RESPONSE TO AUDIT ISSUES

APR1400 Topical Reports
Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD
Docket No. PROJ0782

Review Section	**TR Realistic Evaluation Methodology for LBLOCA of the APR1400**
Application Section	**Topical Report: APR1400-F-A-TR-12004 Realistic Evaluation Methodology for Large-Break LOCA of the APR1400**
Issue Date	**08/13/2015**

Audit Issues No. 47

The guidance in RG 1.157, Section 3.11 establishes acceptable controls regarding the calculation of core flow distribution. Section 4.2.2.1.2 of the topical report states that the uncertainty in the high importance phenomenon of [ ]^{TS} is not determined because it is included in the steam binding bias. Flow through the top nozzles is a complex multidimensional process with liquid down flow through the lower power outer assemblies and steam and entrained liquid up flow through the central higher power assemblies. Bias in the steam binding process is not directly related to the uncertainty in the countercurrent flow at the top nozzles. Demonstrate how the bias in the steam binding process bounds the uncertainty in countercurrent flow at the top nozzles or provide the bases for neglecting the relevant uncertainty.

Response

The meaning of the term “top nozzle” is to be understood as a component that has the smallest flow area along the flow path from core to upper plenum. The term “tie plate” is used for the following discussions according to the term used in the 2D/3D research project. [

]^{TS}

CCFL is discussed on the junctions between node 170 and node 180 in the same figure. CCFL on the tie plate has been studied in UPTF-10C test. The results of the study are well described in the reference [1]. Figure 4.4.1 of the reference [1] depicts the CCFL phenomena occurring on the tie plate. Part of the figure and summary is redrawn in Figure 1 for the clarification of the following discussions. Reference [1] also describes the CCFL phenomena as “the steam/water up-flow from the core and the water fallback through the tie plate being uniform across the vessel”.

The phenomena mentioned in the question as, “a complex multidimensional process with liquid down flow through the lower power outer assemblies and steam and entrained liquid up flow through the central higher power assemblies”, is the recirculation process that may occur during the core reflood. It is not the CCFL phenomena, which were studied by UPTF-10C test, but the recirculation phenomena that will effectively help the cooling of the core. In the CAREM, it is not allowed by modeling single flow path at tie the plate.

The current nodding of core is a conservative approach for PCT by essentially removing the favorable recirculation process.

Returning to the CCFL phenomena, CCFL on tie plate is very complicated hydraulic phenomena. As shown in Figure 1, CCFL phenomena consist of three flow streams, the steam and water up-flow from the core and the water fallback. REALP5 has two fluid flow fields. Therefore, it is not easy to correctly model the CCFL phenomena with RELAP5. RELAP5 treats CCFL with a general model that allows the user to select the Wallis form, the Kutateladze form, or a form in between the Wallis and Kutateladze forms[2].

In general, experiments on CCFL are well correlated with the Kutateladze number as shown in Figure 1. Most important thing to check is the limiting gas velocity, $v_{s,Limit}$, above which no down-flow is possible.

$$K_x^* = \frac{\dot{M}_x}{\rho_x A_{tie}} \left(\frac{(\rho_x)^{\frac{1}{2}}}{\left(g\sigma(\rho_w - \rho_s)\right)^{\frac{1}{4}}} \right)$$

$$\sigma = 0.0002822(Pa \cdot s)@100^oC\ liquid$$

$$\rho_w = 958.4(kg/m^3)@100^oC$$

$$\rho_s = 0.59(kg/m^3)@1bar = 1.651(kg/m^3)@3bar$$

$$K_{s,}^*@3bar = v_s \left(\frac{(\rho_s)^{\frac{1}{2}}}{\left(g\sigma(\rho_w - \rho_s)\right)^{\frac{1}{4}}} \right) = \frac{v_s(1.651)^{.5}}{\left(9.8 \times 0.0002822 \times (958.4 - 1.651)\right)^{0.25}} = \frac{1.285v_s}{1.275} = 1.0v_s$$

$K_{s,Limit}^* = 4.0$, From Figure 1

$$v_{s,Limit}@3bar = \frac{4.0}{1.0} = 4.0(m/s\ )$$

$$v_{s,Limit}@1bar = \frac{4.0}{0.6} = 6.7(m/s\ )$$

As exemplified in the above calculations, $v_{s,Limit}$ is 6.7 m/s. The steam velocity at the tie plate for APR-1400 is shown in Figure 2. It is always greater than 6.7 m/s during the reflood period, between 70 sec and 200 sec. The steam and liquid flow at the tie plate are shown in Figure 3. The liquid flow is generally upward in all reflood period except the time period between 170 ~ 250 sec, which is consistent with the $v_{s,Limit}$ consideration. Thus, the code predicts thermal hydraulic behavior on the tie plate reasonably even without CCFL model.

One more concern of the CCFL is its implementation in the code. Since the CCFL changes the flow, RELAP5 implements it by changing the momentum equations (refer to reference [3], section 3.4.7). The implemented CCFL models are validated mainly through steady state experiments. But the flow during the reflood period is very oscillatory. There is a strong tendency that the implemented CCFL model in RELAP5 amplifies the oscillation during the reflood. This tendency is the same as that with critical flow model used on the internal junctions. In general, any model that manipulates the momentum equations during its implementation makes it difficult to get a stable solution. Considering this situation, CAREM does not use CCFL option on the tie plate junctions.

RELAP5 in CAREM over-predicts the water carry-over rate from core to upper plenum. These facts are shown in the assessments of FLECHT-SEASET (Reference [4], Appendix P, pp. P-11) and NEPTUN (Topical Report, Appendix C, section 4.3.4).

The flow regime in upper plenum during reflood period is mainly annular or annular/mist type. There is no model for the de-entrainment by internal structures in upper plenum. Therefore, liquid flow from upper plenum to hot leg depends on the liquid volume fraction of upper plenum and it usually over predicts. Liquid volume left in upper plenum is under predicted. Such a process can be found in the result of UPTF-10B simulation (Reference [4], Appendix P, pp. P-13). As a result of these series of process, liquid flow to steam generator is excessive and ensuing steam binding is too excessive. It is necessary to implement a de-entrainment model in the upper plenum to solve the problem.

An effective de-entrainment model can be constructed by controlling the droplet fraction in annular flow regime. Reducing the droplet fraction to 10 % of the RELAP5 prediction value makes the liquid fraction in upper plenum close to the UPTF-10B experimental value (Reference [4], Appendix P, pp. P-13).

Lastly, there are only limited experiments that can be used for assessing the behavior of the droplet reaching to steam generator. Due to the lack of experimental data, the problem dealing with the behavior of droplet transferred to steam generator is decided to be treated as a bias. The method is to evaporate all liquid drops that pass through steam generator. By reducing the droplet size and increasing heat transfer coefficients, it is possible to make all drops evaporate in steam generator.

In summary;

1. Steam velocity at the tie plate is greater than CCFL limit velocity, CCFL option is not

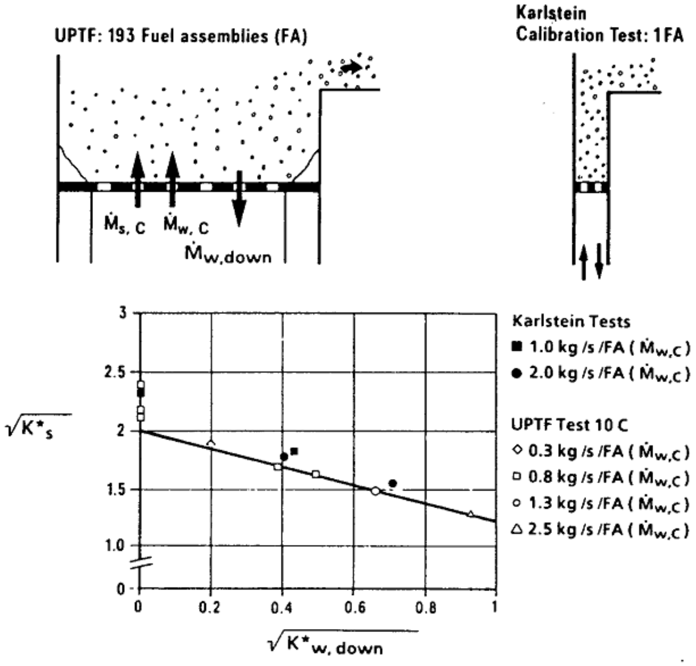
needed. Due to the unstable behavior of the CCFL option, the CCFL option is not recommendable on the tie plate junction. Therefore, it is not used in the CAREM.

2. RELAP5 in the CAREM over-predicts the water carry-over rate from core to upper plenum. But it is used as it is in the CAREM. This is a conservative approach with respect to PCT.

3. An effective upper plenum de-entrainment model is constructed by controlling the droplet fraction in annular flow regime using UPTF-10B experiment. It is treated as a bias.

4. The behavior of droplet transferred to steam generator is treated as a bias.

Using the above processes, the CCFL phenomena at the tie plate, upper plenum de-entrainment phenomena, and the behavior of the droplet in the steam generator, during the reflood period, are treated conservatively as biases.



COUNTERCURRENT FLOW OF SATURATED STEAM AND WATER AT THE TIE PLATE

FIGURE 4.4-1

Figure 1. Figure 4.4-1 of the reference [1]

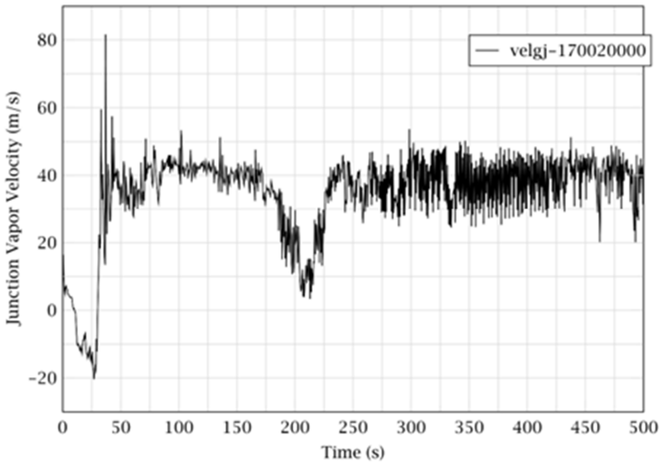


Figure 2. Steam Velocity at Tie-Plate

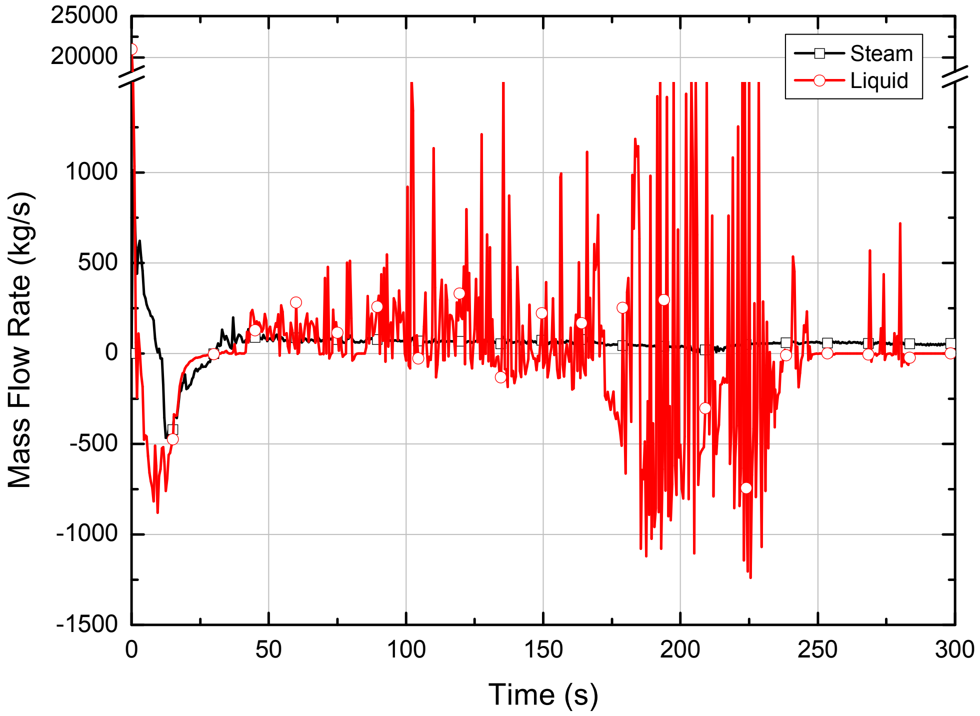


Figure 3. Steam and Liquid Flow Rate through the Tie Plate

References

[1] “2D/3D Program Work Summary Report,” NUREG/IA-0126, GRS-100, MPR-1345, 1993.

[2] “RELAP5/MOD3.3 Code Manual Volume IV: Models and Correlations,” Nuclear Systems Analysis Division, March 2006.

[3] “RELAP5/MOD3.3 Code Manual Volume I: Code Structure, System Models, and Solution Methods”, Nuclear Systems Analysis Division, March 2003.

[4] “Topical Report for the Realistic Evaluation of Emergency Core Cooling System”, TR-KHNP-0002, 2002. (Appendix P Evaluation of Steam Binding Using UPTF and PKL Test)

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

There is no impact on any Technical, Topical, or Environmental Report.