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The Development of a Realistic LOCA Evaluation Model Applicable to the Full Range of Breaks Sizes: Westinghouse Full Spectrum LOCA (FSLOCA™) Methodology

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Abstract

Recently changes in the regulatory environment toward a risk informed approach combined with more efficient and demanding fuel power cycles, and utilization of margins put more emphasis in scenarios traditionally defined as Small and Intermediate Break LOCA. As a result, Westinghouse made several upgrades and added several new functionalities to its realistic Large Break LOCA methodology based on the use of the WCOBRA/TRAC code. The new code has been renamed to WCOBRA/TRAC-TF2, for the purpose of extending the Evaluation Model (EM) applicability to smaller break sizes. The new EM is called Westinghouse Full Spectrum LOCA (FSLOCA™) Methodology and is intended to be applicable to a full spectrum of LOCAs, from small to intermediate break as well as large break LOCAs. This paper describes the market and regulatory drivers, the functional requirements for the new evaluation model (EM). An overview of the EM and key conclusions on its applicability to LOCA safety analysis are here summarized.

Keywords: Thermal hydraulics, LOCA, Evaluation Model, Safety Analysis

1. Introduction

Westinghouse has historically maintained separate evaluation models (EM) for analyzing design-basis small and large break loss-of-coolant accidents (LOCA). This is due to the differences in the physical phenomena of importance for different break sizes, and the challenges in developing a single computer code which is robust enough to cover the entire break spectrum. Advances in computational tools and the use of statistical methods have also tended to be focused on the large break LOCA, as it has traditionally been more limiting from a design perspective than the small break LOCA.

Safety analysis of Small Break LOCA scenario has been segregated to conservative or bounding evaluation models as stipulated in Appendix K of 10 CFR 50.46 rule. However, regulatory initiatives to risk-inform the 10 CFR 50.46 rule, combined with operational initiatives that call for increased margins to support power uprates and improved operational flexibility, have increased the interest in improved and more realistic analytical capabilities for the small and intermediate break portion of the LOCA spectrum. Furthermore, while historically the focus in LOCA analysis have been on assessing system performance in term of Peak Clad Temperature (PCT) reached during the postulated transient, more emphasis is now given to the Maximum Local Oxidation (MLO) and its impact in maintaining a coolable geometry during a LOCA. At the same time, the MLO during a small break LOCA can 'artificially' challenge the limits for certain classes of Pressurized Water Reactors (PWRs) when the analysis is performed with conservative Appendix-K methods. Finally, data-driven best-estimate plus uncertainty methods are now preferred both by regulators and industry overall since they provide a more realistic representation of the physics and phenomena involved in such analyses.

In order to respond to these needs, it is desirable to have the capability to have a single analytical method, or EM, that covers the entire spectrum of break sizes, in a realistic fashion.

The engine of the currently licensed Westinghouse Large Break LOCA (LBLOCA) EM [1] is the WCOBRA/TRAC thermal-hydraulic system computer code which is the Westinghouse evolution of the original COBRA/TRAC code developed at Pacific Northwest Laboratory [2] by combining the COBRA-TF code [3] and the TRAC-PD2 code [4]. The COBRA-TF code, which has the capability to model three-dimensional flow behavior in a reactor vessel, was incorporated to replace the TRAC-PD2 vessel model. Westinghouse continued the development and validation of COBRA/TRAC through the FLECHT-SEASET program [5] and the code was renamed WCOBRA/TRAC. WCOBRA/TRAC code has been shown to adequately model LBLOCA phenomena and the first Safety Evaluation Report (SER) was received by the NRC in 1996.

In 2005 Westinghouse initiated a development program to fulfill the objective of extending the code applicability to smaller break sizes such that the same code can be applied to a full spectrum of LOCAs, from small to intermediate break as well as large break LOCAs. In order to properly model the Small Break LOCA scenario the code was subject to a significant amount of changes which led to the creation of the advanced WCOBRA/TRAC-TF2 computer code. The development of WCOBRA/TRAC-TF2 started by combining the 3D module of the current WCOBRA/TRAC MOD7A, Rev. 7 with the TRAC-P V.5.4.8. More detailed on the development of the new code were already provided by the authors in a previous paper [6].

The development of the new evaluation model, called Westinghouse Full Spectrum LOCA (FSLOCA™), was just completed and submitted to the US NRC for their review and approval [7].

The development of the new evaluation model followed the Evaluation Model Development and Assessment Process (EMDAP) which is outlined in the Regulatory Guide (RG) 1.203 [8] and the Standard Review Plan (SRP) discussed in the NUREG-0800 [9]. RG 1.203 describes a structured Evaluation Model Development and Assessment Process (EMDAP) which follows the same principles of the CSAU roadmap [10]. One key step in the EMDAP process (as well as in the CSAU) is the Phenomena Identification and Ranking Table (PIRT). The process is used to develop the functional requirements for the new evaluation model as well as to define the validation data base. In the past, separate PIRTs have been developed by focusing on the LBLOCA or the SBLOCA scenarios as two different entities. Here an integrated PIRT was developed to span over the full spectrum of break sizes. The concept of a Full Spectrum LOCA integrated PIRT was presented by the author in a previous paper [11]. Summary and conclusions from the PIRT exercise are discussed in Section 2.

The purpose of this paper is to provide a summary on the functional requirements for the new EM, its validation and assessment of biases and uncertainties. The high level functional requirements are presented in Section 2. Some of the key changes on the constitutive models and preliminary results from the code assessment against Separate and Integral Effect Tests (SETs and IETs) were already presented in a previous paper by the authors [6]. Further improvements were included in subsequent years and updated results presented in the following Section. Section 3 describes briefly the uncertainty methodology and applicability to plant analysis.

2. Significant Code Upgrades and Assessment Results

The scenario being addressed by the FSLOCA methodology is a postulated loss of coolant accident that is initiated by an instantaneous rupture of a reactor coolant system (RCS) pipe. The break size considered for a split break ranges from the break size at which the break flow is beyond the capacity of the normal charging pumps up to a size equal to the area of a double ended guillotine rupture.

The following is the list of highly important phenomena for the purpose of modeling a LOCA transient in a PWR with cold leg safety injection [6]:

- Break flow
- Break path resistance (mainly for large breaks)
- Initial stored energy/fuel rod
- Core heat transfer
- Delivery and bypassing of the ECC (mainly for large breaks)
- Steam binding/entrainment (mainly for large breaks)
- Cold-leg/downcomer condensation
- Non-condensable gases/accumulator nitrogen
- Core void distribution (mixture level)
- Horizontal flow regime in the loops
- Loop seal clearance (mainly for smaller breaks)
- Steam generator thermal-hydraulics (mainly for smaller breaks)
- Core-to-break venting (mainly for smaller breaks)

The modeling of these phenomena, as well as other of a lesser importance, over the full spectrum of LOCA scenarios, required significant changes to the original WCOBRA/TRAC computer code which was renamed to WCOBRA/TRAC-TF2 to reflect the changes in its structure. One of the most significant was the replacement of the 1D module of the code (the TRAC part) which is intended for modeling the Reactor Coolant System (RCS) loops and the Emergency Core Cooling System (ECCS) piping. The original TRAC-PD2 five-equation drift-flux formulation was replaced with the more mechanistic six-equation two-fluid formulation of TRAC-PF1.

The three–dimensional (3D vessel) module of WCOBRA/TRAC-TF2 is based on a two-fluid, three-field representation of two-phase flow. As part of the development of WCOBRA/TRAC-TF2 [6] the 3D module was upgraded by including one additional mass conservation equation for the non-condensable species. The non-condensable gas is transported within the gas phase now representing the gas mixture, rather than the water vapor only. The gas species within the gas mixture are assumed to be in thermodynamic equilibrium.

Closure of the field equations requires specification of thermodynamic functions, inter-phase heat and mass transfer, and other constitutive relationships. Some of these models have been upgraded to improve the code capability in describing the phenomena of interest. Separate Effect Tests (SETs) have been used to validate such model. In this paper the following models and its assessment will be discussed:

- Break flow
- Core void distribution (mixture level)
- Core heat transfer

- Horizontal flow regime in the loops
- Cold-leg/downcomer condensation

Section 2.6 provides some additional information about the code assessment against Large Scale and Integral Test Facilities while Section 2.7 provides a summary of the results and how it addresses the intent of Regulatory Guide 1.203.

2.1 Break (Critical) Flow Model

The break flow is what determines the evolution of the LOCA and therefore is ranked high in the PIRT for any break size. During a LOCA, the break flowrate determines the depressurization rate as well as the mass inventory of the primary system of a PWR. These parameters in turn influence the timing of various engineered safeguard system responses, such as reactor trip and safety injection. The break flow model in WCOBRA/TRAC-TF2 was assessed relative to various effects on the break flow in addition to the accuracy relative to data, such as: a) break path length; c) break flow area variation; d) upstream pressure variation; e) variation in degree of subcooling during liquid discharge; f) upstream void fraction/quality variation; g) break entrance geometry and; f) non-condensable gas concentration in the vapor phase.

The critical flow model [12] was extended to include the non-condensable gas capability [13]. The model was assessed against small and large scale test datasets [14] covering pressure (13-2300 psia), upstream condition (subcooled to quality of 1.0), break path (orifice to 2335 mm), and hydraulic diameter (0.418-500 mm). As seen in [14], the model prediction bias shows no apparent trend relative to the variation in pressure, quality, break path length, and hydraulic diameter. Figure 1 below shows the comparison of all points in the test matrix with $\pm 1\sigma$ lines above and below the 45° line. Bias and standard deviation were also computed based on the upstream fluid state are, since greater accuracy and precision was achieved for the subcooled liquid region. This information has been utilized in the development of the overall uncertainty methodology.

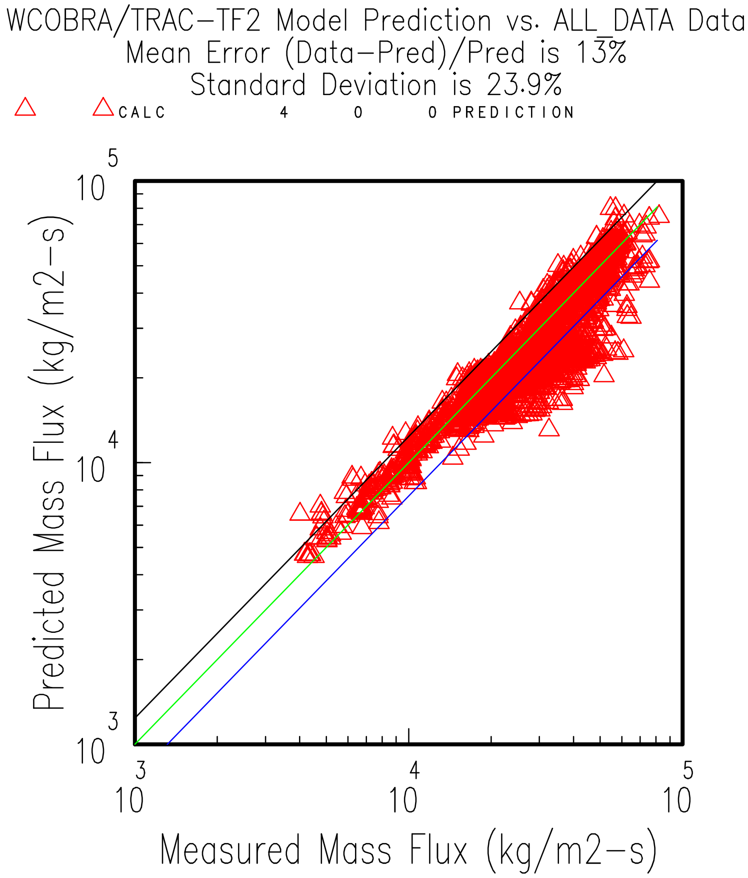

Figure 1- Comparison of Predicted and Measured Critical Flows

2.2 Core Void Distribution and Mixture Level

Prediction of the mixture level swell and tracking of the mixture level are important in the later stages of a small break or intermediate break LOCA. Everything else being the same, the void generation/void distribution/level swell in the core is what determine the portion of the core uncovered during a postulated LOCA event and the clad temperature excursion and oxidation in that region.

There are several separate effects experimental tests that provide data on the mixture level and sometimes mass inventory distribution in a rod bundle under small break LOCA thermal-hydraulic conditions. The assessment of the level swell was based on the ORNL-THTF Uncovered Bundle Tests [15]; the Westinghouse G-1 Core Uncovery Tests; The Westinghouse G-2 Core Uncovery Tests, EPRI NP-1692 [16] and the JAERI-TPTF Critical Heat Flux Bundle Tests [17]. Preliminary results were presented in a previous paper [6]. Here some key results from the final assessment of the code are shown. The parameter of interest is the code ability in predicting the two-phase mixture level swell. The “mixture level swell,” is here defined as the difference between the two-phase mixture level and the collapsed level divided by the collapsed level. More specifically the level swell S is defined by the following formula:

$$S = \frac{(Z_{2\Phi} - Z_{SAT}) - (Z_{CLL} - Z_{SAT})}{Z_{CLL} - Z_{SAT}}$$

where Z_{CLL} is the collapsed liquid level, $Z_{2\Phi}$ is the two-phase mixture level, and Z_{SAT} is the elevation where the liquid reaches the saturation point. Using this definition, a swell of zero corresponds to a two-phase mixture level which is the same as the collapsed liquid level.

Figure 2 shows the predicted and observed level swell for the G1 and G2 boil-off tests. Validation against the boil-off and reflood tests using full length bundle show reasonable agreement under various pressures, subcooling, and bundle power. This information was then used to develop a proper uncertainty methodology to be used in the plant analysis.

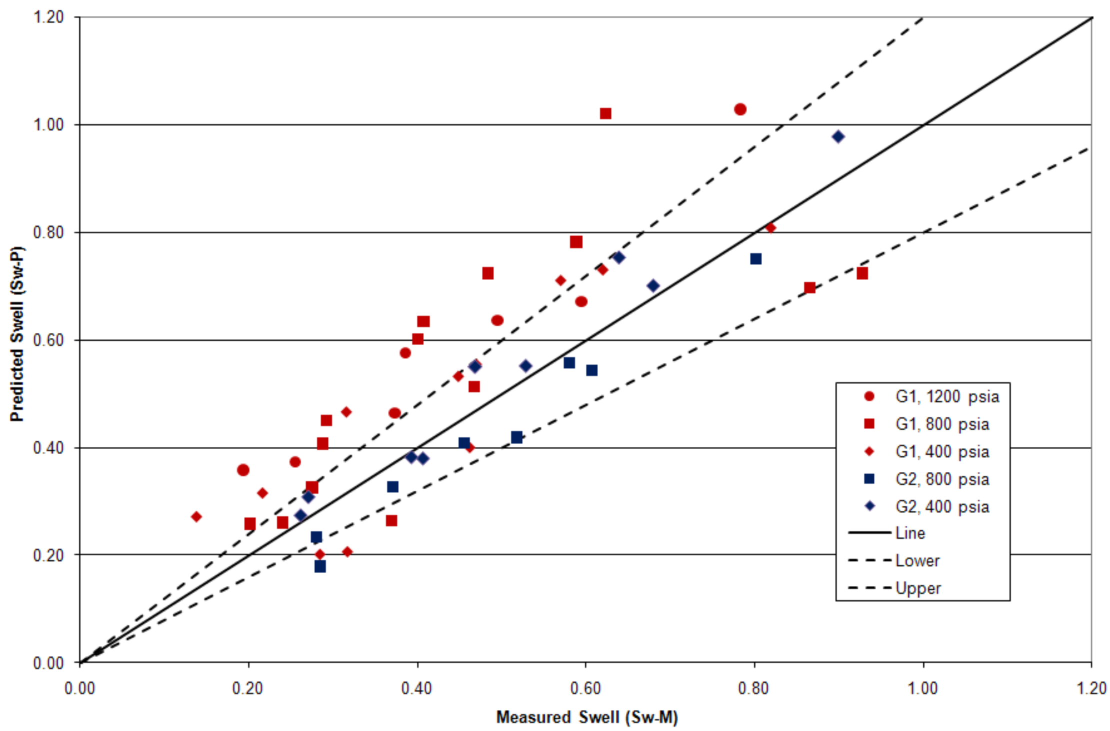

Figure 2 - Predicted Versus Measured Level Swell for the G1 and G2 Boil-off Simulations

2.3 Post-CHF Core Heat Transfer

Post-CHF core heat transfer is obviously a key modeling aspect in order to obtain a sufficiently accurate cladding heat-up response and the corresponding degree of maximum local oxidation. Post-CHF heat transfer is modeled in the code as a regime-dependent, three step process. Specific models and correlations are used for heat transfer from the wall to the vapor field, heat transfer from the wall to the liquid fields, and interfacial heat transfer between the phases. Each of these processes is flow regime dependent and is based on the local hydrodynamic conditions in the computational cell. The same heat transfer package in WCOBRA/TRAC-TF2 is applicable to small, intermediate and large break phenomena.

The assessment of the heat transfer package to the data was broken down in a detailed assessment of two main regimes: single phase vapor (SPV) and dispersed flow film boiling (DFFB). Other post-CHF heat transfer regimes (e.g. inverted annular, transition boiling, etc.) lead to much higher heat transfer rates therefore the models as coded were judged adequate. The SPV heat transfer regime is important during both the refill and the reflood phases of a large break and the boil-off and recovery phases of a small break. Heat transfer in DFFB is relevant when the steam velocity is sufficiently high to entrain and carry droplets. This regime is particularly important during the blowdown and reflood phase of larger breaks.

The SPV database is made of the Oak Ridge National Laboratory (ORNL) Uncovered Bundle Heat Transfer tests [15] and Westinghouse/NRC/EPRI FLECHT-SEASET Reflood Tests [18]. The pressure range of the tests (15 psia to 1090 psia) covers the entire typical plant range except for the highest pressures expected in the PWR. The range of vapor Reynolds numbers in the test cases is consistent with the typical plant conditions, as is the range of rod linear heat rates. The DFFB database is made of the following test series: a) Oak Ridge National Laboratory (ORNL) High Pressure Film Boiling Tests [19], [20], and [21]; b) Westinghouse 1974 G-1 Intermediate Pressure Blowdown Tests; c) Westinghouse 1976 G-2 Low Pressure Refill Tests. In addition SPV and DFFB data was extracted from reflood experiments such as: a) Westinghouse/NRC/EPRI FLECHT-SEASET Reflood Tests [18]; b) Westinghouse/NRC FLECHT Low Flooding Rate Tests [22]; c) Westinghouse/NRC FLECHT Skewed Power Reflood Tests [23]; d) Westinghouse/Aerojet FLECHT Supplemental Tests; f) Westinghouse 1975 G-2 Reflood Tests and g) FEBA Reflood Tests [24].

A sample of typical results from the post-CHF heat transfer assessment is shown in Figure 3 (only shown for subset of the data set). Predictions of single phase vapor and dispersed flow film boiling, and reflood heat transfer test results are sufficiently accurate for use in a full spectrum LOCA analysis. The resulting biases and uncertainties will be used in the PWR uncertainty analysis. Note that the assessment of the heat transfer package also includes the evaluation of the Critical Heat Flux (CHF) and minimum film boiling temperature (TMIN). A detailed discussion of such assessment is beyond the scope of this paper.

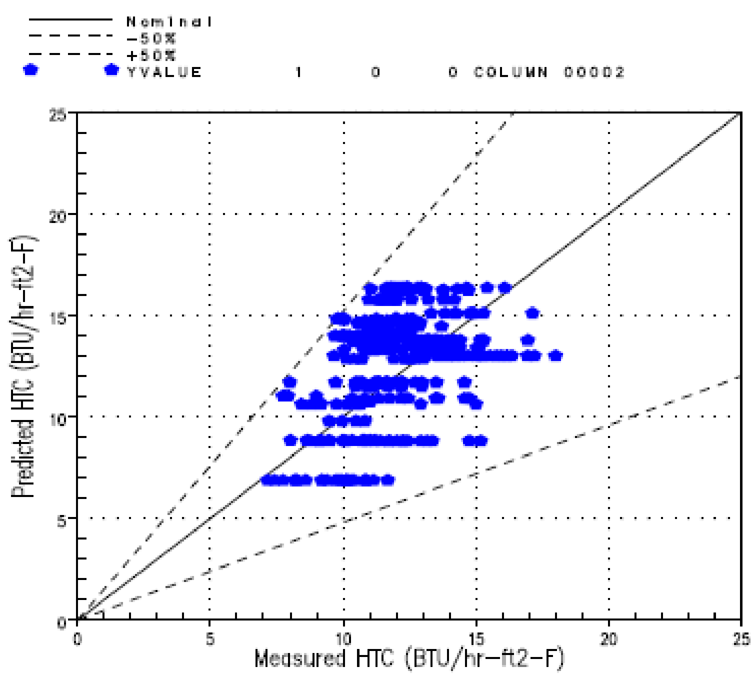

Figure 3 - Predicted vs. Measured Heat Transfer Coefficients from Forced Reflood Tests at Elevations 6-ft and 10-ft

2.4 Improved Horizontal Flow Regime Map for the Loop Components

The horizontal stratified flow regime has relevance during the loop seal clearance, boil-off, and recovery periods for small breaks, when the two-phase level drops in the cold legs and the break uncovers. The capability of the code in predicting the transition from the horizontal stratified or wavy-dispersed regimes to other intermittent flow regimes (bubbly slug, churn, and annular-mist) or interpolation region is very important because interface characteristics (interfacial drag and interfacial heat transfer) change by several orders of magnitude as the flow regime changes across those regimes.

In the 1-D module of WCOBRA/TRAC-TF2 computer code, a horizontal stratification criterion was developed by combining the Taitel-Dukler model [25] and the Wallis-Dobson model [26], which approximates the viscous Kelvin-Helmholtz neutral stability boundary [27]. A wavy-dispersed model which shares similarities with the annular-mist flow was also added to the code to better approximate the segregation of the phases in horizontal pipes. A detailed discussion on the flow regime, transition criteria and applicability can be found in [27].

The applicability of the new horizontal flow regime map is well supported by relevant data, in particular the JAERI Two-Phase-Test-Facility (TPTF) [28] and [29]. The TPTF was designed and built by Japan Atomic Energy Research Institute (JAERI) to study the nature of small break LOCA.

2.5 Safety Injection Condensation

The condensation of steam by the cold liquid injected from the SI in the cold leg is an important phenomenon during both small and large break LOCAs. For smaller break, the condensation is important during the boil-off period and the recovery period. During these periods, the flow in the cold leg is stratified flow which would lead to a negligible condensation. However the impingement of the SI jet into the layer of liquid in the cold enhances condensation greatly. Figure 4 provides a schematic of such condensation mode.

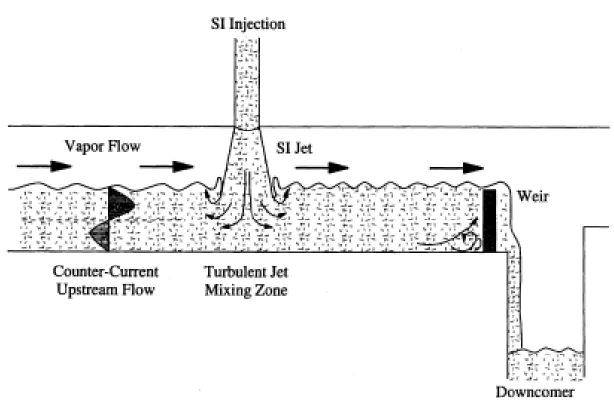

Figure 4 - Schematics of flow regime and condensation in COSI experiment.

As the break size increases, the effect of the accumulator injection and of the higher pumped SI flow rates leads to an increased importance of condensation in the jet region. More details on the SI direct condensation processes were also discussed in separate papers [30] and [31].

As introduced originally in [30], a special ad-hoc model was developed and coded in WCOBRA/TRAC-TF2 to calculate the condensation rate in a situation when the cold leg is expected to be in the horizontal stratified flow regime while the cold water is injected in the cold leg from the ECCS line. The model was based on observations obtained from the Westinghouse COSI test facility which is a 1:100 scale model of the cold leg and safety injection ports of a Westinghouse-type PWR. The model was assessed against an independent data set, and its applicability extended to consider situations for which the flow regime in the cold leg is predicted to be horizontal stratified or wavy-dispersed flow, regardless of the break size or pressure. The data base also included ROSA IV, SB-CL-05 [32] and [33], and data from the UPTF-8 experiment [34] and [35] which was designed for large break LOCA. The model and its assessment are discussed in [31], (Figure 5),

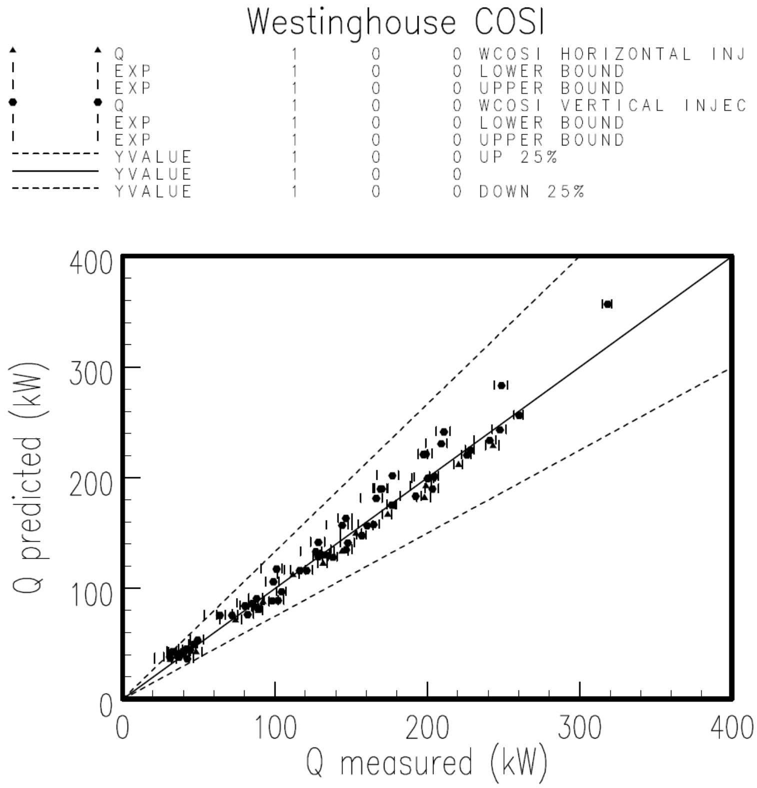

Figure 5 - Comparison between the predicted condensation heat transfer rate and the measured condensation heat transfer rate in Westinghouse COSI experiments.

2.6 Additional Code Assessment (Large Scale and Integral Test Facilities)

The licensing basis of the current Westinghouse Large Break LOCA (LBLOCA) EM [1] relies on the assessment of the WCOBRA/TRAC thermal-hydraulic system computer code with the suite of large scale tests which were part of the international 2D/3D program [34] and [35]. To confirm that the new code (WCOBRA/TRAC-TF2) performs similarly when it comes to Large Break LOCA scenario, the assessment was repeated against a subset of key experiments such as the Upper Plenum Test Facility (UPTF), and the Cylindrical Core Test Facility (CCTF). Results indicated that similar conclusions could be achieved.

The loop seal behavior was identified as an important process affecting the evolution of a small break LOCA transient [36]. The UPTF loop seal tests [37] were used to assess the code.

The integral effect tests assessment was based on the ROSA test facility (ROSA IV/LSTF) [32]. The LSTF is a 1/48 volume scale representation of a Westinghouse four-loop 3423 MW_t PWR (Figure 6). Several experiments were considered in the assessment (SB-CL-01, SB-CL-02, SB-CL-03, SB-CL-

05, SB-CL-14, SB-CL-12, SB-CL-15, SB-CL-16, SB-CL-18, and ST-NC-02). SB-CL-18 is a 5% cold leg break test which is considered to be the reference transient and is the international standard problem No. 26 [38]. SB-CL-01, SB-CL-02, and SB-CL-03 are 2.5% cold leg break tests with the break located at side, bottom and top. SB-CL-12, SB-CL-15, and SB-CL-16 studied the same break orientation effect but at 0.5% break size. SB-CL-14 is a 10% break test. SB-CL-12, SB-CL-01, SB-CL-18, and SB-CL-14 form a break size sensitivity study covering a break range of 0.5% to 10%. SB-CL-05 is another 5% cold leg break test and it is the only test with the high-head safety injection (SI) activated.

The analysis of the results of the various ROSA-IV LSTF test simulations demonstrated that WCOBRA-TRAC-TF2 is capable of simulating with sufficient accuracy the key thermal-hydraulic phenomena that might occur during PWR small break LOCA accident. Figure 7 compares calculated and measured inner vessel differential pressure, which is an indicator of the inner vessel collapsed level. Core heat-up occurs during the loop seal clearance period as the core is temporarily uncovered. Figure 8 compares the PCT predicted by WCOBRA/TRAC-TF2 to the maximum cladding heat-up observed in the data. Further analysis indicated that the code calculates somewhat excessive liquid holdup in the steam generator U-tubes that contributes to deeper and longer core uncovery and as a result higher rod heat up during the loop seal clearance period. However this was considered an acceptable conservative bias.

LOFT Integral Effect Tests (IETs) [39] (Figure 9) were originally used to assess the capability of the code to predict intermediate and large break LOCA events. The LOFT facility (operated by EG&G Idaho Inc. for the Department of Energy) was designed to represent a 1/60 scale (by volume) of a four loop PWR. The facility was also provided with a core with nuclear rods, rather than electrical heated rods.

LOFT L2-2, L2-3, L2-5 and LB-1 were designed to represent double-ended cold leg pipe breaks (200%) in a full-scale PWR at various power levels with and without a pump running. LOFT L3-1 was configured to simulate a PWR Loss of Coolant Accident (LOCA) caused by a cold leg small break equivalent to a 4-inch pipe rupture (2.5%) and LOFT 5-1 represents an intermediate break PWR LOCA caused by a 14-inch accumulator injection line rupture (25%). Figure 10 and Figure 11 show the measured and predicted (black line) peak cladding temperatures in the hot assembly region. L2-3 is a case with the pump operating, which makes the behavior of this transient sensitive to the break flow. Figure 10 shows both the nominal and a sensitivity case with the two-phase discharge coefficient increased by 5%, a small amount compared to the model uncertainty seen in Figure 1. The comparisons are judged to be reasonable. In particular the blowdown heatup is well predicted and the effect of the pump properly captured.

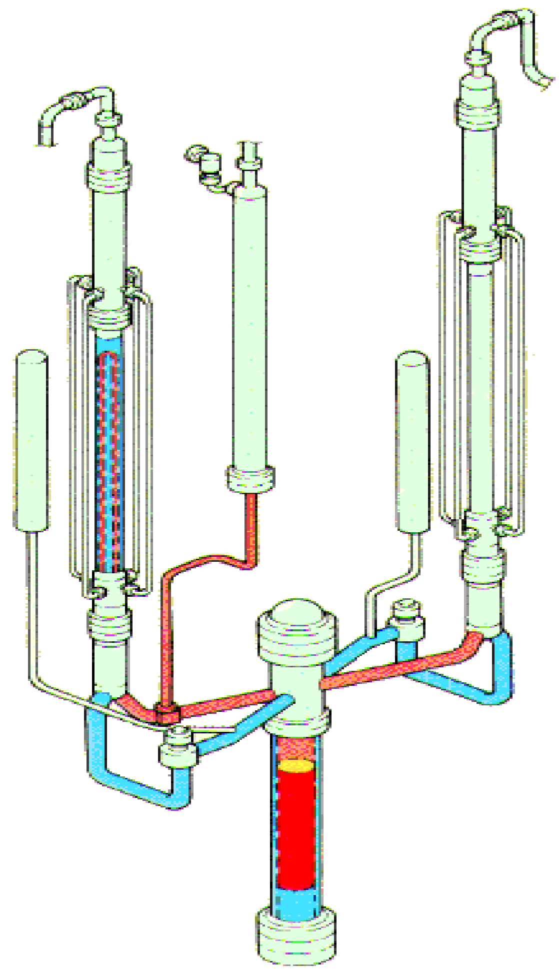

Figure 6 - JAERI ROSA-IV Large Scale Test Facility General View

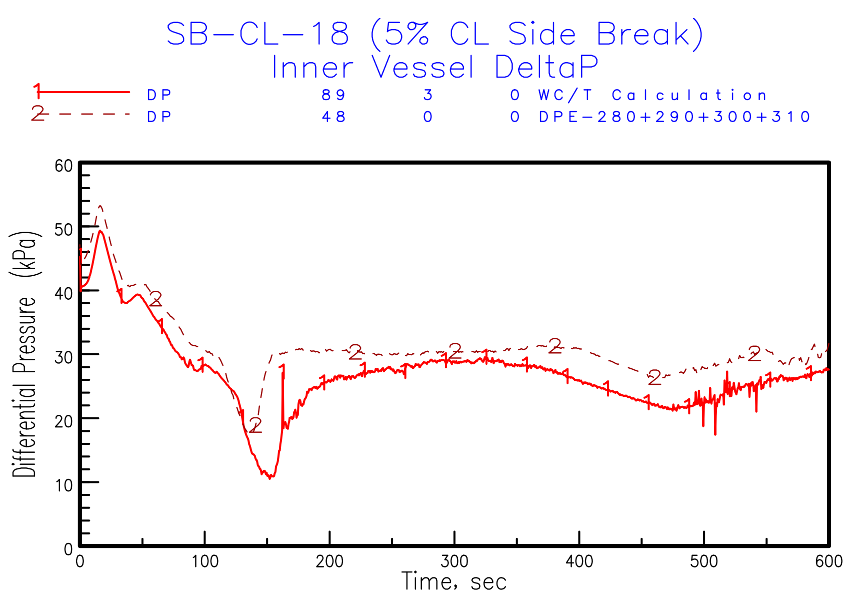

Figure 7- Inner Vessel Differential Pressures

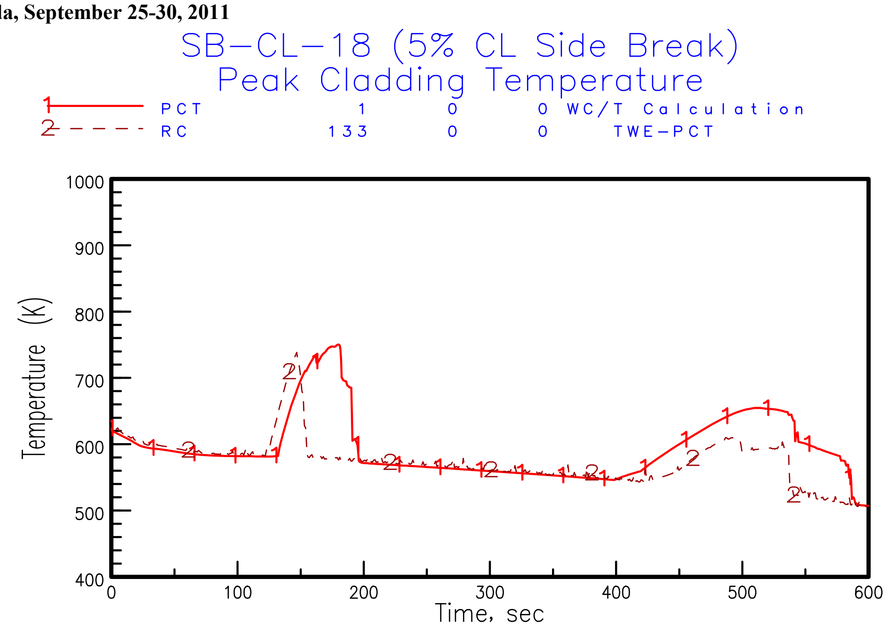

Figure 8 - Calculated and Measured Peak Cladding Temperatures

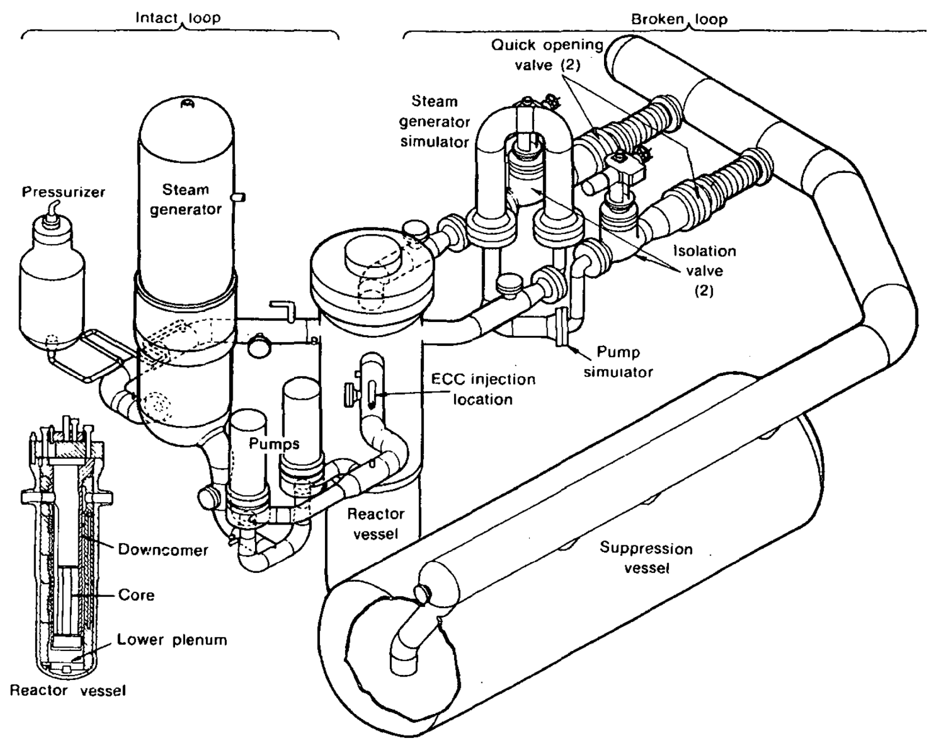

Figure 9 - Schematic of LOFT Facility

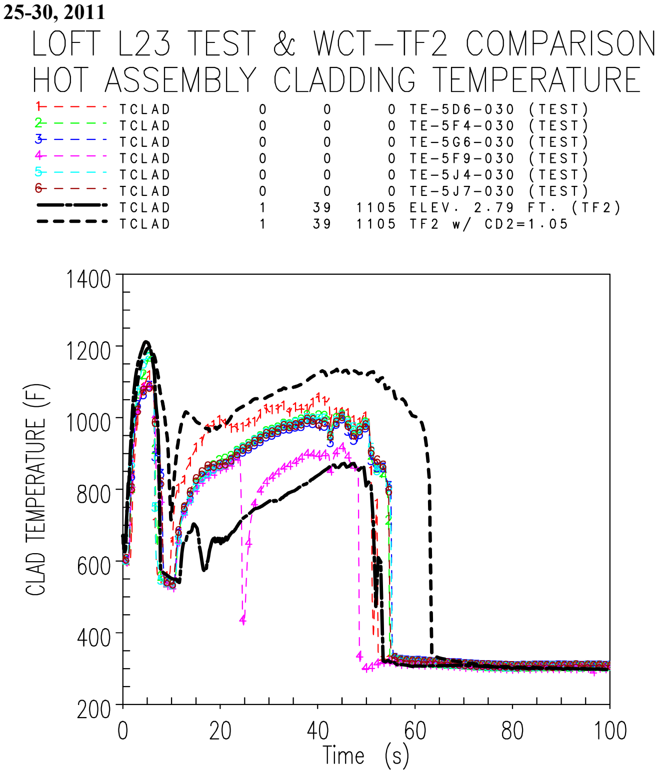

Figure 10 - Predicted (2.79 ft) and Measured Cladding Temperature in the Hot Channel, Test L2-3

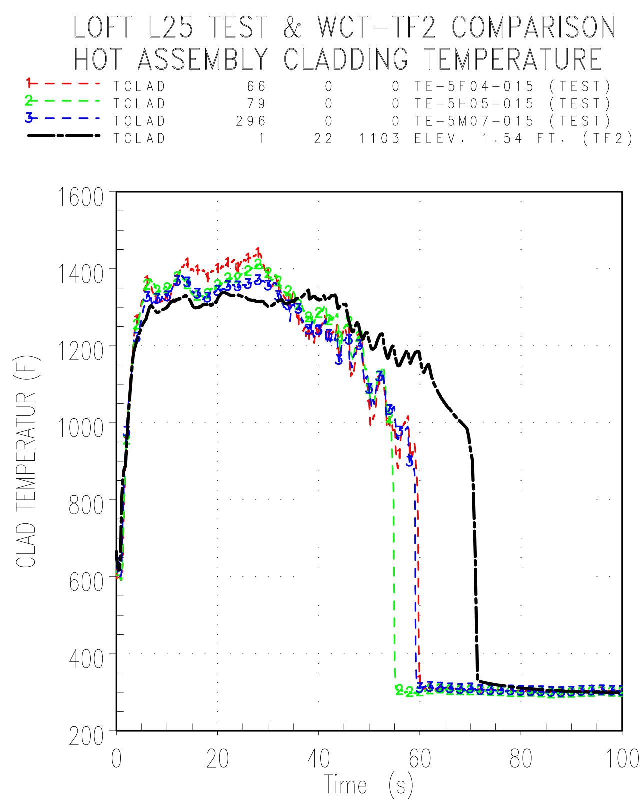

Figure 11 - Predicted (1.54 ft) and Measured Cladding Temperature in the Hot Channel, Test L2-5

2.7 Conclusions on the Assessment and Compliance with Regulatory Guide 1.203

Regulatory Position 1 of RG 1.203 - "Evaluation Model Development and Assessment Process" – was rigorously followed in the development of the Westinghouse FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (EM). The application envelope of Westinghouse FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (EM) was defined at the beginning of this Section. As far as the power plant class the PIRT was intended to be comprehensive and therefore to cover the same power plant class included in the previous methodology (ASTRUM) which include Westinghouse designed 3- and 4-loop plants with emergency core cooling system (ECCS) injection into the cold legs, Westinghouse designed 2-loop plants with upper plenum injection (UPI) and Combustion Engineering designs. One cornerstone of the RG 1.203 is the result of Element 4 which leads to the "EM Adequacy Decision". The adequacy decision is based on the final assessment of the WCOBRA/TRAC-TF2 performances. The standard suggested in the Regulatory Position 1.5 was followed here. The High-ranked PIRT phenomena are reviewed in the following Table. Some of processes have being combined to ease the analysis. For each of the PIRT item, the EM capability was assessed following these standards:

- Excellent Agreement – Applies when the code exhibits no deficiencies in modeling a given behavior. Major and minor phenomena and trends are correctly predicted. The calculated results are judged to agree closely with data.
- Reasonable Agreement – Applies when the code exhibits minor deficiencies. Overall, the code provides an acceptable prediction. All major trends and phenomena are predicted correctly. Differences between calculated values and data are greater than are deemed necessary for excellent agreement.
- Minimal Agreement – Applies when the code exhibits significant deficiencies. Overall, the code provides a prediction that is not acceptable. Some major trends or phenomena are not predicted correctly, and some calculated values lie considerably outside the specified or inferred uncertainty bands of the data.
- Insufficient Agreement – Applies when the code exhibits major deficiencies. The code provides an unacceptable prediction of the test data because major trends are not predicted correctly. Most calculated values lie outside the specified or inferred uncertainty bands of the data.

For high-ranked phenomena in PIRT, the standard for acceptability with respect to fidelity is generally "reasonable agreement." For phenomena whose assessment are in Minimum agreement and insufficient agreement category would require conservative treatment in the EM. A conservative treatment for phenomena whose assessments are in Reasonable agreement is sometimes selected when the effort of developing an uncertainty range is not justified.

The assessment summary of high PIRT ranked phenomena and models was tabulated and presented in the Topical report submitted to the NRC for their review. In addition to the adequacy rating and assessment findings, the uncertainty treatment for each phenomenon in the EM was identified.

3. Uncertainty Methodology and Typical Full Spectrum LOCA Analysis Results

The uncertainty methodology is based on a direct Monte Carlo sampling of the uncertainty contributors. The process is overall similar to the approved methods [1]. However some of the implementation details have been re-worked to properly address some concerns relative to the sample size and the need of providing an adequate coverage and consideration of all break sizes which are considered by the Full Spectrum LOCA EM.

As statistical methods are implemented to perform LOCA safety analyses, a statistical statement which estimates or bounds the 95th quantile of the population with a 95% confidence level has been suggested by the NRC as acceptable to demonstrate the required "high probability." In the previous approved methodology [1] the 95th quantile of the joint-distribution of PCT, MLO and CWO is bounded with at least 95% confidence level. Consistent with the previously approved methodology the 95/95 criterion is considered for the Full Spectrum LOCA EM methodology. Details of the methodology to demonstrated compliance with the 10 CFR 50.46 criteria are discussed in the Topical report [7] provided to the NRC for their review and approval.

Westinghouse approach to the overall calculation uncertainty has been to separate the uncertainty contributors into two general classifications; the code and models uncertainty contributors and the plant conditions uncertainty contributors. Each uncertainty contributor is varied simultaneously in the calculations performed for the uncertainty analysis.

The code and models uncertainty contributors account for the uncertainty in predicting the important thermal-hydraulic phenomena identified in the PIRT, and important modeling assumptions. Controlling parameters of the important phenomena are ranged via use of multipliers. Each multiplier is characterized by a Cumulative Distribution Function (CDF) which represents the bias and uncertainty for the corresponding model. Development of the CDFs is a critical step in the development of the EM. The CDFs were developed by performing a systematic assessment of the uncertainty associated with the code prediction relative to the data. The assessment of the thermal-hydraulic models in WCOBRA/TRAC-TF2 used a large number of test comparisons to ensure that estimates of the model uncertainties were well-founded, and included potential scaling effects.

The plant conditions uncertainty calculation account for the different possible operating conditions and accident initial conditions that the plant could experience. Similarly to the code model uncertainty contributors, some are explicitly ranged in the uncertainty methodology; others are bounded to ease the analysis when it is not practical to treat these conditions in a statistical fashion.

The selected approach was deemed to satisfy the intent of Regulatory Position 4 of RG 1.157, "Estimation of Overall Calculational Uncertainty"

4. Summary and Conclusions

A new realistic LOCA Evaluation Model (EM) called FULL SPECTRUM LOCA™ methodology was developed by Westinghouse Electric Company. The term 'Full Spectrum' specifies 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 PWR. The break sizes considered in the Westinghouse FULL SPECTRUM LOCA™ include any break size in which break flow is beyond the capacity of the normal charging pumps, up to and including a double ended guillotine (DEG) rupture with a break flow area equal to two times the pipe area.

The new EM build upon the previously approved best-estimate large break loss-of-coolant accident (LBLOCA) methodology which addressed Large Break LOCA scenarios with a minimum size of 1.0 $ft^2$and was applicable to Westinghouse designed 3- and 4-loop plants with emergency core cooling system (ECCS) injection into the cold legs, Westinghouse designed 2-loop plants with upper plenum injection (UPI) and Combustion Engineering designs. The new methodology extends the applicability of the Westinghouse best-estimate LOCA EM by considering smaller break size, therefore including what traditionally are defined as Small and Intermediate Break LOCA scenarios.

As in previous EMs, the FULL SPECTRUM LOCA™ methodology was patterned after the Code Scaling, Applicability, and Uncertainty (CSAU) methodology developed under the guidance of the US Nuclear Regulatory Commission (NRC) [10]. The development roadmap is consistent with Regulatory Guide 1.203 (Evaluation Model Development and Assessment Process, or EMDAP).

This paper provided an overview of the model upgrades and the assessment against the experimental database. The selected code validation matrix covers the range of conditions expected during a PWR LOCA transient, to the extent practical. Uncertainty in the experimental data was considered in the overall uncertainty assessment. The final product was intended to satisfy principles and guidelines provided in Regulatory Guides 1.157 and 1.203.

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