A Sample Technique for Estimating an Unknown Key Boundary Condition for RPV Water Level Prediction in the Fukushima Daiichi Unit 3 Accident Simulation

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Simulations of the Fukushima Daiichi (1F) Units 1, 2, and 3 severe code damage accidents have been performed by Fauske and Associates, LLC (FAI) using an advanced version of the MAAP5 code (an EPRI owned and licensed software), specifically MAAP 5.03. Due to the station blackout (SBO) nature of the accident, the normal breadth of plant data for key instruments and safety system status was seriously lacking, although not entirely absent. If the MAAP5 code is to provide an adequate portrayal of plant response during these simulations, MAAP5 must be presented with at a least limited set of boundary conditions providing the base information.

Consequently, part of the simulation effort has involved the reconstruction of inadequate (or entirely missing) boundary condition information from the available information. The 1F Unit 3 (termed 1F3) simulation is an interesting case study for such a reconstruction. One example is filling in a gap in the reactor pressure vessel (RPV) water level data that occurred prior to uncovering of the core. Specifically, Figure 1 shows the plant data gap between "Wide-Range Level (Corrected)" at time 12-03-11 20:45 and "Fuel-Range Level (Corrected)" at time 13-03-11 04:00. The level measurement is expressed in terms of a reference zero at the top of active fuel (TAF). Thus, once the level falls below 0 meters at TAF, the top of the fuel begins to uncover. Continued level decrease below 0 meters yields a progressively greater percentage of fuel uncovering, leading to the onset of fuel overheating and eventual severe fuel damage. Therefore, this so-called "coolant boil-off" phase of the accident is an important predecessor for any severe accident code that is intent upon representing all key phases of the accident, which includes initial loss of safety injection through core uncovery and severe core damage to eventual fuel relocation to the RPV lower plenum.

Unfortunately, the initial onset of RPV level decrease from 4 meters to 0 meters is not known due to the data gap. (Note, the stoppage of wide-range level data at 12-03-11 20:45 does not imply that RPV level decrease started at this time since the trend shows persistent level above 4 meters prior to data stoppage.) As a means of filling in this important gap, focus turns to what is known. It is known that, after reactor core isolation cooling (RCIC) safety injection system failed, the high-pressure coolant injection (HPCI) safety injection system initiated on low RPV level at 12-03-11 12:00. Also, it is known that HPCI failed at 13-03-11 02:30. Figure 2 shows the RPV depressurization due to HPCI steam extraction from the vessel, which is necessary to drive the HPCI steam turbine that provides the motive force for the HPCI pump. Also, Figure 2 shows the subsequent RPV re-pressurization when the HPCI system fails due to isolation of the HPCI steam extraction flow.

It appears that the boundary condition for loss of HPCI injection is clearly set by HPCI steam termination at 13-03-11 02:30. However, if this event is used as the boundary condition, the MAAP5 code predicts core TAF initial uncovery at roughly 13-03-11 09:00 (Not shown here.). This is far too late when the fuel-range data shows a level of -1 meters at 13-03-11 04:00 in Figure 1. MAAP5 is an advanced code and therefore is expected to provide an accurate assessment of RPV coolant boil-off. Indeed, MAAP5 demonstrated good level agreement in the Fukushima Unit 2 (1F2) simulation where boil-off phase plant data was available.

On this basis, it can be concluded confidently that actual loss of HPCI injection to the RPV did not coincide with HPCI system termination. After reviewing the preliminary MAAP5 simulation and seeing the noted discrepancy between the timing of actual and predicted core uncovery, Tokyo Electric Power Company (TEPCO), the plant owner, surmised that earlier HPCI injection stoppage may have occurred while the HPCI system was still operating, due to the lower RPV pressure driving the HPCI steam turbine. After discussions with TEPCO, FAI consulted HPCI system documentation and subject-matter experts to provide a technical basis to support (or possibly refute) this theory. Both documentation and expert opinion recommended operating the HPCI steam turbine above a minimum RPV pressure source of 200 psi (1.4 MPa). Below this threshold pressure, HPCI injection flow could become degraded, or it could approach zero if the pump total developed head (THD) did not exceed the RPV pressure, which is also the discharge pressure for the HPCI pump.

Of course, the precise extent of injection degradation is not readily known without a rigorous plant-specific HPCI hydraulic analysis. So, as an initial estimate, FAI focused on the substantial RPV depressurization that occurred around 12-03-11 18:00. Pressure decreased below 200 psi (1.4 MPa) shortly after 18:00. Therefore, 18:00 was selected as an estimated boundary condition for the time of loss of HPCI injection. The resulting MAAP5 prediction of RPV water level is shown in Figure 1. The estimated boundary condition leads to a much better "MAAP 5.03 Core" prediction versus the "Fuel-Range Level A (Corrected)" data, which begins at 13-03-11 04:00.

The MAAP5 prediction requires some additional refinement of the boundary condition. Specifically, for the RPV downcomer water level, the "MAAP 5.03 Downcomer" predicted level decrease at 12-03-11 18:00 is too early, since the "Wide-Range Level A (Corrected)" persists above 4 meters until at least 12-03-11 20:45. Refinement of the HPCI injection termination from 12-03-11 18:00 to 12-03-11 20:30, for example, will improve the wide-range level agreement, but the fuel-range level prediction at 13-03-11 04:00 will slightly over-predict the fuel-range data. (This refined prediction is not shown here.)

So, while not perfect, the uncertainty range (12-03-11 18:00 to 20:30) in the estimated boundary condition for early HPCI injection termination results in a range of predictions that brackets the wide-range level at 12-03-11 20:45 (at the front end of the data gap) and also the fuel-range level at 13-03-11 04:00 (at the back end of the data gap). This boundary condition estimate for early loss of HPCI injection certainly yields a substantial improvement in results, compared to using the HPCI steam turbine isolation timing as the boundary condition.

In summary, judicious use of collateral plant data and HPCI safety system design information can yield a sufficient, justifiable estimate of the HPCI injection boundary condition, thereby overcoming the data gap for RPV water level during the crucial period of coolant boil-off and core TAF uncovery. This refinement leads to an improved MAAP 5.03 simulation of the 1F3 accident.

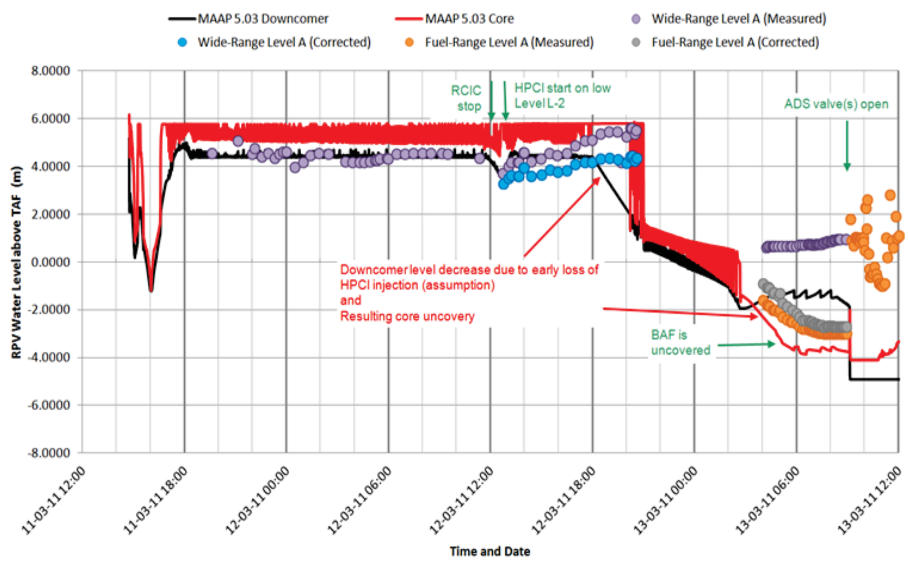

Figure 1 RPV Water Level Data and Prediction for the 1F3 Simulation

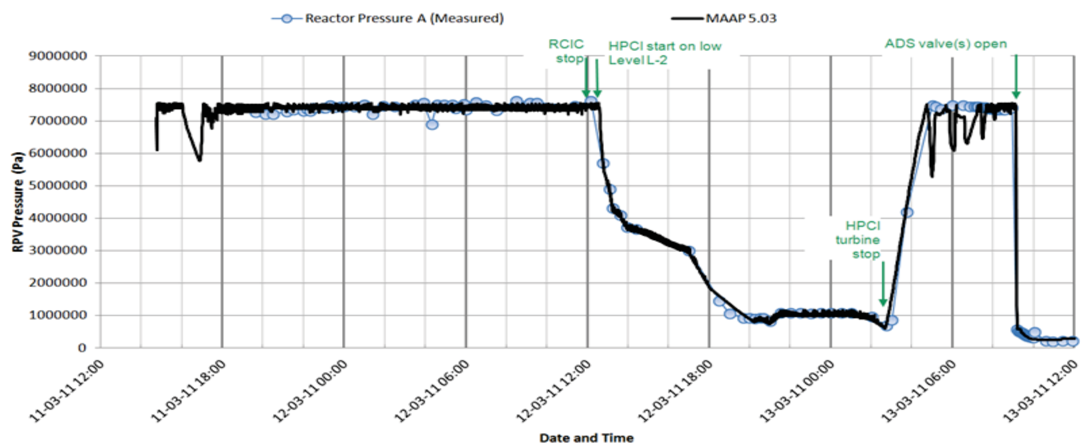

Figure 2 RPV Pressure Data and Prediction for the 1F3 Simulation

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