System Components	The applicability evaluation of the integrated code to model plant systems and components was performed as part of the WC/T-TF2 assessment.	Volume II (SET assessments)	
	18. Prepare Input and Perform Calculations To Assess System Interactions and Global Capability	IET assessments for SBLOCA (ROSA, LOFT) and LBLOCA (LOFT, CCTF) performed. Consistent nodalization in code assessments against test data and in NPP applications.	Section 19 (CCTF) Section 21 (ROSA) Section 22 (LOFT)	

Table 5: FSLOCA™ EM Mapping to RG 1.203 EMDAP Elements 3 and 4, continued

	19. Assess Scalability of Integrated Calculations and Data for Distortions	Consideration of differences between assessment calculations and experiments among facilities or between predictions and measured data for the same facility provided. Assessment of compensating errors in EM performance performed.	Volume II Section 24	
	20. Determine Evaluation Model Biases and Uncertainties	FSLOCA™ EM determines calculational uncertainty due to contributors related to code/model uncertainty and to plant conditions (initial/boundary conditions, equipment availability). Contributors in both categories are either bounded or ranged simultaneously using a Monte Carlo technique to propagate uncertainties in a LOCA transient. Break size spectrum is divided in two interfaced regions with **[** **]** sampling. Region I covers SBLOCAs and Region II covers LBLOCAs with probability statements obtained for each region.	Section 25 (plant sources) Section 29 (code sources) Section 30 (propagation of uncertainties) (Volume III)	

4.0 TECHNICAL EVALUATION

4.1 Technical Evaluation Process

This section describes the technical evaluation process and identifies the supporting technical documentation considered in the resolution of technical findings identified during the FULL SPECTRUM™ LOCA EM review process. Specifically, documents with additional information provided by Westinghouse in support of the review of the FULL SPECTRUM™ LOCA EM documented in the original submittal of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, are identified here. This additional information, along with the technical basis documented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, represents the technical basis considered as part of the TR review. The review process resulted in methodology updates, which were documented by Westinghouse in a revised FULL SPECTRUM™ LOCA EM TR, which was submitted to NRC as WCAP-16996-P/ WCAP-16996-NP, Volumes I, II, and III, Revision 1, in 2015. The updates in the revised TR were also considered as part of the FULL SPECTRUM™ LOCA EM review.

4.1.1 Description of the Technical Evaluation Process

The technical evaluation of the FULL SPECTRUM™ LOCA Methodology documented in Revision 0 of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, resulted in findings that needed the formulation of specific RAIs. Draft formulations for RAIs were prepared by the contractor, ISL, and submitted to NRC in separate sets as part of the review process. Altogether, ISL and the NRC staff prepared and submitted nine sets of RAIs. These sets also included RAI input from the NRC technical staff. These RAIs were included in the ISL compiled sets, so that the RAIs could be submitted for processing by the NRC in batches.

Following the issuance of the round one RAIs by the NRC, Westinghouse provided its final responses to the NRC RAIs in individual letters during the course of the review. The final responses to the NRC round one RAIs were reviewed by ISL, and the staff and review findings documented in RAI review templates for each Westinghouse letter providing such responses. In some cases, the review of the Set One RAI final responses resulted in the identification of remaining open items related to specific RAIs. Such open items were also documented in the RAI review templates for the final responses to the NRC round one RAIs, which were submitted to NRC. Identified open items related to final round one RAI responses were discussed with Westinghouse at three NRC Audits of the FSLOCA™ EM that took place on August 12-15, 2013, August 6-7, 2014, and June 8, 2015.

Westinghouse provided additional information to address specific open items related to final responses to the NRC set one RAIs discussed at the August 6-7, 2014, NRC audit of the FULL SPECTRUM™ LOCA EM in three parts submitted to the NRC with individual letters. The additional information in these documents was reviewed by the NRC staff and contractor, and the review findings along with remaining open items documented in review templates for each of the Westinghouse submittals providing such additional information. The review templates were developed and the review findings related to remaining open items were discussed with Westinghouse during the June 8, 2015, NRC audit of the FULL SPECTRUM™ LOCA EM. Following the June 8, 2015, NRC audit, Westinghouse provided additional information to address all remaining open items related to final responses to NRC round one RAIs. This information was submitted to the NRC in three parts with individual letters. The additional information in these documents was reviewed by the staff and ISL, and found satisfactory to close all outstanding open items and round one RAIs.

In addition to the final responses to the NRC set one RAIs and the additional information for open items related to final responses to such RAIs, Westinghouse also provided important additional information in support of the TR WCAP-16996-P/WCAP-16996-NP review at several major NRC audits of the FULL SPECTRUM^{TM} LOCA EM. The additional information presented at such NRC audits was included in the Audit summary documents, which were submitted to the NRC with individual letters following each NRC audit. This information was also considered in the TR review.

The FULL SPECTRUM^{TM} LOCA methodology updates resulting from the review process were documented by Westinghouse in Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III. Westinghouse submitted to NRC Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volume I, with letter LTR-NRC-15-24 dated April 14, 2015, Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volume II, with letter LTR-NRC-15-54 dated June 29, 2015, and Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volume III, with letter LTR-NRC-15-83 dated October 1, 2015. The revised TR volumes were reviewed by the NRC staff and ISL to confirm that the documented methodology updates are acceptable and consistent with accepted RAI responses, and the additional information provided by Westinghouse to resolve identified open items related to final responses to NRC set round RAIs.

Telephone conference calls between Westinghouse and the NRC staff took place on numerous occasions during the TR review to discuss resolution of RAIs responses and identified open items. The contractor, ISL, also attended such teleconferences and provided additional technical support to the NRC staff. Technical letter reports for the conference calls were also prepared and documented.

4.1.2 Technical Documents Considered in the TR Evaluation

The technical evaluation documented in this report included the review of original submittal of the FULL SPECTRUM^{TM} LOCA methodology documented in Revision 0 of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III. The final responses to NRC round one RAIs as well as the additional information provided by Westinghouse on identified open items related to RAI responses were reviewed as part of the technical evaluation. The additional information presented by Westinghouse at NRC audits of the FSLOCA^{TM} EM and included in the audit summary documents submitted to NRC was also considered in the review. The above identified technical documents considered in the TR evaluation are identified and described below.

Table 6 identifies the Westinghouse transmittal letter to NRC submitting the original FULL SPECTRUM^{TM} LOCA methodology TR documented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0.

Table 6: Identification of the Westinghouse Letter Transmitting the Original Submittal of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0

No.	Letter	Date	Submitted Documents	ADAMS Accession No.
1	LTR-NRC-10-73	November 23, 2010	WCAP-16996-P/WCAP-16996-NP, Volume I, Revision 0, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology - WCOBRA/TRAC-TF2 Models and Correlations.”	ML103610186
			WCAP-16996-P/WCAP-16996-NP, Volume II, Revision 0, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology) - WCOBRA/TRAC-TF2 Assessment.”	
			WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 0, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology) - Full Spectrum LOCA Uncertainty Methodology and Demonstration Plant Analysis.”	

As a result of the review of original submittal of the FULL SPECTRUM™ LOCA methodology documented in Revision 0 of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, ISL and the NRC staff prepared nine sets of round one RAIs containing 137 individual RAIs and submitted them to NRC. All nine RAI sets are documented in Appendix A to this report. Specific RAIs included in these sets incorporated input from or were prepared by the NRC technical staff as identified in Appendix B. All of these 137 Set One RAIs were issued by NRC as proposed or, in some cases, with minor editorial changes. In addition to these RAIs, the NRC technical staff formulated Round One RAI No. 45, which was issued individually by NRC, and Round One RAI No. 77, which was issued by NRC as part of NRC RAI Set No. 5. Thus, 139 round one RAIs were issued altogether by the NRC during the FULL SPECTRUM™ LOCA EM review. The NRC issued these round one RAIs in eight individual sets as identified in Table 7 below.

Table 7: Sets of round one RAIs Issued by the NRC During the Review of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0

NRC RAI Set No.	Date Issued	RAIs Issued	Corresponding Set of RAIs Submitted by ISL	ADAMS Accession No.
1	June 26, 2012	RAIs No. 1 through No. 19	Set No. 1	ML121070151
2	August 15, 2012	RAIs No. 20 through No. 29	Set No. 2	ML121070393
3	October 25, 2012	RAIs No. 30 through No. 35	Set No. 3	ML121070402
4	August 15, 2012	RAIs No. 36 through No. 44	Set No. 4	ML121070414
5	June 11, 2013	RAIs No. 46 through No. 77	Sets No. 5 and No. 6	ML13070A383
6	November 7, 2013	RAIs No. 78 through No. 106	Set No. 7	ML13255A313
7	November 7, 2013	RAIs No. 107 through No. 121	Set No. 8	ML13255A313
8	November 7, 2013	RAIs No. 122 through No. 139	Set No. 9	ML13255A313

The Westinghouse letters transmitting final responses to the NRC round one RAIs are identified in Table 8.

Table 8: Westinghouse Final Responses to NRC round one RAIs from the Review of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0

No.	Westinghouse Letter	Date	Provided Final Responses to NRC round one RAIs	Total Responses	ADAMS Accession No.
1	LTR-NRC-13-31	May 30, 2013	30, 31, 32, 33, 34, 35	6	ML13156A223
2	LTR-NRC-13-32	May 30, 2013	40, 41, 42, 43, 44	5	ML13169A166
3	LTR-NRC-13-33	May 31, 2013	20, 21, 22, 23, 24, 25, 26, 27, 28, 29	10	ML13169A404
4	LTR-NRC-13-37	June 5, 2013	1 through 8, 10, 11, 13 through 19	17	ML13162A412
5	LTR-NRC-13-40	June 13, 2013	45	1	ML13169A280
6	LTR-NRC-13-41	June 21, 2013	72, 73, 74, 76	4	ML13183A374
7	LTR-NRC-13-45	June 26, 2013	9, 12	2	ML13183A071
8	LTR-NRC-13-73	October 28, 2013	46 through 58, 75, 77 (RAI Set No. 5)	15	ML13310A290
9	LTR-NRC-13-75	November 7, 2013	59 through 71	13	ML13326A480
10	LTR-NRC-14-4	January 30, 2014	127, 132 through 135, 137 through 139	8	ML14041A162
11	LTR-NRC-14-9	February 12, 2014	122 through 126, 128 through 131, 136	10	ML14051A634
12	LTR-NRC-14-12	March 12, 2014	77 (RAI Set No. 6) through 82, 86, 87, 93, 112	10	ML14090A019
13	LTR-NRC-14-17	March 24, 2014	36 through 39	4	ML14090A022
14	LTR-NRC-14-19	April 2, 2014	83 through 85, 88 through 92, 94, 95, and 113 through 119	17	ML14100A465
15	LTR-NRC-14-21	April 4, 2014	96 through 105, 107	11	ML14100A380
16	LTR-NRC-14-33	June 13, 2014	108, 120, 121	3	ML14171A094
17	LTR-NRC-14-70	October 31, 2014	109, 110, 111	3	ML14314A819

Table 9 below provides the Westinghouse letters transmitting additional information on open items related to final responses to NRC round one RAIs.

Table 9: Westinghouse Letters Transmitting Additional Information on open items Related to Final Responses to NRC round one RAIs

No.	Westinghouse Letter	Date	Transmitted Additional Information on open items Related to NRC round one RAIs	Total RAIs	ADAMS Accession No.
1	LTR-NRC-14-60	September 17, 2014	23, 36, 37, 38, 39, 46, 47, 48, 51, 85, 95, 127, 132, 133, and 134	15	ML14268A308
2	LTR-NRC-15-6	January 30, 2015	20, 22, 29, 30, 79, 80, 86, 89, 90, 91, 96, 97, 98, 99, 101, 102, 104, 105, 107, 112, 113, 115, and 116	23	ML15035A489
3	LTR-NRC-15-11	February 24, 2015	26, 51, 52, 53, 54, 55, 57	7	ML15061A147
4	LTR-NRC-15-67	July 24, 2015	22, 86, 96, 108, 109, 110, 112, 122	8	ML15215A509
5	LTR-NRC-15-70	September 16, 2015	26, 46, 51, 55, 57	5	ML15265A546
6	LTR-NRC-15-85	October 1, 2015	50, 77 (RAI Set No. 5), 86, 87, 113	5	ML15295A164

In letter LTR-NRC-15-91, Westinghouse provided an FSLOCA™ EM roadmap document. This document identified information contained in final responses to the NRC round one RAIs that has become obsolete during the review process of the FSLOCA™ EM and provided references to where the updated information was presented, typically either a later audit summary and/or in Revision 1 of the updated TR. The NRC round one RAIs considered in the FSLOCA™ EM roadmap document provided in letter LTR-NRC-15-91 are identified in Table 10 below.

Table 10: NRC round one RAIs Considered in the FSLOCA™ EM Roadmap Document

No.	Westinghouse Letter	Date	NRC Round One RAIs with Final Responses Containing Obsolete Information	Total RAIs	ADAMS Accession No.
1	LTR-NRC-15-91	October 20, 2015	3, 4, 6, 8-11, 13, 14, 17-19, 26, 33, 40-47, 50, 52, 58-71, 63, 65-77, 80, 83, 85, 91, 96-99, 106, 107, 109-112, 115, 116, 122-129, 136	69	ML15295A165

Information presented by Westinghouse at the NRC audits of the FULL SPECTRUM™ LOCA EM, including presentation materials and additional information related to open items discussed at the audits, was submitted to the NRC in audit summary documents prepared for each NRC audit. The Westinghouse letters transmitting such NRC audit summary documents are identified in Table 11 below, which also contains descriptions of the provided information. Westinghouse letters transmitting the NRC audit summary documents containing only additional information on open items relative to final responses to the NRC round one RAIs and identified in Table 9 above, are also included for completeness.

Table 11: Westinghouse Letters Transmitting Audit Summary Documents Related to the NRC Audits of the FSLOCA^{TM} EM

No.	Westinghouse Letter	Letter Date	NRC Audit Date	Audit Summary Description	ADAMS Accession No.
1	LTR-NRC-13-70	October 10, 2013	July 16-17, 2013 August 12-15, 2013	Summary of July 16-17, 2013 NRC FSLOCA^{TM} Code Workshop. Presentations from August 12-15, 2013 NRC FSLOCA^{TM} Audit.	ML13297A362
2	LTR-NRC-14-29	June 5, 2014	May 12-13, 2014	Additional information supporting the licensing of the FSLOCA^{TM} EM. Presentations from May 12-13, 2014 NRC FSLOCA^{TM} Audit.	ML14164A336
3	LTR-NRC-14-38	June 27, 2014	June 3-4, 2014	Additional information supporting the licensing of the FSLOCA^{TM} EM. Presentations from June 3-4, 2014 NRC FSLOCA^{TM} Audit.	ML14183B535
4	LTR-NRC-14-55	August 21, 2014	February 19-20, 2014	Presentations from February 19-20, 2014 NRC FSLOCA^{TM} Audit.	ML14245A457
5	LTR-NRC-14-60	September 17, 2014	August 6-7, 2014	Summary of August 6-7, 2014 NRC FSLOCA^{TM} Audit, Part 1 (Additional Information on open items related to RAI Responses).	ML14268A308
6	LTR-NRC-15-6	January 30, 2015	August 6-7, 2014	Summary of August 6-7, 2014 NRC FSLOCA^{TM} Audit, Part 2 (Additional Information on open items related to RAI Responses).	ML15035A489

Table 11: Westinghouse Letters Transmitting Audit Summary Documents Related to NRC Audits of the FSLOCA™ EM, continued

7	LTR-NRC-15-11	February 24, 2015	August 6-7, 2014	Summary of August 6-7, 2014 NRC FSLOCA™ Audit, Part 3 (Additional Information on open items related to RAI Responses).	ML15061A147
8	LTR-NRC-15-67	July 24, 2015	June 8, 2015	Summary of June 8, 2015 NRC FSLOCA™ Audit, Part 1 (Additional Information on open items related to RAI Responses).	ML15215A509
9	LTR-NRC-15-70	September 16, 2015	June 8, 2015	Summary of June 8, 2015 NRC FSLOCA™ Audit, Part 2 (Additional Information on open items related to RAI Responses).	ML15265A546
10	LTR-NRC-15-82	September 28, 2015	September 14, 2015	Additional information supporting the licensing of the FSLOCA™ EM. Presentation from September 14, 2015 NRC FSLOCA™ Audit.	ML15282A490
11	LTR-NRC-15-85	October 1, 2015	June 8, 2015	Summary of June 8, 2015 NRC FSLOCA™ Audit, Part 3 (Additional Information on open items related to RAI Responses).	ML15295A164
12	LTR-NRC-15-88	October 12, 2015	October 7, 2015	Additional information supporting the licensing of the FSLOCA™ EM. Presentation from October 7, 2015 NRC FSLOCA™ Audit.	ML15302A059

In the FSLOCA™ EM roadmap document provided in letter LTR-NRC-15-91 and identified in Table 10 above, Westinghouse also identified the NRC audit summary documents containing information that has become obsolete during the review process of the FSLOCA™ EM. As in the case of affected the NRC round one RAIs discussed above, the roadmap provided references to where the updated information was presented, again typically either a later audit summary and/or in Revision 1 of the TR. The NRC audit summary documents considered in the FSLOCA™ EM roadmap document in LTR-NRC-15-91 are identified in Table 12 below.

Table 12: Audit Summary Documents Considered in the FSLOCA™ EM Roadmap Provided in Westinghouse Letter LTR-NRC-15-91

No.	Westinghouse Letter	Letter Date	NRC Audit Date	Audit Summary Description	ADAMS Accession No.
1	LTR-NRC-13-70	October 10, 2013	July 16-17, 2013 August 12-15, 2013	Summary of July 16-17, 2013 NRC FSLOCA™ Code Workshop. Presentations from August 12-15, 2013 NRC FSLOCA™ Audit.	ML13297A362
2	LTR-NRC-14-55	August 21, 2014	February 19-20, 2014	Presentations from February 19-20, 2014 NRC FSLOCA™ Audit.	ML14245A457
3	LTR-NRC-15-11	February 24, 2015	August 6-7, 2014	Summary of August 6-7, 2014 NRC FSLOCA™ Audit, Part 3 (Additional Information on open items related to RAI Responses).	ML15061A147
4	LTR-NRC-15-67	July 24, 2015	June 8, 2015	Summary of June 8, 2015 NRC FSLOCA™ Audit, Part 1 (Additional Information on open items related to RAI Responses).	ML15215A509

Westinghouse submitted to the NRC Revision 1 of TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, with three letters transmitting each TR volume individually. These letters are identified in Table 13 below. Following the submittal of Revision 1 of the TR in these letters and as a result of the ongoing review process, Westinghouse introduced changes to Revision 1 of the TR necessary to include core-wide oxidation in the uncertainty analysis and updates associated with proposed treatment of the sample size for Region II analyses. Specifically, Westinghouse submitted updates to Sections 30 and 31 of TR WCAP-16996-P/ WCAP-16996-NP, Revision 1, containing the main changes to the submitted TR Revision 1 related to the above topics. The updated Sections 30 and 31 of TR WCAP-16996-P/ WCAP-16996-NP, Revision 1, were transmitted to the NRC with letter LTR-NRC-15-88. Finally, in the FSLOCA™ EM roadmap document, provided in letter LTR-NRC-15-91 and identified in Table 10 above, Westinghouse provided further updates to Revision 1 of the TR WCAP-16996-P/WCAP-16996-NP to correct errata discovered in TR Revision 1 and reflect the updated core-wide oxidation treatment, except for Sections 30 and 31 transmitted in LTR-NRC-15-88 as discussed above. It was also clarified in the FSLOCA™ EM roadmap document in letter LTR-NRC-15-91, that "all of the updates from LTR-NRC-15-88 and herein will be reflected in the approved version of the Topical Report." Westinghouse letters LTR-NRC-15-88 and LTR-NRC-15-91 are also listed in Table 13 below.

Table 13: Identification of Westinghouse Letters Submitting TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1 and Following Updates to TR Revision 1

No.	Westinghouse Letter	Date	Document Description	ADAMS Accession No.
1	LTR-NRC-15-24	April 14, 2015	WCAP-16996-P Volume I, Revision 1 and WCAP-16996-NP Volume I, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology) - WCOBRA/TRAC-TF2 Models and Correlations."	ML15112A365
2	LTR-NRC-15-54	June 29, 2015	WCAP-16996-P Volume II, Revision 1 and WCAP-16996-NP Volume II, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology) - WCOBRA/TRAC-TF2 Assessment."	ML15202A078
3	LTR-NRC-15-83	October 1, 2015	WCAP-16996-P Volume III, Revision 1 and WCAP-16996-NP Volume III, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology) - FULL SPECTRUM™ LOCA Uncertainty Methodology and Demonstration Plant Analysis."	ML15292A351
4	LTR-NRC-15-88	October 12, 2015	Updated Sections 30 and 31 of WCAP-16996-P/ WCAP-16996-NP, Revision 1.	ML15302A059
5	LTR-NRC-15-91	October 20, 2015	Updates to WCAP-16996-P/WCAP-16996-NP, Revision 1, to correct errata discovered in TR Revision 1 and reflect the updated core-wide oxidation treatment.	ML15295A165
6	LTR-NRC-17-47 (See App. A)	May 31, 2017	Supplemental Package to Correct the FSLOCA EM Statistical Method for Region II (Proprietary /Non-Proprietary)	ML17157B405

4.2 FULL SPECTRUM™ LOCA Methodology and RG 1.203 Regulatory Positions

As discussed in Section 3.1 of this report, the FULL SPECTRUM™ LOCA EM was developed consistently with RG 1.203, whereas the previously approved methodologies ASTRUM (WCAP-16009-P-A) and CQD (WCAP-12945-P-A) were based on RG 1.157. The following sections summarize the review of the FSLOCA™ EM when compared to the requirements of Regulatory Positions 1 through 5 in RG 1.203, of which Regulatory Position 1 includes the 20 EMDAP steps.

4.2.1 Regulatory Position 1: EMDAP

This section provides a compliance summary description of the FSLOCA™ EM following the first four EMDAP principles along with the pertaining twenty steps based on the requirements provided in Regulatory Position 1, "Evaluation Model Development and Assessment Process (EMDAP)," in RG 1.203. Considerations related to the adequacy decision to determine whether the EM meets an adequacy standard for performing plant event analyses and conclude the EMDAP are also provided.

Element 1: Determine Requirements for the Evaluation Model (Steps 1 – 4)

The four steps in this element serve the goal of determining the exact application envelope of the EM.

Step 1: Specify Analysis Purpose, Transient Class, and Power Plant Class

TR WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, documents a methodology that was developed by Westinghouse to perform BE analyses of LOCA events for the entire spectrum of break sizes, including SBLOCA, IBLOCA, and LBLOCA transients, occurring in a certain group of PWR plant designs. The scenario, addressed by the FSLOCA™ methodology, is a postulated LOCA initiated by an instantaneous rupture of a RCS pipe with the most limiting single failure to the ECCS. The break type considered is either a double-ended guillotine (DEG), defined as a complete severance of the pipe resulting in unimpeded flow from either end, or a split break, defined as a partial tear. The break sizes covered by the WEC FSLOCA™ BE EM methodology include any break size with a break flow which is beyond the capacity of the normal charging pumps up to and including a DEG rupture with a break flow area equal to two times the pipe area. With regard to break location, WCAP-16996-P/ WCAP-16996-NP, Volumes I, II, and III, Revision 1, "Executive Summary," states that "the new EM is intended to resolve the full spectrum of LOCA scenarios which result from a postulated break in the cold leg of a pressurized water reactor."

During the review process, the applicant clarified that an initial approval for the application of the FSLOCA™ EM to Westinghouse designed three-loop plants only was sought. Following such an initial approval, Westinghouse indicated that in a longer run it would pursue an approval of the FSLOCA™ EM to analyze Westinghouse designed four-loop plants with CL ECCS injection, Westinghouse designed two-loop plants with UPI and CE designs. Westinghouse made this important clarification in the August 2013 NRC audit of the FSLOCA™ EM.

By determining the specific analysis purpose, transient class, and power plant class, Westinghouse fulfilled the requirements for EMDAP Step 1.

Step 2: Specify Figures of Merit

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, Section 1.2.2, "EMDAP Element 1 (Step 2): Specification of Figures of Merit," specifies that for the purpose of a LOCA analysis, the figures of merit are the first three criteria of 10 CFR 50.46: (1) Peak Clad Temperature (PCT), (2) Maximum Local Oxidation (MLO), and (3) Core-Wide Oxidation (CWO).

Additional code performance measures were also used in code assessments presented in the TR as physical tracking points and proof of accuracy. By specifying these specific figures of merit, Westinghouse fulfilled the requirements for EMDAP Step 2.

Step 3: Identify Systems, Components, Phases, Geometries, Fields, and Processes That Must Be Modeled

The systems, components, phases, geometries, fields, and processes subject to modeling in the FSLOCA™ EM are defined though the phenomena identification and ranking table (PIRT) process described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, Section 2.3.2, "Identification of System, Components, Processes and Ranking." Thus, Westinghouse fulfilled the requirements for EMDAP Step 3.

Step 4: Identify and Rank Key Phenomena and Processes

A single PIRT was provided for the FSLOCA™ methodology using existing LBLOCA and SBLOCA PIRTs previously developed by Westinghouse. Three ranking criteria designating levels of high (H), medium (M), and low (L) importance for considered processes were used. Table 2-1, "PIRT for Full Spectrum LOCA for Westinghouse and Combustion Engineering Plants," WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, provides a summary of the FSLOCA phenomena and the relative rankings of processes. In this way, Westinghouse fulfilled the requirements for EMDAP Step 4.

Element 2: Develop an Assessment Base Consistent with the Determined Requirements (Steps 5 – 9)

Step 5: Specify Objectives for Assessment Base

The FSLOCA™ assessment database was constructed to include three important elements:

1. SETs used to develop and assess groups of empirical correlations and other closure models associated to the important phenomena.
2. Integral Effect Tests (IETs) used to assess system interactions and global code capability.
3. Simple test problems used to illustrate fundamental calculational device capability.

Regulatory Guide 1.203 refers to two additional categories: 1) plant transient data (if available) and 2) benchmarks with other codes (optional). Both categories were not included in the FSLOCA™ assessment database, which is found acceptable by the NRC staff as no suitable plant LOCA data exists in the first category and the second one is optional. Thus, the requirements for EMDAP Step 5 were fulfilled by Westinghouse.

Step 6: Perform Scaling Analysis and Identify Similarity Criteria

WCAP-16996-P/WCAP-16996-NP, Volume I, "WCOBRA/TRAC-TF2 Models and Correlations," Sections 3 through 11 include scaling considerations to address scaling and applicability concerns of the code models from a bottom-up viewpoint and provide statements regarding their scaling and applicability for the purpose of LOCA analysis in PWRs. In addition, considerations related to scaling analysis are presented in Volumes II, "WCOBRA/TRAC-TF2 Assessment," for each SET and IET included in the code assessment. By providing this information, Westinghouse fulfilled the requirements for EMDAP Step 6.

Step 7: Identify Existing Data and/or Perform Integral Effects Tests and Separate Effects Tests to Complete the Database

A systematic process for identification of a comprehensive assessment data base is outlined in Section 2.6, "Development of the Assessment Database." The validation and verification (V&V) database for the FSLOCA™ EM development used most of the database for the previously approved BE LBLOCA methodology (WCAP-12945-P-A) to confirm LBLOCA applicability of the new WCOBRA/TRAC-TF2 code. In addition, the validation basis was extended to cover small and intermediate breaks. The FSLOCA™ EM development was based on two distinct datasets. One dataset was used for the development of physical models and correlations necessary to close the conservation equations, as presented in WCAP-16996-P/WCAP-16996-NP, Volume I, "WCOBRA/TRAC-TF2 Models and Correlations," and an independent dataset was utilized for the code assessment described in Volume II, "WCOBRA/TRAC-TF2 Assessment." The overall assessment basis is presented in Table 2-3, "V&V Matrix for Large Break LOCA Sub-Scenario, Phases: Blowdown and Refill," Table 2-4, "Table 2-4 V&V Matrix for Large Break LOCA Sub-Scenario, Phases: Reflood and Refill," Table 2-5, "V&V Matrix for Small Break LOCA Processes, Separate Effect Tests," and Table 2-6, "V&V Matrix for Small Break LOCA Processes, Integral Effect Tests," in Volume I. Thus, the requirements for EMDAP Step 7 were fulfilled by Westinghouse.

Step 8: Evaluate Effects of Integral Effects Test Distortions and Separate Effects Test Scaleup Capability

Identification and consideration of IETs distortions and SETs scaleup capability are provided in Volume II as part of describing each test considered in the methodology assessment. In addition, Sections 3 through 11 in Volume I include such considerations as appropriate on a case-specific basis. Therefore, it is concluded that the requirements for EMDAP Step 8 were fulfilled by Westinghouse.

Step 9: Determine Experimental Uncertainties as Appropriate

Regarding uncertainties in the utilized database, possible contributing sources, such as related to the uncertainty in the test measurements or associated with the data reduction process, were given consideration in the FSLOCA™ EM development. These characterizations of uncertainties were provided based on availability of information and relevant considerations were given in the uncertainty analysis using the FSLOCA™ methodology. In this way, the requirements for EMDAP Step 9 were fulfilled by Westinghouse.

Element 3: Develop the Evaluation Model (Steps 10 – 12)

Regulatory Guide 1.203 defines an EM as "a collection of calculational devices (codes and procedures) developed and organized to meet the requirements established in Element 1" discussed previously. This element consists of three steps as presented in the following.

Step 10: Establish an Evaluation Model Development Plan

Section 2.5, "WCOBRA/TRAC-TF2 Development Strategy," summarizes the EM development plan for the FSLOCA™ EM and presents the software development plan for WCOBRA/TRAC-TF2. Regulatory Guide 1.203 Step 10 identifies six areas of focus (design specifications for the calculational device, documentation requirements, programming standards and procedures, transportability requirements, quality assurance procedures, configuration control procedures) and Section 1.2.7, "EMDAP Element 3 (Steps 10, 11 and 12): Develop Evaluation Model," explains that the WCOBRA/TRAC-TF2 development plan followed software development standards and procedures, which are an integral part of Westinghouse Software Development Quality Assurance (QA) procedures and best practices. According to Section 1.2.7, such procedures satisfy RG 1.203 guidelines, which identify the following specific focal areas: (1) design specifications, (2) documentation requirements, (3) programming standards and procedures, (4) transportability requirements, (5) quality assurance procedures, and (6) configuration control procedures. Therefore, it is considered that Westinghouse fulfilled the requirements for EMDAP Step 10.

Step 11: Establish Evaluation Model Structure

The general structure requirements and functional requirements for the 3D vessel module and the 1D (primary loops) module in FSLOCA™ EM are presented in Section 2.5, "WCOBRA/TRAC-TF2 Development Strategy." RG 1.203 Step 11 identifies six ingredients for the code structure (systems and components, constituents and phases, field equations, closure relations, numerics, additional features) and the FSLOCA™ EM structure incorporates all six of them. In this way, the requirements for EMDAP Step 11 were fulfilled by Westinghouse.

Step 12: Develop or Incorporate Closure Models

Sections 3 through 11 of Volume I describe in detail the code structure, starting from the development of the basic conservation equations and their numerical integration, and following with the description of all the closure relationships required to close the equation set. In this way, the requirements for EMDAP Step 12 were fulfilled by Westinghouse.

Element 4: Assess the Adequacy of the Evaluation Model (Steps 13 – 20)

In the following discussion, Steps 13, 14, and 15 provide considerations related to bottom-up evaluation of models and correlations by considering their pedigree, applicability, fidelity to appropriate fundamental or SET data, and scalability as presented in Sections 3 through 11 of Volume I. The second part of the adequacy assessment is considered in EMDAP Steps 16, 17, 18, and 19 below, which provide top-down evaluations of code-governing equations, numerics, and the integrated performance of the overall EM, referred to as code V&V. It is the topic of Volume II.

Step 13: Determine Model Pedigree and Applicability to Simulate Physical Processes

The objective of examining all important closure models and correlations by considering their pedigree in terms of physical basis of a closure model, assumptions, and limitations attributed to the model, and details of the adequacy characterization at the time the model was developed, is the objective of Sections 3 through 11 of Volume I. The applicability evaluation of whether the model, as implemented in the code, is consistent with its pedigree or whether use over a broader range of conditions is justified, is also among the objectives of these sections. Thus, the requirements for EMDAP Step 13 were fulfilled by Westinghouse.

Step 14: Prepare Input and Perform Calculations to Assess Model Fidelity or Accuracy

The models or closure relationships implemented in WCOBRA/TRAC-TF2 were developed or available in the existing database literature. When specialized models were developed using specific SET data, the data was excluded from the V&V database used in Volume II for transparency in the assessment. As part of the WCOBRA/TRAC-TF2 development, some models have been evaluated and, if necessary, modified or improved, to better simulate the full spectrum of conditions expected in a LOCA transient. In this way, the requirements for EMDAP Step 14 were fulfilled by Westinghouse.

Step 15: Assess Scalability of Models

In developing the FSLOCA™ EM, the goal was to ensure that the same fundamental correlations apply over the wide range of conditions, which cover the full spectrum of break sizes. Thus, the models were not tailored to a specific scenario or break size and were based, at their fundamental level, on the local thermal-hydraulic conditions. This was the process of addressing models range applicability and scalability concerns as part of the FSLOCA™ EM development. Therefore, the requirements for EMDAP Step 15 were fulfilled by Westinghouse.

Step 16: Determine Capability of Field Equations to Represent Processes and Phenomena and the Ability of Numeric Solutions to Approximate Equation Set

WCOBRA/TRAC-TF2 field equations are considered in WCAP-16996-P/WCAP-16996-NP, Volume I, "WCOBRA/TRAC-TF2 Models and Correlations," Section 3, which describes the model basis and as-coded computational cell structure for the two-fluid, three-field (gas, continuous liquid, and entrained liquid drops) formulation including the sub-channel coordinate formulation for the 3D vessel component. The section also considers the two-phase two-fluid field equations and as-coded computational cell structure for the one-dimensional loop components. The numerical solution method for the vessel 3D component and the 1D loop components, the network matrix equation, code solution routines, and numerical stability are presented in Section 3 as well. The assessment of the capability of the integrated field equations in the code to represent intended processes and phenomena, the appropriateness of the introduced assumptions and the suitability of the numerical solution was completed on the basis of analyzing SETs, IETs, and additional numerical or analytical benchmark problems. Therefore, the requirements for EMDAP Step 16 were fulfilled by Westinghouse.

Step 17: Determine Applicability of Evaluation Model to Simulate System Components

WCOBRA/TRAC-TF2 incorporates a 3D vessel component dedicated to the modeling of the PWR reactor pressure vessel and internals. Specialized 1D components of the EM (pipe, tee, pump, pressurizer, valve, break and fill, heat structure, and containment component) were implemented to simulate the remaining PWR system components. The EM components, along with reactor kinetics and decay heat models, are described in WCAP-16996-P/WCAP-16996-NP, Volume I. A consistent noding philosophy was developed for the code validation against experimental data and for NPP applications. In addition, consistency with the PWR nodalization schemes developed for the approved WEC realistic LBLOCA methodology (WCAP-16009-P-A) was preserved to the degree possible by minimizing noding changes both in the vessel component as well as in the loops. The applicability of the EM to simulate the PWR system components was assessed on the basis of analyzing SETs, IETs, and additional numerical or analytical benchmark problems presented in Volume II. In addition, Section 20, "Additional Component Model Assessments," in Volume II presents specific studies assessing the EM accumulator component, pump component, and mass and energy conservation across the 1D/3D junction. In this way, the requirements for EMDAP Step 17 were fulfilled by Westinghouse.

<u>Step 18: Prepare Input and Perform Calculations to Assess System Interactions and Global Capability</u>

The overall behavior of the EM and interaction among sub-models were studied using IETs. Tests performed at the Rig-of-Safety Assessment (ROSA) test facility, as well as the LOFT facility, were initially selected to assess the EM for SBLOCA scenarios. In addition, experiments performed at the Loss-of-Fluid-Test (LOFT) and the large scale Cylindrical Core Test Facility (CCTF) were used to cover the LBLOCA scenarios. Nodalization and option selection were consistent between the experiment and the PWR models for important components. In addition, specific nodalization convergence studies were performed. As part of the assessment analyses presented in Volume II, differences between calculated results and experimental data for important processes and phenomena were considered and the ability of the EM to model system interactions were evaluated. Two pilot plant input decks for V. C. Summer and Beaver Valley Unit 1 three-loop PWRs were developed for LOCA applications using the FSLOCA™ EM. Therefore, the requirements for EMDAP Step 18 were fulfilled by Westinghouse.

<u>Step 19: Assess Scalability of Integrated Calculations and Data for Distortions</u>

RG 1.203 Step 19 asks for scalability evaluations to determine whether the assessment calculations and experiments exhibit unexplainable differences among facilities or between calculated and measured data for the same facility, which may indicate experimental or code scaling distortions. Instances of this nature were given consideration on a case specific basis when identified as part of the assessment analyses presented in WCAP-16996-P/ WCAP-16996-NP, Volume II. In some instances, code model changes and enhancements were implemented as part of the review process to resolve identified modeling deficiencies in code performance. In this way, the requirements for EMDAP Step 19 were fulfilled by Westinghouse.

<u>Step 20: Determine Evaluation Model Biases and Uncertainties</u>

The uncertainty part of the FSLOCA™ EM is the topic of WCAP-16996-P/ WCAP-16996-NP Volume III, "Full Spectrum LOCA Uncertainty Methodology and Demonstration Plant Analysis." Specifically, the development of the uncertainty methodology is discussed in Section 29, "Assessment of Uncertainty Elements." As part of the code assessment, model biases and uncertainties were determined and quantified as described in WCAP-16996-P/ WCAP-16996-NP, Volume II, "<u>W</u>COBRA/TRAC-TF2 Assessment." The uncertainty is propagated statistically during the plant analysis using a proposed statistical procedure described in Section 30, "Technical Basis of Statistical Procedures Applied in FULL SPECTRUM LOCA Uncertainty Methodology."

During the TR review process, the initially proposed procedure for assessing uncertainty for the small break region (Region I) in the FSLOCA™ methodology was reconsidered by Westinghouse in response to specific concerns by the NRC staff. A revised Region I analysis method was presented during the May 12-13, 2014, NRC audit of the FSLOCA™ methodology and described in Section 4.0 of Westinghouse LTR-NRC-14-29. Accordingly, Westinghouse provided a complete description of the revised approach for uncertainty assessment in the updated Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III. The uncertainty part of the FSLOCA™ EM is reviewed in detail in Section 4.7 of this SE. Therefore, it is concluded that the requirements for EMDAP Step 20 were fulfilled by Westinghouse.

EMDAP Adequacy Decision

Regulatory Guide 1.203, Part C, "Regulatory Position," Section 1, "Evaluation Model Development and Assessment Process (EMDAP)," Item 1.5, "Adequacy Decision," requires this final step to ensure that, at the end of the process, "all the earlier answers are satisfactory and that intervening activities have not invalidated previous acceptable responses." In particular, this position requires the following.

(1) If unacceptable responses to questions concerning the adequacy of the EM indicate significant EM inadequacies, the code deficiency should be corrected and the appropriate steps in the EMDAP should be repeated to evaluate the correction.

(2) EM documentation should be updated as code improvements and assessment are accomplished throughout the process.

(3) Documentation related to the phenomena identification and ranking should be revised as appropriate based on analysis, assessment, and sensitivity studies can also lead to reassessment of the EM PIRT.

Section 32.2.1 of WCAP-16996-P/WCAP-16996-NP, Volume III, "Regulatory Position 1, 'Evaluation Model Development and Assessment Process,'" states that "the adequacy decision is based on the final assessment of the WCOBRA/TRAC-TF2 code performance." To reach the decision, Westinghouse applied the following process. The FSLOCA™ EM capabilities were assessed for each of the high-ranked phenomena in the FSLOCA™ EM PIRT based on the degree of agreement between calculated results and data using the following four categorizations: (1) "excellent" with no deficiencies in code modeling, (2) "reasonable" when code exhibits minor deficiencies, (3) "minimal" when code exhibits significant deficiencies, and (4) "insufficient" when code exhibits major deficiencies. The assessment summary is documented in Table 32-1, "Summary of Assessment Results and Uncertainty Treatment for High PIRT Ranked Phenomena," which lists 23 FSLOCA™ EM PIRT high-ranked phenomena groups. Phenomena in the "minimum" and "insufficient" assessment categories would require conservative treatment in the EM. Such conservative treatment was also selected for some phenomena in the "reasonable" agreement category when "the effort of developing an uncertainty range is not justified." Table 32-1 assigns "reasonable" agreement for all identified 24 phenomena groups, of which two (Item No. 15, "Spilling Flow Treatment (Pumped SI)" and Item No. 24, "Containment Pressure") were modeled in a bounding manner for uncertainty treatment in plant analysis. Therefore, it is concluded that the requirements for the EMDAP adequacy decision step were fulfilled by Westinghouse thus meeting the requirements in RG 1.203 Part C, "Regulatory Position," Section 1, "Evaluation Model Development and Assessment Process (EMDAP)."

4.2.2 Regulatory Position 2: Quality Assurance

The fifth principle of the EMDAP in RG 1.203 requires the applicant "Follow an appropriate quality assurance protocol during the EMDAP." The principle identifies the quality assurance standards, as required in Appendix B to 10 CFR Part 50, as a key feature of the development and assessment process. Section III, "Design Control," in Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50, specifically requires that design control measures shall be applied to items such as the following: reactor physics, stress, thermal, hydraulic, and accident analyses;…" With regard to the FSLOCA™ EM, Section V, "Instructions, Procedures, and Drawings," Section VI, "Document Control," Section XVI, "Corrective Action," and Section XVII, "Quality Assurance Records," in Appendix B to 10 CFR Part 50 are also relevant to the EMDAP. In identifying this principle, RG 1.203 also specifies the need for a peer review by independent experts when complex computer codes are involved.

Section 1.2 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, "Mapping of FSLOCA EM Development to Regulatory Guidance, Regulatory Guide 1.203 (EMDAP)," states that quality assurance standards, as required in Appendix B to 10 CFR Part 50, were followed during the development and assessment of WCOBRA/TRAC-TF2 and associated documentation. It also mentions that "several engineering design reviews, which included a panel of independent experts, were held at different stages of the development process." It explains that the code development plan for WCOBRA/TRAC-TF2 "followed software development standards and procedures, which are an integral part of Westinghouse Software Development Quality Assurance (QA) procedures and best practices" and states that "such procedures satisfy RG 1.203 guidelines, such as design specifications, documentation requirements, programming standards and procedures, transportability requirements, quality assurance procedures and configuration control procedures." When it comes to EM reviews, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, Section 32.2.2, "Regulatory Position 2, "Quality Assurance"," explains that "an independent and interdisciplinary design review team was convened five separate times over the course of the development and once during the licensing of the FSLOCA EM in order to review major components of the methodology and important decisions made during the methodology development." Based on the above, it is concluded that the requirements in RG 1.203 Regulatory Position 2, "Quality Assurance," were fulfilled by Westinghouse.

4.2.3 Regulatory Position 3: Documentation

The sixth principle of the EMDAP in RG 1.203 requires the applicant "provide comprehensive, accurate, up-to-date documentation" that "allows appraisal of the EM application to the postulated scenario." Specifically, RG 1.203 Part C, "Regulatory Position," Item 3, "Documentation," identifies the following seven categories of information regarding the EM documentation and provides specific requirements for proper EM documentation: (1) EM requirements, (2) EM methodology, (3) code description manuals, (4) user manuals and user guidelines, (5) scaling reports, (6) assessment reports, and (7) uncertainty analysis reports.

Section 32.2.3 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, "Regulatory Position 3, 'Documentation,'" explains that the FSLOCA™ EM functional requirements (Category 1 documentation) and methodology description (Category 2 documentation) are provided in Section 2 of the TR. It clarifies that Sections 3 through 11 of Volume I describe the modeling theory and associated numerical scheme and solution models thus serving as "computational device description manuals" (Category 3 documentation). Furthermore, the section explains that scaling considerations are disseminated throughout the TR instead of providing a separate scaling report (Category 5 documentation). Also, the section clarifies that Volume I presents scalability considerations as part of the "Bottom-Up" review of the closure relations, their pedigree, applicability and scalability whereas scaling analyses used to support the viability of the experimental database are presented for each test facility as described within each section of Volume II. Section 32.2.3 also states that Volume II Sections 12 through 24 "can be seen as the "WCOBRA/TRAC-TF2 assessment report"

(Category 6 documentation) that followed the intent of assessment purposes (1) through (15) as identified in RG 1.203 Part C, “Regulatory Position,” Item 3.6, “Assessment Reports.” Specifically, Section 24, “Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2,” is identified as documenting a compensating error analysis. It is explained in Section 32.2.3 that the FSLOCA™ EM uncertainty methodology (Category 7 documentation) is presented in Volume III.

With regard to user manuals and user guidelines (Category 4 documentation), RG 1.203 Part C, “Regulatory Position,” Item 3.4 requires that the user manual completely describes how to prepare all required and optional inputs while the user guidelines describe recommended practices for preparing all relevant input. Both the manual and the guidelines serve the goal of minimizing the risk of inappropriate program use by providing the following information: (1) proper use of the program for the particular plant-specific transient or accident being considered, (2) range of applicability for the transient or accident being analyzed, (3) code limitations for such transients and accidents, and (4) recommended modeling options for the transient being considered, equipment required, and choice of nodalization schemes (plant nodalization should be consistent with nodalization used in assessment cases). With regard to user manuals and user guidelines, Section 32.2.3 explains that WCOBRA/TRAC-TF2 User’s Manual is a separate document from WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III. Regarding guidelines on noding and modeling strategy, Section 32.2.3 refers for discussion in Section 26 of TR Volume III and states that “reinforcing noding consistency to the extent practical between the SETs, IETs and the PWR ensure that same conclusions with respect to biases and uncertainties derived from the code and model assessments are applicable to the PWR LOCA simulations for which the EM was designed.” Section 32.2.3 also states that “exceptions to the general noding philosophy are discussed and justified on a case by case basis throughout the report.” Based on the review of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, it is found that the requirements in RG 1.203 Regulatory Position 2, “Quality Assurance,” were fulfilled by Westinghouse.

4.2.4 Regulatory Position 4: General Purpose Computer Programs

The FSLOCA™ EM is based on the general purpose transient analysis computer program WCOBRA/TRAC-TF2. Section 3.1.1 of this report describes the FSLOCA™ EM methodological background. The EM was developed to analyze a class of transient events (scenarios) defined as a postulated LOCA that is initiated by an instantaneous rupture of an RCS pipe in a class of PWR plants. As described in Section 3.1.1 of this report for EMDAP Step 1, the break type considered is either a DEG, defined as a complete severance of the pipe resulting in unimpeded flow from either end, or a split break, defined as a partial tear. Importantly, the break size considered for the latter type includes any break size resulting in a break flow that is beyond the capacity of the normal charging pumps. As the BE EM name indicates by itself, the proposed methodology was developed to analyze LOCA events resulting from the entire size spectrum of possible breaks on a generic basis. With regard to the long-term cooling phase following a LOCA, WCAP-16996-P/WCAP-16996-NP, Volume III Section 32, “Methodology Summary,” states that “the Westinghouse methodology used to satisfy the long-term cooling criterion defined in 10 CFR 50.46(b)(5) is unaffected by the use of best-estimate techniques for the short-term transient calculation.” In reference to the same criterion, Section 30, “Technical Basis of Statistical Procedures Applied in FULL SPECTRUM LOCA Uncertainty Methodology,” sates that “typically the last criterion (long-term cooling) is satisfied outside the LOCA analysis.” During the TR review process, the staff questioned the supporting technical basis for long-term cooling, which was the subject of round one RAI No. 7 issued by NRC. In its response to this RAI, provided in LTR-NRC-13-37, Westinghouse clarified that “the FSLOCA methodology does not treat boric acid precipitation, and long-term cooling cannot be completely addressed with this methodology. Therefore, the long-term cooling criterion defined in 10 CFR 50.46(b)(5) cannot be stated as being satisfied by application of the FSLOCA methodology." This restriction of the FSLOCA™ EM, which defines its applicability range as being exclusive of analyzing the long-term core cooling phase of postulated LOCA transients for the purpose of demonstrating compliance with 10 CFR 50.46(b)(5), is reflected in the proposed FSLOCA™ EM **Limitation No. 1** formulated below.

Limitation No. 1: FSLOCA™ EM Applicability with Regard to LOCA Transient Phases

The FSLOCA™ EM applicability for performing PWR LOCA analyses is defined in terms of applicable accident transient phases so that the FSLOCA™ EM cannot be applied for analyzing the long-term core cooling phase of LOCA transients for the purpose of demonstrating compliance with the long-term core cooling requirement set forth in 10 CFR 50.46(b)(5). This limitation specifically addresses the condition that the FSLOCA™ EM does not treat boric acid precipitation and therefore lacks capabilities to address adequately this aspect of post-LOCA long-term core cooling.

During the review process, Westinghouse clarified that the FSLOCA™ EM was intended to cover the same class of PWR power plants that were included in the previously approved LBLOCA BE methodology (ASTRUM): Westinghouse designed three- and four-loop plants with CL ECCS injection, and in the near future, Westinghouse designed two-loop plants with UPI, and CE designs. Regarding the current application, WCAP-16996-P/ WCAP-16996-NP, Volume I, Section 2.4, "Requirement Analysis/Assessment for WCOBRA/TRAC-TF2 Models," states that "however, for the current implementation, the FSLOCA EM focus is limited to cold leg injection PWRs." Furthermore, as stated at the August 12-15, 2013, NRC audit of the FSLOCA™ EM and documented in the NRC audit summary in LTR-NRC-13-70, Westinghouse clarified that an initial approval for the application of the FSLOCA™ EM to Westinghouse designed three- and four loop PWR plants only was sought. Accordingly and as addressed in RG 1.203, Regulatory Position 4, "General Purpose Computer Programs," this restriction of the FSLOCA™ EM applicability is addressed in the proposed FSLOCA™ EM **Limitation No. 2** formulated below.

Limitation No. 2: FSLOCA™ EM Applicability with Regard to Type of PWR Plants

The FSLOCA™ EM applicability for performing PWR LOCA analyses is defined in terms of applicable types of PWR plants so that the EM can be applied for LOCA analyses of Westinghouse designed three-loop and four-loop PWR plants only.

Plant-specific applications will generally be considered acceptable if they follow the modeling guidelines to be developed by Westinghouse to meet the requirement pertinent to FSLOCA described in WCAP-16996-P/WCAP-16996-NP, Revision 1, LTR-NRC-17-47, LTR-NRC-15-88, and LTR-NRC-15-102, Revision 2, in addition to complying with and meeting the NRC limitations and conditions set forth herein. Plant-specific licensing actions referencing FSLOCA analyses should include a statement summarizing the extent to which the guidelines were followed, and justification for any departures. Should the NRC staff review determine that absolute adherence to the modeling guidelines is inappropriate for a specific plant, additional information may be requested using the RAI process?

4.2.5 Regulatory Position 5: Graded Approach to Applying EMDAP

RG 1.203 Part C, "Regulatory Position," Item 5, "Graded Approach to Applying the EMDAP Process," requires the consideration of four EM attributes when determining the scope and depth of applying the full EMDAP process to the EM on the basis of a graded approach: (1) novelty of the revised EM compared to the currently acceptable model, (2) complexity of the event being analyzed, (3) degree of conservatism in the EM, (4) extent of any plant design or operational changes that would require reanalysis.

Although the FSLOCA™ EM is an evolution of the currently approved LBLOCA EM (ASTRUM, WCAP-16009-P-A), WCAP-16996-P/WCAP-16996-NP, Volume III, Section 32.2.5, "Regulatory Position 5, 'Graded Approach to Applying the EMDAP Process,'" states that "a graded approach to the EMDAP process was deemed not practical and justifiable in this case" by the applicant. The section explains that the application of the full EMDAP process was necessary due to the following two factors: (1) the extent of the changes in the FSLOCA™ EM and (2) the novelty of including SBLOCA scenarios in the BE EM analysis events. Accordingly and as reflected by the findings made in the previous sections, it is confirmed that the full EMDAP process was applied to the FSLOCA™ EM.

4.3 FULL SPECTRUM™ LOCA PIRT Evaluation

The FSLOCA™ PIRT, summarized in WCAP-16996-P/WCAP-16996-NP, Volume I, Table 2-1, "PIRT for Full Spectrum LOCA for Westinghouse and Combustion Engineering Plants," was developed following the CSAU approach in NUREG/CR-5249 starting with the existing LBLOCA and SBLOCA PIRTs. WCAP-16996-P/WCAP-16996-NP, Volume I, Section 2.3.2, "Identification of System, Components, Processes and Ranking," provides the description of the FSLOCA™ PIRT by considering processes (phenomena) that take place during the phases of SBLOCA, IBLOCA, and LBLOCA transients as identified in Section 2.3.1, "LOCA Scenario Specification." The phases considered for an SBLOCA include blowdown, natural circulation, loop seal clearance, boiloff, and recovery. The phases of an IBLOCA include blowdown, accumulator injection, and safety injection. The phases considered for an LBLOCA include blowdown, refill, and reflood.

In round one RAI No. 3, the staff asked for more specific description of the original LBLOCA and SBLOCA PIRTs that have been approved by the NRC and used in the FSLOCA™ PIRT development. In particular, this RAI asked for identification and explanation of the differences between the original approved LBLOCA PIRT and the FSLOCA™ PIRTs for LBLOCA and IBLOCA. In addition, the RAI asked for identification of the technical basis for the original SBLOCA PIRT and explanation of the differences between the original approved SBLOCA PIRT and the FSLOCA™ PIRT for SBLOCA. In its response to this RAI, provided in LTR-NRC-13-37, Westinghouse explained that the original ranking of the LBLOCA PIRT for three- and four-loop Westinghouse plants was developed as part of the Westinghouse BE LBLOCA methodology development and was documented in Section 1-3-3-3 of WCAP-12945-P-A. The PIRT for PWRs with UPI was developed later and was presented in Section 2-4, Table 2-3 of WCAP-14449-P-A and in Section 1-2-3, Table 1-1 of the ASTRUM BE EM TR WCAP-16009-P-A. Table A-1 in Appendix-A of WCAP-16009-P-A contains an extension to CE type PWRs. The combined PIRT (Tables I-1 and A-I from WCAP-16009-P-A) was converted to use consistent ranking and added to the LBLOCA portion of the integrated FSLOCA™ PIRT in WCAP-16996-P/WCAP-16996-NP. The RAI response provides also a detailed comparison of the FSLOCA™ LBLOCA PIRT against the WCAP-12945-P-A/WCAP-16009-P-A PIRT and documents the identified differences in Table 1-1 of the response. It was also clarified in the

RAI response that the previously developed SBLOCA PIRT was documented in Section 1-4, "Small Break LOCA PIRT," of WCAP-14936, Volumes 1 through 4, "Code Qualification Document for Best Estimate Small Break LOCA Analysis," August 2001, and provided details regarding its development. Table 2-1 in the RAI response provides a detailed comparison of the FSLOCA™ SBLOCA PIRT against the SBLOCA PIRT in WCAP-14936.

As a result of addressing the NRC round one RAI Nos. 36 through 39 related to fuel pellet thermal conductivity degradation (TCD) and the analysis of fuel beyond the first cycle of operation, Westinghouse determined that **[**

] were necessary. Rod internal pressure can increase with increased rod burnup and if cladding temperatures become high enough due to increased stored energy when TCD is accounted for, rod burst early in the LOCA transient can occur. Accordingly, **[**

] to account adequately for the importance of the processes when considering increased initial stored energy from TCD in high burnup fuel.

Based on the review, the NRC staff determined that the FSLOCA™ PIRT, as presented in WCAP-16996-P/ WCAP-16996-NP, and along with the clarifications provided in the response to NRC round one RAI No. 3 and the modification based on the additional information provided in the responses to NRC round one RAI Nos. 36 through No. 39, is based on an adequate technical basis that supports the SBLOCA, IBLOCA, and LBLOCA parts of the developed unified PIRT. The integral FSLOCA™ PIRT covers appropriately and with an adequate degree of detail the governing phenomena that take place during the typical phases for each of the three categories of LOCA transients (SBLOCA, IBLOCA, and LBLOCA) subject to analysis with the FSLOCA™ BE EM. Thus, FSLOCA™ PIRT serves its intended goal as part of the EMDAP process that was followed in the development of the FSLOCA™ BE EM in WCAP-16996-P/ WCAP-16996-NP.

4.4 WCOBRA/TRAC-TF2 Code Assessment Matrices

Separate FSLOCA™ Validation & Verification (V&V) matrices were developed for the WCOBRA/TRAC-TF2 assessment for LBLOCA and SBLOCA modeling. The approach for developing these matrices was based on the FSLOCA™ PIRT. The high and medium ranked phenomena in the FSLOCA™ PIRT defined the phenomenological content of the V&V matrices and then available SETs and IETs were selected and included to provide the database for the WCOBRA/TRAC-TF2 assessment.

4.4.1 LBLOCA V&V Assessment Matrices

As explained in WCAP-16996-P/WCAP-16996-NP, Volume I, Section 2.6.2, "Definition of the Assessment Base (SETs and IETs)," the database used to confirm the LBLOCA applicability of the new WCOBRA/TRAC-TF2 code included most of a large V&V database that was considered for the previously approved ASTRUM BE LBLOCA Methodology (WCAP-12945-P-A). Table 2-3 in WCAP-16996-P/WCAP-16996-NP documents the V&V matrix for the LBLOCA phases of blowdown and refill and includes eight different SET and IET facilities. Tables 2-4 documents the V&V matrix for the LBLOCA refill and reflood phases and contains 10 different SETs and IETs. Both tables list each individual IET/SET separately. The same V&V matrices are also shown in Tables 24.2-1 and 24.2-2 in Volume III of WCAP-16996-P/WCAP-16996-NP, which are structured so that each individual phenomenon is listed in a separate row.

The NRC staff found that the V&V database for WCOBRA/TRAC-TF2 assessment for LBLOCAs was based on the previously approved ASTRUM BE LBLOCA Methodology (WCAP-16009-P-A). Taking into account the developmental evolution of the FSLOCA™ BE EM and the application history of the approved ASTRUM BE LBLOCA Methodology, staff concluded that the developed V&V database, as documented in the V&V LBLOCA matrices, is adequate for the purpose of assessing the applicability of WCOBRA/TRAC-TF2 for LBLOCA analyses.

4.4.2 SBLOCA V&V Assessment Matrices

After establishing the LBLOCA V&V matrices, the next step followed in the development of the WCOBRA/TRAC-TF2 validation database was to extend the LBLOCA basis to cover SBLOCA and IBLOCA transients. This was done by developing two separate SBLOCA V&V matrices based on available SETs and IETs. One matrix included selected SETs and the second matrix consisted of selected IETs. In both cases, the selected tests represented experiments typically used in the assessment of thermal-hydraulic codes for SBLOCA applications. Table 2-5, reproduced also as Table 24.2-3, documents the V&V matrix with SETs for SBLOCA whereas Table 2-6, shown also as Table 24.2-4, represents the V&V matrix with IETs for SBLOCA. Both V&V matrices are considered separately in the following two sections.

4.4.2.1 SBLOCA V&V SET Assessment Matrix

The V&V matrix with SETs, developed for SBLOCA assessment of WCOBRA/TRAC-TF2, served as a database for achieving a broader goal than a typical code assessment as previously performed for benchmarking of conservative SBLOCA EMs developed in accordance with Appendix K to 10 CFR Part 50. The reason for this is that the SBLOCA SET V&V matrix was also developed and used for rigorous WCOBRA/TRAC-TF2 assessment to develop the uncertainty ranges for key thermal-hydraulic parameters describing phenomena and processes of importance for SBLOCA prediction and related uncertainty calculation. As part of this process, separate databases were used for model assessment and development of uncertainty ranges of relevant parameters. These assessment studies are presented in detail in Volume II of WCAP-16996-P/WCAP-16996-NP.

Taking into account the above provided considerations and the review of the SBLOCA SET assessment studies presented in detail in Volume II of WCAP-16996-P/ WCAP-16996-NP, it is concluded that the developed SBLOCA SET V&V database and the corresponding matrix are adequate for the purpose of assessing individual processes and phenomena for demonstration of the applicability of the WCOBRA/TRAC-TF2 code to SBLOCA applications.

4.4.2.2 SBLOCA V&V IET Assessment Matrix

The review of the SBLOCA IET V&V matrix and IET assessment studies, presented in the original submittal of WCAP-16996-P/WCAP-16996-NP, Volume II, Revision 0, revealed that the IET database used for WCOBRA/TRAC-TF2 assessment for SBLOCA analysis was insufficient. Two main considerations contributed to this finding. The fact that the FSLOCA™ EM was based on the ASTRUM EM, which as approved by the NRC and applied for LBLOCA analyses only, contributed to this finding as the WCOBRA/TRAC-TF2 code lacked an established assessment and application record for SBLOCA analyses. In addition, the IET database applied to assess WCOBRA/TRAC-TF2 for SBLOCA analysis as part of the FSLOCA™ EM development was found insufficient as discussed below.

WCAP-16996-P/WCAP-16996-NP, Volume II, Revision 0, Section 21, "ROSA-IV Test Simulations," presents WCOBRA/TRAC-TF2 assessment results against SBLOCA IETs conducted at the LSTF as part of the ROSA No. 4 (ROSA-IV) experimental program. In addition, Section 22, "Loss-Of-Fluid Test (LOFT) Integral Test," Subsection 22.6, "Small Break LOFT Simulation Using WCOBRA/TRAC-TF2," presents assessment results against the 2.5 percent small break LOFT Test L3-1. However, these assessments did not reveal WCOBRA/TRAC-TF2 capabilities to predict core level swell, post-critical heat flux (CHF) heat transfer, fuel rod temperatures, and other important parameters under elevated core heat-up as observed experimentally in other test facilities such as Semiscale. The single Semiscale boiloff test assessment presented in Section 23, "Additional Validation and Numerical Problems," Subsection 23.1.2, "Semiscale Tests," was performed only for the boiloff phase of Semiscale Test S-07-10D (10% cold leg break) that followed the loop seal clearance in both test loops. This assessment was performed in a SET configuration with a model that employed only a VESSEL component representing the Semiscale pressure vessel. Boundary conditions were used to specify the mass flow between the external downcomer and the test vessel and BREAK components were connected to the hot legs to provide the depressurization boundary conditions based on the test measurement.

To address the identified concern related to the SBLOCA IET V&V matrix and the SBLOCA IET assessment database, the NRC issued round one RAI Nos. 109, 110, and 111, which requested Westinghouse perform additional WCOBRA/TRAC-TF2 assessments based on Semiscale Mod-2C, IETs, S-LH-1 and S-LH-2 and consider sensitivity studies related to the steam generator (SG) nodalization as it pertains to the Semiscale facility configuration. Despite the inherent scaling distortions and facility limitations associated with Semiscale, it was found necessary to request including Semiscale tests in the WCOBRA/TRAC-TF2 IET assessment database for SBLOCAs. This was done in consideration of the importance of governing SBLOCA phenomena and the degree of their manifestation as observed in Semiscale tests.

Westinghouse submitted its final responses to NRC round one RAI Nos. 109, 110, and 111 in letter LTR-NRC-14-70 providing the requested additional Semiscale IET assessments. The RAI responses included a description of the WCOBRA/TRAC-TF2 model used to simulate the Semiscale Mod-2C facility configuration, simulation results for Test S-LH-1 and Test S-LH-2, and comparison against experimental data. In addition, sensitivity results related to the SG nodalization were provided. The responses were reviewed and specific findings documented in an RAI review template and discussed with Westinghouse at the June 8, 2015, NRC audit of the FSLOCA™ EM. Following the audit, Westinghouse provided additional information on the remaining open items related to the final responses to these NRC round one RAIs in LTR-NRC-15-67. The provided additional information on the identified open items was reviewed and found sufficient to resolve them thus closing round one RAI Nos. 109, 110, and 111. This conclusion was augmented by comparing the FSLOCA™ small break IET assessment database with the databases used in two other SBLOCA EM submittals that have been reviewed by the NRC. These EMs are documented in TR EMF-2328(NP)(A), Revision 0, "PWR Small Break LOCA Evaluation Model, S-RELAP5 Based," Framatome ANP Richland, Inc., March 2001 and in TR MUAP-07013-NP-A(R2), Revision 2, "Small Break LOCA Methodology for US-APWR," Mitsubishi Heavy Industries, Ltd., June 2013, respectively. Both EMs have been approved pursuant to 10 CFR Part 50 Appendix K. In its considerations related to the review of the S-RELAP5 SBLOCA EM, the NRC Advisory Committee on Reactor Safeguards (ACRS) relied on comparisons with system tests, in particular Semiscale data, for increasing confidence in the code's suitability for analyzing SBLOCAs (see ACRS letter from G. E. Apostolakis to W. D. Travers, "Review of the Siemens Power Corporation S-RELAP5 Code to Appendix K Small-Break Loss-Of-Coolant Accident Analyses," ACRSR-1929, February 13, 2001, ADAMS Accession No. ML010460306). More recently, the NRC staff requested and relied on assessments against Semiscale small break tests in evaluating the M-RELAP5 SBLOCA EM (see NRC Letter from J. Ciocco to Y. Ogata, "United States – Advanced Pressurized Water Reactor Final Topical Report Safety Evaluation for Topical Report MUAP-7013-P, Revision 2, 'Small Break LOCA Methodology for US-APWR,'" ADAMS Accession No. ML13233A211). The SBLOCA IET assessment databases for these EMs are compared in Table 14 below. In addition, the table details the Three Mile Island (TMI) Action Plan Requirements related to assessment of EMs for SBLOCA modeling. TMI Action Plan Task II.K, "Measures to Mitigate Small-Break Loss-Of-Coolant Accidents and Loss-Of-Feedwater Accidents," Item II.K.3(30), "Revised Small-Break LOCA Methods to Show Compliance with 10 CFR 50, Appendix K," asked for additional system verification of SBLOCA evaluation models in accordance with Part II, "Required Documentation," Item 4 in 10 CFR Part 50 Appendix K. In this regard, NUREG-0660, "NRC Action Plan Developed as a Result of the TMI-2 Accident," states that "the revised analyses were to account for comparisons with experimental data, including data from the LOFT and Semiscale test facilities." Specifically, the provisions for code assessment for SBLOCA listed in NUREG-0737, "Clarification of TMI Action Plan Requirements," November 1980, identify two system tests, Semiscale Test S-07-10D and LOFT Test L3-1, which are listed in Table 14. It is seen that the FSLOCA™ EM is in line with when it comes to the number of IET facilities considered while exceeding the number of individual tests analyzed.

Table 14: Comparison of WCOBRA/TRAC-TF2 SBLOCA IET Assessment Database with Other EM Databases

Facility	Experiment	**NUREG-0737** TMI Action Plan Item II.K.3(30)	Evaluation Methodology		
			S-RELAP5 EMF-2328 (Appendix K)	**M-RELAP5** MUAP-07013 (Appendix K)	**WC/T-TF2** WCAP-16996 (Best-Estimate)
LOFT 1:55 volume	LP-SB-03 (0.45%) (Δ)		▪		
	L3-1 (2.5%)	▪		▪	▪
Semiscale 1:1705 volume 1:1 elevation 2 non-equal volume loops	S-07-10D	▪			
	S-UT-8, Mod-2A (5%)		▪		
	S-LH-1, Mod-2C (5%)			▪	▪
	S-LH-2, Mod-2C (5%)				▪
BETHSY 1:100 volume 1:1 height 3 loops	9.1b, ISP-27 (0.5%)		▪		
ROSA/LSTF 1/48 volume 2 equal-volume loops	SB-CL-18, ISP-26 (5%)			▪	▪
	SB-CL-09 (10%)			▪	
	IB-CL-02 (17%)			▪	
	SB-CL-05 (5%)				▪
	SB-CL-14 (10%)				▪
	SB-CL-01 (2.5%)				▪
	SB-CL-02 (2.5%)				▪
	SB-CL-03 (2.5%)				▪
	SB-CL-12 (0.5%)				▪
	SB-CL-15 (0.5%)				▪
	SB-CL-16 (0.5%)				▪
Total Number of Facilities (Tests)		**2 (2)**	**3 (3)**	**3 (5)**	**3 (12)**

(Δ) Percentage number provides break area relative to cold leg area.

4.5 WCOBRA/TRAC-TF2 Code and Evaluation Models Application Changes

The general architecture of the WCOBRA/TRAC-TF2 code was developed as a combination of the 1D capabilities of TRAC-PF1/MOD2 with the 3D VESSEL module of the COBRA-TF code. This was achieved by inserting the COBRA-TF 3D module, used in the approved ASTRUM and CQD methodologies, into the TRAC-PF1/MOD2 code in lieu of using the 3D component available in TRAC-PF1/MOD2. The code developmental strategy included some major updates impacting the structure of the conservation equations and the numerical scheme. One such change was a modified coupling logic at the 1D/3D junction of WCOBRA/TRAC-TF2 to accommodate the two-fluid six-equation formulation versus the previous drift-flux five-equation formulation in the 1D module. It is stated in Section 2.5.3 of WCAP-16996-P/WCAP-16996-NP that the implementation of the two-fluid six-equation formulation capabilities of TRAC-PF1/MOD2 eliminated a significant mass error due to the prior drift-flux formulation in the approved ASTRUM and CQD EMs. Another such update was the addition of the non-condensable gas transport equation in the 3D module of COBRA-TF. Sections 2.5.1, 2.5.2 and 2.5.3 of WCAP-16996-P/ WCAP-16996-NP identify code updates related to the numerical engine, the 3D module and the 1D module of WCOBRA/TRAC-TF2, respectively. The following sections address specific code changes as part of the WCOBRA/TRAC-TF2 development and review.

4.5.1 Addition of Non-Condensable Gas Transport in the 3D VESSEL Module

One of the major changes in WCOBRA/TRAC-TF2 was the addition of an explicit non-condensable gas transport continuity equation within the 3D VESSEL module of COBRA-TF. Non-condensable transport was also already implemented in TRAC-PF1/MOD2. The FSLOCA^{TM} PIRT assigns a ranking of high (H) for the safety injection period during intermediate breaks to reflect the effect of a non-condensable gas on condensation heat transfer by the presence nitrogen. The VESSEL mass continuity formulation used four 3D equations that include separate equations for the combined-gas field and for the non-condensable gas field. The formulation assumes that the non-condensable gas phase is in thermal and mechanical equilibrium with the steam phase.

The gas transport capability of WCOBRA/TRAC-TF2 was assessed against available LOFT and ACHILLES tests that simulated the effect of the non-condensable injection in the reactor downcomer and its impact on the initial core reflood process. The LOFT simulations, presented in Section 20 and Section 22 of WCAP-16996-P/WCAP-16996-NP, showed that WCOBRA/TRAC-TF2 was capable of predicting the non-condensable gas effect reasonably well compared to test data. In addition, the simulation of ACHILLES International Standard Problem 25 test, discussed in Section 20, examined the effect of nitrogen discharge at the end of accumulator blowdown and demonstrated that WCOBRA/TRAC-TF2 predicted the effects of nitrogen injection into the downcomer reasonably well. In addition, non-condensable gas transport test and condensation test thought problems were used to study how the code simulates the transport of non-condensable gas and condensation effects. Section 23 of WCAP-16996-P/WCAP-16996-NP presents the results for a condensation test using a 3D VESSEL model that analyzed the condensation process in a vessel initially filled with saturated steam at 1,000 psia with and without the presence of non-condensable gas. One case modeled the process when the connected pipe was supplying saturated steam at 1,000 psia and a second case simulated the condensation when the partial pressure of non-condensable in the pipe was set at 1,000 psia. The test demonstrated the code's capabilities in simulating the non-condensable gas transport and its impact on the condensation process using a 3D VESSEL. In addition, Section 23 of WCAP-16996-P/WCAP-16996-NP presents the results for a manometer test problem simulated with a 3D VESSEL component, in which the gas volume was filled with non-condensable gas to eliminate the complication of interfacial heat and mass transfer. Based on the presented assessment results, it is concluded that the newly added non-condensable gas transport capability in the 3D VESSEL module of WCOBRA/TRAC-TF2 was adequate for the purposes of LOCA analyses in PWRs with cold leg injection.

4.5.2 Control Rod Insertion Capability

For large breaks, the FSLOCA™ EM assumes that the reactor will shut down rapidly due to voiding in the core and no credit for control rod insertion is given for Region II breaks that are **[**

] Accordingly, the FSLOCA™ EM credits control rod drop and models negative reactivity insertion assuming a maximum rod drop time for breaks **[** **]** For smaller breaks, RCCA insertion is necessary to preclude re-criticality in the core and may impact the boron concentration assumed in the LOCA analysis. Also, the RCCA insertion leads to a slightly higher core flow rates since the thimble tubes would no longer be empty. This approach is consistent with previous findings, cited in the FSLOCA™ EM, that combined seismic and LOCA loads do not distort the control rod guide tubes and the control rods may be assumed to drop during the LOCA for cold leg breaks **[** **]** The implementation of the control rod insertion capability and its application for modeling LOCAs of various sizes in WCOBRA/TRAC-TF2 was found appropriate.

4.5.3 Addition of a **[** **]**

[

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4.5.4 Other Code Changes as Part of the Evaluation Model Development

Other code changes, as identified in WCAP-16996-P/WCAP-16996-NP, Sections 2.5.1, 2.5.2 and 2.5.3, include modifications related to the following areas: **[**

] These code changes were validated through the WCOBRA/TRAC-TF2 assessment process.

4.5.5 Changes Resulting from the WCAP-16996-P/WCAP-16996-NP Review

The review of the WCAP-16996-P/WCAP-16996-NP TR resulted in additional EM changes pertaining to both the WCOBRA/TRAC-TF2 code and the FSLOCA™ EM application procedure. Such changes were implemented by Westinghouse to address safety issues, including modeling deficiencies, identified during the TR review. These changes pertain to the following main categories: (a) implementation of new models, (b) updates to existing models, (c) code changes to correct identified code errors, and (d) changes to the EM application procedure for plant analyses. Significant WCOBRA/TRAC-TF2 code changes and changes to the EM application procedure were implemented by Westinghouse as a result of the WCAP-16996-P/ WCAP-16996-NP TR NRC staff review. These changes are identified below. These changes were also reviewed as part of reviewing the corresponding features and capabilities of the FSLOCA™ EM.

(1) CCFL capability implementation in 3D VESSEL and 1D loop components.
(2) Two-phase flow interfacial drag model updates.
(3) Addition of reactor core two-phase mixture level tracking in WCOBRA/TRAC-TF2.
(4) Method updates to address thermal conductivity degradation (TCD) and other burnup related phenomena.
(5) Correction of coding errors related to decay heat modeling.
(6) Changes to the application of the EM uncertainty procedure to **[**
]
(7) Removal of the Forslund-Rohsenhow droplet wall contact model, since drops do not contact hot walls.

4.6 Evaluation of Key Models

The following sections of this SE present the evaluation of FSLOCA™ models, for which it was found necessary to propose certain limitations and/or conditions concerning the applicability of the FSLOCA™ EM for performing licensing LOCA analyses. These proposed limitations and conditions are formulated in the following sections and numbered sequentially considering Limitations No. 1 and 2 included earlier in Section 4.2.4 of this SE.

Since there are limitations associated with the key models and phenomena governing SBLOCA discussed below, it is important to provide a brief background description of the thermal and hydraulic behavior governing small breaks that produces a plant characteristic curve of PCT vs break size, particularly in the one to four inch diameter range. The NRC staff emphasizes the importance of locating the limiting break size in this small diameter range since small changes in break size in this region can produce hundreds of degrees Fahrenheit change in the cladding peak temperature, while coarse break size sampling can completely miss the worst break in this region. The NRC staff discussed the details of SBLOCA behavior and the need for a method to carefully resolve the break spectrum PCTs for these smaller breaks in “Approach to Evaluating the Small Break Region I within the PWR FULL SPECTRUM™ LOCA Methodology Topical Report WCAP-16996-P by L. Ward.” A summary of this “white paper” is discussed next because it is necessary for the understanding the basis for many of the restrictions and limitations.

The NRC staff presented recommendations regarding the sampling analysis and input requirements for the uncertainty evaluation of Region I comprising the small break part of the break spectrum within the framework of the best estimate FULL SPECTRUM™ LOCA (FSLOCA™) Methodology in WCAP-16996-P/WCAP-16996-NP. Specifically, this discussion evaluates the small break spectrum consisting of break sizes within the range from 0.02 ft^2 to 1.0 ft^2. It is noted that LBLOCAs consist of break sizes of 1.0 ft^2 up to and including the DEG break. As a result of concerns with key phenomenological models governing the small break LOCA response and the very limited amount of integral experimental validation presented in the FSLOCA™ TR, the NRC staff proposed an analysis approach aimed at compensating for identified code and methodology deficiencies. The discussion of this analysis approach is described below.

During the review of the FSLOCA™ BE methodology, the NRC staff has identified a number of concerns and key issues with the physical models, input requirements, and statistical sampling of key variables affecting the SBLOCA phenomenological behavior. These concerns were expressed throughout the review process during several audits, technical meetings, and teleconferences with the applicant. The discussion below provides some background information regarding key models affecting expected SBLOCA performance, identifies key issues and concerns, and then delineates recommendations for resolution of these key issues.

A typical small break spectrum analysis produces a characteristic PCT versus break size response, which is shown in Figure 1. Of particular significance in this response is the observed limiting break region with a maximum in the PCT at approximately 0.055 ft^2. The depicted PCT vs break size curve is typical of plants with low capacity high pressure safety injection pumps or those undergoing extended power uprates. It is important to further note that for some plants the predicted PCT can increase by a few hundred degrees Fahrenheit when the break size changes within the limiting break region from approximately 0.05 ft^2 to 0.06 ft2. For example, it has been observed for many PWR plants that the PCT can increase by ~100 ^oF when the break area changes by as little as 0.005 ft^2 within this break region so that the PCT at a 0.055 ft^2 break is considerably higher than the PCTs at both 0.05 ft^2 and 0.06 ft^2 breaks. Furthermore, this limiting break region is characterized by a RCS pressure that depressurizes to a pressure value just above the safety injection tank (SIT) or accumulator actuation pressure. Because such behavior characterizes a large number of PWR plants, it is necessary to resolve the limiting break region confining the worst break controlled entirely by the high pressure injection pump. The core uncovery period for breaks in this limiting range of relatively small breaks can be as long as 45 minutes to one hour. For some plants, the two-phase mixture level in the core can recede slowly to depths near the core mid-plane during this period. Such long term core uncovery LOCAs emphasize the significance of the BE two-phase level swell modeling and PCT, controlled by interfacial drag, steam cooling heat transfer, loop seal clearing behavior, decay heat, and condensation at the safety injection port, to name the most significant. Clearly, with the core being uncovered for a period of up to one hour, very small changes in the core two-phase mixture level during such uncovery periods can result in very large PCT changes.

Thus, the modeling of two-phase level swell is perhaps the most important of the phenomenological models governing the small break LOCA response.

While this limiting range of small break sizes is most pronounced when employing 10 CFR 50.46 Appendix K analysis assumptions, related safety concerns still require an adequate evaluation and resolution utilizing BE LOCA analysis methodologies. This is of particular importance since future increases in power levels and peak linear heat generation limits as a result of applying such BE methods in analyzing the small break region of the spectrum can produce this characteristic PCT vs break size profile with a sharply defined PCT maximum within a certain limiting break region as displayed in Figure 1. In addition, limiting break sizes can sometimes result in pressures that are just slightly above the SIT injection set point so that injection is approached, but not actuated. A slightly larger break size could just actuate the SIT's for a short period. In this case, a small amount of injection after a deeper core uncovery can often lead to the worst break. For such a break, SIT injection quickly terminates producing only a small increase in the core level as the RCS pressure quickly increases as a result of the small core level increase and higher steam addition to the RCS. Given such characteristic system behaviors, addressing the safety concern related to the evaluation of the small break region of the LOCA spectrum (Region I) requires the implementation of an approach for adequate analysis, identification, and resolution of a possible limiting break region that can occupy the lower end of the SBLOCA. The goal of such an approach is to assure that the SBLOCA region and associated limiting Figures of Merits (FOMs) are accounted for when determining the combined results that apply to the entire break spectrum, which encompasses both the small and the large break regions, Region I and Region II, respectively.

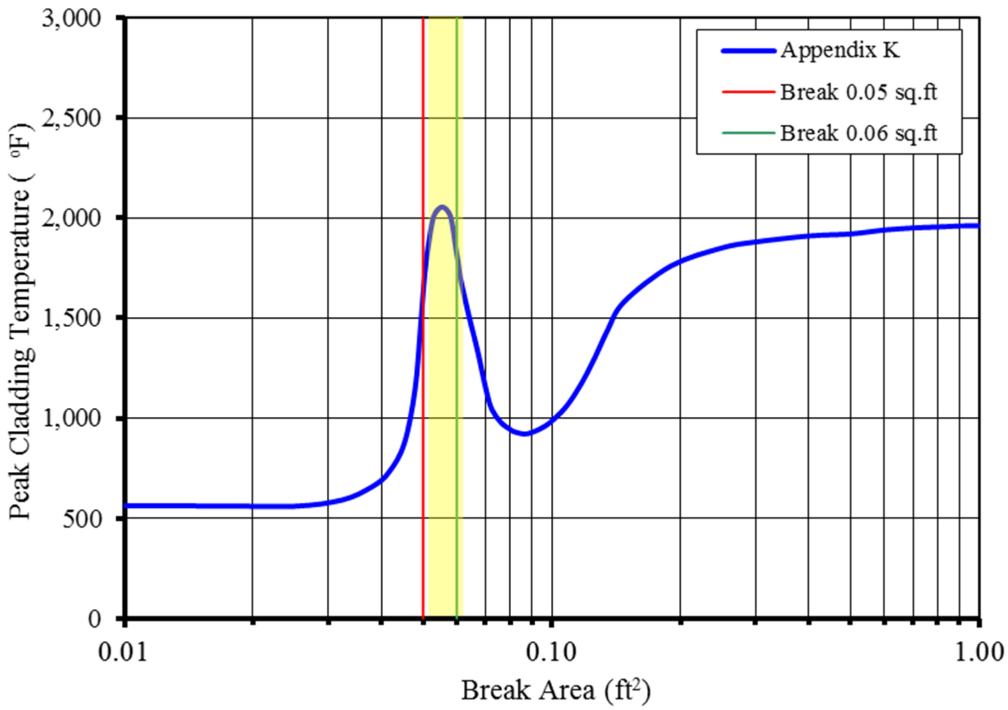

Figure 1: A Characteristic PCT Response to Break Size Variation Observed in Analyses Using 10 CFR Part 50 Appendix K and in Power Uprate Small Break LOCA Analysis

In view of the discussed characteristic behavior of the limiting small breaks, a first priority in the analysis of the SBLOCA response is an accurate prediction of the inner vessel two-phase mixture level. It is extremely important to resolve the behavior of the core response, including incurred PCT, in the critical small break region that most likely will occupy the low end of the break spectrum for Region I. It is further emphasized that it will be necessary to have accurate models capable of predicting the key phenomenological behavior governing the two-phase level response in inner vessel (i.e., lower plenum, core, and upper plenum), as these models will determine the depth and duration of any potential core uncovery. Important or key phenomenological models governing the SBLOCA response are listed below.

(1) Interfacial drag (two-phase level swell/core uncovery).
(2) Loop seal dynamics.
(3) Condensation due to emergency core cooling (ECC) injection
(4) Bypass effects (no hot leg nozzle gap or core barrel flange leakage).
(5) Heat transfer in core above two-phase level (steam cooling, thermal radiation).
(6) Steam generator (SG) condensation.
(7) SG liquid hold-up.
(8) Wall heat release.
(9) Decay heat.
(10) Non-equilibrium thermodynamics.
(11) Break flow.

The interaction of these models will determine the core two-phase mixture level in the inner vessel that will directly affect the magnitude of the PCT for the SBLOCA spectrum.

The staff review of these key models revealed a number of concerns and deficiencies, which were documented in the December 2012 technical meeting, the February 21 and 22, 2013, technical meeting, and the July and August 2013 audit meetings.

As NRC staff pointed out, a major shortcoming in the validation effort is a lack of comparisons of the WCOBRA/TRAC-TF2 code predictions to data from small break experiments on Integral Effects Test (IET) facilities. Westinghouse chose to compare the code to only two facilities, ROSA-IV and LOFT, which displayed no long term core uncovery that is characteristic of the limiting small breaks described above and illustrated in Figure 1. From the ten small break tests simulated (nine ROSA-IV and one LOFT), only three produced minimal core uncovery when the PCT was found to be less than 940 K (1,232 ^{o}F). Because of the lack of long term core uncovery and the very low PCTs observed for this facility, comparisons to this facility does not challenge the code capabilities nor does it adequately test the interaction of the key physical models governing the SBLOCA response. The NRC staff suggested additional tests from other facilities for integral experimental validation, which included SEMISCALE, LOBI, and PKL, to name a few. The lack of benchmarking of the WCOBRA/TRAC-TF2 code to other integral test facilities is considered a major validation shortcoming.

Of further concern to the NRC staff was the fact that WCOBRA/TRAC-TF2 also does not have a proven history of application for analyzing SBLOCA responses since prediction of a LBLOCA has been the focal point of the WCOBRA/TRAC LOCA analyses over the years.

The NRC staff also noted issues and concerns with the drag modeling, which determines the two-phase mixture level in the core and the clad temperatures achieved during a given SBLOCA event. The drag model displayed behavior, which affected the accuracy of the two-phase level swell modeling capabilities. Comparisons of WCOBRA/TRAC-TF2 to two-phase level swell and bundle uncovery test data showed anomalous void distribution behavior, [

] (see the attached figures in "Approach to Evaluating the Small Break Region I within the PWR FULL SPECTRUM LOCA Methodology Topical Report WCAP-16996-P", by L. Ward showing the WCOBRA/TRAC-TF2 void behavior).

Given the above discussed issues and the fact that the WCOBRA/TRAC-TF2 code has no proven history of successful simulation of SBLOCAs, the NRC staff formulated the following approach to identifying and analyzing the limiting break region for the SBLOCA spectrum as illustrated in Figure 1. The entire small break spectrum (Region I) is defined as:

Small Break LOCA Spectrum (Region I): all split break sizes from 0.02 ft^2 to ~1.0 ft^2

In general, the limiting break region will lie between 2 inches and 4 inches in equivalent break diameters in the cold leg, but may differ slightly due to plant power level, geometry, and ECCS characteristics. [ ] the approach to locate this limiting region of break sizes between 2 and 4 inches in diameter that produce a sharply defined peak in predicted PCTs is suggested below along with additional variable sampling and input recommendations as described in the following section.

To provide adequate resolution, a large number of runs, using diameter increments of 0.1 inch, for example, are to be performed for small break sizes between 2 inches (0.0218 ft^2) and 4 inches in diameter (0.0873 ft^2) [ ] The analysis of this 2- to 4-inch diameter limiting break range should be conducted using the approach [ ] with some additions that include the following assumptions specific to Region I analysis.

(1) Locate the break with the maximum PCT in the 2- to 4-inch limiting break range from 0.0218 ft^2 to 0.0872 ft^2 by running break diameter increments of 0.1 inch.

(2) Bias the following key parameters to their limiting values/conditions in lieu of sampling as [ ]

a) Interfacial drag, YDRAG equals to the lower bound of data,
b) Single phase heat transfer coefficients, SPV1 and SPV2, equal to lower bounding value,
c) Only one loop seal is allowed to clear in a non-broken loop.
d) Critical velocity for slug transition in the loop seal, HS_SLUG, equals to the upper bound to delay transition to slug flow.
e) Decay heat multiplier, DECAY HT, set at biased upper limit value.
f) Only one loop seal is allowed to clear below break sizes of 4 inches or less (inspection of all available integral SBLOCA data show that below 4 inches only one loop seal clears).
g) Demonstrate that partial clearing of two loop seals is not more limiting than allowing only one loop seal to clear.
h) Power shape; limiting top skewed axial shape.

The analysis using the above approach should locate the break with a maximum PCT in the 2- to 4-inch limiting small break region. Once this has been done, this specific break is then to be analyzed by sampling the full range of variables as defined in the FSLOCA™ methodology, but with the following parameters/variables set to the following recommended limiting values contained within the **[**

] A compilation of the uncertainty parameter values and ranges can also be found in Table I of LTR-NRC-15-85:

i) Hot rod PLHGR set to its maximum value, i.e., F_Q set at maximum.
j) Decay heat multiplier set at nominal (1.0), sample uncertainty between 0 and 2.
k) COSI condensation multiplier, KCOSI set at lower bound.
l) YDRAG =lower bound.
m) **[** **]** =lower bound.
n) HS_SLUG = upper bound.
o) Limiting loop seal conditions applied (one unbroken loop seal cleared or two loop seals partially cleared).
p) Hot leg nozzle gaps and core barrel flange leakage paths all closed.
q) All other variable/parameters **[**
]

To overcome the lack of integral experimental validation and the shortcomings associated with the drag modeling, a set of biased inputs for the above variables and the loop seal limiting conditions are prescribed as identified above. With these limiting conditions, the NRC staff is confident that the FSLOCA™ methodology will capture or bound the PCT and oxidation criteria with a high probability and acceptable confidence level.

Of great importance is **[**

] the NRC staff found such an approach acceptable, given the limited integral effects test validation, drag modeling and sampling concerns discussed above. **[**

] The NRC staff found this modified approach acceptable for analysis of SBLOCA performance for Region I. The details of the analysis procedure chosen by Westinghouse to address the NRC staff concerns **[**
] was found acceptable and is discussed in those sections below that deal specifically with SBLOCA key phenomenological behavior. As such, some of the **[**

] It is also noted that some sections deal only with the LBLOCA behavior.

4.6.1 Containment Pressure Calculation in WCOBRA/TRAC-TF2 LOCA Analyses

The FSLOCA™ PIRT recognizes the importance of the containment pressure for determining the break flow and the pressure throughout the RCS during a LOCA and in particular during the reflood period of large and intermediate breaks. WCOBRA/TRAC-TF2 was modified so that the thermal-hydraulic calculations for the RCS and the containment calculations are performed in an integrated manner by passing the mass and energy boundary conditions back and forth through the break between the W̲COBRA/TRAC-TF2 code and the integrated containment code COCO at each W̲COBRA/TRAC-TF2 time step. This was achieved by the introduction of a new BREAK component type (IBTYP=101) to handle the interface with COCO. The COCO component is described in Section 10.11, "COCO Component," of WCAP-16996-P/WCAP-16996-NP. It is used to predict the containment pressure response following a LBLOCA for dry containment buildings. Modeling assumptions are implemented to calculate a conservatively low containment pressure considering the effects of all the installed pressure reducing systems and related processes. The same code was also used in a stand-alone mode in the ASTRUM EM to generate tables defining the pressure in the BREAK component connected to the break. Westinghouse confirmed the proper performance of the integrated COCO model by benchmarking a solution obtained with the integrated COCO code against a corresponding stand-alone calculation. The COCO code was also identified and discussed in Section 25, "Plant Sources of Uncertainty," Subsection 25.6, "Containment Response," of WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 0. COCO was the only containment code described in the original submittal of TR WCAP-16996-P/WCAP-16996-NP.

In round one RAI No. 46, the NRC staff requested additional information to clarify the frozen code version of the stand-alone COCO containment code used to develop the integrated W̲COBRA/TRAC-TF2 containment model, major modeling assumptions, validation studies, specification of key input parameters in plant-specific applications, and sampling of related parameters in the uncertainty analysis. In its final response to this RAI in letter LTR-NRC-13-73, Westinghouse provided additional information clarifying that the coupled W̲COBRA/TRAC-TF2 and COCO containment pressure calculation in the FSLOCA™ EM was intended to produce a lower bound of the containment pressure response given appropriately defined input values that take into account plant-specific containment design parameters and features. Open items related to the final RAI response were identified, documented in an RAI review template and discussed with Westinghouse at the August 6-7, 2014, NRC audit of the FSLOCA™ EM. Following the audit, Westinghouse provided additional information on the identified open items relative to round one RAI No. 46 provided with letter LTR-NRC-14-60. In the additional information transmitted with this letter, Westinghouse formulated certain specific conditions related to the modeling of containment coatings and initial containment temperature in PWR plant-specific analyses using the FSLOCA™ EM, which are addressed in the limitation proposed at the end of this section. Upon the review of the additional information in LTR-NRC-14-60, specific remaining open items were identified, documented in a review template, and discussed with Westinghouse at the June 8, 2015, NRC Audit of the FSLOCA™ EM. Following the audit, Westinghouse provided additional information on the identified remaining open items relative to RAI No. 46 in LTR-NRC-15-70. The provided additional information was reviewed and found sufficient to resolve these remaining Open them thus closing NRC round one RAI No. 46.

The review of the information provided in the above identified Westinghouse letters relevant to round one RAI No. 46 confirmed that the approach proposed by Westinghouse to calculate and use a lower bound of the containment pressure response to model intermediate and large break LOCA in Region II analyses is intended as a conservative one and therefore deemed acceptable by the NRC staff. At the same time, to ensure that the approach is applied appropriately in plant-specific analyses with the FSLOCA™ EM, it was found necessary to propose certain specific restrictions regarding the application of the coupled W̲COBRA/TRAC-TF2 and COCO methodology for Region II breaks. The proposed restrictions reflect the above discussed conditions formulated by Westinghouse in LTR-NRC-14-60. The proposed limiting conditions regarding the application of the coupled W̲COBRA/TRAC-TF2 and COCO codes to calculate the containment backpressure response in plant-specific LOCA analyses for Region II breaks using the FSLOCA™ EM are formulated in **Limitation No. 3** provided at the end of this section of the report.

As part of the revised FSLOCA™ EM, Westinghouse identified and discussed the application of another containment code LOTIC2 for the purpose of calculating the containment pressure in ice condenser containments. The use of LOTIC2 was described in Subsection 25.6, "Containment Response," of WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 1, submitted to NRC with letter LTR-NRC-15-83 dated October 1, 2015. It was explained in the updated Subsection 25.6 that for a plant with an ice condenser containment design, a containment reference transient is defined to calculate an appropriate backpressure to be assumed for all Region II break sizes with a break diameter larger than the SI line diameter. It was stated that the LOTIC2 containment code was not integrated into the WCOBRA/TRAC-TF2 thermal-hydraulic code. It is noted that the ASTRUM EM also used LOTIC2 in a stand-alone mode to calculate the containment pressure for ice condenser containments. Similar to the ASTRUM methodology, a nominal double-ended guillotine break with characteristics tending toward minimum containment pressure is assumed as the reference break to calculate a conservatively low containment pressure response using LOTIC2 as part of the FSLOCA™ EM. As the use of the LOTIC2 code was not included in the original submittal of the FSLOCA™ EM described in WCAP-16996-P/WCAP-16996-NP, Revision 0, its application was not reviewed by the NRC staff along with the review of the application of the COCO component, which was integrated into WCOBRA/TRAC-TF2. Therefore, the NRC staff proposed to limit the application of the FSLOCA™ EM for plant designs with dry containment buildings only, which restriction was included in the original formulation of Limitation No. 3.

During the meeting with NRC on November 17, 2015 to discuss draft limitations and conditions proposed by the NRC staff on the FSLOCA™ EM, Westinghouse presented information regarding the use of the LOTIC2 code, which was identified in the revised FSLOCA™ EM presented in TR WCAP-16996-P/WCAP-16996-NP Revision 1. At the November 2015 meeting, Westinghouse stated that the limitation on the FSLOCA™ applicability to dry containment designs was unnecessary as the LOTIC modeling approach proposed for the FSLOCA™ EM was the same as in the CQD and ASTRUM EMs. Accordingly, Westinghouse referred to the information provided on the cover page of LTR-NRC-15-83, which states that "the LOTIC2 code version used within the FSLOCA evaluation model is the same as for the approved ASTRUM evaluation model, except for the changes reported under "General Code Maintenance" and "LOTIC2 Error Corrections" in LTR-NRC-12-37 (ML12207A081), and under "General Code Maintenance" in LTR-NRC-13-16 (ML13101A189)." Westinghouse included the discussed information relative to Limitation No. 3 in the meeting presentation materials, which were submitted to NRC with letter LTR-NRC-15-96 dated November 16, 2015.

As a result of the discussion with the NRC staff during the November 2015 meeting and in response to questions by the NRC staff, Westinghouse agreed to provide supporting information regarding the request to remove the aspect related to ice condenser designs in the draft Limitation No. 3. Such additional information was presented by Westinghouse and discussed with the NRC staff during the meeting with NRC on December 10, 2015, to further discuss draft limitations and conditions proposed by the NRC Staff on the FSLOCA™ EM. Following the December 2015 meeting, Westinghouse submitted to NRC further information relative to the ice condenser aspect of Limitation No. 3 with letter LTR-NRC-15-102 Revision 1 dated December 15, 2015.

Furthermore, the item was discussed between Westinghouse and NRC during a telephone conference call on January 7, 2016. During this discussion, the NRC staff questioned specific aspects related to the initial containment pressure, observed increase in the calculated transient containment pressure, and convergence of calculation results in an existing ASTRUM analysis for D. C. Cook Unit 2 presented by Westinghouse as an example of the use of the LOTIC2 code. In response to the questions by the NRC staff, Westinghouse submitted additional clarifying information related to the use of the LOTIC2 code to NRC with letter LTR-NRC-15-102, Revision 2 dated January 19, 2016. This letter contained a summary of November 2015, December 2015, and January 2016 discussions on draft limitations and conditions and supplemental information on the FSLOCA™ EM.

The NRC staff reviewed the information provided in the revised FSLOCA™ EM in LTR-NRC-15-83 relative to the use of the LOTIC2 code as well as the additional information provided in this regard to NRC in Westinghouse letters LTR-NRC-15-96, LTR-NRC-15-102 Revision 1, and LTR-NRC-15-102 Revision 2 discussed above. Based on the review of the provided information and the interactions with Westinghouse during the November 2015, December 2015, and January 2016 discussions related to the use of the LOTIC2 code within the FSLOCA™ EM, the NRC staff determined that LOTIC2 can be used in a stand-alone manner and as described to calculate a conservative containment pressure response for ice condenser containments in FSLOCA™ EM plant analysis applications. Accordingly, the NRC staff agreed to remove the related aspect initially included in the proposed draft Limitation No. 3. Nonetheless, as reiterated by the NRC staff and recognized by Westinghouse, the remaining two aspect of the proposed limitation discussed above as part of the review of the use of the COCO containment module coupled with WCOBRA/TRAC-TF2 and related to the initial containment temperature and containment coatings, will apply to the use of the LOTIC2 code as well. **Limitation No. 3**, related to the application of COCO in a coupled mode and LOTIC2 in a stand-alone mode to calculate the containment backpressure responses for dry containment and ice condenser containment designs, respectively, in plant-specific LOCA analyses for Region II breaks using the FSLOCA™ EM, is formulated below.

Limitation No. 3: FSLOCA™ EM Applicability for Containment Pressure Modeling

The coupled WCOBRA/TRAC-TF2 and COCO codes or standalone LOTIC2 code will be applied to calculate the containment backpressure in PWR LOCA analyses for Region II so that a conservatively low, although not explicitly bounded, containment pressure will be predicted and used. For this purpose, the input to the COCO model and its prediction results will be based on appropriate plant-specific containment design parameters and initial conditions and will simulate accordingly engineered safety features and installed systems capable of affecting the containment pressure including their actuation, performance, and associated processes. The following specific limitations will apply for Region II analyses using the FSLOCA™ EM: (1) an acceptable plant-specific initial containment temperature will be determined based on input from the utility for the purpose of modeling the containment pressure response with COCO or LOTIC2; and (2) unqualified or indeterminate coatings throughout containment and qualified coatings within the break jet zone-of-influence will not be credited for the purpose of modeling the containment pressure response using COCO or LOTIC2 consistent with the bounding treatment of this parameter (conservatively low containment pressure).

4.6.2 Decay Heat Modeling

WCOBRA/TRAC-TF2 models the primary heat sources during a postulated LOCA, which include fission product decay heat, fission heat, actinide decay heat, and cladding chemical reaction. The models in WCOBRA/TRAC-TF2 related to the first three heat sources are described in Section 9 of WCAP-16996-P/WCAP-16996-NP. As in the ASTRUM CQD EM, the fission product decay heat is calculated using the American National Standards Institute/ American Nuclear Society (ANSI/ANS) 5.1-1979 model with consideration of the spatial distribution, uncertainty of the decay heat, and the power history during the transient. Uncertainty in decay heat is considered in the FSLOCA™ EM through the application of the ANSI/ANS 5.1-1979 Standard.

Based on the review of the decay heat model and its treatment in the uncertainty analysis as described in the original submittal of the TR, specific items requiring additional information were identified and formulated in round one RAI Nos. 13, 20, 21, 22, 25, 26, 27, 28, and 29. These RAIs were issued by NRC asking Westinghouse provide clarifications regarding modeling aspects related to the calculation of heat sources as they contribute to the assessed nominal decay heat and associated uncertainties in the decay heat power predictions. Among these RAIs, RAI No. 26 asked specifically for additional information regarding the prediction of the actinides decay heat power, RAI No. 27 asked for explanation of each component of decay power and prediction results as used in demonstration plant calculations, RAI No. 28 requested explanation of the method of calculating the dependency of the decay heat uncertainty distribution on the fuel burnup and enrichment, and RAI No. 29 asked for additional clarification on the decay heat sampling approach in the FSLOCA™ EM. Related concerns with the decay heat sampling were also discussed at the FSLOCA™ Code Workshop held between Westinghouse and NRC on July 16-17, 2013, as well as at the August 12-15, 2013, NRC FSLOCA™ audit. To address such concerns, Westinghouse presented a new approach to decay heat sampling applicable to Region I LOCA analyses at the May 12-13, 2014, NRC FSLOCA™ audit.

Westinghouse provided the final response to RAI No. 13 with letter LTR-NRC-13-37 and the final responses to RAI Nos. 20, 21, 22, 25, 26, 27, 28, and 29 with letter LTR-NRC-13-33. Separately from these final RAI responses, pertaining additional information related to the July 16-17, 2013, Code Workshop as well as the presentations from the August 12-15, 2013, NRC Audit were provided to NRC with letter LTR-NRC-13-70. Additional such information, including the presentations from May 12-13, 2014, NRC FSLOCA™ audit, was submitted to NRC with letter LTR-NRC-14-29. Upon the review of the provided final RAI responses and the additional information provided in the last two letters, specific open items were identified and documented in RAI review templates and discussed with Westinghouse at the August 7-8, 2014, NRC audit of the FSLOCA™ EM.

In the responses to the above identified NRC round one RAIs, Westinghouse provided applicable additional information including results from additional supporting analyses. It is noted that in addressing RAI Nos. 21 and 27, Westinghouse identified and corrected four code errors in the existing configured WCOBRA/TRAC-TF2 code version related to the calculation of decay heat power and its uncertainty in the code, which findings were documented in the final responses to these RAIs. Considering the dominant effect due to decay heat treatment on PCT observed in SBLOCA sensitivity analyses for Region I and recognized in the July 16-17, 2013, FSLOCA™ Code Workshop summary in LTR-NRC-13-70, Westinghouse proposed to address the decay heat issue with **[** **]** for Region I.

Following the August 7-8, 2014, NRC audit of the FSLOCA™ EM, Westinghouse provided additional information on open items relative to the final round one RAI responses pertaining to decay heat. Such information on open items was provided to NRC in letter LTR-NRC-15-6 relative to RAI Nos. 20, 22, and 29 and in letter LTR-NRC-15-11 relative to RAI No. 26. Regarding decay heat uncertainty sampling for Regions I and II relative to RAI No. 29, Westinghouse clarified that for the **[**

] (per Section 4.2 of LTR-NRC-14-29). Regarding the concern on decay heat power contribution by actinides relative to RAI No. 26, the additional information including analysis results provided in Tables RAI-26-1 through RAI-26-12 in LTR-NRC-15-11 **[**

] This condition is addressed in the limitation proposed at the end of this section. The additional information provided in the letters identified in the above paragraph was reviewed and several remaining unresolved Open Times were identified, documented in review templates, and discussed with Westinghouse at the June 8, 2015, NRC audit of the FSLOCA^{TM} EM. Following this audit, Westinghouse provided additional clarifying information on the remaining open items in letter LTR-NRC-15-67 relative to RAI Nos. 21 and 22 and in letter LTR-NRC-15-11 for RAI No. 26. The provided additional information was reviewed and found sufficient to resolve the remaining Open them thus closing NRC round one RAIs on decay heat identified in this this section. Limiting conditions resulting from the review of the decay heat model in WCOBRA/TRAC-TF2 are proposed in **Limitation No. 4** formulated below as they pertain to plant-specific LOCA analyses for Region I and Region II breaks using the FSLOCA^{TM} EM.

Limitation No. 4: Decay Heat Modeling in FSLOCA^{TM} EM Applications

As implemented by Westinghouse and found acceptable from the review of the decay heat model in the FSLOCA^{TM} EM, the following conditions will apply with regard to decay heat modeling and sampling in PWR LOCA analyses for Region I and Region II: (1) decay heat uncertainty will be **[**
] in uncertainty analyses for both Region I and Region II according to Table 29-4 in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume III, Section 29; (2) the FSLOCA^{TM} EM cannot be applied for transient time longer than 10,000 seconds following shutdown unless the decay heat model is shown to be acceptable for the analyzed core conditions. The latter limitation is **[**

] The sampled value of the decay heat uncertainty multiplier, DECAY_HT, reported in units of σ and absolute units, as applied for the limiting runs in Region I and Region II in the plant-specific analysis as part of a License Amended Request submittal, will be provided as part of the submittal.

4.6.3 Fuel Burnup, Thermal Conductivity Degradation, and Initial Stored Energy

The review of the original submittal of the FSLOCA^{TM} EM in WCAP-16996-P/WCAP-16996-NP, Revision 0, determined that the treatment of fuel burnup and modeling of burnup-dependent parameters important for LOCA analyses, such as fuel pellet thermal conductivity, initial core stored energy, rod internal pressure (RIP), clad corrosion thickness, axial power distribution and related fuel peaking factors, and decay heat, was consistent with the ASTRUM EM

(WCAP-16009-P, June 2003) submitted to NRC for review and approval. It was found that the FSLOCA™ EM methodology considered only fuel in its first cycle of irradiation presuming that such fuel is limiting with regard to the PCT, MLO, and CWO criteria. Also, it did not account explicitly for TCD due to burnup and related effects on initial core stored energy. Specifically, the review of Section 11.4, "Thermal Properties of Nuclear Fuel Rod Materials," determined that the default nuclear fuel rod model in WCOBRA/TRAC-TF2 computes the UO_2 thermal conductivity from a MATPRO-9 correlation, which does not account for fuel pellet TCD with burnup. According to Section 29.4.2.2, "Initial Calibration of the Steady-State Condition for the Nuclear Rods," the initial fuel temperature and RIP for Westinghouse PWRs were calibrated against the Performance Analysis and Design (PAD) 4.0 fuel performance code documented in WCAP-15063-P, "Westinghouse Improved Performance Analysis and Design Model (PAD 4.0)," Revision 1, 1999 and for CE PWRs these parameters were calibrated against the FATES3B code documented in CEN-161(B)-P, "Improvements to Fuel Evaluation Model," Supplement 1-P-A, CE, 1992. The identified codes do not explicitly model TCD with burnup.

Consistent with the recognition in NRC Information Notice (IN) 2009-23 dated October 8, 2009 (ADAMS Accession No. ML091550527), that "safety analyses performed for reactors using pre-1999 methods may be less conservative than previously understood" when it comes to burnup-related effects on pellet TCD and the effect of initial core stored energy in LOCA analyses, round one RAI Nos. 23, 36 through 39, and 40 were proposed by ISL and issued by the NRC to address concerns identified from the review of the FSLOCA™ EM as discussed below. In RAI No. 23, Westinghouse was asked to clarify and provide the fuel burnup limits applicable to the FSLOCA™ EM. RAI No. 36 was issued to address the concern that the default thermal conductivity model in WCOBRA/TRAC-TF2, based on a MATPRO-9 correlation, did not explicitly account for pellet TCD with burnup. RAI No. 37 requested that Westinghouse explain how the FSLOCA™ EM accounted for fuel burnup effects in obtaining core thermal-hydraulic parameters and fuel thermal response under steady state for the purpose of initialization of LOCA analyses and asked for consideration of factors related to fuel in different reactor cycles, time-in-cycle of reactor operation, and core relevant nodalization. The RAI also requested clarification regarding the codes that were used in the FSLOCA methodology to initialize, calibrate, benchmark, match, or in other way alter WCOBRA/TRAC-TF2 calculated results that have an impact on the initial pellet stored energy including the frozen code versions and their approval status with the NRC. In addition, the RAI requested that Westinghouse explain why WCOBRA/TRAC-TF2 predictions results for LOCAs should be considered acceptable by the staff in terms of describing the core fuel transient responses when the FSLOCA methodology employs initial calibration of the steady state conditions for the nuclear rods using results from other codes. RAI No. 38 requested Westinghouse to clarify the consideration of burnup effects on nuclear fuel rod related parameters in the FSLOCA™ EM and the accounting for such effects in LOCA analyses. Specifically, the RAI asked for identification of parameters that were treated as burnup-dependent and description of their importance with regard to the impact on steady state initialization results and LOCA transient predictions obtained with the FSLOCA™ EM. The RAI requested that Westinghouse explain the functional dependence of each of the identified parameters on fuel burnup, provide the burnup range that was considered, and explain how burnup is accounted for in the definition of the sampling ranges and sampling distributions for each of the identified burnup dependent parameters. RAI No. 39 asked Westinghouse to clarify the process of fuel burnup sampling proposed for the FSLOCA™ methodology and explain how it accounts for fuel burnup variability with regard to position considering fuel assemblies with different burnup in the core (e.g., fresh, once-burned, and twice-burned fuel) as well as for fuel burnup variability with regard to time considering different fuel cycles (non-equilibrium and equilibrium) and reactor operation time-in-cycle. Westinghouse provided the final response to

RAI No. 40 with letter LTR-NRC-13-32, to RAI No. 23 with letter LTR-NRC-13-33, and to RAI Nos. 36 through 39 with letter LTR-NRC-14-17.

In addressing the concerns formulated in the above identified NRC round one RAIs regarding the treatment of fuel burnup-related effects in LOCA analyses performed with the FSLOCA™ EM, Westinghouse found it necessary to introduce a number of major updates and improvements to the original methodology. The proposed updates were presented and discussed in detail with Westinghouse at the June 3-4, 2014, NRC FSLOCA™ audit. At this audit, Westinghouse was asked to provide additional information related to the quantification and initialization of the initial stored energy in WCOBRA/TRAC-TF2 runs as well to address a concern related to the proposed method of processing of axial power distributions that could result in axial distributions for the hot rod that are lower in power at the topmost portion of the core. Following the audit, Westinghouse submitted to NRC additional supporting information along with the audit presentations with transmittal letter LTR-NRC-14-38. The review of the final responses to NRC round one RAI Nos. 23, 36 through 39, and 40 and the relevant additional information provided in letter LTR-NRC-14-38 found that the provided information was acceptable by the staff and sufficient to address most of the concerns while identifying several remaining open items related to RAI Nos. 36 through 39. The review findings were documented in RAI review templates, provided to NRC, and the identified open items discussed with Westinghouse at the August 7-8, 2014, NRC audit of the FSLOCA™ EM. Following the audit, Westinghouse submitted to NRC additional information relevant to the remaining open items with letter LTR-NRC-14-60. This additional information was reviewed and the review findings documented in a review template submitted to NRC concluding that the provided additional information on the open items was acceptable to the staff and sufficient to resolve them thus closing the remaining round one RAI Nos. 36 through 39. It is noted that the resolution of the RAIs discussed in this section necessitated a set of significant and extensive changes to the FSLOCA™ EM, which were reflected in a number of specific TR sections. Westinghouse letter LTR-NRC-14-17 provided the updated TR sections, which included: Section 2 (Section 2.3.2.1), Section 8 (Sections 8.4, 8.4.1, and 8.6), Section 11 (Section 11.4), Section 25 (Introduction, Sections 25.1, 25.2, 25.8), Section 26 (Sections 26.4, 26.5), Section 29 (Introduction, Sections 29.4.1, 29.4.2, 29.5.1, and 29.7), Section 30 (Sections 30.1, 30.4, 30.5, 30.6, and 30.7), and Section 32 (Sections 32.1, 32.2, and 32.4). These updated sections of the FSLOCA™ EM were reviewed and the included changes found consistent with the final RAI responses in letters LTR-NRC-13-33 and LTR-NRC-14-17 and the additional information in letter LTR-NRC-14-60. The same sections in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume I, II, and III, were also examined and it was confirmed that they reflect accurately the updates documented in LTR-NRC-14-17. Specific review details related to the NRC round one RAIs identified and discussed in this section are provided in the following four sections of this report with a focus on areas that necessitated the formulation of proposed limitations and conditions regarding the applicability of the FSLOCA™ EM.

4.6.3.1 Assembly Average and Peak Rod Average Fuel Burnup Limits

In the final responses to NRC round one RAI Nos. 23 and 40 provided in letters LTR-NRC-13-33 and LTR-NRC-13-32 respectively, it was stated that "Westinghouse fuel is currently licensed to a peak rod burnup of **[ ]** " the limit of which was based on the fuel rod design limit with the use of PAD 4.0. It was also explained in the response to

RAI No. 23 that WCOBRA/TRAC-TF2 models the [

] was considered sufficient to model a core with a peak fuel rod burnup limit

of [ ] In the additional information provided by Westinghouse in the August 7-8, 2014, NRC FSLOCA™ audit summary in letter LTR-NRC-14-60 relative to this RAI, it was further clarified that that the maximum assembly average burnup is limited to [ ] and the maximum peak rod average burnup is limited to [ ] As a fuel channel in the WCOBRA/TRAC-TF2 core model represents [ ] the provided final RAI response was found sufficient and acceptable to the staff given the above discussed clarification in letter LTR-NRC-14-60. A limiting condition reflecting the above identified maximum burnup values is proposed in **Limitation No. 5** formulated below.

Limitation No. 5: Fuel Burnup Limits in FSLOCA™ EM Applications

The maximum assembly average burnup will be limited to [ ] and the maximum peak rod length-average burnup will be limited to [ ] within the FSLOCA™ EM.

4.6.3.2 Modeling of Thermal Conductivity Degradation and Related Fuel Rod Phenomena

The FSLOCA™ EM was updated to use a version of the Nuclear Fuels Industries (NFI) thermal conductivity model as modified in FRAPCON 3.3 (NUREG/CR-6534, Volume 4, "FRAPCON-3 Updates, Including Mixed-Oxide Fuel Properties," Pacific Northwest National Laboratory, 2005). The model explicitly accounts for TCD with burnup and it will be used in PWR plant analyses and for simulations of validation tests that involve UO_2 fuel pellets such as LOFT. The range of fuel conditions expected in such FSLOCA™ methodology applications is covered by the range of conditions for which the modified NFI fuel thermal conductivity model is considered applicable according to NUREG/CR-6534 (temperature variation from 300 to 3,000 K, rod-average burnup variation from 0 to 62 GWD/MTU, and as-fabricated fuel density from 92 to 97% of the theoretical value). As described, the implemented model was found appropriate and acceptable to the staff.

As explained in the final response to NRC round one RAI No. 40 in LTR-NRC-13-32, WCOBRA/TRAC-TF2 will be interfaced with the PAD 5.0 code in the updated FSLOCA™ EM. PAD 5.0, an updated version of the PAD fuel performance code designed by Westinghouse to supersede PAD 4.0 and FATES3B, was submitted to the NRC for review and approval as WCAP-17642-P/WCAP-17642-NP, Revision 0, "Westinghouse Performance Analysis and Design Model (PAD5)," in 2013. As stated in LTR-NRC-14-17, "the final, approved version of PAD5 will be the fuel performance interface to the FSLOCA EM" used for initialization of the fuel rod conditions prior to computing a LOCA transient. Importantly, the submitted PAD 5.0 code explicitly accounts for TCD with burnup. The code features detailed fuel rod models for prediction of fuel pellet temperatures and RIP over the life of the fuel and includes models for prediction of fission gas release. The fuel rod conditions are predicted as a function of the local linear heat rate and rod average burnup. The interface technique uses PAD 5.0 predictions to calibrate and treat the following WCOBRA/TRAC-TF2 initial fuel-related parameters: (a) pellet average temperature and uncertainties, (b) RIP and uncertainties, and (c) gap gas composition. In view of the commitment by Westinghouse in the final response to NRC round one RAI No. 40 that "once PAD 5.0 is approved, PAD 5.0 will replace PAD 4.0 as the current fuel performance interface to the FSLOCA EM," a limiting condition is proposed in **Limitation No. 6** formulated below, which reflects the current status of the PAD5 code as being still under NRC review.

Limitation No. 6: WCOBRA/TRAC-TF2 Interface with PAD5 in the FSLOCA™ EM

In the FSLOCA™ EM applications for PWR LOCA analyses, the latest version of an NRC approved version of the latest fuel performance code will be used to initialize the fuel rod initial conditions. If the PAD 5.0 code is the latest approved version for fuel performance LOCA evaluations, then this version will be used to interface with WCOBRA/TRAC-TF2. The fuel performance code utilized shall be used to initialize WCOBRA/TRAC-TF2 using appropriate calculative methods to maximize the initial fuel stored energy and gap pin pressure, as well as adhere to any restrictions and limitations that resulted from the staff review and acceptance. The fuel performance code calculative methods should therefore exercise those modeling techniques approved by the staff for initializing WCOBRA/TRAC-TF2 for LOCA evaluations. The fuel performance code shall also include the effects of fuel thermal conductivity degradation and its attendant effects on fuel rod behavior for application to the WCOBRA/TRAC-TF2 code.

[

] The model update was found appropriate and acceptable to the staff. Westinghouse also updated the uncertainty distributions for **[**

] As described, the introduced modifications were found appropriate and acceptable to the staff.

4.6.3.3 Treatment of Fuel Burnup

In a major update from the original FSLOCA™ EM, **[**

] In the updated methodology, the MLO is calculated as the sum of the pre-accident oxidation and the oxidation experienced during a LOCA and the total calculated MLO is compared against the 17 percent. In this regard, the updated FSLOCA™ EM is found consistent with NRC IN 98-29, which clarifies that the 10 CFR 50.46(b)(2) 17 percent MLO criterion "includes both pre-accident oxidation and oxidation occurring during a LOCA." The pre-transient corrosion in the updated FSLOCA™ EM is determined **[** **]** using approved corrosion models for ZIRLO™ and Optimized ZIRLO™ cladding, which are documented in WCAP-12610-P-A and CENPD-404-P-A, "Westinghouse Clad Corrosion Model for ZIRLO and Optimized ZIRLO," Addendum 2-A, 2013. Specifically, **[**

]

[

]

[

]

The implemented update represents an important improvement to the originally submitted FSLOCA^{TM} EM in which TCD was not explicitly considered, first cycle assembly was presumed to be limiting for PCT, MLO, and CWO and [

] is found appropriate and acceptable to the staff.

4.6.3.4 Treatment of Core Power Distributions and Peaking Factors

[

]

[

]

[

] To address this concern, Westinghouse provided additional information related to RAI Nos. 36 through 39 in the August 6-8, 2014, NRC FSLOCA^{TM} audit summary document transmitted to NRC with letter LTR-NRC-14-60. Specifically, an illustrative 93-case Region I analysis for Beaver Valley Unit 1, **[** **]** documented in Section 4.3 of the May 12-13, 2014 NRC FSLOCA^{TM} Audit summary document transmitted to the NRC with letter LTR-NRC-14-29, **[** **]** The results, documented in LTR-NRC-14-60, **[** **]** (see Figures 16 and 18 in LTR-NRC-14-60). Based on this assessment, the conclusion by Westinghouse that **[** **]** not significantly impact the analysis results for Region I **[** **]** was found acceptable to the staff.

Overall, it is also concluded that the proposed update to **[** **]** As such, the approach related to peaking factors implemented in the updated FSLOCA^{TM} EM was found appropriate and acceptable to the staff.

4.6.4 Two-Phase Interfacial Drag and Core Level Swell

The WCOBRA/TRAC-TF2 models and capabilities in predicting the core void distribution and the resulting two-phase mixture level swell were reviewed with the recognition that the two-phase mixture level is of governing importance in the analysis of SBLOCAs. For a given geometry and flow conditions, the two-phase mixture level is determined by the interfacial drag between the vapor and liquid phases, which is modeled in the employed two-fluid two-phase flow model as dependent on the encountered two-phase flow regimes. To account for the importance of interfacial drag, the FSLOCA^{TM} EM implemented an interfacial drag multiplier that was sampled within a proposed range to account for the assessed uncertainty related to this quantity. The original approach was described inWCAP-16996-P/WCAP-16996-NP, Revision 0, Section 13, "Core Void Distribution and Mixture Level Swell." This section described the assessment of the WCOBRA/TRAC-TF2 capabilities to predict core void distribution and the resulting two-phase mixture level swell. Given the lack of prior WCOBRA/TRAC-TF2 assessments and applications for SBLOCA analyses and considering the importance of interfacial drag modeling in predicting the safety criteria for Region I LOCA analyses with the FSLOCA^{TM} EM, round one RAI Nos. 58 through 76 were proposed by ISL and issued by NRC to address specific review findings and related concerns. The items identified in these RAIs pertained to the following three major areas: (1) implemented constitutive models and assumptions in modeling two-phase flow maps and interfacial drag, (2) prediction of reactor core two-phase mixture level, and (3) WCOBRA/TRAC-TF2 assessment and uncertainty evaluation and sampling of interfacial drag for the 3D VESSEL module. In particular, observed void fraction dipping with increasing bundle axial elevation in presented simulations of ORNL THTF experiments raised specific concerns. To address the items in the first two groups, Westinghouse identified and resolved modeling deficiencies by updating the interfacial drag package and enhancing the code logic for determining the mixture level elevation in the 3D VESSEL module of WCOBRA/TRAC-TF2 as discussed in the following. The third group of items was addressed by reassessing the uncertainty associated with the interfacial drag in the 3D VESSEL module, which resulted in updating the sampling range associated with the applied interfacial drag multiplier in the updated FSLOCA^{TM} EM. In addition, to resolve concerns specifically related to the associated effect on analyses for Region I, Westinghouse proposed to **[** **]** Westinghouse provided the final responses to RAI Nos. 58 and 75 with letter LTR-NRC-13-73, the final response to RAI Nos. 59 through 71 with letter LTR-NRC-13-75, and the final responses to the remaining RAI Nos. 72, 73, 74, and 76 with letter LTR-NRC-13-41. The provided RAI responses were reviewed and specific findings documented in RAI review templates and discussed with Westinghouse at the February 19-20, 2014, May 12-13, 2014, and August 7-8, 2014, NRC audits of the FSLOCA™ EM. It was agreed between NRC and Westinghouse at the August 7-8, 2014, NRC audit of the FSLOCA™ EM that instead of updating some of the provided responses to the above identified NRC round one RAIs to reflect the latest code and methodology updates, specific pertinent information would be provided as part of the revised submittal of WCAP-16996-P/WCAP-16996-NP. Such related updates in WCAP-16996-P/WCAP-16996-NP, Revision 1, included revised assessment results, were reviewed and found acceptable to the staff as part of reaching RAI closure. Specific review considerations related to the NRC round one RAIs identified and discussed in this section are provided below with a focus on areas that necessitated the formulation of proposed limitations and conditions regarding the applicability of the FSLOCA™ EM.

In addressing the concerns formulated in the above identified NRC round one RAIs related to two-phase interfacial drag and core level swell, Westinghouse found necessary to introduce a number of coding changes in WCOBRA/TRAC-TF2 and related updates in the original FSLOCA™ EM. Such updates were presented and discussed in detail with Westinghouse at the February 19-20, 2014, and May 12-13, 2014, NRC audits of the FSLOCA™ EM. Code updates related to the two-phase mixture level output, calculation of the axial vapor velocity accounting for vapor generation in **[** **]** were discussed at the February 19-20, 2014, NRC audit of the FSLOCA™ EM. Following the audit, Westinghouse submitted relative additional information as part of the audit presentation materials included in the audit summary document transmitted to NRC with letter LTR-NRC-14-55. Updated WCOBRA/TRAC-TF2 assessment results were presented for selected FLECHT-SEASET reflood tests, ORNL THTF core uncovery and level swell tests, G2 boil-off tests, and ROSA-IV LSTF 2.5 percent and 5 percent small cold leg break tests. In addressing RAI Nos. 59 through 71, noding sensitivity results for ORNL THTF and G2 tests were presented. The results revealed a **[**

] Further updates related to the WCOBRA/TRAC-TF2 interfacial drag package for the 3D VESSEL module were discussed in detail at the May 12-13, 2014 NRC FSLOCA™ EM Audit. Following the audit, Westinghouse submitted relative additional information including the audit presentation materials in the audit summary document transmitted to NRC with letter LTR-NRC-14-29. The modelling deficiencies causing the observed dipping in the axial void fraction profile in some of the assessed ORNL THTF tests were traced back to the drag model in the **[** **]** The deficiencies were resolved by implementing code changes in the drag model. Specifically, the following code updates were implemented: **[**

]

Updated WCOBRA/TRAC-TF2 assessment results were included in the audit summary document to demonstrate the code performance with the updated drag package. It is noted that after the audit, it was discovered that only the first and third changes, above, were required to remedy the unwanted behavior in the level swell predictions. Updated WCOBRA/TRAC-TF2 assessment results were then presented for selected ORNL THTF core uncovery and level swell tests, G2 boil-off tests, GE blowdown tests, and ROSA-IV LSTF 2.5 percent and 5 percent small cold leg break tests. The reassessments showed that the code predicted well the bundle void distribution for the ROSA level swell and the THTF core uncovery and level swell tests, the heat-up elevation for the G2 boil-off tests was reasonably to conservatively predicted and the IET ROSA LSTF simulations continued to conservatively predict the measured PCTs. Importantly, the **[ ]** package eliminated previously observed dipping in the void fraction profiles and mitigated oscillatory behavior in the GE blowdown predictions.

4.6.4.1 <u>Two-Phase Flow Interfacial Drag Multipliers</u>

Directly related to the calculation of the interfacial drag in <u>W</u>COBRA/TRAC-TF2 are **[ ]** which were added in the code to allow ranging capability on the two-phase flow interfacial drag. These multipliers are identified in WCAP-16996-P/WCAP-16996-NP, Section 29, “Assessment of Uncertainty Elements,” Table 29-2, “Uncertainty Elements – Thermal-Hydraulic Models,” as the **[ ]** Section 29.1.5, “Interfacial Drag in the Core Region,” presents the probability density functions (PDFs) proposed for the interfacial drag **[ ]** for use in <u>W</u>COBRA/TRAC-TF2 uncertainty assessment. Importantly, the section states that **[ ]** in the 3D VESSEL module of <u>W</u>COBRA/TRAC-TF2. Table 15 below provides a summary description of the implemented interfacial drag multipliers, their established ranges, and applicable values based on the updated FSLOCA™ EM documented in WCAP-16996-P/ WCAP-16996-NP, Revision 1.

Table 15: Interfacial Drag Multipliers Implemented in the 3D VESSEL Module of <u>W</u>COBRA/TRAC-TF2

Flow Regime	Void Fraction α (%)	Applicable Multiplier (core region only)	Applicable Drag Multiplier			Note
			YDRAG (-)		**[ ]**	
			Region I	Region II		
Small Bubble	$0 < \alpha \leq 20$	**[ ]**	**[ ]**	**[ ]**	**[ ]**	Specified on an individual cell basis
Small-to-Large Bubble	$20 < \alpha \leq 50$					
Churn-Turbulent	$50 < \alpha \leq \alpha_{crit}$	**[ ]**	**[ ]**	**[ ]**	**[ ]**	Specified on an individual cell basis
Film/Drop	$\alpha_{crit} < \alpha \leq 100$	**[ ]**	**[ ]**	**[ ]**	**[ ]**	Specified on an individual cell basis

4.6.4.2 THTF Rod Bundle Assessment of Interfacial Drag

WCOBRA/TRAC-TF2 assessment results using six THTF bundle uncovery tests (3.09.10I, 3.09.10J, 3.09.10K, 3.09.10L, 3.09.10M, and 3.09.10N) and six THTF level swell tests (3.09.10AA, 3.09.10BB, 3.09.10CC, 3.09.10DD, 3.09.10EE, and 3.09.10FF) are presented in WCAP-16996-P/ WCAP-16996-NP, Section 13.4.2. For these tests, a void profile over the entire axial length of the rod bundle was obtained. The selected tests cover a pressure range from 520 psia to 1,170 psia and span the expected range of conditions for core uncovery in SBLOCA PWR analyses. The THTF tests along with the **[ ]** values that were applied in their simulation are summarized in Table 16 below.

Table 16: ORNL THTF Tests Used in Assessing WCOBRA/TRAC-TF2 Interfacial Drag

Test Facility	Test Bundle	Test Runs	Number and Type of Test Runs		YDRAG/**[ ]** and Test Runs Analyzed		
			Bundle Uncovery	Level Swell	**[ ]**	**[ ]**	**[ ]**
					[ ]	**[ ]**	**[ ]**
ORNL THTF	8×8	12	6	6	12	12	12

4.6.4.3 G-1/G-2 Rod Bundle Assessment of Interfacial Drag

WCAP-16996-P/WCAP-16996-NP, Section 13.4.3 and Section 13.4.4 describe the application of Westinghouse ECCS High Pressure Test Facility (HPTF) G-1 and G-2 test data to assess the interfacial drag in WCOBRA/TRAC-TF2. The analyzed G-1 tests covered **[**

] Whereas the ORNL THTF tests were applied in the FSLOCA™ EM to established **[ ]** the Westinghouse HPTF G-1 and G-2 tests provided the technical basis for establishing the uncertainty range for the bubbly flow interfacial drag multiplier, YDRAG as discussed in WCAP-16996-P/WCAP-16996-NP Section 29.1.5. In code simulations of G-2 test runs, the **[**

] Based on the results from the simulations for the selected G-2 tests using this technique, the **[ ]**
Table 17 summarizes the Westinghouse ECCS HPTF G-1 and G-2 assessment tests.

Table 17: Westinghouse HPTF G-1 and G-2 Tests Used in Assessing WCOBRA/TRAC-TF2 Interfacial Drag

Test Facility	Test Bundle	Test Runs	Data Points	Note
W ECCS HPTF	G-1 (15×15)	16	33	**[ ]**
W ECCS HPTF	G-2 (19×19)	19	38	**[ ]**

4.6.4.4 TPTF Rod Bundle Assessment of Interfacial Drag

WCAP-16996-P/WCAP-16996-NP, Section 13.4.5 describes the application of Japan Atomic Energy Research Institute (JAERI) Two-Phase Test Facility (TPTF) experiments to assess further the interfacial drag in WCOBRA/TRAC-TF2 and the sensitivity to the interfacial drag multiplier, YDRAG. Eighteen critical heat flux (CHF) experiments were conducted at the TPTF that covered a pressure range from 464 psia to 1,773 psia, mass fluxes from 3.49 to 19.18 lbm/ft^2-sec, and peak linear heat rates from 0.38 to 2.12 kW/ft. These parameters are applicable to the expected range of core uncovery conditions expected during PWR SBLOCA and IBLOCA transients. Fourteen of these experiments were used to assess WCOBRA/TRAC-TF2 as the remaining four tests exhibited a systematic shift due to the possibility that no steady-state condition had been achieved when the CHF data was measured. All fourteen tests were analyzed using the nominal **[ ]** One low power, low pressure case and one high power, high pressure case were used to perform sensitivity analysis on **[ ]** Table 18 summarizes the JAERI TPTF assessment for YDRAG.

Table 18: JAERI TPTF Tests Used in in Assessing WCOBRA/TRAC-TF2 Interfacial Drag

Test Facility	Test Bundle	CHF Test Runs	YDRAG Values and Test Runs Analyzed			Note
			[ ]	**[ ]**	**[ ]**	
JAERI TPTF	5×5	14	14	2	2	**[ ]**

The limitation of the WCOBRA/TRAC-TF2 approach in assessing interfacial drag uncertainty was related to the application of a “global” interfacial drag multiplier, YDRAG, which could be varied to directly modify, as part of the uncertainty sampling process, the interfacial drag term in the momentum conservation equation of the 3D VESSEL module across several two-phase flow regimes. Thus, the YDRAG multiplier was applied **[ ]** At the same time, the fidelity of each of the drag correlations that apply to individual two-phase flow regimes under the reactor core thermal-hydraulic conditions during an SBLOCA transient carries its own contribution to the overall code capability in predicting the axial void fraction profile and associated level swell that govern core uncovery. The implemented approach with the YDRAG multiplier caused a significant impact on code PCT results. To address the concern related to such an effect on plant predictions for Region I SBLOCA analyses due to limitations of the models included in the interfacial drag package for the 3D VESSEL module in WCOBRA/TRAC-TF2, it was proposed by Westinghouse at the May 12-13, 2014, the NRC audit of the FSLOCA™ EM to **[ ]** as reflected in the audit presentation materials included in the audit summary document submitted to NRC with LTR-NRC-14-29. Given the discussed limitation of the implemented approach in treating interfacial drag uncertainty in WCOBRA/TRAC-TF2, the proposed application of **[ ]** as implemented by Westinghouse in the updated FSLOCA™ EM and described in WCAP-16996-P, Revision 1, Section 13.4.4.8 and Section 29.1.5 is found acceptable to the staff. It was also found necessary to propose **Limitation No. 7** restricting the application of the FSLOCA™ EM to the established **[ ]** in Region I and formulated below.

Limitation No. 7: Interfacial Drag Uncertainty in FSLOCA™ EM Region I Analyses

As implemented by Westinghouse and found appropriate based on the review of the two-phase interfacial drag model of the 3D VESSEL module in WCOBRA/TRAC-TF2 and its assessment, the interfacial drag multiplier, YDRAG, applied to the small bubble, small-to-large bubble, and churn-turbulent flow regimes of the “Cold Wall” two-phase flow map and to the “Hot Wall” two-phase flow map interfacial drag will be **[**

] established for YDRAG in the FSLOCA™ EM as described in WCAP-16996-P/WCAP-16996-NP, Revision 1, Section 13.4 and Section 29.1.5 as lower interfacial drag reduces the two-phase mixture thus promoting core uncovery. **[**

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4.6.5 Cold Leg Condensation on Safety Injection

WCAP-16996-P/WCAP-16996-NP, Section 6.3.6, “Special Model: Cold Leg Condensation Model,” describes the model development for predicting direct contact condensation on the safety injection (SI) water for both SBLOCA and LBLOCA applications. The model employs an empirical correlation that was derived from a best fit to a subset of data obtained from tests at the Westinghouse Condensation on Safety Injection (COSI) test facility. Specifically, Westinghouse COSI data obtained with a vertical SI line injection were selected to determine the fitting coefficients in the correlation using a data subset consisting of 60 experimental points. This facility configuration is referred to as the Westinghouse vertical COSI test facility and the tests as the Westinghouse vertical COSI tests. The diameter of cold leg pipe was **[** **]** and its length was approximately **[** **]** The SI port was connected at **[** **]** for both the azimuthal and longitudinal orientations and the SI piping had an internal sleeve, which allowed for variation of the internal diameter. The tests were performed with two different SI line diameters of **[** **]** A removable weir with a height of half the cold leg diameter was incorporated into a spool piece at the cold leg exit end and was used in some of the tests. The tests were performed at two different downcomer water levels of **[** **]** Section 17.2, “Small Break LOCA Experiments – COSI and ROSA SB-CL-05,” provides the assessment results for the cold leg condensation model as implemented in WCOBRA/TRAC-TF2. A database consisting of 15 data points from **[** **]** tests performed with **[** **]** were used for validation of the condensation model. The model was validated using additional high pressure data from tests conducted as part of the COSI program by Framatome and from ROSA-IV LSTF Test SB-CL-05. Table 19 below summarizes major geometric parameters for these experiments. Additional assessment results are presented in Section 19.3, “Upper Plenum Test Facility Tests (UPTF),” using data obtained at low pressures from UPTF Test 8A and UPTF Test 25A.

Table 19: Major Geometric Parameters for the Westinghouse High-Pressure Cold Leg Condensation Test Facilities

Parameter	W vertical COSI	W horizontal COSI	Framatome COSI	LSTF	Prototype	Length Ratio
Cold leg diameter (in/m)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
SI line diameter 1 (in/m)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
SI line diameter 2 (in/m)	[ ]	[ ]			[ ]	[ ]
Cold leg pipe length (ft/m)	[ ]		[ ]	[ ]	[ ]	[ ]
Azimuthal angle (deg)	[ ]	[ ]	[ ]	[ ]	[ ]	-
Longitudinal angle (deg)	[ ]	[ ]	[ ]	[ ]	[ ]	-

A cold leg condensation multiplier, KCOSI, was added in WCOBRA/TRAC-TF2 and applied to the cold leg condensation heat transfer rate to allow for sampling in the uncertainty analysis. This multiplier is described WCAP-16996-P/WCAP-16996-NP, Section 29.1.6, "Cold Leg Condensation (KCOSI)." The uncertainty range for KCOSI associated with the sampling of the cold leg condensation for Region I was determined based on 15 data points from the Westinghouse horizontal COSI tests and 17 data points from the Framatome COSI tests at maximum safety injection flow rates. In the as-submitted FSLOCA™ EM, **[**

] The review of the proposed cold leg condensation model in WCOBRA/TRAC-TF2 resulted in specific review findings requiring additional information. NRC issued round one RAI Nos. 30 through 35 requesting such information. In particular, RAI Nos. 30 and 35 were related to modeling aspects pertaining to scaling, RAI No. 31 addressed concerns related to the effect of downcomer condensation, and RAI No. 32 asked for clarification on experimental heat losses and associated uncertainty in deriving the cold leg condensation rates. RAI No. 33 asked for additional information on the effect of condensation in the horizontal cells representing the cold leg and RAI No. 34 asked for clarification on data qualification.

Westinghouse provided the final responses to NRC round one RAI Nos. 30 through 35 with letter LTR-NRC-13-31. The response to RAI No. 30 clarified that the COSI volumetric scaling ratio of 1:100 relative to a PWR cold leg and reported in Sections 6.3.6 and 17.2.1 of WCAP-16996-P/WCAP-16996-NP was misleading and suggested that considering parameters related to specific geometric components including the **[**

] was more appropriate for the purpose of the scaling analysis. In the response to RAI No. 31, Westinghouse presented a revised data reduction process for both the Westinghouse and Framatome COSI tests to capture more accurately the cold leg condensation rate and address a scalability issue related to the application of downcomer condensation rate obtained at **[ ]** to tests at higher pressure. By addressing the concern regarding downcomer condensation, Westinghouse was able to recognize the influence of **[**

] were identified in the RAI response as being of primary importance. It was also clarified that Tables 17-2, 17-3, and 17-5 in Section 17.2 of WCAP-16996-P/WCAP-16996-NP would be updated in the revised TR to reflect the condensation heat transfer rates obtained for the Westinghouse COSI and Framatome COSI tests with the revised data reduction process. In addressing RAI No. 32, the measured heat loss of the individual test series was utilized in the revised data reduction process described in the response to RAI No. 31. At the August 12-15, 2013, NRC audit of the FSLOCA™ EM, Westinghouse provided additional details on the cold leg condensation model including cold leg condensation sensitivity results for ROSA-IV LSTF tests SB-CL-05 (SI on) and SB-CL-18 (SI off) indicating that **[**

] This information, contained in the audit presentation materials, was submitted to NRC as part of the audit summary document in letter LTR-NRC-13-70, which also included sensitivity calculation for the Beaver Valley three-loop Westinghouse plant related to the effect of KCOSI. The additional information provided in the final RAI responses was reviewed and found sufficient to close RAI Nos. 31 through 34. The review findings including identified open items relative to RAI Nos. 30 and 35 on scaling and applicability of the cold leg condensation model to PWR were documented in an RAI review template. The open items were discussed at the May 12-13, 2014, NRC audit of the FSLOCA™ EM. At this audit, Westinghouse proposed to address the recognized concern by **[**

] The updated approach was documented in Table 4-1 in the additional information provided in the audit summary document as well as reflected in the audit presentation materials also included in the audit summary document. This information was submitted to NRC with LTR-NRC-14-29. The concern with the cold leg condensation model was also discussed at the August 6-7, 2014, NRC audit of the FSLOCA™ EM. Following the audit, additional information on the open items relative to the final responses to RAI Nos. 30 and 34 was provided by Westinghouse in the audit summary document transmitted to NRC with letter LTR-NRC-15-6. In the additional information, Westinghouse emphasized on a key assumption in the cold leg condensation model in WCAP-16996-P/WCAP-16996-NP that **[**

] The additional information on the open items relative to the final response to RAI No. 30 provided in LTR-NRC-15-6 was reviewed and findings documented in a review template. In addition, the updated information related to the cold leg condensation model and provided in the revised submittal of the FSLOCA™ EM TR in WCAP-16996-P/WCAP-16996-NP, Revision 1, Section 6.3, Section 17.2, Section 19.3, and Section 29 (including Section 29.1.6 and Section 29.2.3) was also reviewed. Specifically, Section 29.1.6 provided an updated range of **[** **]** for the KCOSI multiplier, which was established so that the code bounded all considered COSI experimental data. The section also described the updated approach to cold leg condensation based on which the uncertainty in the condensation model would be only **[**

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This approach was also reflected in the updated Table 29-2, "Uncertainty Elements – Thermal-Hydraulic Models," found in Volume III of WCAP-16996-P/WCAP-16996-NP, Revision 1. Based on the review of the updated approach documented in the revised TR submittal, it was concluded that it addressed to a certain degree the remaining open items so that NRC round one RAI Nos. 30 and 35 could be closed. The proposed approach to accounting for cold leg condensation uncertainty in WCOBRA/TRAC-TF2 using a **[** **]** implemented by Westinghouse in the updated FSLOCA™ EM and described in WCAP-16996-P/WCAP-16996-NP, Revision 1, Section 6.3, Section 17.2, Section 19.3, and Section 29 (including Section 29.1.6 and Section 29.2.3), is found acceptable to the staff. It was also found necessary to propose a limiting condition restricting the application of the FSLOCA™ EM to the established **[** **]** of the cold leg condensation multiplier in Region I. This proposed restriction is included as part of **<u>Limitation No. 8</u>** provided in the following section of this SE.

4.6.6 <u>Horizontal Two-Phase Flow Stratification</u>

The two-fluid six-equation formulation of the two-phase flow in the 1D loop components in WCOBRA/TRAC-TF2 includes capabilities for simulation of horizontally stratified flow important for SBLOCA analyses. In WCOBRA/TRAC-TF2, the horizontal stratified flow (including wavy-dispersed flow) is superimposed onto the basic two-phase flow regime map. TR WCAP-16996-P/WCAP-16996-NP, Section 4, "WCOBRA/TRAC-TF2 Flow Regime Maps and Interfacial Area," Subsection 4.4.5, "Horizontal Stratified Flow," describes a hybrid transition criterion for predicting the transition from horizontal stratified flow to non-horizontal stratified flow developed and implemented in WCOBRA/TRAC-TF2. The approach was based on the **[** **]** criteria applying a modified form of the former criterion at high void fractions and transitioning to the latter criterion at lower void fractions with the **[** **]** at lower void fractions. As implemented in the WCOBRA/TRAC-TF2 flow regime map, horizontal flow is allowed only for pipe inclination angles below **[** **]** In addition, the code models also a wavy-dispersed flow regime as a special horizontal stratified flow regime, which prevents intermittent flow under high pressure SBLOCA conditions by allowing for liquid entrainment in the steam core. Section 16, "Horizontal Stratified Flow and Wavy-Dispersed Flow," presents the assessment of the of the horizontal stratified flow regime against TPTF stratified flow data obtained at the JAERI using steam-water stratified flow test with a large scale pipe diameter, high pressure, and broad range of flow rates and void fractions. The assessment results presented in Figure 16-8 of Section 16 utilized only data limited to **[** **]** The code assessment results exhibited a good agreement with the experimental data, which were predicted within an accuracy of **[** **]** For the purposes of the uncertainty analysis, a horizontal stratified flow regime transition boundary multiplier, HS_SLUG, is introduced in Section 29.1.7, "Horizontal Stratified Flow Regime Transition Boundary (HS_SLUG)." The multiplier can be used to adjust the critical relative velocity for horizontal stratified flow. A [ ] for HS_SLUG was proposed in Section 29.1.7 based on the demonstrated capability of the proposed transition criterion to envelope void fraction data obtained from [ ] as shown in Figure 4-17 in Section 4.

The WCOBRA/TRAC-TF2 capabilities to predict the transition from stratified or wavy-dispersed flow regimes to other intermittent flow regimes is important for the SBLOCA modeling due to the related impact on the following process. Such a transition leads to a much stronger coupling, in terms of interfacial drag and heat transfer, between the phases with these characteristics changing by orders of magnitude and thus affecting the steam venting capability from the vessel to the cold legs and the break. In addition, cold leg condensation reduces significantly under stratified flow conditions, except for the node connected to the ECC piping where WCOBRA/TRAC-TF2 models condensation using a cold leg condensation model developed from the COSI experiments. Also, stratified flow affects break discharge and a special offtake model is used to properly account for the beginning of liquid entrainment for breaks at the top and incipience of vapor pull-through for break at the bottom. Stratified flow affects loop seal clearance as the low interfacial drag associated with this flow regime affects the loop seal clearance process and the residual water level in the loop seal. Finally, the stratified flow in the hot legs has an impact on the natural circulation as it affects the venting capability of the hot legs. The WCOBRA/TRAC-TF2 stratified flow model was reviewed taking into account the above discussed considerations. While the proposed horizontal stratification criterion was found to be adequately supported by the reported assessment results, NRC RAIs Nos. 83, 84, 85, 94, and 95 were formulated to address specific questions related to the description and applicability of the proposed modeling approach. Specifically, RAI No. 83 asked for clarifications regarding lack of consistency and clarity in descriptions relative to the HS_SLUG multiplier throughout various sections of the original submittal of the TR, its assignment and assurance of proper application to individual one-dimensional components of a plant model in LOCA analyses, and identification of specific plant model components that are affected by thus sampling parameter. In its final response to this RAI provided in letter LTR-NRC-14-19, Westinghouse provided the requested clarifications including the need for specific changes to the TR. Also, the RAI response reported identified errors in the SG component noding diagram for the Beaver Valley Unit 1 PWR loop model as shown in Figure 26.3-15 in Volume III of the original TR submittal and provided the correct noding diagram to replace the incorrect figure in the revised TR. RAI No. 84 questioned the validity of Equations 4-113 and 4-116 in Section 4.4.5, "Horizontal Stratified Flow," in Volume I of the original TR submittal and asked for clarification regarding the introduced interpolation technique affecting the horizontal stratified flow regime and flow regimes in the basic flow regime map. Specifically, the RAI asked if other two-phase flow quantities, in addition to the interfacial flow area, were affected by the interpolation technique in the one-dimensional hydraulic components of WCOBRA/TRAC-TF2. In the final response to this RAI in letter LTR-NRC-14-19, Westinghouse provided the correct formulations for Equations 4-113 and 4-116 stating that both equations would be corrected accordingly in the revised TR. The response also explained that the interpolation region was introduced to [ ] and pointed out to the fact that the approach was validated as part of the of 1-D component flow regime map against the JAERI TPTF tests in Section 16, COSI tests in Section 17, loop seal tests in Section 18, UPTF and CCTF tests in Section 19, ROSA IV tests in Section 21, and the LOFT tests in Section 22 of the TR. The response also clarified that besides the interfacial flow area, the linear interpolation technique was applied to adjust the interfacial drag coefficient, interfacial heat transfer factors, and wall drag factors. RAI No. 85 addressed specific questions related to the application of the stratified model with regard to the applicable inclination angle and the consideration of this parameter in PWR plant component models. In the final response to RAI No. 85 in letter LTR-NRC-14-19, Westinghouse provided additional information clarifying the application of the model in representing the PWR **[**

] RAI No. 94 asked for clarification regarding the weighting factor, W_{st}, defined by Equation (4-117) in Section 4.4.5 as a function of the absolute relative phase velocity, $|u_g – u_l|$, the critical relative phase velocity, Δu_c, and two adjustable constants, C_{hs_slug} and C_{stfru}, and used to define the interpolation range when modeling stratified flow in WCOBRA/TRAC-TF2. In the final response to RAI No. 94 in letter LTR-NRC-14-19, Westinghouse explained that the interpolation region is considered as non-stratified flow since the interfacial area and drag of the flow regimes in the basic flow regime map are orders of magnitude higher than those for the stratified flow and small deviations of W_{st} from unity would result in interfacial drag values significantly larger than those for stratified flow when W_{st}=1.0. The response also confirmed that the applicable range for C_{hs_slug} (HS_SLUG) in LOCA analyses using the FSLOCA™ EM is **[** **]** which was different from the allowable input range from 0.1 to 9.99 for this parameter. RAI No. 95 asked for clarification regarding the treatment of the C_{stfru} constant used in the definition of the weighting factor, W_{st}, in WCOBRA/TRAC-TF2 applications. In the final response to RAI No. 95 in letter LTR-NRC-14-19, Westinghouse confirmed that **[** **]** was the default input value for this parameter while its allowable input range in WCOBRA/TRAC-TF2 was set from **[** **]** and stated that the default value was validated in all pertinent WCOBRA/TRAC-TF2 assessment cases documented in the FSLOCA™ TR. The response also explained that the quality assurance (QA) program implemented by Westinghouse effectively prevents an inappropriate parameter from being used in LOCA safety analyses. The response also provided results from a sensitivity study for a 2.6-inch SBLOCA in Beaver Valley Unit 1 that examined the effect of reduction in the interpolation region by setting **[** **]** instead of its default value of **[** **]** The RAI response included two comparison plots for the computed reactor vessel coolant inventories and PCTs using both C_{stfru} values that showed **[** **]** The additional information in the final responses to NRC round one RAI Nos. 83, 84, 85, 94, and 95 provided in LTR-NRC-14-19 was reviewed and the findings were documented in a review template. The findings were discussed with Westinghouse at the NRC FSLOCA™ EM audit on August 6-7, 2014, resolving all remaining questions. It was also confirmed that WCAP-16996-P/WCAP-16996-NP, Revision 1, Volumes I and III, provided in letters LTR-NRC-15-24 and LTR-NRC-15-83 respectively, implemented properly relative corrections identified in the final responses to RAI Nos. 83 and 84. Based on the review of the additional information provided in the above discussed final RAI responses, the discussion at the August 6-7, 2014, NRC FSLOCA™ EM audit, and the review of the updated information relative to the horizontal stratified flow model, including the HS_SLUG multiplier, found in Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, it was concluded that NRC RAIs Nos. 83, 84, 85, 94, and 95 could be closed.

In addition to the above discussed RAIs, Westinghouse provided additional information relative to the effect of the horizontal stratified flow multiplier on plant analysis results in the context of the revised approach for uncertainty assessment proposed for FSLOCA™ Region I analyses as part of addressing NRC round one RAI Nos. 9 and 12 related to the original FSLOCA™ approach to Region I analysis. Specifically, in the final response to RAI No. 9 in letter LTR-NRC-13-45, Westinghouse provided sensitivity results for a three-loop Westinghouse PWR plant that was different from the demonstration three-loop Westinghouse V. C. Summer (CGE) plant examined in Section 31.3 of the original TR submittal. The PCT prediction results for cold leg break sizes ranging from 2 in to 6 in were obtained for HS_SLUG values of **[ ]** and presented in Figures 4 and 5 in the RAI response. The results indicated that **[**

] In analysis results performed for an example three-loop Westinghouse PWR plant in support of demonstrating the revised approach for FSLOCA™ Region I analysis and presented at the May 12-13, 2014 NRC FSLOCA™ EM audit, Westinghouse **[** **]** with the presumption that this would promote core uncovery and cladding heatup. The results were documented in the audit summary document transmitted to NRC with letter LTR-NRC-14-29. Furthermore, in Section 28.2, "Small Break Scoping Study Results," Subsection 28.2.12, "Horizontal Stratified Flow (HS_SLUG) – SBLOCA," in Revision 1 of WCAP-16996-P/WCAP-16996-NP Volume III submitted in LTR-NRC-15-83, Westinghouse provided scoping and sensitivity studies relative to HS_SLUG using the pilot three-loop Westinghouse plant models for V. C. Summer (CGE) and Beaver Valley Unit 1 (DLW). In the case of the V. C. Summer (CGE), the results showed that **[**

] Based on these observations, it was concluded that while producing a relatively small impact on the degree of heatup in SBLOCA transients, **[**

] Accordingly, Section 29.1.7 in the revised TR explained that "for the purpose of the PWR uncertainty analysis for Region I, HS_SLUG is biased high (HS_SLUG=1.5) to maximize the stratified flow regime range to increase the tendency to stratify, and thus retain more liquid in the cross-over legs following loop seal clearance." For FSLOCA™ Region II, a random value of HS_SLUG is **[** **]** as it was the case for both Region I and Region II in the original submittal of the WCAP-16996-P/WCAP-16996-NP, Revision 0, TR. Based on the above considerations, the proposed approach to accounting for uncertainty in the modeling of horizontal two-phase flow stratification in <u>W</u>COBRA/TRAC-TF2 by **[**

] as implemented by Westinghouse in the updated FSLOCA™ EM and described in WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 1, Sections 28.2.12 and 29.1.7 is found acceptable to the NRC staff. It was also found necessary to propose a limiting condition reflecting this restriction in the application of the FSLOCA™ EM related to **[** **]** LOCA analyses. This proposed restriction is included as part of **<u>Limitation No. 8</u>** provided below. The formulation below also includes the condition discussed in the previous section of this SE.

<u>Limitation No. 8: Biased Uncertainty Contributors in FSLOCA™ EM Region I Analyses</u>

As implemented by Westinghouse and found acceptable to the NRC staff from the review of the corresponding <u>W</u>COBRA/TRAC-TF2 models, certain uncertainty contributors will be set at **[ ]** for Region I analyses with the FSLOCA™ EM according to Table 29.2.3-1 and Table 29-2 in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume III, Section 29.2.3. Specifically, the **[**

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established in the FSLOCA™ EM and described in WCAP-16996-P/WCAP-16996-NP, Revision 1, Section 17.2.3 and Section 29.1.6 for KCOSI and in Section 4.4.5 and Section 29.1.7 for HS_SLUG. Lower condensation heat transfer in the cold legs may influence depressurization rate during an SBLOCA boil-off period. A higher transition boundary delays transition to non-stratified flow thus increasing residual liquid in the loop seal regions and decreasing vapor venting capacity. These **[**

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4.6.7 Loop Seal Clearance and Associated Bypass Effects

The loop seal clearance phenomenon, which is of governing importance in the analysis of SBLOCA transients, was recognized as one of the five distinct phases occurring sequentially during an SBLOCA and identified in Section 2.3.1.1, "Small Break LOCA Periods Specification," in Volume I of the original TR submittal as blowdown, natural circulation, loop seal clearance, boiloff, and recovery. Accordingly, it was included in the SBLOCA part of the developed PIRT as presented in Table 2-1 in the TR. Section 2.4.2, "Review of WCOBRA/TRAC and TRAC-P **[** **]** Capabilities and Assessment Results," recognized the pump suction piping/loop seal clearance processes among the phenomena requiring improved physical models relative to the functional requirements for the 1D module of WCOBRA/TRAC-TF2 based on TRAC-P **[** **]** This recognition was also reflected in Table 2-2, "Requirement Assessment against FSLOCA PIRT: Model Availability and Need," in the TR. The assessment matrices for the small break processes in the FSLOCA™ EM presented in Table 2-5, "V&V Matrix for Small Break LOCA Processes, Separate Effect Tests," and in Table 2-6, "V&V Matrix for Small Break LOCA Processes, Integral Effect Tests," identified the full-scale UPTF loop seal clearance tests as the SET database and ROSA-IV LSTF 10 percent, 5 percent, 2.5 percent and 0.5 percent cold leg break tests as the IET data base for assessing the capabilities of WCOBRA/TRAC-TF2 to predict adequately loop seal clearance. Section 18, "Loop Seal Clearance," in its Subsection 18.2, "Important Physical Processes and Scaling Laws," discussed important physical processes and scaling features of the loop seal clearance phenomenon as supported by data from available experiments. Specifically, insights from scaled U-tube experiments performed with air and water at atmospheric pressure as part of the ECTHOR (an acronym from French "Ecoulements dans des Tuyauteries Horizontales en Eau-Air" which stands for "Air-Water Flow in Horizontal Pipes") Program carried out under an agreement between Framatome, Électricité de France, Commissariat à l'Energie Atomique, and Westinghouse were discussed in detail in Section 18.2.1.3, "Analysis of PWS 2.3 Test Results." In addition, experimental results from the full-scale separate effect test facility constricted by Imatran Voima Oy (IVO) in Finland were discussed in Section 18.2.1.4, "Effect of Scale," and void fraction data points were compared against three different limiting lines in Figure 18.2.2-12, "IVO Full-Scale Final Void Fraction and Limit Lines," related to CCFL in vertical flow, onset of wave instability in horizontal stratified flow, and beginning of liquid entrainment. The section also illustrated the effect of geometry and pressure scale on the discussed limits. Furthermore, full-scale separate effect experiments describing the loop seal clearing process in a PWR primary loop during a LOCA produced as part of the Transient and Accident Management (TRAM) experimental program, carried out at the full-scale Upper Plenum Test Facility (UPTF) in Mannheim, Germany, were discussed in Section 18.2.2, "Full-Scale Steam-Water Tests," from a phenomenological viewpoint. Section 18.3, "WCOBRA/TRAC-TF2 Modeling of Loop Seal Clearing Process," presented the code assessment results regarding the code capabilities to predict adequately the loop seal clearing phenomenon in a PWR in a separate effect mode with a focus on the residual liquid level in the loop seal and differential pressure across the loop seal following the loop seal clearance. With regard to the integral effect aspects of the loop seal clearance processes relative to the number of cleared loop seals and preference in loop seal clearance, Section 18.3 referred to Section 28, “Scoping and Sensitivity Studies,” and Section 31, “FULL SPECTRUM^{TM} LOCA Demonstration Analysis.”

The WCOBRA/TRAC-TF2 assessment presented in Section 18.3 was based on the UPTF TRAM loop seal clearance SETs. The assessment results were documented in Subsection 18.3.1, “WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests.” The analyzed tests were performed using combined steam and water or steam injection only with various flow rates and at two different pressure levels of 0.3 MPa and 1.5 MPa (43.5 psia and 217.6 psia). Following the review of presented material, NRC round one RAI Nos. 113 through 119 were issued to address specific questions regarding the code validation against the UPTF test data and related to the employed loop seal model features and nodalization (RAI No. 113), UPTF loop seal instrumentation and adequacy of the loop seal model (RAI No. 114), effect of sampled parameters and special options applicable to loop seal modeling (RAI Nos. 115 and 119), used UPTF TRAM loop seal clearance data (RAI No. 116), and sensitivity to loop seal nodalization (RAI No. 117). Westinghouse provided the final responses to NRC round one RAI Nos. 113 through 119 with letter LTR-NRC-14-19. The additional information provided in the final RAI responses was reviewed and the findings were documented in a review template. The review findings, including identified open items related to RAI No. 113, 115, and 116, were discussed with Westinghouse at the NRC FSLOCA^{TM} EM audit on August 6-7, 2014. Following the audit, Westinghouse provided additional information on the identified open items relative to RAIs Nos. 113, 115, and 116 with letter LTR-NRC-15-6. In the additional information transmitted with this letter, Westinghouse provided additional clarifications related to the observed WCOBRA/TRAC-TF2 capabilities in predicting the residual liquid in the loop seals relative to RAI No. 113, clarified that the default value of **[ ]** for the parameter C_{stfru} (STFRU) was used in the base case calculations provided in the final response to RAI No. 115 in LTR-NRC-14-19, and provided selected legible plots from two UPTF SET cases (Jg*=0.076 at 3 bar and Jg*=0.178 at 15 bar) originally presented the final response to RAI No. 116 in LTR-NRC-14-19 along with a noding diagram. Upon the review of the additional information in LTR-NRC-15-6, the findings, including a remaining Open Item relative to RAI No. 113, were documented in a review template and discussed with Westinghouse at the June 8, 2015, NRC audit of the FSLOCA^{TM} EM. Following the audit, Westinghouse provided additional information on the identified remaining Open Item relative to RAI No. 113 in LTR-NRC-15-85. The provided additional information was reviewed and found sufficient to resolve the Open Item relative to RAI No. 113. Thus, the above discussed NRC RAIs Nos. 113 through 119 were closed.

The NRC RAIs Nos. 88 through 90 were based on the review of Section 21, “ROSA-IV Test Simulations,” in Volume II of the original TR submittal and addressed questions related to the LSTF loop seal modeling including nodalization of the horizontal piping and bend regions, noding adequacy with regard to instrumentation locations, and use of multipliers and model flags. Furthermore, NRC RAIs No. 91 addressed items related to the loop seal models applied in the Virgil C. Summer and Beaver Valley Unit 1 plant models used for the analyses presented in WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 0, Section 26, “WCOBRA/TRAC-TF2 Model of Pilot Plants.” Finally, NRC RAI No. 92 asked for clarifications regarding the approach to representing the loop seal in plant models and the consistency between the loop seal models used in SET, IET, and PWR plant models. Westinghouse provided the final responses to NRC RAIs Nos. 88 through 92 with letter LTR-NRC-14-19. The additional information provided in the final RAI responses was reviewed and the findings were documented in a review template. The review findings, including identified open items were discussed with Westinghouse at the NRC FSLOCA^{TM} EM audit on August 6-7, 2014. Following the audit, Westinghouse provided additional information on the identified open items relative to the RAIs Nos. 89, 90, and 91 with letter LTR-NRC-15-6. Specifically, in the additional information provided with regard to RAI No. 91, Westinghouse clarified that it considered the loop seal modeling approach acceptable to the NRC staff if the inclination angle for the center cell face of the bend regions remained less than **[ ]** The additional information was reviewed and found sufficient to resolve the identified open items and close NRC RAIs Nos. 88 through 92.

4.6.8 Droplet Wall Contact Model (Forslund-Rohsenhow)

The WCOBRA/TRAC-TF2 code utilized the Forslund-Rohsenow correlation for dispersed flow film boiling which consists of a droplet wall contact model developed for low quality, high mass flux conditions in a small diameter tube. The model is applicable only to a small localized region just above the quench front, where the wall temperatures are below the rewet temperature. Physically, the droplet wall contact begins at the inverted annular regime and increases through the agitated inverted annular regime where the effect is at a maximum due to either high turbulence or some possible droplet wall contact. Downstream of the agitated region, the droplet wall contact effect decreases rapidly and becomes non-existent once the highly dispersed flow region develops and the cladding wall temperature exceeds the minimum film boiling temperature. Moreover, this particular model in WCOBRA/TRAC-TF2 was applied throughout the dispersed flow region, particularly at the hot spot where the PCT occurs and turns around in the FLECHT data. Because the drops do not contact the wall above the quench front, a highly superheated boundary layer develops along the cladding, leaving the droplets to reside only in the central portion of the channel. The Forslund-Rohsenow model neither applies at elevations above the quench front nor at the PCT location since the wall temperatures are well above the rewet temperature. This model, in effect, represents an application of a quench front droplet wall contact model to capture other key phenomena governing dispersed flow film boiling in the tests including:

a) Interfacial heat transfer between the drops and the vapor,
b) Turbulence in the central portion of the channel due to drop flow,
c) Radiation heat transfer from the vapor to the droplets,
d) Evaporation of the droplets,
e) Droplet break-up and heat transfer enhancement due to spacer grids, and
f) Thermal rod-to-rod radiation.

The NRC staff raised concerns in RAI No. 56 the correlation does not present a true BE representation of the above phenomena and is not appropriate. Since the Forslund-Rohsenow correlation is highly dependent on void fraction, over-estimation of the entrainment can propagate large errors into the heat transfer during reflood.

The NRC staff also noted that RG 1.157 (BE Calculations of Emergency Core Cooling System Performance) states “A best-estimate calculation uses modeling that attempts to realistically describe the physical processes occurring in a nuclear reactor.” RG 1.157 further states “A best-estimate model should provide a realistic calculation of the important parameters associated with a particular phenomenon to the degree practical with the currently available data and knowledge of the phenomenon….the effects of all important variables should be considered.”

Given the concerns discussed above, there is no justification for the continued use of the Forslund-Rohsenow correlation to determine PCT. And, based on these considerations Westinghouse agreed to remove the correlation from the dispersed flow film boiling model in WCOBRA/TRAC-TF2, resolving this key issue.

4.6.9 Hot Channel Thermal Hydraulic Model

The staff questioned the adequacy of the 1-D hot channel fluid hydraulic model representation in the WCOBRA/TRAC-TF2 code. Since WCOBRA/TRAC-TF2 as well as all the industry T/H codes including RELAP5, FLASH-4, RETRAN, and TRACE is 1-D, the vapor temperature and droplets are distributed evenly across the hot channel during the dispersed flow film boiling reflood phase of an LBLOCA. The code computed cross-section averaged quantities fail 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 can be over predicted, or certainly not properly calculated with a 1-D model of the channel. This is a major limitation for all 1-D codes and is also the subject of RAI No. 56. Test data shows that the channel is 3-D with accumulation of drops in the central region and a highly superheated boundary layer region near the walls, absent droplets. Modeling 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 portion of the channel and not the highly superheated layer near the walls. WCOBRA/TRAC-TF2 as well as all T/H codes suffers from this deficiency, there are no model adjustments that can be made to the DFFB model components to overcome this major discrepancy. That is, the sink temperature is not the entire average hot channel temperature for computing single phase heat transfer, and the interfacial heat transfer between the drops and the vapor is controlled by the lower vapor temperature only in the central core where the drops reside. It is at the boundary between the central part of the channel containing the drops and the superheated wall boundary layer where potential cooling, although very limited, takes place. Interfacial heat transfer between this central core channel region and the superheated boundary layer is not modeled due to the limitations of the 1-D modeling approach in WCOBRA/TRAC and all industry T/H codes. Furthermore, due to this simplified one-dimensional averaging of thermodynamic quantities in WCOBRA/TRAC-TF2 and the limited data in the literature, it is difficult to quantify all of the component contributions to DFFB. Without the knowledge of all of the individual component contributions to DFFB (also noted in the previous section), it becomes very difficult to know and verify the magnitude of the droplet contribution in the WCOBRA/TRAC-TF2 model. Without detailed knowledge of the magnitude of all of the components to DFFB, proper validation of this model against reflood data may result in including other phenomena and effects that are not pertinent to the heat transfer benefits from the droplet break up model, for example. Thus, there are limitations in applying a 1-D model to capture 3-D effects such as those described here and RAI No. 56. Westinghouse in its response understands this issue and states that there is uncertainty in the hot channel model because of these limitations. Westinghouse further notes that the uncertainties are accounted for through the use of multipliers on the heat transfer rate developed based on a comparison to a large reflood heat transfer data based from the separate effects FLECHT tests. Thus, if the heat transfer is over-estimated, then the multipliers developed from the reflood data base will compensate for this deficiency. **[**

] While the staff recognizes that the use of a 1-D model of 3-D effects characteristic of DFFB is deficient as explained above, the treatment of this important heat transfer regime is adjusted through the use of multipliers and tuning of the other component model parameters in the best attempt to capture the bulk sink and clad surface temperatures. The staff also notes that there is also a lack of critical data (for example, radial sink temperature distribution in the hot channels of the separate effects reflood tests and radial location of the drops) to properly develop a DFFB model, and as such, this limits the ability to development better DFFB models. Given these considerations, the staff believes that the WCOBRA/TRAC-TF2 model for DFFB model and heat transfer multiplier uncertainty treatment provides an appropriate adjustment to compensate for the deficiencies in the 1-D model presentation. Comparisons to the FLECHT reflood tests demonstrates that this modeling approach captures and bounds the clad temperature response for a wide range of reflood conditions, including variations in pressure, reflood rate, power level, and axial shape characteristic of LBLOCAs. Based on these considerations, the NRC staff finds the DFFB model treatment of DFFB acceptable for applications to LBLOCA evaluations.

Please see references "Effect of the Cross Sectional Droplet Distribution in Dispersed Flow Film boiling at Low Mass flux," Andreani, M. and Yadigaroglu,G. Cr-3363, Lehigh University, June 1983 and "A 3-D Eulerian-Lagragian Model of Dispersed Flow Film Boiling," Andreani, M. and Yadigaroglu, G. Int J. Heat and Mass Transfer, Vol 40, No. 8, pp.1753-1793July, 1997 for more detailed information regarding DFFB.

4.7 Evaluation of the FSLOCA™ EM Uncertainty Approach

4.7.1 Regulatory Basis for Uncertainty Determination

The BE option in the ECCS Rule in 10 CFR 50.46(a)(1)(i) sets forth the following specific requirements for analyzing ECCS cooling performance with an acceptable EM.

(1) A number of postulated LOCAs of different sizes, locations, and other properties must be calculated sufficient to provide assurance that the most severe postulated LOCAs are calculated.
(2) The EM must include sufficient supporting justification to show that the analytical technique realistically describes the behavior of the reactor system during a LOCA.
(3) 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.

With regard to the last requirement, 10 CFR 50.46(a)(1)(i) states that "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." Appendix K to 10 CFR Part 50, Part II, "Required Documentation," Item 5, "General Standards for Acceptability," requires that "elements of evaluation models reviewed will include technical adequacy of the calculational methods, including: … for models covered by § 50.46(a)(1)(i), assurance of a high level of probability that the performance criteria of § 50.46(b) would not be exceeded."

Regulatory guidance regarding the uncertainty determination is found in RG 1.203 Section 1.4.8, "Step 20: Determine Evaluation Model Biases and Uncertainties," which defines the ultimate objective of the uncertainty analyses as "providing a singular statement of uncertainty, with respect to the acceptance criteria set forth in 10 CFR 50.46, when using the best-estimate option in that rule. This singular uncertainty statement is accomplished when the individual contributions are determined." The section further clarifies that "the individual uncertainty (in terms of range and distribution) of each key contributor is determined from the experimental data (Step 11), input to the nuclear power plant model, and the effect on appropriate figures of merit evaluated by performing separate nuclear power plant calculations." Regulatory Guide 1.203 Section 1.4.8 also refers to RG 1.157 and the CSAU approach in NUREG/CR-5249 for additional guidance regarding uncertainty determination. Further information is provided in Appendix A, "Additional Considerations in the Use of this Regulatory Guide for ECCS Analysis," to RG 1.203, Section A.3, "Uncertainty Methodology."

4.7.2 Relevance of the FSLOCA™ Uncertainty Method to the ASTRUM Method

Referring to the uncertainty method in the approved ASTRUM EM, WCAP-16996-P/ WCAP-16996-NP, Volume III, Section 32.3, "Compliance with Regulatory Position with Respect to the Uncertainty Methodology," emphasize that during the ASTRUM EM development limitations associated with the response surface technique suggested by CSAU were recognized and resolved by replacing the response surface step with a direct Monte Carlo sampling of the uncertainty combined with a non-parametric order statistics technique to show compliance with 10 CFR 50.46 acceptance criteria. Identifying the applicable basis for FSLOCA™ uncertainty method, the section states in part that "the same approach was extended and further improved for the FSLOCA EM.…" As the FSLOCA™ EM uncertainty approach is based on the approved ASTRUM EM (WCAP-16009-P-A), a brief summary of the approved ASTRUM uncertainty method is presented first.

4.7.2.1 Summary of the Approved ASTRUM EM Approach

WCAP-16009-P-A, Section 13, "Methodology Summary," states that "the overall uncertainty in PCT, LMO, and CWO is determined using a non-parametric statistical method. Uncertainties in break type and size, code models, power distribution related parameters, and plant initial conditions are sampled for each PWR case. The limiting case from a series of 124 PWR cases is considered to be the 95th percentile case, with 95-percent confidence." WCAP-16009-P-A, Section 12-5, "Development of Run Matrix," clarifies that "during resolution of the USNRC Requests for Additional Information (RAIs), as documented in Appendix C-1, the ASTRUM statistical approach was modified to consider PCT, LMO, and CWO as independent variables, thus requiring 124 runs to be performed.…" The original formulation of the ASTRUM statistical treatment of uncertainties was based on the assumption that the limiting PCT case would be used for the calculations of the LMO and CWO thus requiring only 59 runs to obtain the 95/95 PCT. Section 12-5 also explains that the list of attributes (or uncertainty contributors), considered in the ASTRUM EM, was divided into two main groups. The first group included all the model uncertainty contributors, which were described by global model and local model parameters. The global model parameters were varied within the WCOBRA/TRAC code whereas the local models were varied within the HOTSPOT code, which was executed once the WCOBRA/TRAC calculation was completed. The second group included the initial condition and power distribution uncertainty contributors, which were considered as plant specific parameters.

4.7.3 Sources of Uncertainty and Uncertainty Quantification in the FSLOCA™ EM

WCAP-16996-P/WCAP-16996-NP, Volume III, Section 32, "Methodology Summary," explains that FSLOCA™ EM approach to the overall calculational uncertainty separates the uncertainty contributors into two main categories described below:

(1) Uncertainty in code capability to represent phenomena and processes identified as highly important in the PIRT (code and models uncertainty contributors).
(2) Uncertainty associated with the input boundary and initial conditions and parameters that define the plant state at the time of the postulated LOCA event including uncertainty related to the break location, break type and size.

In the FSLOCA™ EM, the uncertainty in quantification of parameters identified as contributors to overall calculational uncertainty was accounted for by applying one of the following three ways of treating uncertainty:

(1) Use a <u>nominal</u> (expected, midpoint) value and ignoring uncertainty.
(2) Use a <u>bounding</u> (conservative) value and ignoring uncertainty.
(3) Use a <u>nominal value with uncertainty</u> (define a range and a distribution).

The parameters whose uncertainty is treated explicitly by defining a nominal value with appropriate uncertainty range and probability distribution (Type 3), account for three main categories of sources of uncertainties as identified below:

(1) Thermal-hydraulic model uncertainties.
    (a) Uncertainties of thermal-hydraulic global models.
    (b) Uncertainties of thermal-hydraulic local models for the Hot Rod.
(2) Power-related parameter uncertainties.
(3) Initial and boundary condition uncertainties.

Table 20 below summarizes the treatment of parameters contributing to the FSLOCA™ overall uncertainty by defining applicable criteria and groups and providing specific examples of parameters meeting individual criteria or related to specific groups. It also refers to tables provided in WCAP-16996-P/WCAP-16996-NP, as well as in other supporting documents that provide related information.

Table 20: Treatment of Parameters Contributing to the FSLOCA™ Overall Uncertainty

<table>
<tr><th colspan="6">Treatment of Parameters Contributing to Uncertainty</th></tr>
<tr><th colspan="2">Nominal without Uncertainty</th><th colspan="2">Bounded</th><th colspan="2">Nominal with Uncertainty</th></tr>
<tr><th>Criteria</th><th>Examples</th><th>Criteria</th><th>Examples</th><th>Groups</th><th>Examples</th></tr>
<tr><td>Tight control</td><td>PRZ level</td><td>Gradual variation with operating history</td><td rowspan="4">Section 32.3.1, Table II in LTR-NRC-15-85</td><td>Thermal-hydraulic global models</td><td>Table 29-2 in Section 29, Table I in LTR-NRC-15-85</td></tr>
<tr><td>Negligible impact on transient</td><td>Auxiliary feedwater flow</td><td>Small impact on transient</td><td>Local models for the Hot Rod</td><td>Table 29-3a and Table 29-3b in Section 29, Table I in LTR-NRC-15-85</td></tr>
<tr><td rowspan="2">Impact dominated by other uncertainty contributors</td><td rowspan="2">Break offtake model</td><td rowspan="2">High effort of developing uncertainty treatment (lack of data, complexity of the phenomenon)</td><td>Power-related parameters</td><td>Table 29-4 in Section 29, Table I in LTR-NRC-15-85</td></tr>
<tr><td>Initial and boundary conditions</td><td>Table 29-5 in Section 29</td></tr>
</table>

The development of the individual uncertainty contributors, ranges, and probability density functions for the uncertainty contributors associated with the global models in Category 1 is summarized in WCAP-16996-P/WCAP-16996-NP, Volume III, Section 29.1, "Generation of Model Uncertainty Parameters and Ranging Distributions," and in Section 29.5, "Evaluation Model Biases and Uncertainty (EMDAP Step 20)." Section 32.2, "Compliance with Regulatory Guide 1.203," explains that **[**

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As part of the review of the information provided in the original submittal of the FSLOCA™ EM, the NRC staff formulated round one RAI No. 77, which was issued as part of NRC RAI Set 5. The RAI requested that Westinghouse provide a complete table with description of parameters that are treated as random variables including the probability density functions from which random realizations of the parameter values are obtained for each code run, the mean values, and the variances of the parameters. Westinghouse provided its final response to RAI No. 77 with letter LTR-NRC-13-73. In addition to the request table, the response provided a second table describing parameters treated in a bounded manner in the FSLOCA™ EM. Information relevant to RAI No. 77 was also found in the final responses to other NRC round one RAIs, RAI Nos. 50, 86, and 87, which were provided with letter LTR-NRC-13-73 for RAI No. 50 and with letter LTR-NRC-14-12 for RAI Nos. 86 and 87. The provided additional information was reviewed and review findings along with identified open items were documented in RAI review templates and discussed with Westinghouse at the August 7-8, 2014, NRC audit of the FSLOCA™ EM. At this audit, Westinghouse was asked to provide updated information relative to RAI No. 77 to reflect important modeling changes and updates and changes in the

FSLOCA™ EM introduced during the TR review. As part of this update, Westinghouse was also asked to include relative information describing code inputs as well as direct and indirect multipliers, parameters, and flags provided in the final responses to RAIs 50, 77, 86, and 87 for consideration as part of evaluating the approach to uncertainty assessment in the FSLOCA™ EM application for plant analyses. The status of this request was also discussed with Westinghouse at the June 8, 2015, NRC Audit of the FSLOCA™ EM. Following the June 8, 2015, NRC audit, Westinghouse provided relative additional information in Part 3 of the audit summary document transmitted to NRC with letter NRC-LTR-15-85. The letter included two updated tables with the first table providing a comprehensive description of the code input multipliers, parameters, and flags applied in the WCOBRA/TRAC-TF2 code and relevant uncertainty elements in the updated FSLOCA™ EM. As requested, the table was integral to the information provided in Tables 50-1, 50-2, and 50-3 in the response to RAI No. 50, Table I in the response to RAI No. 77, information in the response to RAI No. 86 and Table 87-1 in the response to RAI No. 87. The second table described the parameters treated as bounded in the FSLOCA™ EM as initially provided in Table 2 in the response to RAI No. 77. The provided additional information was reviewed and found sufficient to resolve the open items thus closing round one RAI No. 77. Specific review considerations related to the subject area discussed in this section are provided below.

RG 1.203, Part C, Section 1.4.8, "Step 20: Determine Evaluation Model Biases and Uncertainties," when it comes to the use of "suitably conservative" input parameters, refers to SRP NUREG-0800 and explains that the "suitability determination may involve a limited assessment of biases and uncertainties, and closely relates to the analyses in Step 16 because what constitutes "suitably conservative" input depends on the set of field equations chosen for the EM." Additionally, it states that "a hybrid methodology (where some parameters are treated in a bounding manner, and other are treated in a probabilistic manner) may also be acceptable." SRP NUREG-0800, Section 15.0.2, "Review of Transient and Accident Analysis Methods," the companion SRP section to RG 1.203, was published after RG 1.203 and basically repeats the language in the RG. SRP NUREG-0800, Section 15.0, "Introduction - Transient and Accident Analyses," Item I.6.C(ii), "Input Parameters and Initial Conditions," adds that "the reviewer verifies that the applicant has … (4) discussed the bases (including the degree of conservatism) used to select the numerical values of the input parameters." RG 1.157 also clarifies that "best-estimate codes may contain certain models that are simplified or that contain conservatism to some degree" and explains that this conservatism may be introduced for the following reasons: (1) the model simplification or conservatism has little effect on the result, (2) the uncertainty of a particular model is difficult to determine and only an upper bound can be determined, (3) the particular application does not require a totally BE calculation so a bias in the calculation is acceptable.

On the basis of the identified regulatory guidelines, the following review conclusions regarding the treatment of uncertainty sources in the FSLOCA™ were found appropriate. It was concluded that the categorization and treatment of the uncertainty sources as well as the treatment of parameters identified as contributors to overall calculational uncertainty in the FSLOCA™ EM were acceptable to the staff. In this regard, the applied approach is consistent with the approved ASTRUM EM (see WCAP-16009-P-A, Section 11-3).

Both RG 1.203 and RG 1.157 consider the use of "suitably conservative" input parameters and require the formulation of specific reasons and criteria for determining what constitutes "suitably conservative" input. Accordingly, the use of bounding (conservative) values in the FSLOCA™ EM was based on the consideration of certain criteria used to justify the application of the approach with regard to specific parameters. This approach was also consistent with the approved ASTRUM method found acceptable to the NRC staff. The proper implementation of individual bounding parameters required consideration of the bases, including demonstration of the degree of conservatism, when selecting the numerical values of individual input parameters. Specific considerations in this regard are provided in various sections of this report that consider such applications of the approach with regard to uncertainty quantification using the FSLOCA™ EM.

4.7.4 FSLOCA™ EM Statistical Approach and Break Spectrum Treatment

A key difference between the approved LBLOCA BE ASTRUM EM (WCAP-16009-P-A) and the FSLOCA™ BE EM is that the FSLOCA™ methodology extends the break area region subject to analyzing to cover the full spectrum of possible break sizes ranging from SBLOCAs to LBLOCAs including break sizes typically not analyzed and classified as IBs. The FSLOCA™ EM **[**

] WCAP-16996-P/WCAP-16996-NP, Volume III, Section 29, "Assessment of Uncertainty Elements," explains that **[**

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In round one RAI No. 8, Westinghouse was asked to provide additional information regarding the proposed approach for determining the upper limit of break size for Region I, which includes SBLOCAs, and the division of the entire break spectrum into two separate regions. In the final response to this RAI provided in letter LTR-NRC-13-37, Westinghouse clarified two key modeling distinctions between Region I and Region II related to the [

] Based on the provided data in the RAI response, the limiting break diameter, break area, and the percentage fraction of the cold leg area corresponding to the break size are provided in Table 21.

Table 21: Lower Break Size Limit for the Large-Break Region in ASTRUM and FSLOCA™ Evaluation Models

EM	PWR Plant	Large-Break Region Lower Boundary		
		Diameter (in)	Area (ft^2)	Fraction of Cold Leg Area (×) (%)
FSLOCA	Two-Loop PWR	[ ]	[ ]	[ ]
	Three-Loop PWR	[ ]	[ ]	[ ]
	Four-Loop PWR	[ ]	[ ]	[ ]
ASTRUM	All types	[ ]	[ ]	[ ]

(×) Based on a cold leg inner diameter of 27.5 in.

In addition, the RAI response provided a table with results for breaks from 0.04% to 24.5% break area from demonstration plant calculations presented in WCAP-16996-P/ WCAP-16996-NP, Volume III, Section 27, “Reference Break Spectrum Analysis,” showing that the PCT behavior was similar on either side of the boundary between Region I and Region II. The provided additional information was reviewed and found sufficient to close round one RAI No. 8. Specific review considerations related to the subject area discussed in this section are provided below proposed limitations and conditions regarding the applicability of the FSLOCA™ EM.

The proposed approach in the FSLOCA™ EM to **[**

] As such, the approach was also found acceptable to the staff for the purpose of analyzing the entire spectrum of break sizes in assuring that the most severe postulated LOCAs are calculated for the purpose of concluding that there is a high level of probability that the applicable safety criteria in 10 CFR 50.46(b) will not be exceeded. The proposed approach of modeling breaks in Region II of the FSLOCA™ EM as either split breaks of a variable area with a uniform break area distribution or as a constant-size DEG break with an equal probability of choosing between a DEG break and a split break is consistent with the approved ASTRUM method and was found acceptable to the staff. The proposed treatment of breaks in Region I of the FSLOCA™ EM as split breaks of a variable area is consistent with modeling of smaller breaks other than a DEG break in Region II and was also found appropriate.

Recognizing the importance of using the **[ ]** in defining the interface between Region I and Region II with the main intent of separating SBLOCA scenarios from LBLOCA scenarios between both regions, **<u>Limitation No. 10</u>** formulated below is proposed to ensure that in plant-specific applications of the FSLOCA™ EM the applicable **[ ]** serves this intended function. It is further noted that the lower break size limit to Region II sampling is 1.0 ft^2, which is consistent with the approved ASTRUM EM.

<u>Limitation No. 10: Boundary between FSLOCA™ EM Region I and Region II Breaks</u>

In PWR plant type-specific application of the FSLOCA™ EM for designs which are not Westinghouse 3-loop PWRs, a confirmatory evaluation will be performed to demonstrate that the applied break size boundary between Region I and Region II serves the intended goal of **[**

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As of part this evaluation, it will be demonstrated that no unexplained behavior in the predicted safety criteria, including PCT, occurs across the boundary between Region I and Region II. In addition, it will be confirmed that the **[**

] is entirely located within Region I. In addition, it is important to also assure that the limiting small break between about 2 and 4 inches in an equivalent break diameter is properly captured by the robust Region I analysis approach. Plants with larger RCS fluid volumes than the TR Beaver Valley test example plant should cover the same 2 to 4 inch range using break area to RCS volume scaling to assure the 2 to 4 inch break range is preserved and not artificially truncated. This confirmatory evaluation will be performed once for each PWR plant type (e.g., Westinghouse design four-loop PWR plant) analyzed with the FSLOCA™ EM and referenced in subsequent plant-specific FSLOCA™ analyses of the same PWR plant type. An additional confirmatory evaluation will be performed once for each PWR plant type to demonstrate that the statistical sampling of the break size for Region II does not weight the results for the PCT, MLO, and CWO acceptance criteria to less limiting breaks as a result of the significant enlargement of Region II by the applied break boundary in the FSLOCA™ EM when compared to the fixed break boundary of 1.0 ft^2 approved for the ASTRUM LBLOCA EM (the ASTRUM boundary corresponds to 24.2 percent while the new FSLOCA™ boundary can amount to **[ ]** based on a 27.5-inch diameter cold leg pipe for some plants). To preclude the lower bound Region II break size from becoming a break size well into the small break size region and to maintain consistency with the approved ASTRUM LBLOCA minimum size, the smallest LBLOCA shall be 1.0 ft^2 for the lower end of the spectrum sampled for Region II spectral analyses.

4.7.5 Sampling of Uncertainty Contributors in the FSLOCA™ EM

In the proposed FSLOCA™ EM approach, each uncertainty contributor is varied simultaneously in the calculations performed for the uncertainty analysis. WCAP-16996-P/WCAP-16996-NP, Volume III, Section 30.5, "Overview of FULL SPECTRUM™ LOCA Statistical Procedure," explains that a representative sample of the LOCA scenario population **[**

] This was achieved by eliminating the stand-alone HOTSPOT code applied in ASTRUM and **[**

] to perform the uncertainty analysis using the FSLOCA™ EM, the described code modification was considered as an improvement in comparison to ASTRUM and was found appropriate.

4.7.6 Compliance with 10 CFR 50.46 PCT, MLO and CWO Criteria

WCAP-16009-P-A, Section 13, "Methodology Summary," states that "the overall uncertainty in PCT, LMO, and CWO is determined using a non-parametric statistical method. Uncertainties in break type and size, code models, power distribution related parameters, and plant initial conditions are sampled for each PWR case. The limiting case from a series of 124 PWR cases is considered to be the 95th percentile case, with 95-percent confidence."

The process for demonstrating compliance with the first three acceptance criteria in 10 CFR 50.46(b), PCT, MLO and CWO, as first proposed in the original submittal of the FSLOCA™ EM, included some adjustments with respect to the approved ASTRUM uncertainty analysis approach. Specifically, the proposed approach **[**

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NRC staff discussed the identified concern with Westinghouse at the September 14, 2015, NRC audit of the FSLOCA™ EM. In response, Westinghouse decided to revise the FSLOCA™ EM and **[**

] It was stated at the September 14, 2015, NRC audit that related methodology updates would be documented and submitted as part of the revised Volume III of WCAP-16996-P/ WCAP-16996-NP. Following the September 14, 2015, NRC audit, Westinghouse submitted to the NRC Revision 1 of WCAP-16996-P/WCAP-16996-NP, Volumes III with letter LTR-NRC-15-83. As necessary methodology updates could not be included in the submittal, such changes were further discussed with Westinghouse at the NRC Audit of the FSLOCA™ EM, which followed on October 7, 2015. At this second audit, Westinghouse presented versions of updated Section 30 and Section 31 of WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 1 reflecting the needed methodology updates, which were examined and discussed with Westinghouse during the audit. Following the audit, Westinghouse submitted to the NRC the official updates of WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 1, Section 30, “Technical Basis of Statistical Procedures Applied in FULL SPECTRUM™ LOCA Uncertainty Methodology,” and Section 31, “FULL SPECTRUM™ LOCA Demonstration Analysis,” as part of the audit summary document transmitted with letter LTR-NRC-15-88. The NRC staff reviewed the changes in the official submittals of both revised TR sections and found them acceptable. Thus, the revised FSLOCA™ uncertainty methodology **[**

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Also consistent with the ASTRUM EM, **[**

] Additional clarifying information on the subject was also provided by Westinghouse in the final response to NRC RAI No. 14 provided in letter LTR-NRC-13-37.

4.7.7 <u>Statistical Sampling Approach for FSLOCA™ Region I (SBLOCA)</u>

In the original FSLOCA™ uncertainty methodology, as described in WCAP-16996-P/ WCAP-16996-NP, Revision 0, the break size was sampled as part of the treatment of all uncertainty attributes assuming **[** **]** Concerns related to the adequacy of the proposed approach to capture critical phenomenology pertaining to the small break region were formulated by the NRC staff in round one RAI No. 9 and the NRC staff white paper discussed above in Section 4.6. To address these NRC staff concerns, Westinghouse decided to revise the proposed approach. The revised Region I analysis method was presented and discussed during the May 12-13, 2014, NRC audit of the FSLOCA™ EM. As described in in Section 4.0 of the audit summary document submitted to NRC with letter LTR-NRC-14-29 following the audit, **[**

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data used in the model development and validation and such were found acceptable by the NRC staff.

To demonstrate that the proposed hybrid approach embeds a degree of conservatism that is appropriate in analyzing Region I for assuring that the most severe postulated LOCAs are calculated using the FSLOCA™ EM, a limiting condition is proposed and formulated as **<u>Limitation No. 9</u>** below.

<u>Limitation No. 9: Effect of Bias in FSLOCA™ EM Applications for Region I</u>

In PWR plant type-specific applications of the FSLOCA™ EM for designs which are not Westinghouse 3-loop PWRs, a confirmatory evaluation will be performed for Region I analyses to assess the effect associated with the **[**

] This confirmatory evaluation will be performed once for each PWR plant type (e.g., Westinghouse design four-loop PWR plant) analyzed with the FSLOCA™ EM and referenced in subsequent plant-specific FSLOCA™ analyses of the same PWR plant type.

4.7.8 <u>Statistical Sampling Approach for FSLOCA™ Region II (LBLOCA)</u>

In the original FSLOCA™ uncertainty method, as described in WCAP-16996-P/ WCAP-16996-NP, Revision 0, **[**

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] The proposed limitation is formulated below as **Limitation No. 11**.

<u>Limitation No. 11: [ ] in FSLOCA™ EM Uncertainty Analyses for Region II and Documentation of Reanalysis Results for Region I and Region II</u>

For each analysis performed using the FULL SPECTRUM™ LOCA methodology, the **[** **]** will be declared and documented prior to performing the uncertainty analysis, and will not be adjusted as a result of the outcome. Should a plant-specific application of the FSLOCA™ EM for such an analysis need be reanalyzed one or more times for the purpose of demonstrating compliance with the applicable acceptance criteria, the performance of each such reanalysis will be discussed in a calculation file and in the ECCS analysis submittal to the NRC, as applicable, to explain the applicable reasons for reanalysis, implemented modeling changes, and an explanation as of how the reanalysis was performed. However, any such reanalysis using the FSLOCA™ EM will use the **[** **]** appropriately modified only for the purpose of reflecting the implemented and described modeling changes. Should a plant-specific application of the FSLOCA™ EM for Region I uncertainty analysis need to be reanalyzed for the same reason as well, the performance of each reanalysis will be also be discussed in a calculation file and in the ECCS analysis submittal to NRC, as applicable, to explain the specific reasons for reanalysis, implemented modeling changes, and an explanation as of how the reanalysis was performed. Any such Region I reanalysis using the FSLOCA™ EM will apply the sample size as defined for Region I in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume III, Section 30.5 (updated in LTR-NRC-15-88) and **[** **]** as used in the original set of runs appropriately modified only for the purpose of reflecting the implemented and described modeling changes. For Regions I and II, no changes to the evaluation model or input deck are to be made except those necessary to permit the criteria to be met.

Furthermore, operating ranges used in a plant-specific analysis as part of the sampling uncertainty analysis for Regions I and II are to be supplied for review by the NRC in a table format for both Regions. In plant-specific reviews, the uncertainty treatment for such plant operating parameters including the sampled distributions and ranges will be considered acceptable if they meet or exceed corresponding design basis and/or TS limiting conditions for operation limits, with uncertainties included, as appropriate.[1] Alternative approaches may be used, provided they are supported with appropriate justification.

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[1] This condition should not be construed to imply that exceeding limiting values by any amount is acceptable; sampling distributions for plant parameters should be realistic and justifiable.

The review of the updated Section 30, “Technical Basis of Statistical Procedures Applied in FULL SPECTRUM™ LOCA Uncertainty Methodology,” and Section 31, “FULL SPECTRUM LOCA Demonstration Analysis,” of WCAP-16996-P/WCAP-16996-NP, Volume III, Revision 1, submitted as part of the audit summary document transmitted with letter LTR-NRC-15-88, revealed the following with regard to the statistical sampling approach for FSLOCA™ Region II. Subsection 30.3.1, “Tolerance Intervals and Sample Size,” states that **[**

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[

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4.7.9 Treatment of the Off-Site Power Availability Assumption

Section 30.4, “Decision on Off-Site Power Availability Assumption via Hypothesis Testing,” in the originally submitted WCAP-16996-P/WCAP-16996-NP, Revision 0, described **[**

]

[

]

The proposed approach for statistical treatment of loss of offsite power for the analysis of Region II, as most recently described in LTR-NRC-15-102, Revision 2 dated January 19, 2016, was reviewed by the NRC staff and was found to be unacceptable for determining the limiting condition for off-site power. In lieu of the approach proposed by Westinghouse that the NRC staff finds unacceptable based upon the information presented in support of the current review, the NRC staff sets the condition of performing a full set of analyses with LOOP and a full set of analyses with offsite power available. This condition is consistent with those imposed on other vendor BE methods for PWR LOCA analysis. Based upon the discussion above, the implementation of Limitation No. 15 formulated below is imposed as a condition for the approval of the TR.

<u>Limitation No. 15: LOOP versus OPA Treatment in FSLOCA™ EM Uncertainty Analyses for Region II</u>

Identification of the offsite power availability limiting condition for the Region II FSLOCA evaluation is required by GDC 35. In lieu of the method proposed by Westinghouse for addressing this requirement, which lacked adequate justification, plant-specific applications of the FSLOCA EM should include two complete sets of sampled statistical evaluations: (1) a complete set with offsite power available and (2) a second complete sampling set without offsite power available. For each set, the calculated statistical results at the 95/95 probability, confidence level should be demonstrated to comply with regulatory limits for PCT, MLO, and CWO. The **[** **]** to provide the required 95/95 probability, confidence statement that addresses the three major criteria of PCT, MLO, and CWO. This condition should be consistent with Limitation No. 11 for establishing the number of sampled runs for each sample set.

4.7.10 <u>Correlation for Oxidation</u>

The requirements in 10 CFR 50.46(b) impose a limit on peak fuel cladding temperature of 2200 °F, and a limit on cladding oxidation of 0.17 times the total cladding thickness before oxidation. The oxidation limit is usually considered as a percentage, and more recently, has been expressed as equivalent cladding reacted (ECR) (i.e., 17% ECR). The Atomic Energy Commission's (AEC) deliberation over the 17% ECR acceptance criterion is discussed in detail in the 1973 Opinion of the Commission regarding acceptance criteria for ECCS for light-water-cooled nuclear power reactors (6 AEC 1085).

In its proceedings, the AEC noted that the "limits specified in these criteria will assure that some ductility would remain in the zircaloy cladding as it goes through the quenching process". The values were selected because experimental data indicated that cladding ductility is influenced not only by oxidation alone, but also by the temperature at which the oxidation occurs. The AEC received recommendations from fuel vendors, the AEC staff, and the public, regarding the selection of an appropriate oxidation limit. The AEC's consideration included not only the total oxidation, but also the thickness of brittle oxidation and zirconium layers in the cladding, and the ratio of the thickness of the brittle layers to the remaining ductile layers. Noting wide agreement on the value of 17 percent ECR as a threshold above which cladding generally exhibited brittle behavior, the AEC settled on this value as the cladding oxidation limit.

The experimental studies supporting this limit evaluated cladding ductile performance and correlated it to the thicknesses of the differing layers, i.e., oxide, brittle zirconium, ductile zirconium, rather than to a measured ECR. The percentage values were calculated, based on the test conditions, using the Baker-Just correlation. Thus, the AEC also noted that "the Regulatory Staff in their concluding statement compared various measures of oxidation (page 90) and concluded that a 17 percent total oxidation limit is satisfactory, *if calculated by the Baker-Just equation*." (6 AEC 1097)

4.7.10.1 Realistic ECCS Research and Additional Cladding Oxidation Correlations

Upon revision to 10 CFR 50.46, in 1988, to allow more realistic emergency core cooling performance calculations, the state of the art for cladding oxidation calculations had evolved. In addition to Baker-Just, Chapter 6.13 of NUREG-1230, "Compendium of ECCS Research for Realistic LOCA Analysis" reviews Cathcart-Pawel alongside two additional oxidation rate equations. The NUREG, as well as RG 1.157, "Best-Estimate Calculations of Emergency Core Cooling Performance," recommend the use of Cathcart-Pawel based on its superior accuracy when compared to Baker-Just.

However, as noted in Research Information Letter (RIL) 02-02, Attachment 2, the original and confirmatory ring compression tests on which the 17 percent ECR criterion was based relied on an ECR value calculated using Baker-Just. As noted on page 9 of RIL 02-02, Attachment 2, "had the Cathcart-Pawel correlation – which did not exist at that time – been used, the cladding oxidation limit would have been about 13 percent. Therefore, the Baker-Just correlation must be used when comparing results with the old 17 percent limit."

4.7.10.2 Safety Implication

The use of a 17 percent limit on ECR, when applied to cladding oxidation values calculated using the Cathcart-Pawel correlation, does not provide the same level of assurance of cladding ductility as the same limit, when applied to a result calculated using the Baker-Just correlation.

In view of these considerations, **Limitation No. 14** is proposed below:

Limitation No. 14: Oxidation Correlation

For demonstration of compliance with the current 10 CFR 50.46 oxidation criterion, the oxidation result using Baker-Just to convert the LOCA transient time-at-temperature to an equivalent cladding reacted shall be compared against the 17 percent limit. If Cathcart-Pawel is used to convert the LOCA transient time-at-temperature to an equivalent cladding reacted, the oxidation result shall be compared to a 13 percent limit with the pre-transient oxide layer thickness being included in the prediction results. Should this measure (Cathcart-Pawel 13 percent limitation) not be carried forth to other NRC approvals of new realistic applications or should the value be changed, this SE and the two associated restrictions will be subsequently revised.

5.0 LIMITATIONS AND CONDITIONS

Table 22 below provides a list of NRC limitations and conditions based on the technical evaluation of the FSLOCA^{TM} EM. These limitations and conditions were documented in the previous sections of this SE. Two of the proposed limitations and conditions included in Table 22 - Limitations Nos. 12 and 13 - resulted from specific NRC round one RAIs.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA^{TM} EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1

No.	Subject	Limitations and Conditions
1	FSLOCA^{TM} EM Applicability with Regard to LOCA Transient Phases	The FSLOCA^{TM} EM applicability for performing PWR LOCA analyses is defined in terms of applicable accident transient phases so that the FSLOCA^{TM} EM cannot be applied for analyzing the long-term core cooling phase of LOCA transients for the purpose of demonstrating compliance with the long-term core cooling requirement set forth in 10 CFR 50.46(b)(5). This limitation specifically addresses the condition that the FSLOCA^{TM} EM does not treat boric acid precipitation and therefore lacks capabilities to address adequately post-LOCA long-term core cooling. The numerical approximations to advection and diffusion in the WCOBRA/TRAC-TF2 code conservation equations have neither been validated nor shown to successfully track the movement of high concentrations of boric acid between the vertical and radial cells with the vessel volumes.
2	FSLOCA^{TM} EM Applicability with Regard to Type of PWR Plants	The FSLOCA^{TM} EM applicability for performing PWR LOCA analyses is defined in terms of applicable types of PWR plants so that the EM can be applied for LOCA analyses of Westinghouse designed three-loop and four-loop PWR plants with cold side emergency core cooling injection, only. Plant-specific applications will generally be considered acceptable if they follow the requirements pertinent to FSLOCA described in WCAP-16996-P/WCAP-16996-NP, Rev. 1, (LTR-NRC-15-88, LTR-NRC-17-47, and LTR-NRC-15-102, Rev. 2) and comply and meet the NRC limitations and conditions in this table (where the later document supersedes the earlier document when differences exist). Plant-specific licensing actions referencing FSLOCA analyses should include a statement summarizing the extent to which the FSLOCA methods and modeling were followed, and justification for any departures. Should NRC staff review determine that absolute adherence to the modeling guidelines is inappropriate for a specific plant, additional information may be requested using the RAI process.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

3	FSLOCA™ EM Applicability for Containment Pressure Modeling	The coupled WCOBRA/TRAC-TF2 and COCO codes or standalone LOTIC2 code will be applied to calculate the containment backpressure in PWR LOCA analyses for Region II so that a conservatively low, although not explicitly bounded, containment pressure will be predicted and used. For this purpose, the input to the COCO model and its prediction results will be based on appropriate plant-specific containment design parameters and initial conditions and will simulate accordingly engineered safety features and installed systems capable of affecting the containment pressure including their actuation, performance, and associated processes. The following specific limitations will apply for Region II analyses using the FSLOCA™ EM: (1) an acceptable plant-specific initial containment temperature will be determined based on input from the utility for the purpose of modeling the containment pressure response with COCO or LOTIC2; and (2) unqualified or indeterminate coatings throughout containment and qualified coatings within the break jet zone-of-influence will not be credited for the purpose of modeling the containment pressure response using COCO or LOTIC2 consistent with the bounding treatment of this parameter (conservatively low containment pressure). Please see LTR-NRC-15-102, Revision 2 (pages P-7 to P-10) for containment modeling.
4	Decay Heat Modeling in FSLOCA™ EM Applications	As implemented by Westinghouse and found acceptable from the review of the decay heat model in the FSLOCA™ EM, the following conditions will apply with regard to decay heat modeling and sampling in PWR LOCA analyses for Region I and Region II: (1) decay heat uncertainty will be **[** **]** in uncertainty analyses for both Region I and Region II according to Table 29-4 in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume III, Section 29; (2) the FSLOCA™ EM cannot be applied for transient time longer than 10,000 seconds following shutdown unless the decay heat model is shown to be acceptable for the analyzed core conditions. The latter limitation is **[** **]** The sampled value of the decay heat uncertainty multiplier, DECAY_HT, reported in units of σ and absolute units, as applied for the limiting runs in Region I and Region II in the plant-specific analysis as part of a License Amendment Request submittal, will be provided as part of the submittal.
5	Fuel Burnup Limits in FSLOCA™ EM Applications	The maximum assembly average burnup will be limited to **[** **]** and the maximum peak rod length-average burnup will be limited to **[** **]** within the FSLOCA™ EM. See WCAP-16996-P, Revision 1, Section 32.4, Methodology Limitations, page 32-21.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

6	WCOBRA/TRAC-TF2 Interface with PAD 5.0 in the FSLOCA™ EM	In the FSLOCA™ EM applications for PWR LOCA analyses, the latest version of an NRC approved version of the latest fuel performance code that is applicable for the LOCA analysis will be used to initialize the fuel rod initial conditions. If the PAD 5.0 code is the latest approved version for fuel performance LOCA evaluations, then this version will be used to interface with WCOBRA/TRAC-TF2. The fuel performance code utilized shall be used to initialize WCOBRA/TRAC-TF2 using appropriate calculative methods to maximize the initial fuel stored energy and gap pin pressure, as well as adhere to any restrictions and limitations that resulted from the staff review and acceptance. The fuel performance code calculative methods should therefore exercise those modeling techniques approved by the staff for initializing WCOBRA/TRAC-TF2 for LOCA evaluations. The fuel performance code shall also include the effects of fuel thermal conductivity degradation and its attendant effects on fuel rod behavior for application to the WCOBRA/TRAC-TF2 code.
7	Interfacial Drag Uncertainty in FSLOCA™ EM Region I Analyses	As implemented by Westinghouse and found appropriate based on the review of the two-phase interfacial drag model of the 3D VESSEL module in WCOBRA/TRAC-TF2 and its assessment, the interfacial drag multiplier, YDRAG, applied to the small bubble, small-to-large bubble, and churn-turbulent flow regimes of the "Cold Wall" two-phase flow map and to the "Hot Wall" two-phase flow map interfacial drag will be **[ ]** established for YDRAG in the FSLOCA™ EM as described in WCAP-16996-P/WCAP-16996-NP, Revision 1, Section 13.4 and Section 29.1.5 as lower interfacial drag reduces the two-phase mixture thus promoting core uncovery. This **[ ]** The comprehensive list of **[ ]** is given in Table 29.2.3-1 of WCAP-16996-P, Revision 1 (see page 29-52).

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

8	Biased Uncertainty Contributors in FSLOCA™ EM Region I Analyses	As implemented by Westinghouse and found acceptable from the review of the corresponding WCOBRA/TRAC-TF2 models, certain uncertainty contributors will be **[ ]** for Region I analyses with the FSLOCA™ EM according to Table 29.2.3-1 and Table 29-2 in WCAP-16996-P/WCAP-16996-NP, Revision 1, Volume III, Section 29.2.3. Specifically, the **[ ]** as established in the FSLOCA™ EM and described in WCAP-16996-P, Revision 1, Section 17.2.3 and Section 29.1.6 for KCOSI and in Section 4.4.5 and Section 29.1.7 for HS_SLUG. Lower condensation heat transfer in the cold legs may influence depressurization rate during an SBLOCA boil-off period. A higher transition boundary delays transition to non-stratified flow thus increasing residual liquid in the loop seal regions and decreasing vapor venting capacity. These **[ ]** To summarize, **[ ]** can be found in Tables 29-1, 29-2, 29-3a, 29-3b, 29-4, and 29-5 in WCAP-16996-P, Revision 1 (see pages 29-5 through 29-11). A compilation of the uncertainty parameter values and ranges can also be found in Table I of LTR-NRC-15-85. Also note that with either of these above references, **[ ]** as documented in LTR-NRC-15-102, Revision 2.
9	Effect of Bias in FSLOCA™ EM Applications for Region I	In PWR plant type-specific applications of the FSLOCA™ EM for designs which are not Westinghouse 3-loop PWRs, a confirmatory evaluation will be performed for Region I analyses to assess the effect associated with the **[ ]** This confirmatory evaluation will be performed once for each PWR plant type (e.g., Westinghouse design four-loop PWR plant) analyzed with the FSLOCA™ EM and referenced in subsequent plant-specific FSLOCA™ analyses of the same PWR plant type.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

10	Boundary Between FSLOCA™ EM Region I and Region II Breaks	In PWR plant type-specific application of the FSLOCA™ EM for designs which are not Westinghouse 3-loop PWRs, a confirmatory evaluation will be performed to demonstrate that the applied break size boundary between Region I and Region II serves the intended goal of **[** **]** As of part this evaluation, it will be demonstrated that no unexplained behavior in the predicted safety criteria, including PCT, occurs across the boundary between Region I and Region II. In addition, it will be confirmed that **[** **]** In addition, it is important to also assure that the limiting small break between about 2- and 4-inch in an equivalent break diameter is properly captured by the robust Region I analysis approach. Plants with larger RCS fluid volumes than the Beaver Valley plant test example in WCAP-16996-P/WCAP-16996-NP, Revision 1, should cover the same 2- to 4-inch range using break area to RCS volume scaling to assure that the 2- to 4-inch break range is preserved and not artificially truncated. This confirmatory evaluation will be performed once for each PWR plant type (e.g., Westinghouse design four-loop PWR plant) analyzed with the FSLOCA™ EM and referenced in subsequent plant-specific FSLOCA™ analyses of the same PWR plant type. The WCOBRA/TRAC-TF2 code is applicable for analysis over the entire break spectrum of LOCA transients. However, for the purpose of the Region II analysis, the minimum of the break area sampling should extend only to 1.0 ft^2 consistent with the ASTRUM LBLOCA EM (WCAP-16009-P-A, “Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM),” Revision 0) in lieu of the Region I/II boundary.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

11	**[ ]** in FSLOCA™ EM Uncertainty Analyses for Region II and Documentation of Reanalysis Results for Region I and Region II	For each analysis performed using the FULL SPECTRUM™ LOCA methodology, the **[ ]** seed, analysis inputs, and **[ ]** to be used for the Region I and Region II uncertainty analyses will be declared and documented prior to performing the uncertainty analyses. The **[ ]** will not be adjusted as a result of the outcome. Should a plant-specific application of the FSLOCA™ EM deviate from the originally declared analysis inputs for the intended purpose of demonstrating compliance with the applicable acceptance criteria, all modification(s) will be discussed in a calculation file and in the ECCS analysis submittal to NRC, as applicable, to explain the applicable reasons for the modification(s). In this instance, the analysis inputs will be modified only for the purpose of reflecting the implemented and described modeling changes. In addition, the calculated preliminary values for PCT, MLO, and CWO for each such case will be summarized for information only in the ECCS analysis submittal to the NRC. Because these preliminary analyses and results are not intended to demonstrate compliance with the criteria of 10 CFR 50.46, formal Appendix B verification and archival documentation of the underlying analyses are not required. Furthermore, operating ranges used in a plant-specific analysis as part of the sampling uncertainty analysis for Regions I and II are to be supplied for review by the NRC in a table format for both regions. In plant-specific reviews, the uncertainty treatment for such plant operating parameters including the sampled distributions and ranges will be considered acceptable if they meet or exceed corresponding design basis and/or Technical Specification limiting conditions for operation limits, with uncertainties included, as appropriate.[2] Alternative approaches may be used, provided they are supported with appropriate justification. **[ ]** are given in Table 1 of LTR-NRC-17-47. Note that **[ ]** as per limitation no. 15 below.
12	Steam Generator Heat Removal During SBLOCAs	In plant-specific applications of the FSLOCA™ EM, a check will be performed to confirm that effects associated with dynamic pressure losses from the steam generator secondary side to the main steam safety valves (MSSVs) are properly considered and adequately accounted for in the plant model used for the design-basis LOCA analyses consistent with NRC Information Notice 97-09, "Inadequate Main Steam Safety Valve (MSSV) Set Points and Performance Issues Associated with Long MSSV Inlet Piping." SBLOCA performance is dependent on secondary pressure as it establishes primary pressure, and the consequential emergency core cooling system injection rate and potential for and degree of core uncovery.

[2] This condition should not be construed to imply that exceeding limiting values by any amount is acceptable; sampling distributions for plant parameters should be realistic and justifiable.

Table 22: Limitations and Conditions Based on the Technical Evaluation of the Updated FSLOCA™ EM Documented in WCAP-16996-P/WCAP-16996-NP, Volume I, II, and III, Revision 1 (Continued)

13	Upper Head Spray Nozzle Loss Coefficient	In plant-specific applications of the FSLOCA™ EM, **[** **]** in the PWR model used to perform the design-basis LOCA transient calculations, to capture the proper core two-phase level response should the core uncover. Additionally, the **[** **]** in such calculations. See Section 29.5.3, Venting, page 29-141 of WCAP-16996-P, Revision 1.
14	Correlation for Oxidation	For demonstration of compliance with the current 10 CFR 50.46 oxidation criterion, the oxidation result using Baker-Just to convert the LOCA transient time-at-temperature to an equivalent cladding reacted shall be compared against the 17 percent limit. If Cathcart-Pawel is used to convert the LOCA transient time-at-temperature to an equivalent cladding reacted, the oxidation result shall be compared to a 13 percent limit with the pre-transient oxide layer thickness being included in the prediction results. Should this measure (Cathcart-Pawel) 13 percent limitation) not be carried forth to other NRC approvals of new realistic applications or should the value be changed, this SE and the two associated restrictions will be subsequently revised. See memorandum Ashok Thadani, Director, RES to Samual J. Collins, Director, NRR ,"Research Information Letter 0202, Revision of 10 CFR 50.46 and Appendix K," dated June 20, 2002, Appendix 2, page 9.
15	LOOP versus OPA Treatment in FSLOCA™ EM Uncertainty Analyses for Region II	Identification of the offsite power availability limiting condition for the Region II FSLOCA™ evaluation is required by GDC 35. In lieu of the method proposed by Westinghouse for addressing this requirement described in LTR-NRC-15-102, Revision 2, page 25, plant-specific applications of the FSLOCA™ EM should include two complete sets of sampled statistical evaluations; (1) a complete set with offsite power available and (2) a second complete sampling set without offsite power available. For each set, the calculated statistical results at the 95/95 probability, confidence level should be demonstrated to comply with regulatory limits for PCT, MLO, and CWO. The **[** **]** to provide the required 95/95 probability, confidence statement that addresses the three major criteria of PCT, MLO, and CWO. This condition should be consistent with limitation number 11 in the table for **[** **]** for each sample set.

6.0 CONCLUSION

Westinghouse has successfully utilized the ASTRUM methodology and the WCOBRA/TRAC code to perform LBLOCA ECCS analysis performance evaluations for both Westinghouse 3-loop and 4-loop designs with cold leg injection systems only. The NRC staff finds that the modifications to extend and enhance this methodology to the intermediate and small break spectra of LOCA transients are acceptable for meeting the regulatory requirements of 10 CFR 50.46.

Furthermore, the findings of this SE apply only to the current version of the FSLOCA™ methodology, which has been extended to include IBLOCA and SBLOCA and do not apply to other LOCA methodologies. This SE, including the limitations and conditions described herein in Section 5.0, approves the FSLOCA™ evaluation methodology with IBLOCAs and SBLOCAs included and its attendant processes of determining the PCT, maximum local oxidation, and core wide oxidation results, but requires that this information be reported on a plant-specific application, which uses this approved version of the FSLOCA™ methodology as defined in the following paragraph. For uses other than that intended and approved as part of the FSLOCA™ methodology of this SE, the process and all of its elements, including a description of its intended use and justification, must be submitted to the NRC for review and approval.

The methodology described in WCAP-16996-P/WCAP-16996-NP, Revision 1, in LTR-NRC-15-88, and with the latest methodology changes described in LTR-NRC-102, Revision 2, dated January 19, 2016, constitutes a separate and unique methodology. Any other version derived from this TR, such as designated by a new revision number, amendment number, addendum number or equivalent designation, would constitute a definition of a new methodology requiring NRC review and acceptance prior to generic application and prior to any specific plant licensing application of a new methodology derived from the FSLOCA™ method.

7.0 REFERENCES

Westinghouse TR Review Documents

WEC - 1 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of WCAP-16996-P Volumes I, II, and III, Revision 0, and WCAP-16996-NP, Volumes I, II, and III, Revision 0, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology),' (Proprietary/Non-Proprietary) for Review and Approval," LTR-NRC-10-73, Westinghouse Electric Company LLC, November 23, 2010 (ADAMS Accession No. ML103610186).

WEC - 2 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information - Third Set' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-31, May 30, 2013 (ADAMS Accession No. ML13156A223).

WEC - 3 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information - Fourth Set' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-32, May 30, 2013 (ADAMS Accession No. ML13169A166).

WEC - 4 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information - Second Set' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-33, May 31, 2013 (ADAMS Accession No. ML13169A404).

WEC - 5 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information - Second Set' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-37, June 5, 2013 (ADAMS Accession No. ML13162A412).

WEC - 6 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-40, June 13, 2013 (ADAMS Accession No. ML13169A280).

WEC - 7 Letter, T. Rodack (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 72, 73, 74 and 76' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-41, June 21, 2013 (ADAMS Accession No. ML13183A374).

WEC - 8 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Support for NRC Review of Westinghouse Topical Report WCAP-16996-P Volumes I, II, and III, Revision 0, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology),' Docket 700, TAC No. ME5244," LTR-NRC-13-41, June 20, 2013 (ADAMS Accession No. ML13190A312).

WEC - 9 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 9 and 12' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," LTR-NRC-13-45, June 26, 2013 (ADAMS Accession No. ML13183A071).

WEC - 10 Letter, J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Summary of July 2013 NRC Code Workshop and August 2013 NRC Audit of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (Proprietary/Non-Proprietary)," Project 700, TAC No. ME5244, LTR-NRC-13-70, October 10, 2013 (ADAMS Accession No. ML13297A362).

U.S. NRC TR Review Documents

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NRC - 2 Letter, E. Lenning (U.S. NRC) to J. A. Gresham (Westinghouse), Request for Additional Information Re: Westinghouse Electric Company Topical Report WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (Full Spectrum™ LOCA Methodology)" (TAC No. ME5244), June 26, 2012 (ADAMS Accession No. ML121070151).

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Attachment 2: Resolution of Comments on Draft SE

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APPENDIX A, "REVIEW OF SUPPLEMENTAL PACKAGE TO CORRECT THE FSLOCA EM STATISTICAL METHOD FOR REGION II (LTR-NRC-17-47) FOR TOPICAL REPORT WCAP-16996-P/WCAP-16996-NP, VOLUMES I, II, AND III, REVISION 1, 'REALISTIC LOSS-OF-COOLANT ACCIDENT EVALUATION METHODOLOGY APPLIED TO THE FULL SPECTRUM OF BREAK SIZES'"

Westinghouse Electric Company (Westinghouse) self-identified an error to the statistical treatment of Region II analysis. The error is in the quantification of the confidence interval for a stated sample size using the non-parametric order statistics methodology contained in the Topical Report (TR), WCAP-16996-P, Revision 1, Reference 1 of LTR-NRC-17-47. The Agency's position is that any Figure of Merit (FOM) must meet its acceptance criterion on a 95 percent probability and with a 95 percent confidence interval (aka 95/95) when using non-parametric order statistics. This confidence level must be obtained jointly when multiple FOMs are considered. The methodology contained in the TR has a **[**

] provided in WCAP-16996-P, Revision 1, the confidence intervals associated with any given number of rejections is over-estimated. This Appendix addresses the methodology correction as submitted in LTR-NRC-17-47, and provides the basis for the NRC staff's conclusion that the corrected sampling approach provides acceptable estimates of the 95/95 OSUTLs for each of the three FOMs.

A.1 Nature of the Error

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] Westinghouse self-identified that this is not the correct interpretation of Wilks, Wald, and Guba-Makai (References 3, 4, and 5 of LTR-NRC-17-47). This approach allows for too many rejections to maintain a 95 percent confidence interval (actual confidence interval for this example scenario with this particular run set was 44.2%).

The correct interpretation, for a **[**

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A.1 Corrected Approach

Westinghouse submitted in the LTR-NRC-17-47 letter dated May 31, 2017 (Reference 1) the corrected statistical equations, calculational procedure, and results (new Table 30-1) to bring the TR into conformance with the NRC staff's position regarding the use of tri-variate, 95/95 OSUTLs when applying non-parametric order statistics. The NRC staff reviewed this material with respect to the references and found the corrections to be fundamentally appropriate, in that the approach is generally consistent with the literature.

To verify that the corrected method was accurate, the NRC staff used FreeMat (a Matlab software clone) to model the calculations and test the method on 2 databases types. The 2 databases included: (1) results provided by Westinghouse for the 3 FOMs and (2) results that the NRC staff created using a random number generator. The NRC staff repeated its random number generation exercise several times to create different distributional databases (normal, uniform, positively correlated, and negatively correlated). With the random number databases, the original and corrected methodologies were tested varying the total population, the number of simulations, and the sample size.

It was confirmed that the original method was not acceptable for **[**

] The NRC staff confirmed that Westinghouse's updated methodology provides the proper tri-variate coverage. There were two conditions noted where the coverage was not met when the number of simulations was small, but that situation was also encountered in the Westinghouse process and subsequently addressed.

The NRC staff performed statistical analyses using the Westinghouse database of FOM results to estimate how much the OSUTLs for the FOMs would change between the original method and corrected method. The CWO and MLO FOMs changed **[**

] This reinforced the need to correct the error but provided little other insight. The NRC staff review concludes that the updated Westinghouse statistical method is mathematically sound and therefore acceptable.

A.2 Statistical Application Review

In LTR-NRC-17-47 (Ref. 1), Westinghouse asserted that the **[**

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The original NRC staff opinion/objection stems from the nature and beginnings of non-parametric order statistics methodology which application to nuclear safety analysis was adapted from manufacturing and quality control processes, where statistical inferences are made based on characteristics of the samples without any *a priori* knowledge of these characteristics. Thus, to **[** **]** may seem counterintuitive, and the NRC staff was concerned that, if not appropriately constrained, this approach could inadvertently introduce information into the statistical sampling approach, which may be obtained *posteriori* .[3] In this particular case, the analysis is of an engineered system where the variability of the parameters and expected outcomes are well known due to an abundance of prior analyses. This fact renders the distinction between *a priori* and *posteriori* knowledge unclear. So, first impressions may thus lead one to believe that stacking the number of rejections on one FOM that is known to be challenging, and not applying rejections to other FOMs that are known to be well-behaved, even if done before the analysis commences, may appear to be an inappropriate, and confidence-reducing, engineering approach to improving the estimation of the limiting results. It is this hypothesis that the NRC staff tested and deliberated.

Using the same method to test the statistical fidelity of Westinghouse's updated calculations, the **[**

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The NRC staff discussed this on several occasions and the lead reviewer finally concluded that the Westinghouse process for **[** **]** is acceptable for the following reasons.

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[3] Updating a sampling-based statistical approach by using information obtained from the characteristics of the sample can reduce the statistical confidence. Refer to Section 24.11, "What's Wrong With This Picture" of NUREG-1475, Revision 1, Applying Statistics.

1.) This analysis is being applied to an engineering system whose operating state inputs are largely not random but are ranges of operating conditions, and the predicted system responses are generally well understood. Thus, there is an amount of *a priori* knowledge regarding both the analysis input parameters and expected results that is distinct from the predicted system behavior and associated variability associated with the results. Therefore, there is no real expectation that knowledge should be discarded. Two purposes of using non-parametric order statistics are to address the unknown correlations of input parameters and low likelihood that extreme system initial conditions and parametric uncertainties stack up unrealistically in a single analysis run.

2.) The **[**
] for practical analyses/applications. Oxidation results are mostly driven by the fuel cladding performance and not the accident scenario for the plant being analyzed. The fuel cladding behavior is well studied by the fuel manufacturer and well characterized. It is not in the interest of the agency or public safety to not allow a vendor to credit the behavior of well perform fuel cladding material because:
    a. That would inhibit the research and devolvement of future improved cladding material and manufacturing processes.
    b. That would retard the incentive for licenses to adopt safer fuel cladding in the future.

3.) Finally, the NRC staff found that there is no clear degradation to the statistical method when using the Westinghouse process.

A.3 Proposed Updates to TR and the NRC staff's Final Safety Evaluation

The NRC staff reviewed the proposed changes to various sections of WCAP-16996-P, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," 2015, and to "Final Safety Evaluation for Westinghouse Electric Company Topical Report WCAP-16996P/WCAP-16996-NP, Volumes I, II, and III, Revision 1, 'Realistic Loss-of-Coolant Accident Evaluation Methodology Applied to the Full Spectrum of Break Sizes' (TAC No. ME5244)," issued on October 19, 2016, and found them all acceptable without exception.

A.4 Conclusion

The NRC staff has reviewed Westinghouse's updated statistical calculational methodology and its application to the Region II analysis contained within WCAP-16996-P, Revision 1, as submitted in LTR-NRC-17-47, and finds them to be acceptable. Furthermore, the NRC staff has reviewed the proposed changes to the Westinghouse TR that would allow to document the updated methodology and found them appropriate. The proposed updates to the NRC staff's SE are also appropriate and acceptable, notable the change to Limitation and Condition No. 11, and those changes are reflected in the revised SE for inclusion in the approved version of Westinghouse's TR.

Reference:

1. LTR-NRC-17-47, "Supplemental Package to Correct the FSLOCA EM Statistical Method for Region II (Proprietary /Non-Proprietary)," May 31, 2017 (ADAMS Accession No, ML17157B405).

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