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INTERM MELCOR SIMULATION OF THE FUKUSHIMA DAIICHI UNIT 2 ACCIDENT REACTOR CORE ISOLATION COOLING OPERATION

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ABSTRACT

Data, a brief description of key boundary conditions and results of Sandia National Laboratories' ongoing MELCOR analysis of the Fukushima Unit 2 accident are given for the reactor core isolation cooling (RCIC) system. Important assumptions and related boundary conditions in the current analysis additional to or different than what was assumed/imposed in the work of SAND2012-6173 are identified. This work is for the U.S. Department of Energy's Nuclear Energy University Programs fiscal year 2014 Reactor Safety Technologies Research and Development Program RC-7: RCIC Performance under Severe Accident Conditions.

ACKNOWLEDGEMENT

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ACRONYMS

BAF	Bottom of Active Fuel
CST	Condensate Storage Tank
gpm	gallons per minute
MSL	Main Steam Line
RCIC	Reactor Core Isolation Cooling
RPV	Reactor Pressure Vessel
SNL	Sandia National Laboratories
SRV	Safety Relief Valve
TAF	Top of Active Fuel
WW	Wetwell

1.0 DISCUSSION

A brief description of key boundary conditions and results of Sandia National Laboratories' (SNL's) ongoing MELCOR analysis of the Fukushima Unit 2 accident are given here. A detailed, albeit dated, description of the analysis exists in SAND2012-6173, "Fukushima Daiichi Accident Study (Status as of April 2012)." Important assumptions and related boundary conditions in the current analysis additional to or different than what was assumed/imposed in the work of SAND2012-6173, are identified here. The most recent release of data recorded during the accident can be accessed at the following website:

https://fdada.info

A brief timeline of the Fukushima Unit 2 accident is given in the Table 1.

Table 1 Fukushima Daiichi Unit 2 Accident Timeline

Date and time	Time after scram (hour)	Event
3/11 14:46	-0.05	Earthquake
3/11 14:47	0.00	Scram
3/11 14:50	0.05	RCIC starts
3/11 14:51	0.06	RCIC stops
3/11 15:00	0.22	RHR starts wetwell cooling
3/11 15:02	0.25	RCIC starts
3/11 15:27	0.67	Tsunami wave
3/11 15:28	0.68	RCIC stops
3/11 15:27	0.80	Tsunami wave
3/11 15:36	0.82	RHR stops
3/11 15:39	0.87	RCIC starts
3/11 15:41	0.90	Station blackout
3/12 04:20	13.55*	RCIC suction switchover to wetwell
3/14 13:25	66.80	RCIC stops (assumed)

* This manual switchover timing is not well represented in the current MELCOR calculation.

The cause of reactor core isolation cooling (RCIC) stopping operation was unknown at the time that the report was completed. It is possible that RCIC functionality may have degraded after 66.8 hours. The pressure response observed for the reactor pressure vessel (RPV) seems to indicate a very rapid pressurization occurring at nearly 70 hours which may indicate loss of functionality for RCIC.

Notable boundary conditions currently imposed on SNL's evolving MELCOR calculation are described below.

RPV pressure

RPV pressure data recorded during the accident was imposed as a boundary condition on the MELCOR calculation. This was accomplished by placing a time-dependent control volume full of saturated steam at the junction from a main steam line that routes steam to the RCIC drive turbine. The pressure in the volume was made to follow the pressure in the data. Steam and liquid passed through the junction as conditions allowed. Mass and energy flows through the junction were monitored and mirrored introductions of both, after decrementing energy to reflect the work done by the turbine, were made to the wetwell (i.e., the mass and energy flows extracted from one place in the model (the inlet to the RCIC turbine) were reintroduced at another place (the wetwell) after an accounting was made for the work done by the turbine).

Wetwell temperature

The assumption was made in the MELCOR calculation that the torus room of the Unit 2 reactor building flooded with sea water and that heat transfer from the water inside the containment wetwell to the water flooding the torus room largely influenced containment pressure in the accident. Energy was extracted from the regions where RCIC and the lowest setpoint safety relief valve (SRV) exhaust in the wetwell as necessary to keep temperature just below the saturation temperature associated with recorded Unit 2 pressure data. In this way, containment pressure in the MELCOR calculation was made to follow the data. Heat was extracted from the balance of the wetwell as necessary to keep temperature from exceeding the temperature at which the RCIC pump would cavitate.

RCIC performance degradation

Liquid water ingress to the RCIC drive turbine was assumed in the MELCOR calculation to degrade RCIC pumping performance. The assumed degradation was simplistic in that a void fraction of unity (i.e., all steam) at the turbine inlet gave an efficiency of 100% (600 gpm) while a null void fraction (i.e., all liquid) gave an efficiency of 0% (0 gpm). The efficiency was linear between these extremes.

Continued RCIC turbine draw after RCIC failure

Steam is assumed to continue to flow through the RCIC governor and turbine after the pump stops delivering water to the reactor. The magnitude of the continued flow is metered to produce the increase in reactor pressure seen in the recorded pressure data.

Figures 1 through 7 present the results of SNL's current MELCOR Fukushima Daiichi Unit 2 calculation. In considering these results, realize that SNL's analysis of the Fukushima accident is ongoing. The results presented here are but a current snapshot of an evolving simulation of the accident at Unit 2. Key points regarding the figures are discussed further.

All data used to create Figures 1 through 7 are provided in an Excel Spreadsheet:

NEUP_RCIC_Data.xlsx

Figure 1 compares reactor pressure in the MELCOR calculation to Unit 2 pressure data. Realize that the data is imposed as a boundary condition on the calculation. While unsubstantiated, the inflection at ~10 hours and 45 minutes is conjectured to reflect RCIC performance first being impacted by liquid water entering the RCIC drive turbine.

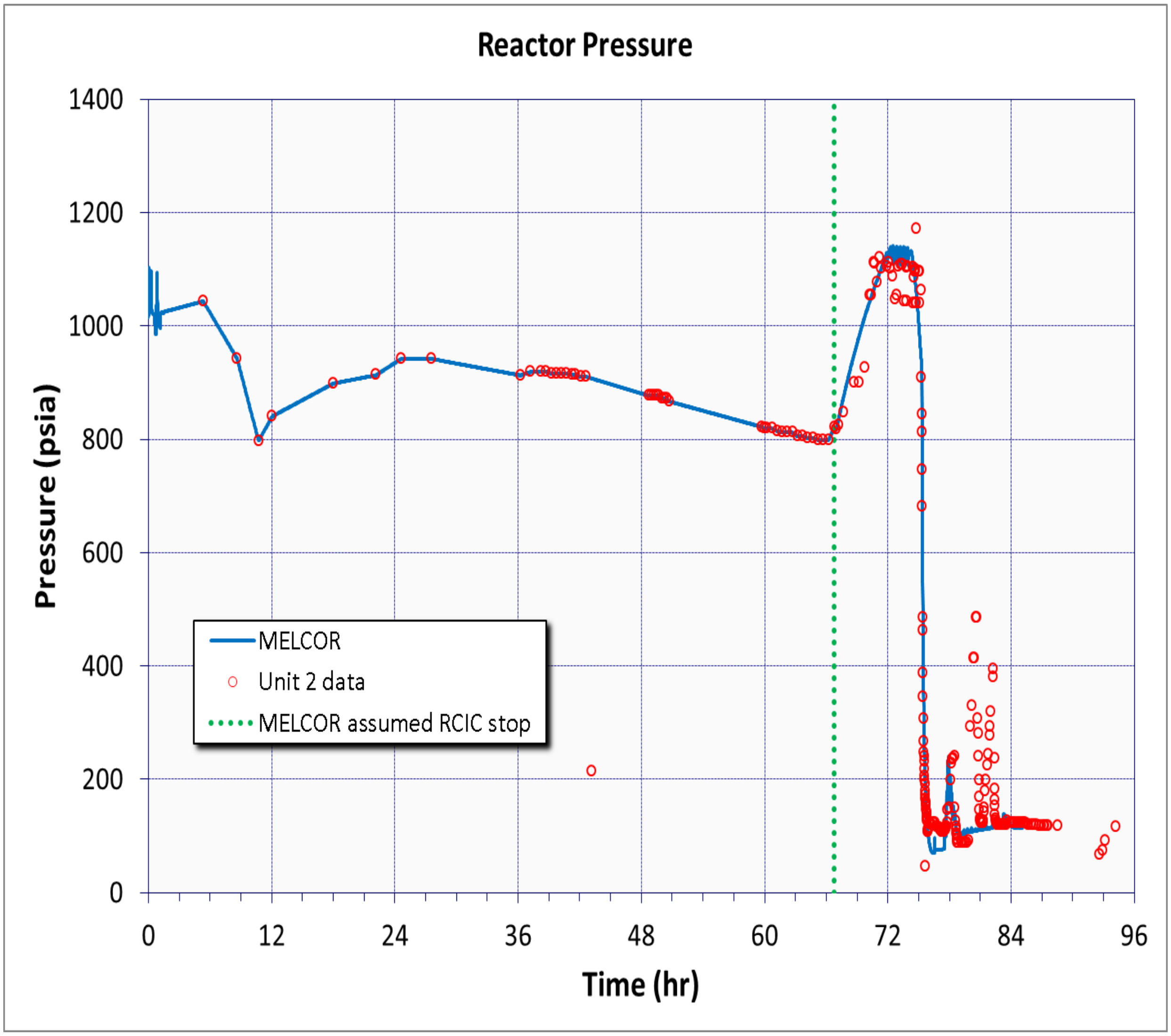

Figure 1 Reactor Pressure

Figure 2 compares containment pressure in the MELCOR calculation to Unit 2 pressure data. Realize that heat rejection from the wetwell to an assumed flooded torus room is being dictated in the calculation such that containment pressure follows the data. Without this heat rejection, calculated containment pressure would substantially exceed the data.

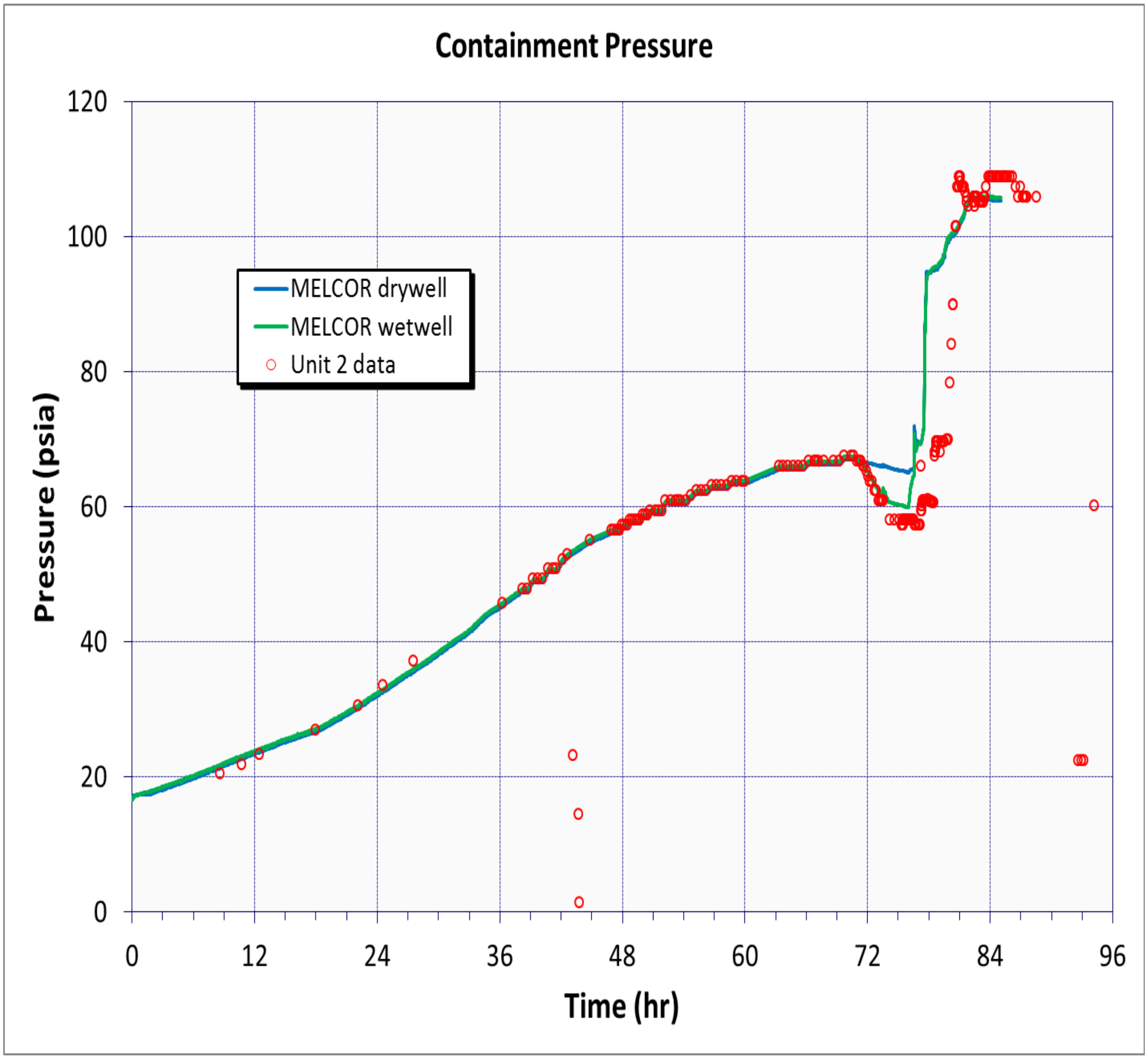

Figure 2 Containment Pressure

Shown in Figure 3 is the calculated level in the RPV downcomer. Note that level data recorded during the accident is known to be in error because of complications resulting from:

1) Elevated temperatures in the containment offsetting the reference legs from their normal condition, and
2) Because of upper limits on indicated level imposed by the physical elevations at which the level instrumentation tubing connects to the RPV.

Identified in the figure is that RCIC, in the MELCOR calculation, is supplying water at a rate greater than steam is being produced. Consequently, the RPV overfills to the elevation of the steam lines and water spills into them. This remains the case until RCIC fails. The spillage to the steam line serving RCIC is ingested by the RCIC drive turbine, and is assumed in the MELCOR calculation to reduce RCIC pumping efficiency. This reduced pumping efficiency is illustrated in Figure 4 where the reduction in RCIC flow with increasing turbine inlet void can be seen. The jump in flow in Figure 4 at 33 hours and 10 minutes is in response to RCIC suction being redirected from the condensate storage tank (CST) to the wetwell (WW). The delivery of the hotter wetwell water results in less spillage to the steam lines and hence greater RCIC pumping efficiency.

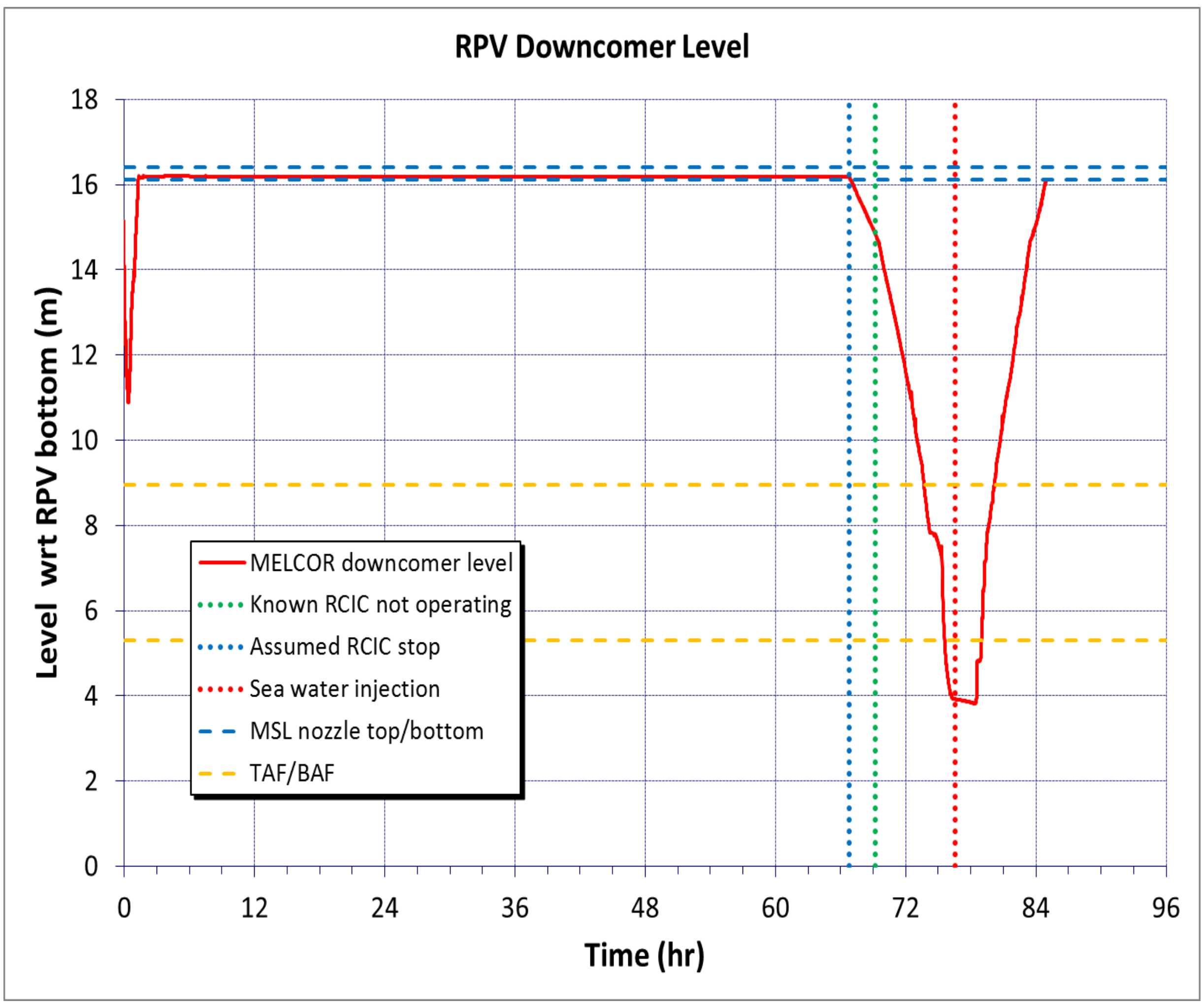

Figure 3 RPV Downcomer Level

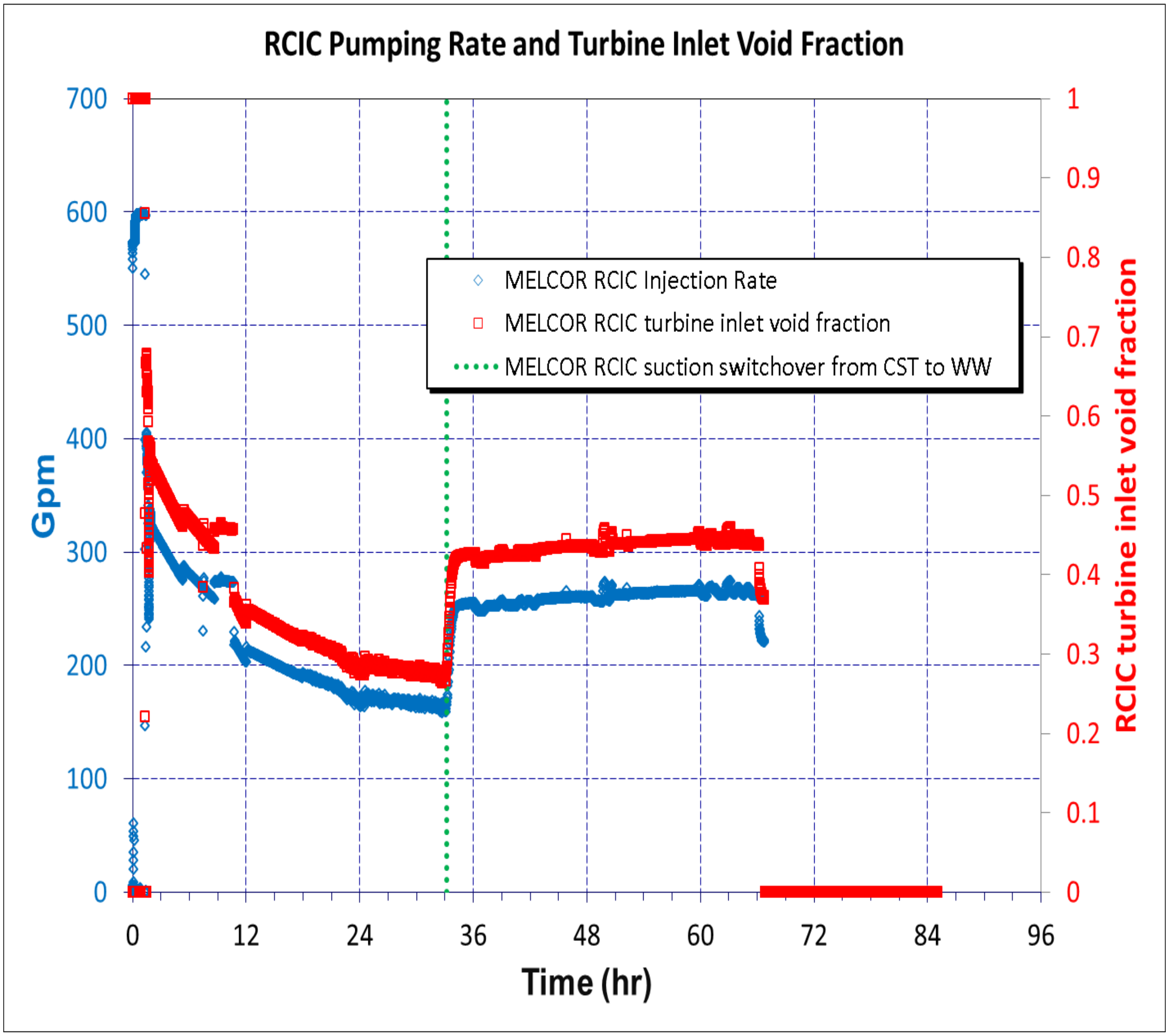

Figure 4 RCIC Pumping Rate and Turbine Inlet Void Fraction

Figure 5 identifies the heat extraction from the wetwell to an assumed flooded torus room dictated in the MELCOR calculation. In considering this figure, realize that the wetwell is divided into three distinct connected regions

- One local to where RCIC exhausts to the wetwell,
- One local to where the lowest setpoint SRV exhausts to the wetwell, and
- One accounting for the balance of the wetwell.

As described earlier, heat is extracted from the regions where RCIC and the SRV exhaust as necessary to keep temperature just below saturation temperature. Heat is extracted from the balance of the wetwell as necessary to keep temperature from exceeding the temperature at which the RCIC pump would cavitate. The results of this heat extraction are illustrated in Figure 6.

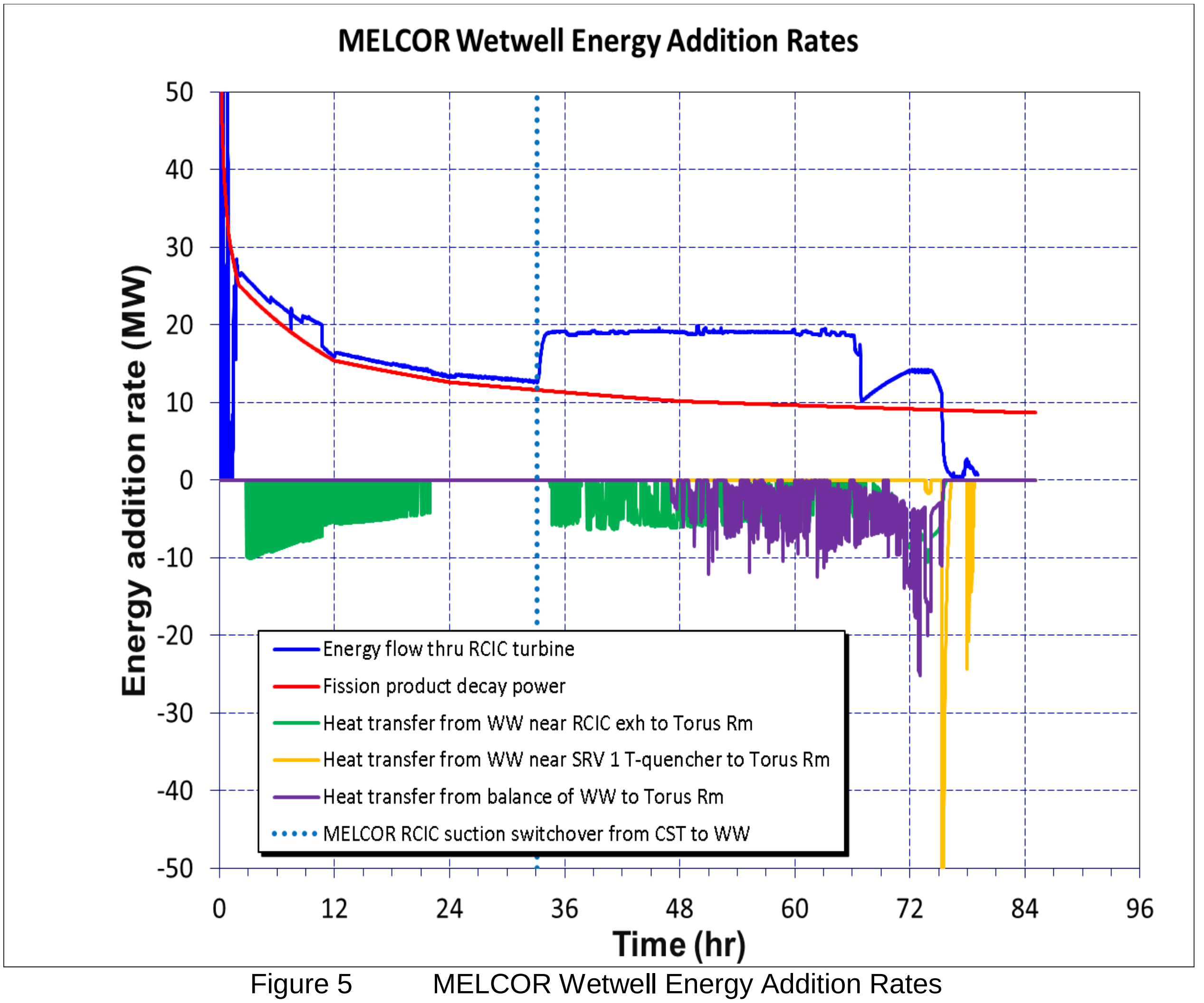

Figure 5 MELCOR Wetwell Energy Addition Rates

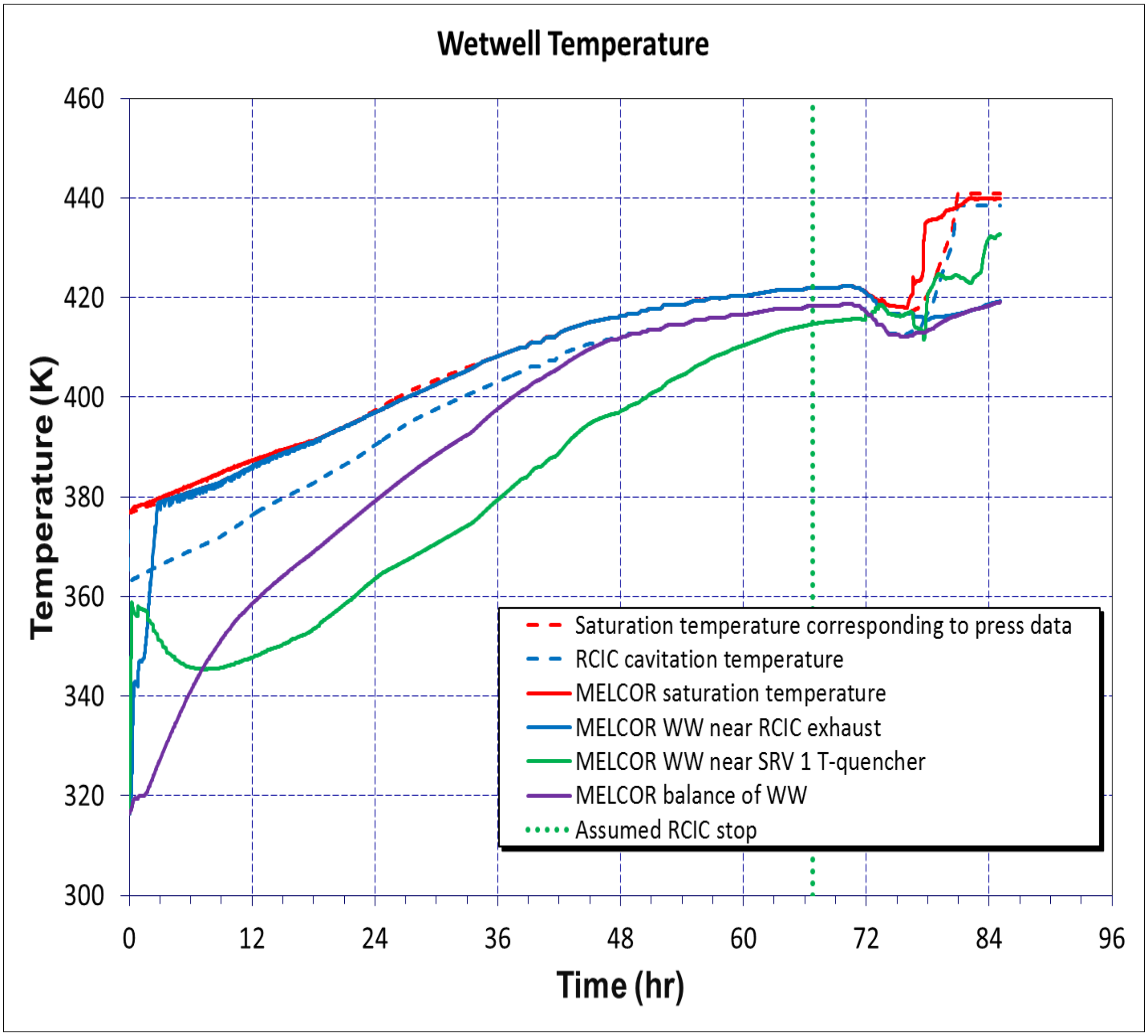

Figure 6 Wetwell Temperature

Figure 7 identifies the associated migration of steam from the wetwell to the drywell through the vacuum breakers serving each region of the wetwell. The domineering flow through the vacuum breaker serving the region where RCIC exhausts identifies that steam emanating from this region of the wetwell drives containment pressurization.

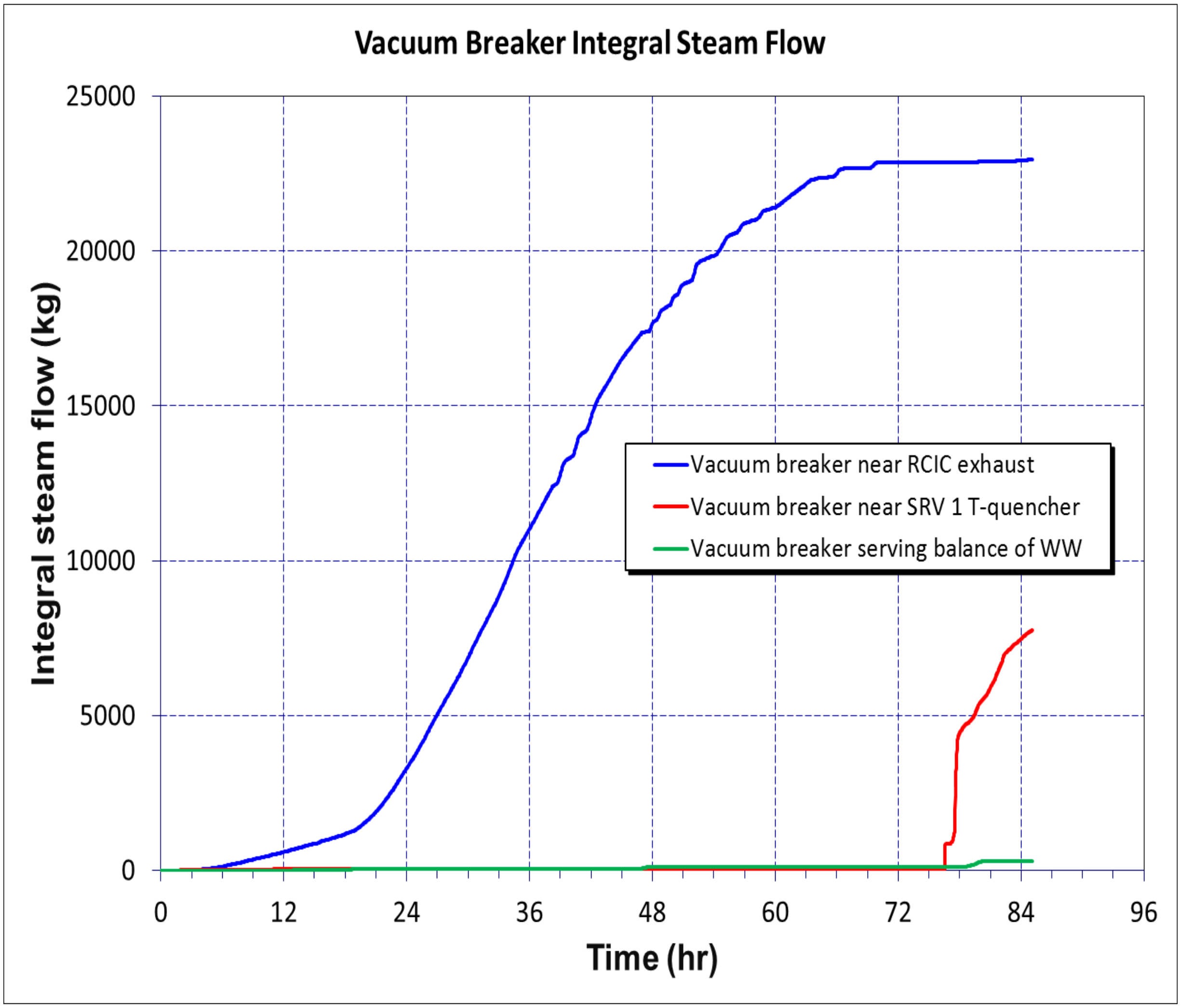

Figure 7 Vacuum Breaker Integral Steam Flow

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