KKM TRACG Validation

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ABSTRACT

Best estimate codes and methodologies provide excellent opportunities to model and analyze real plant response. However, using such tools require extensive qualification and validation prior to leveraging their benefits. TRACG is a GE Hitachi Nuclear Energy Company (GEH) proprietary version of the Transient Reactor Analysis Code (TRAC). It is a best-estimate code for analysis of boiling water reactor (BWR) transients, based on a multi-dimensional two-fluid model for the reactor thermal-hydraulics, and a three-dimensional neutron kinetics model for the reactor core. TRACG has an extensive qualification history against separate effects test data, component performance tests, integral system effects tests and plant data. NRC reviewed and approved in detail the qualification record covering BWR/2s through BWR/6s, ABWR, and ESBWR designs. TRACG code is also being used to evaluate loss of coolant accident (LOCA) response for the Mühleberg Nuclear Power Plant (KKM). The first step in this evaluation is to, in addition to the extensive TRACG qualification described above, validate the KKM TRACG model.

KKM performed a total loss of feedwater (LOFW) test in 1993 in order to confirm expected plant response at the uprated power level and used the obtained plant data for plant analysis and model validation efforts. The event involved a number of plant components and control systems and was well instrumented, which makes it ideal for model validation. Though the analyzed event is not a LOCA scenario and no low pressure injection systems were activated to mitigate the event, a large number of systems and components that are also relevant to LOCA mitigation and modeling are active during the event. Therefore, it provides a relevant basis for validation of the LOCA application. These systems and components include, but are not limited to; Reactor SCRAM logic and power response, MSIV control logic, Pump trip logic, RPV level measurement and setpoints, RPV pressure response, SRV and PRV control logic, RCIC control logic.

This paper describes the event, the KKM TRACG model to simulate the event, and comparisons between the plant data and TRACG results for the LOFW event.

KEYWORDS
TRACG LOCA, KKM, best estimate, validation, qualification

1. INTRODUCTION

KKM performed a total LOFW test in 1993 in order to confirm expected plant response at the uprated power level and used the obtained plant data for plant analysis and model validation efforts. The event involved a number of plant components and control systems and was well instrumented, which makes it ideal for model validation. This paper describes the event, the KKM TRACG model to simulate the event, and comparisons between the plant data and TRACG results for the LOFW event.

TRACG is a GE Hitachi Nuclear Energy Company (GEH) proprietary version of the Transient Reactor Analysis Code (TRAC). It is a best-estimate code for analysis of boiling water reactor (BWR) transients, based on a multi-dimensional two-fluid model for the reactor thermal-hydraulics, and a three-dimensional neutron kinetics model for the reactor core. In addition to the basic thermal-hydraulic models, TRACG contains a set of component models for the recirculation pumps, jet pumps, fuel channels, steam separators, and dryers. TRACG also contains a control system model capable of simulating major BWR control operations.

The TRACG model described in this paper utilizes several different TRACG systems and components to simulate the event. These systems and components include, but are not limited to:

- Reactor SCRAM logic and power response
- MSIV control logic
- Pump trip logic
- RPV level measurement and setpoints
- RPV pressure response
- SRV and PRV control logic
- RCIC control logic

2. DESCRIPTION OF THE EVENT

On September 8, 1993 KKM initiated a planned LOFW test from a steady state operating condition by simultaneously turning off two Feedwater Pumps. Third Feedwater Pump had been manually disabled prior to event initiation. The feedwater pumps coasted down rapidly. The level in the RPV subsequently dropped to the SCRAM setpoint. The SCRAM caused a significant void collapse in the core, which caused the level to further decrease to the Level 2 setpoint. The Level 2 setpoint initiated closure of the MSIVs, tripped both recirculation pumps, and triggered the logic for RCIC system initiation. First, RCIC pump B started injecting into the feedwater line at about a minute into the event. RCIC Pump B continued injecting for the duration of the event. RCIC Pump A had been disabled manually prior to the event. CRD flow was also being injected into the vessel during the event.

Following SCRAM, the vessel pressure decreased due to a decreasing steam generation rate in the core and continued steam flow out of the vessel. At about 15 seconds into the event the turbines were tripped and the TCVs closed shortly after. Simultaneous to the turbine trip, the TBVs opened because the pressure regulator setpoint post-SCRAM dropped to about 66.6 bar. However, in about 20seconds MSIVs were completely closed and the pressure in the vessel began to increase. The RPV pressure increased after MSIV closure until the first SRV setpoint was reached. A single SRV opened and remained open until the SRV closing setpoint was reached. The opening of the SRV caused a temporary swell in the RPV water level and subsequent closing of the valve caused a level to void collapse as well as the inventory loss through the SRV. For the remainder of the event pressure was controlled by manually opening and closing a single PRV. This occurred three times before the Recirculation Pump B was restarted manually at about 660 seconds into the event.

After the SRV actuation the RPV water level continued to gradually increase due to the constant RCIC and the Control Rod Drive (CRD) flows.

3. DESCRIPTION OF KKM TRACG MODEL

The TRACG model presented in this report is based on the specific configuration of KKM. The level of detail and nodalization of the model are consistent or more detailed than the generic inputs used for the demonstration analyses presented in Reference 1. Key features of the model are given below:

- The vessel component is divided into 22 axial levels and 4 radial rings.
- The 240 physical fuel bundles are represented by 28 channel components based on the GNF2 fuel design.
- There are two recirculation loops represented by multiple pipe, tee, valve, and pump components.
- The 12 jet pumps are represented by two symmetric, hydraulically-scaled jet pump components.
- The steam separators are modeled with three representative separator components
- The 4 physical steam lines leaving the vessel are modeled as two steam lines. One represents a single steam line and the other represents three lumped lines. Associated with these steam lines are the inboard and outboard MSIVs, modeled with valve components. Also associated with the steam lines are the SRVs with open area fraction determined by the TRACG control system where the opening and closing setpoints of each physical valve can be specified.
- A flow boundary condition connected to the steam line upstream of the SRVs is used to model RCIC turbine steam extraction.
- The modeled steam lines include components to represent the TCV and TBV. The model considers a single turbine rather than explicitly modeling the dual-turbine arrangement at KKM. This is acceptable for vessel isolation scenarios including the LOFW event given that the steam line losses and lengths are conserved in the model.
- The feedwater lines are represented by a single lumped line. A flow boundary condition is connected to the feedwater line model to model the RCIC liquid injection. The mass flow rate and enthalpy for the feedwater and RCIC system is provided through the TRACG control system.
- The control and protection range indicated vessel levels are calculated by TRACG control system logic based on the differential pressure between the flow boundary condition components.
- The control rod guide tubes are modeled by three pipe components (one for each radial ring in the core region).

4. ASSUMPTIONS AND INITIAL CONDITIONS

The KKM TRACG basedeck is setup with certain modeling assumptions important to the simulation of the LOFW event as well as the best estimate LOCA application described in Reference 1. Key assumptions and initial conditions used in this evaluation are listed below:

- Decay heat: A best estimate decay heat curve with the ANS94 standard and ORIGEN 10x10 inputs is used to characterize the decay heat for the LOFW event. The ANS94 standard is very flexible and highly dependent on input assumptions for capture time, actinide yield, fission fraction, fission energy, operating time, etc. A realistic decay heat curve can be obtained by providing these inputs from an ORIGEN burn using BWR 10x10 fuel. The best-estimate decay heat model documented in Reference 2 is used in this validation analysis. The adequacy of the decay heat model is tested and confirmed by how well the pressurization (Figure 5) is predicted in the early part of the event after MSIV isolation.
- TBV: TBV open area is set to approximately match the depressurization up to the time of MSIV isolation. Suitable valve characteristics of the TBV were not available for this simulation; however the key response parameters for validation occur at times after MSIV closure.

- RCIC Temperature: The RCIC injection temperature for the event is not available. Therefore, an estimated base value is used for the validation runs. In order to evaluate the reasonableness of this base temperature history, two other bounding temperature histories are modeled as well. These two additional histories represent appropriate bounding high and low temperatures. Figure 1 illustrates the temperature of the liquid in the last cell of the feedwater line prior to the vessel for each of the three cases. This represents the temperature of the liquid being injected into the vessel. The flow boundary condition where the RCIC enthalpy is specified is located on a side branch coming off the feedwater line. All three histories are identical until the RCIC system begins injecting at around 54 seconds. For the first approximately 16 seconds the water level in the vessel is above the elevation of the feedwater line. The liquid in the line stays at a roughly constant temperature because it is in contact with subcooled liquid in the vessel. When the water level in the downcomer drops below the feedwater line elevation the liquid in the line is then exposed to saturated vapor, which is at a much higher temperature. The liquid temperature in this cell begins to heat up in the next 30 seconds or so due to the contact with the saturated vapor. The temperature at the injection point decreases in all cases initially after RCIC injection starts as the relatively cool RCIC water mixes with the water that remained in the feedwater piping after the pumps were tripped. Differences begin to emerge after about 100 seconds as the remaining warmer liquid in the feedwater line has been pushed into the vessel and replaced completely by the RCIC injection. The temperature at the injection point will eventually approach the temperature of the RCIC suction source. The "Best Approximation" curve represents a temperature history that produces good agreement in the measured long-term pressure behavior. Furthermore, the heat capacitance in the feedwater line is not modeled. Modeling these details precisely would not impact the temperature history at the vessel injection point that produces agreement with the pressure data. These details would only slightly impact the enthalpy specified at the RCIC flow boundary to account for energy addition or removal along the feedwater line. Changes of this magnitude are bounded by the upper and lower bound RCIC temperatures considered in this analysis.

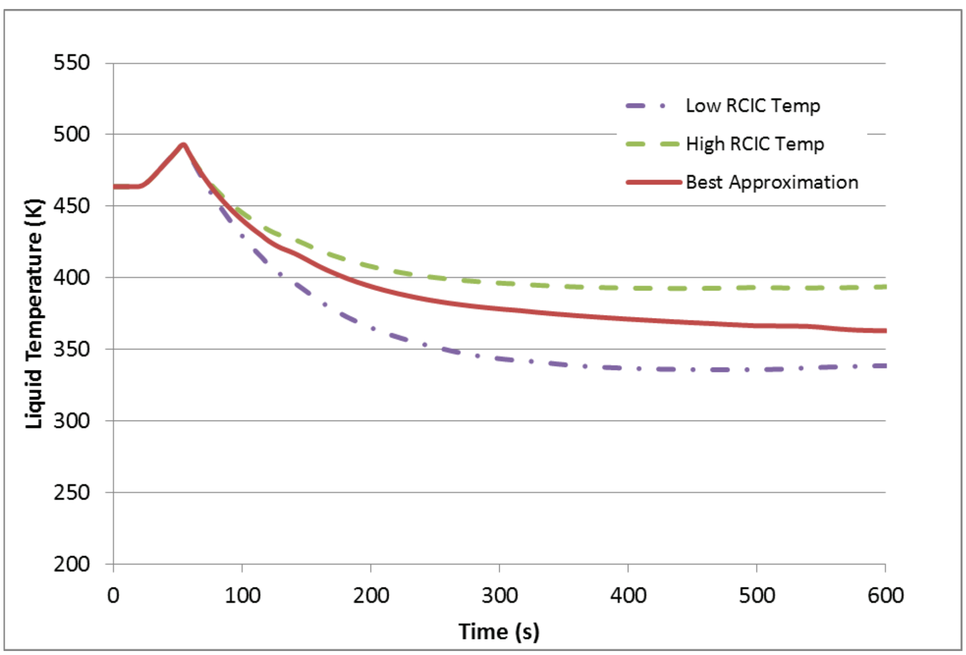

Figure 1. Liquid Injection Temperature

- Recirculation Pump Coastdown: Recirculation pump speed is provided as an input condition for the LOFW event such that the recirculation pump flow predicted by TRACG aligns approximately with plant data. The plant data on the recirculation pump flow shows that the two recirculation pumps behaved independently and did not follow a standard coastdown behavior. It is surmised that at least one pump experienced a partially-powered coastdown. Regardless of the reason for the non-standard behavior, assuming an equivalent speed coastdown in TRACG would under-predict the recirculation flow during the coastdown, which would in turn cause a larger decrease in the reactor power prior to scram and a mismatch in key parameters for the event. For this reason the pump speed was specified to better match the recirculation flow. The agreement between TRACG recirculation pump speed and the pump speed obtained from plant data gives an indication as to the accuracy of the TRACG pump curves (Figure 2).

- SCRAM Timing: The SCRAM timing assumed in TRACG-LOCA evaluations was used instead of implementing KKM event-specific SCRAM timing. The TRACG-LOCA SCRAM timing, illustrated in Figure 3, is conservative relative to indicated plant data. However, the difference is only a few seconds in SCRAM timing before the dominant influence is the decay heat. The event behavior is influenced predominantly by the decay heat and RCIC temperature with SCRAM timing being of minimal impact.
- Initial Conditions: The measurements of the reactor power, RPV pressure, water level, steam flow, and feedwater flow immediately prior to the event initiation were available in plant data. Table 1 lists the values obtained from the plant event report as well as the values obtained from the steady state TRACG run. The table indicates that these key plant parameters are met by the TRACG model, which gives confidence that the LOFW event has the correct starting point.

Table I. Initial Conditions

Parameter	Plant Data	TRACG Steady State
Power	1047 MWt	1047 MWt
Dome Pressure	7.23×10^6 Pa	7.23×10^6 Pa
Water Level	12.89 m	12.89 m
Steam Flow	~532 kg/s	532 kg/s
Core Flow	~3500 kg/s	3499 kg/s

5. RESULTS

The following set of figures compare a number of key plant parameters taken from the plant event reports to the TRACG results. In most cases the TRACG data represents the result from the best-approximation RCIC temperature history. The level and pressure behavior, however, include all three TRACG simulations. There is no noticeable difference between the different cases for other parameters because the major impact of the transient occurs early on in the event for those parameters before the RCIC system begins to inject.

Figure 2 shows the behavior of the recirculation pumps during the event. As mentioned in Section 4, the recirculation pump speed was specified such that the flow rates were approximate to the coastdown observed in the plant data for this event. At about 8 seconds into the event a recirculation runback is encountered due to the total feedwater flow dropping below 1200 t/h. Recirculation Pump B runs back significantly faster, while Recirculation Pump A appears to experience a partially powered coastdown. The inflection point in the Recirculation Pump A behavior coincides with the Level 2 setpoint being reached, which trips the recirculation pumps. After this point Recirculation Pump A experiences a faster coast down.

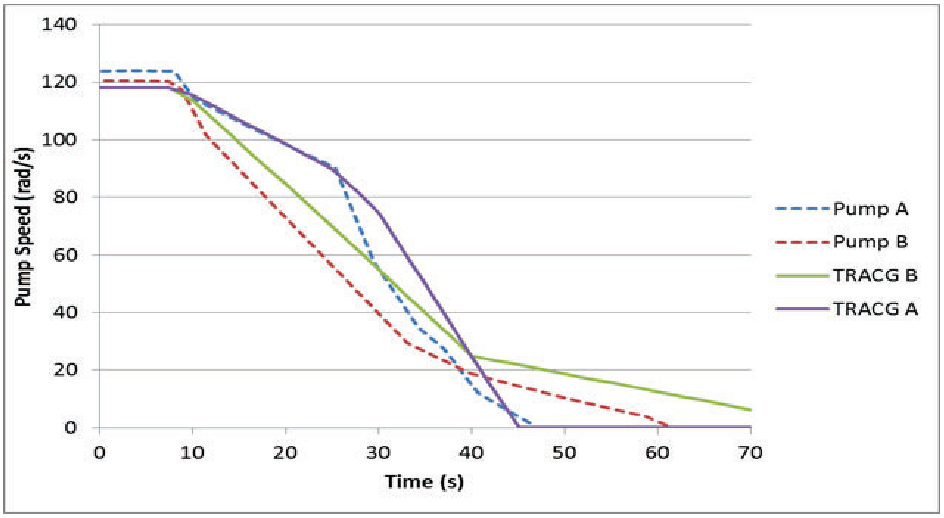

Figure 2. Recirculation Pump Speed

Figure 3 shows the reactor power during the event as a percentage of initial power. When the recirculation pumps runback at about 8 seconds the core flow decreases, as seen in Figure 4. A decrease in core flow causes an increase in void fraction throughout the core, which adds negative reactivity. The core power then decreases as a result to about 70% power just before the SCRAM water level is reached. The SCRAM occurs at about 14 seconds in the TRACG simulation. Measured reactor power quickly decreases after SCRAM as expected. The core flow essentially follows the average relative behavior of the recirculation pumps as expected. The forced core flow is greatly reduced by 60 seconds. After this point in time, core flow is driven largely by natural circulation. The steam flow decreases gradually over the first nearly 15 seconds due to the power decrease from the recirculation runback. The power decrease slows the rate of steam generation in the core. After reactor SCRAM the steam flow decreases dramatically with the drop in reactor power and subsequent drop in void production in the core. The steam flow out of the vessel terminates when the MSIVs fully close at about 34 seconds.

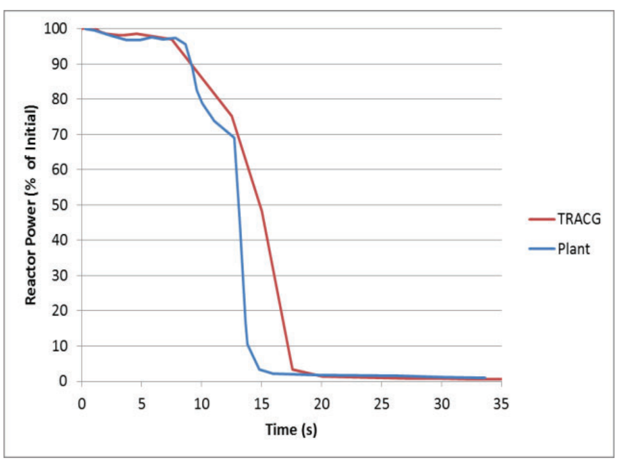

Figure 3. Reactor Power

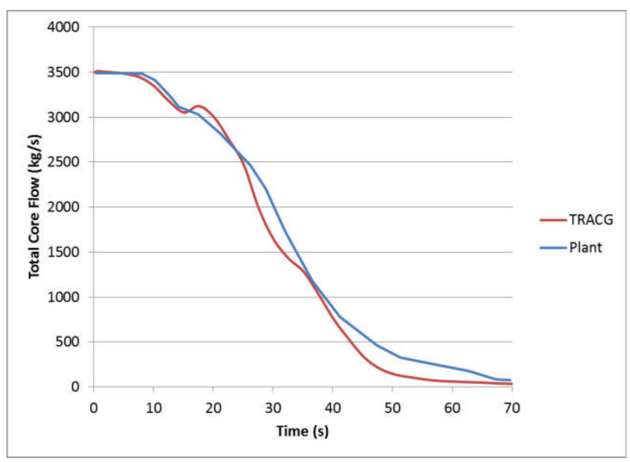

Figure 4. Core Flow

Figure 5 shows the dome pressure for the plant and for the three TRACG cases performed with different RCIC temperature histories. No significant difference in the cases is seen until approximately 200 seconds into the event. The RCIC temperature has no impact on the event prior to RCIC injection at 54 seconds (Level 2 water level signal plus signal delay) and very little impact for the next couple minutes as the temperature at the injection point is very similar for all cases due to the initial mixing with therelatively hot liquid remaining in the feedwater line. After 200 seconds, the impact of the injection temperature becomes apparent. The upper bounding RCIC temperature results in a faster pressure rise, which causes the PRV opening setpoint to be reached sooner. On the other hand, the lower bound RCIC temperature slows the pressurization to the point that the second PRV opening is never encountered. The best-approximation RCIC temperature history reasonably predicts the pressure behavior for the entire 10 minutes of the TRACG simulation.

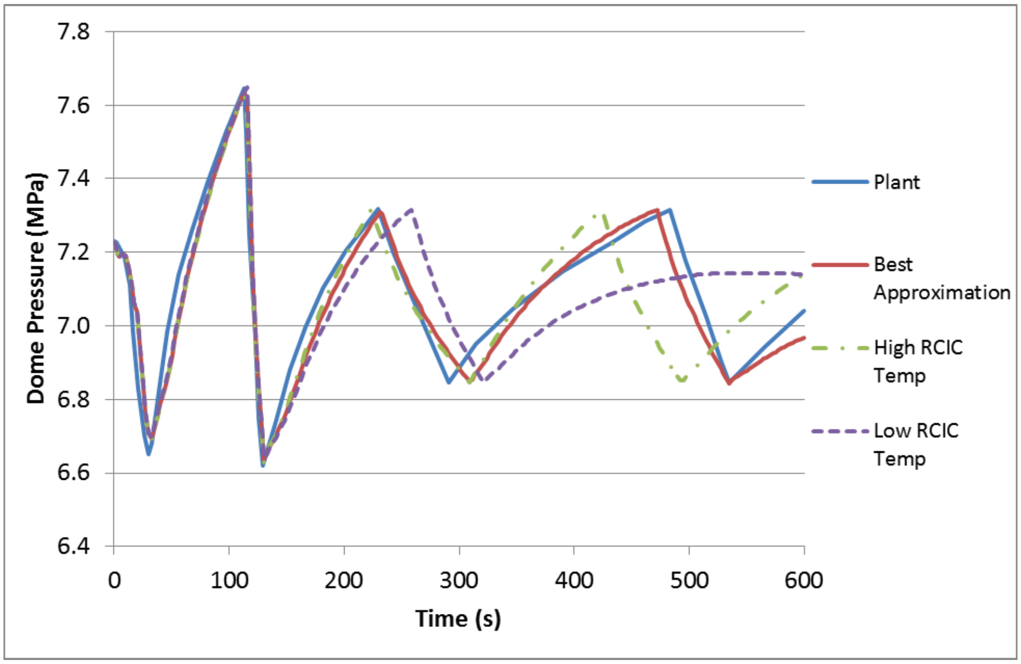

Figure 5. Reactor Pressure

The temperature at the injection point to the vessel is a function of the temperature of the liquid at the RCIC pump suction source. This source temperature information is not available during the event. The fluid is pumped from the source to the reactor and early on in the event the fluid increases in temperature as it mixes with water that is present in the feedwater line and removes heat from the hot feedwater piping. In the longer term it is expected that the initial inventory in the feedwater line will be cleared out and the temperature at the injection point will approach the source temperature plus any residual energy added to the fluid between the source and the vessel. The low RCIC temperature in Figure 1 represents a specified constant temperature at the RCIC flow boundary approximate to a reasonable expectation of the source temperature (~320K). This represents a case of minimal heatup prior to this point. The high RCIC temperature is a constant temperature of 385K at the same point. This would effectively bound any heatup from the source to the feedwater line including seasonal variations in source temperature, heat addition from the RCIC pump, and any heat addition along the RCIC piping. The best-approximation curve reflects a temperature between the two extremes (~350K) that would allow for some heatup in the RCIC line. Ultimately, in the absence of plant data, the exact RCIC temperature cannot be directly speculated. It is however, instructive to see the impact of changing the temperature of the fluid being injected on the pressure and level response in the long-term. The temperature of the injected fluid is the only significant unknown in the energy balance of the RPV after the MSIVs close; therefore, the bounding RCIC temperature sensitivities are included in this report to provide a level of confidence in the best-approximation RCIC temperature history given that the geometry of the vessel and the SRV/PRV control is well represented.

Figure 6 shows the protection (wide) range water level for the first 10 minutes of the event simulated by TRACG. The water level drops rapidly in the first 25 seconds as the feedwater flow goes to zero, followed by the recirculation pump runback, and the void collapse caused by the reactor SCRAM. The plant data indicates that the minimum level is reached at about 34 seconds. The TRACG cases predict that the opening of the TBV after the turbine trip arrests the level decrease and ultimately causes a level swell due to flashing from about 22 seconds to 33 seconds. When the MSIVs close completely at around 34 seconds, due to pressurization, another void collapse and a subsequent level drop is observed, which is not present in the plant data. The reason that TRACG predicts this but the plant data does not show this phenomenon is unknown as a similar level swell and collapse behavior is captured by both plant data and TRACG when the SRV opens and closes. The response speed of the TBV opening likely contributes to the differing level behaviors during this time. After MSIV closure the level behavior is predicted quite well by TRACG, including the level swell and collapse due to the SRV opening and closing. After this point the RCIC and CRD flow into the vessel account for the gradual level increase. The injection amount appears to be accurate as the TRACG predicted level for the best-approximation RCIC temperature history and plant data remain parallel for the remainder of the event. The mismatch between TRACG and plant data after the SRV actuation is consistently between 15 and 20 cm for the remainder of the event. As seen in Figure 6, the impact of the injection temperature on the level is small, though more noticeable in the last few minutes of the simulation as the high bounding temperature shows a diverging path compared to plant data (more frequent PRV actuations) and the low bounding temperature appears to begin to converge with the plant data (no second PRV actuation).

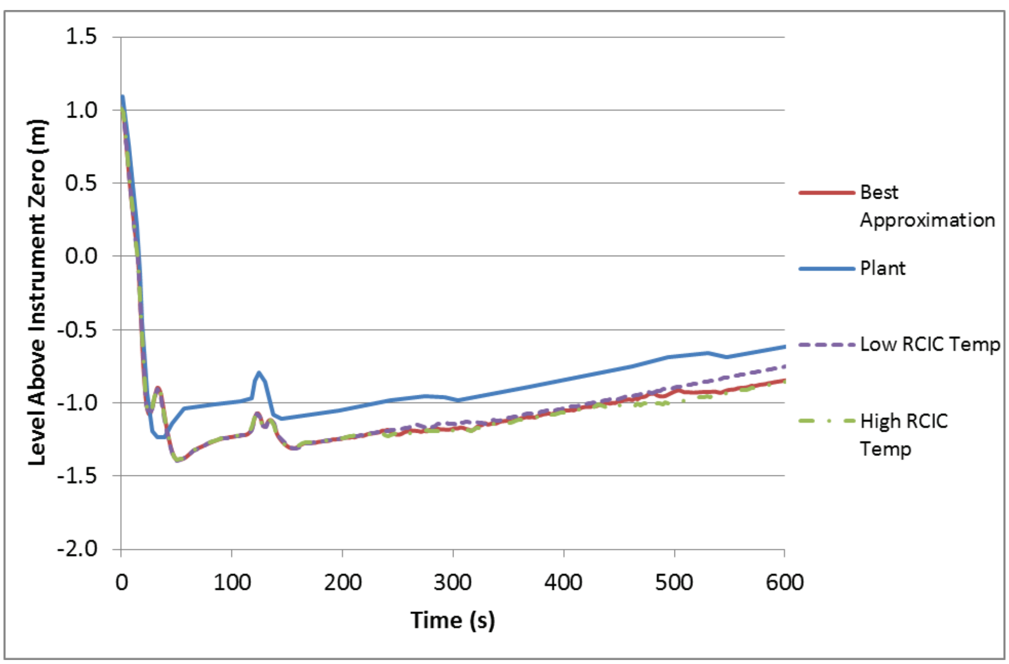

Figure 6. Protection Range Water Level

6. CONCLUSIONS

The simulated TRACG results for the loss of feedwater event show very good agreement with the plant data, assuring the accuracy of the KKM TRACG model. Furthermore, the LOFW event includes a number of systems that are important for other events/accident simulations such as SCRAM logic and power response, level setpoints and measurement, MSIV logic, SRV and PRV modeling, RCIC logic, and pressure behavior/control. TRACG has been generally validated as a suitable code to predict plant behavior during events that involve loss and/or addition of inventory as will be the case in a LOCA scenario. The results of the TRACG analysis for the KKM 1993 LOFW transient, presented in this report, demonstrate that this validation extends to the LOCA type applications for KKM.

NOMENCLATURE

BWR	Boiling Water Reactor
CRD	Control Rod Drive
KKM	Kernkraftwerk Mühleberg
LOCA	Loss of Coolant Accident
LOFW	Loss of Feedwater
MSIV	Main Steam Isolation Valve
NRC	Nuclear Regulatory Commission
PRV	Pressure Relief Valve
RCIC	Reactor Core Isolation Cooling
RPV	Reactor Pressure Vessel
SRV	Safety/Relief Valve
TBV	Turbine Bypass Valve
TCV	Turbine Control Valve
TRACG	Transient Reactor Analysis Code

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