Summary of August 2014 NRC Audit Part 1 of FULL SPECTRUM LOCA (FSLOCA) Evaluation Model" (Non-Proprietary)

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August 2014 FULL SPECTRUM LOCA Audit Summary – Part 1

Introduction

The review of the FULL SPECTRUM™ LOCA (FSLOCA™) evaluation model has spanned a four year period. During that time, there were a series of interactions with the Nuclear Regulatory Commission (NRC) that included draft Requests for Additional Information (RAIs), formal RAIs, periodic meetings and audits.

During the recent August 2014 audit, a plan to close all of the open items related to the RAI responses was established. The plan is to provide additional information to the NRC in a two part audit summary. Part one of the audit summary, provided herein, transmits the additional information that was requested for a subset of the open items. The remaining information will be transmitted in the part two audit summary.

Considerable effort is required to prepare the audit summaries. This requires a diversion of resources resulting in an impact to the current schedule for updating the topical report. Westinghouse is re-evaluating the schedule to determine a revised delivery date of the updated volumes.

RAI-23

It is clarified that the maximum assembly [ ]a,c and the maximum peak rod [ ]a,c

RAI-36

[

]a,c

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[

]a,c

Rod stored energy was shown to be [ ]a,c in Section 4.0 of LTR-NRC-14-38 [3].

RAI-37

Regarding the conformance of the results shown in Figures RAI37-1 through 37-4 of LTR-NRC-14-17 with the proposed [ ]a,c please see the discussion on page P-16 of LTR-NRC-14-17. Specifically, see the passage: [

]a,c

It is clarified that "Average temperatures" for WCOBRA/TRAC-TF2 and PAD5 are volume-averaged quantities. The rod stored energy was shown to be [
]a,c in Section 4.0 of LTR-NRC-14-38.

The fuel thermal conductivity and gap conductance models in WCOBRA/TRAC-TF2 are [

]a,c

RAIs 36 through 39 – Gap Conductance

During the audit, the NRC requested additional information related to the fuel rod initialization process discussed in the response to RAIs 36 and 37, originally provided in LTR-NRC-14-17. [

]a,c

RAIs 36 through 39 – Processing of Axial Power Distributions

[

]^{a,c}

[

]a,c

[

]a,c

[

]a,c

Conclusions

[

]a,c

RAI-46

Code Version and Input

The version of COCO that is coupled to WCOBRA/TRAC-TF2 is COCO_A Version 1.4. COCO_A Version 1.4 was released in September 2001. As such, COCO_A Version 1.4 has been used for all Automated Statistical Treatment of Uncertainty Method (ASTRUM) analyses (WCAP-16009-P-A [6]) that included a re-calculation of the containment back-pressure for dry containment designs.

A list of updates for coupling COCO_A Version 1.4 to WCOBRA/TRAC-TF2 and references to the theoretical bases are given in the response to Question 1 of RAI 46 (see LTR-NRC-13-73 [7]). They are summarized as follows:

- WCAP-8327-P [8]: This document contains a description of the models in COCO.
- WCAP-8471-P-A [9]: This document contains NRC approval of COCO for use with the 1974 Appendix K Evaluation Model (EM).
- WCAP-8339 [10]: Appendix A of this document contains guidance for application of COCO. Much of this guidance still applies, but an updated list of inputs and assumptions is given in the response to Question 4 of RAI 46 (see LTR-NRC-13-73).
- WCAP-9220-P-A, Revision 1 [11]: This document contains a discussion of the modeling of paint in COCO.
- WCAP-10266-P-A, Revision 2 [12]: This document contains NRC approval of COCO for use with the BASH Appendix K EM.

The most complete user's manual is that for containment integrity analyses, which explains all inputs. For Large Break LOCA (LBLOCA) analyses to confirm emergency core cooling system (ECCS) performance, some generic inputs and additional user guidance are given in guidance documents.

Standalone Version Comparison to Coupled Version

A Double-Ended Guillotine (DEG) break case and a split break case were performed to compare the results of a standalone COCO run with those of a coupled COCO run. In each of these test cases, a case is first run with the coupled COCO model. Then, the mass and energy releases (M&Es) from the reactor coolant system (RCS) for that run are used as input for a standalone COCO_A Version 1.4 run. The pressure comparisons for the test cases are included in Figures 19 and 20. These figures show that [

]a,c

Containment Leakage

[

]a,c

[

]a,c

Non-Condensable Gas Treatment

[

]a,c

Paint/Coating Qualification

A proposed methodology for Generic Safety Issue 191 (GSI-191) analysis was created by industry representatives in NEI-04-07 [13]. From Section 3.4.3.3.4 of Volume I of NEI-04-07, all indeterminate and design basis accident (DBA)-unqualified and unacceptable coatings are considered to fail. In NEI-04-07, the definitions of DBA-qualified/acceptable, DBA-unqualified/unacceptable, and indeterminate coatings are taken from ASTM D5144-00; however, this document has been superseded, and the most appropriate document is Regulatory Guide 1.54, Revision 2 [14]. In addition to the DBA-unqualified/unacceptable and indeterminate coatings, any DBA-qualified/acceptable coatings within the Zone of Influence (ZOI) of the break are considered to fail.

ZOIs were proposed in NEI-04-07, but the issue was finally resolved in Reference [15], in which the NRC allows a ZOI with a radius of 4 times the pipe diameter for epoxy coatings, and a ZOI with a radius of 10 times the pipe diameter for un-topcoated inorganic zinc coatings.

In order to conform to the standards for GSI-191, unqualified or indeterminate coatings throughout containment and qualified coatings within the ZOI will not be credited in FSLOCA analyses. Although the DBA-qualification testing makes use of a containment pressure/temperature transient that is at significantly higher temperature and pressure than is expected for a LBLOCA ECCS performance analysis (see ANSI N101.2-1972 [16] for an example of DBA-qualification testing), data is not readily available to justify use of unqualified coatings. As such, no attempt will be made to credit these coatings, which is conservative.

Typographical Error

In the response to Question 2 in LTR-NRC-13-73, the statement in modelling assumption c) should be changed to: "...only multilayered flat walls are considered and heat transfer is neglected in any direction **except** perpendicular to the wall surface."

Heat Sink Noding

Each layer of a heat sink requires inputs for the number of nodes in the layer, the thickness of the layer, the thermal conductivity of the layer, the volumetric heat capacity of the layer, and the heat transfer coefficient/emissivity with the next layer. Based on this, a layer can simply be considered a section with user-supplied thickness and number of nodes which is used to model a change in heat transfer characteristics, whereas a node is simply a subdivision of a layer to perform the heat transfer calculations across the walls.

[

]^{a,c}

Interior Walls

[

]^{a,c}

Initial Containment Temperature

For the FSLOCA methodology, a plant-specific initial containment temperature value will be determined based on customer input, and the assumption of [ ]^{a,c} for initial containment temperature will not be used.

Generic End of Blowdown Time and Energy Released

The directions of conservatism for the [

]^{a,c} are explained in the response to Question 5 in LTR-NRC-13-73. However, the magnitudes of the values are considered below. A representative set of plants was used to determine the bounding nature of these values by checking the plant-specific COCO values that are currently used for several analyses.

- [

]^{a,c}

Based on these investigations, the [

]^{a,c}

Tagami Equation Exponential Decay

The Tagami correlation is based on the work done in (Tagami, 1966) [17]. The heat transfer coefficient is given by (units are BTU/hr-ft^2-°F):

$$h_s = h_{stag} + (h_{max} - h_{stag})e^{-0.05(t-t_p)}, t > t_p$$

Where:

$$h_{stag} = 2 + 50x, x = steam\ to\ air\ weight\ ratio\ in\ containment$$

Based on review of (Tagami, 1966), it is apparent that this correlation is based on Section 4 of (Tagami, 1966). The h_{stag} correlation is from a linear curve fit to the data in Figure 4.3. For the remainder of the heat transfer coefficient equation, Figures 4.6 and 4.7 are used. Using the heat transfer coefficient equation above, a curve was created for all the points after blowdown in Figure 4.6. In addition, a curve was created with the same equation with [
]^{a,c} (this is the method currently used for FSLOCA analyses). In both of these equations, a constant h_{stag} set to the end of transient value was used in order to simplify the calculations.

These curves are both presented in Figure 21, along with the data from (Tagami, 1966). Based on Figure 21, [

]^{a,c}

Emissivity of Exterior Containment Walls

The basis for the [ ][a,c] emissivity is explained in the response to Question 4 in LTR-NRC-13-73. A sensitivity study is shown herein that justifies the use of the [

][a,c]

RAI-47

It is clarified that the input flag [ ][a,c] within the FSLOCA evaluation model.

[

][a,c]

RAI-48

The steam generator noding was primarily derived from the simulation of the Rig-of-Safety Assessment (ROSA) Large Scale Test Facility (LSTF) natural circulation tests. The original steam generator noding utilized a [

][a,c] Various noding sensitivity studies were executed to examine the impact on the simulation results, including the loop circulation flows and liquid holdup in the uphill side of the generator at different fluid inventories.

The noding sensitivity studies included the addition of a [

][a,c]

[

]a,c

It is clarified that the statement that the single-pipe steam generator model produces conservative results is based on the liquid holdup behavior in the steam generator. It was shown that the single-pipe model tends to retain excess liquid in the uphill side of the steam generator tubes relative to the measured data, which results in increased pressure drop through the steam generator and hangs up the primary side pressure under SBLOCA conditions.

RAI-51

The data from (Lee and Ryley, 1968) [19] are presented against the code predictions in Figure 23. It can be seen that the code [

]a,c The (Yuen and Chen, 1978) [20] data are presented against the code predictions in Figure 24, which indicates that [

]a,c

RAI-85

It is clarified that the meaning of [

]a,c Since the interfacial drag decreases significantly with flow stratification, the lack of stratification ensures that the interfacial drag will remain higher, which is more likely to result in limiting the liquid downflow against the forward vapor flow. It is also noted that the methodology was updated to [ ]a,c as described in the presentation attached to LTR-NRC-14-29, and discussed more in the following paragraph.

[

]a,c

[

]a,c

RAI-95

After the FSLOCA evaluation model is approved, a working level procedure will be written for analysts that details the implementation of the approved method for production. This is the same approach that was employed for prior, approved best-estimate evaluation models such as ASTRUM (WCAP-16009-P-A) and Code Qualification Document (CQD) (WCAP-12945-P-A [23]).

RAI-127

It is clarified that for Region I (small breaks), the [

]a,c

RAI-132

It is clarified that the pressure drop from the steam generator secondary side to the Main Steam Safety Valves (MSSVs) will be [ ]a,c

RAI-133

[

]a,c

The steam generator secondary-side conditions control the vessel average temperature. Since the plants control to a target vessel average temperature, the reduction in the heat transfer coefficient on the outside of the tubes impacts the steam generator secondary-side conditions (pressure, temperature) in order to maintain the desired vessel average temperature. Hand calculations were performed that indicate [

]a,c This behavior is consistent with that expected for plant operation when fouling accrues on the secondary side.

It is clarified that Figure 133-3 in the response to RAI 133 in LTR-NRC-14-4 [24] shows the steam generator secondary-side pressure. From Table 132-1 in the response to RAI 132 in LTR-NRC-14-4, the setpoint pressure is [

]a,c

RAI-134

The plant-specific steam generator tube plugging (SGTP) level to be analyzed is provided as input to the FSLOCA analysis as described in Section 5.0 of LTR-NRC-14-4.

The impact of the SGTP level on the PCT during the blowdown phase of a LBLOCA was discussed in Section 2.1 of LTR-NRC-14-4. To summarize, it was stated that the [

]a,c

References

1) NUREG/CR-6534, Volume 4, "FRAPCON-3 Updates, Including Mixed-Oxide Fuel Properties," May 2005.

2) LTR-NRC-14-17, "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 36-39' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," March 24, 2014.

3) LTR-NRC-14-38, "Summary of June 2014 NRC Audit of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," June 27, 2014.

4) WCAP-8385 (P), "Power Distribution Control and Load Following Procedures," 1974.

5) LTR-NRC-14-29, "Summary of May 2014 NRC Audit of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," June 5, 2014.

6) WCAP-16009-P-A, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment Of Uncertainty Method (ASTRUM)," January 2005.

7) LTR-NRC-13-73, "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 46-58, 75, and 77' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," October 2013.

8) WCAP-8327-P, "Containment Pressure Analysis Code (COCO)," July 1974

9) WCAP-8471-P-A, "The Westinghouse ECCS Evaluation Model: Supplementary Information," April 1975.

10) WCAP-8339, "Westinghouse Emergency Core Cooling System Evaluation Model – Summary," June 1974.

11) WCAP-9220-P-A, Revision 1, "Westinghouse ECCS Evaluation Model 1981 Version," February 1982.

12) WCAP-10266-P-A, Revision 2, "The 1981 Version of the Westinghouse ECCS Evaluation Model Using the BASH Code," March 1987.

13) NEI-04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," December 2004. (ADAMS Accession Numbers ML050550138 for Volume I, ML050550156 for Volume II)

14) Regulatory Guide 1.54, Revision 2, "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants," October 2010.

15) NRC Letter, "Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,'" April 2010. (ADAMS Accession Number ML100960495)

16) ANSI N101.2-1972, "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities," May 1972.

17) Tagami, Takashi, "Interim Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June, 1965 (No. 1)," February 28, 1966.

18) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

19) Lee, Kwan and Ryley, D. J., "The Evaporation of Water Droplets in Superheated Steam," *Journal of Heat Transfer*, Vol. 90, pp. 445-451, 1968.

20) Yuen, M. C. and Chen, L. W., "Heat-Transfer Measurements of Evaporating Liquid Droplets," *Int. J. Heat Mass Transfer*, Volume 21, pp. 537-542, 1978.

21) Glaeser, H. and Karwat, H., "The contribution of UPTF experiments to resolve some scale-up uncertainties in countercurrent two phase flow," *Nuclear Engineering and Design*, 145, pp. 63 - 84, 1993.

22) Mayinger, F., et al., "Two-phase flow phenomena in full-scale reactor geometry," *Nuclear Engineering and Design*, 145, pp. 47 - 61, 1993.

23) WCAP-12945-P-A, "Code Qualification Document for Best Estimate LOCA Analysis," March 1998.

24) LTR-NRC-14-4, "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 – Set 8 RAIs 127, 132-135 and 137-139' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," January 30, 2014.

Table 1: Average Blowdown PCT as a Function of the Steam Generator Tube Plugging

[ ] a,c

[ ] a,c

Figure 1: [ ]a,c

[ ]a,c

Figure 2: [ ]a,c

[ ]a,c

Figure 3: [ ]a,c

[ ]a,c

Figure 4: [ ]a,c

a,c

Figure 5: [ ]a,c

[ ]a,c

Figure 6: [ ]a,c

a,c

Figure 7: [ ]a,c

a,c

Figure 8: [ ]a,c

a,c

Figure 9: [ ]a,c

a,c

Figure 10: [ ]^{a,c}

a,c

Figure 11: [ ]a,c

a,c

Figure 12: [ ]a,c

[ ]a,c

Figure 13: [ ]a,c

[ ]a,c

Figure 14: [ ]a,c

[ ]a,c

Figure 15: [ ]a,c

[ ]a,c

Figure 16: [ ]a,c

a,c

Figure 17: [ ]a,c

a,c

Figure 18: [ ]a,c

a,c

Figure 19: Double-Ended Guillotine Break Containment Pressure Comparison between Calculations with COCO Integrated into WCOBRA/TRAC-TF2 and Calculations with COCO_A Version 1.4

a,c

Figure 20: Split Break Containment Pressure Comparison between Calculations with COCO Integrated into WCOBRA/TRAC-TF2 and Calculations with COCO_A Version 1.4

a,c

Figure 21: Tagami Data and Calculated Heat Transfer Coefficients

[ ] a,c

Figure 22: Emissivity Sensitivity Study Results

[ ] a,c

Figure 23: Comparison of WCOBRA/TRAC-TF2 DFFB Interfacial Heat Transfer to the Data from Lee and Ryley, 1968

a,c

Figure 24: Comparison of WCOBRA/TRAC-TF2 DFFB Interfacial Heat Transfer to the Data from Yuen and Chen, 1978

a,c

Figure 25: Cumulative Distribution Function of the Region II Blowdown PCT Results for Different Steam Generator Tube Plugging Levels