19QB DHR Reliability Study

19QB.1 Offsite Dose and Operator Recovery Calculations

This attachment covers five different calculations that were completed for various aspects of the ABWR Decay Heat Removal Reliability Study. The calculations are:

(1) Offsite doses following RPV boiling in Mode 5

(2) Time to reach RPV boiling for specific plant conditions and decay heat loads

(3) Time for RPV water level to reach top of active fuel (TAF)

(4) Human Reliability Analysis

(5) Decay heat removal capability of CUW and FPC

19QB.1.1 Offsite Doses

For the ABWR Decay Heat Removal Reliability Study, the success criteria for Mode 5 allows boiling of water in the RPV or spent fuel pool. The following calculation of offsite doses assuming boiling in the RPV and spent fuel pool substantiates why boiling is a viable success criteria in Mode 5.

The equation for calculating offsite doses is:

Dose = RR * DF * BR * DCF

Dose = Offsite dose for 24 hour period (Sv)

RR = Release rate for 24 hours

$$= \frac{\text{Decay Heat Load (joule/h)}}{\text{2039 joule/kg Water}} * 5.92\ (B_q / g\ \text{I} - 131) * 0.015(\text{I}-131\text{carryover}) * 24$$

DF = Dispersion factor = 1.2×10^{-3} s/m^3

BR = Breathing rate = 3.47×10^{-4} m^3/s

DCF = Thyroid dose concentration factor = 2.92×10^{-7} Sv/B_q

The values in the above equation such as I-131 carryover, I-131 concentration, and dispersion factor are conservative estimates based on ABWR Tier 2 analysis and regulatory guidance.

The decay heat loads at 3 and 14 days following shutdown are 17.29 x 10^6 w (5.9 x 10^7 Btu/h) and 9.378 x 10^6 w (3.2 x 10^7 Btu/h), respectively. Using the above equation, the doses for 24 hours at 3 and 14 days are 7.5 x 10^{-6} and 4.04 x 10^{-6} Sv, respectively. This is significantly below the FEMA limit of 0.05 Sv per 24 hours for normal plant operations. Thus boiling in Mode 5 will not exceed any offsite dose limits and is a viable success criteria.

19QB.2 Time to Reach Boiling

The time for an operator to recover a failed RHR system in the ABWR Decay Heat Reliability Study is conservatively based on the time to boiling in the RPV or the spent fuel pool. The following discussion addresses the calculation of time to boiling for the RPV and RPV plus spent fuel pool at various times after shutdown.

It is assumed that the initial temperature of the RPV or spent fuel pool is 333.15 K (140°F). This is typical for normal Mode 4 or 5 operation.

The equation for time to boiling is:

$$t = [\Delta T / \text{heat up rate}(°K/h)]$$

$$t = \frac{373.15°K - 333.15°K}{(\text{Decay Heat Rate}/\text{Mass of Water})}$$

Table 19QB-1 shows the results for time to boiling for the RPV alone at 2 and 3 days following shutdown and for the RPV plus spent fuel pool (i.e., reactor cavity flooded and fuel pool gates opened) at 3 and 14 days. As can be seen, the time for operator action varies from a little over an hour for the RPV alone to approximately one day for the RPV plus spent fuel pool 14 days after shutdown.

19QB.3 Time for RPV Water Level to Reach Top of Active Fuel

This subsection summarizes the calculations for the time to reach top of active fuel in Modes 3, 4, and 5. The results show it will take 6.4 hours in Mode 3, 13 hours in Mode 5, 15 hours in the early part of Mode 5 before flooding of the cavity, and more than a week after cavity flooding in Mode 5. Assuming that it takes 9.76 x 10^5 joules (925 BTU) to vaporize 0.4536 kg (1 lb) of water, the decay heat at a specific time is divided by 9.76 x 10^5 joules to find the rate of vaporization. Division of water mass by this vaporization rate results in the time for RPV water level to reach TAF. Table 19QB-2 shows the results.

19QB.4 Human Reliability Analysis (HRA)

19QB.4.1 Purpose

The purpose of this HRA is to calculate the human error probabilities (HEPs) for the decay heat removal reliability study.

19QB.4.2 Summary

Tables 19QB-3 and 19QB-4 show the HEPs which were calculated for various time frames and plant modes for two cases.

Case a Operator action required before water starts to boil.

Case b Operator action required to prevent core damage (CD).

However, it was decided that more conservative values should be used in the PRA. These values are also shown in these tables.

19QB.4.3 Methodology

The HEP calculations were performed conservatively using the procedure for normal human reliability analysis (HRA) in Table 8-1, Reference 19QB-1, with the following steps:

(a) The displays and alarms available to the operator were identified.

(b) The times to boiling and core damage were identified.

(c) The times for diagnosis and post-diagnosis actions were allocated.

(d) The HEPs for diagnosis and post-diagnosis actions were calculated using Figure 8-1 and Table 8-3 and 8-5 of Reference 19QB-1.

(e) Higher than calculated values were assigned conservatively for use in the PRA.

(f) It is assumed that at least two operators are in the control room at all times during shutdown.

19QB.4.3.1 Control Room and Alarms

Table 19QB-5 shows the relevant alarms which are available in the CR (Reference 19QB-2). Operator is alerted to the failure of the operating RHR by means of one of the RHR specific alarms. If none of these alarms work, he will be alerted to the RPV parameters alarm 2 (though RPV pressure and water level may not be available prior to boiling). With these multiple alarms, it is reasonable to assume that all operators will be promptly alerted to the RHR failure.

In Mode 5 with the reactor cavity flooded, the operator would be made aware of heating the fuel pool by many other indications. Personnel on the refueling floor will all sense the increased temperature and will see steam formation. If no personnel notice the fuel pool heatup, the operator would receive an alarm of low fuel pool level and initiation of fuel pool level make up.

19QB.4.3.2 Allocation of Times to Diagnosis and Post-Diagnosis Actions

The time available to the operators was allocated between time for diagnosis and time for post-diagnosis action. Table 19QB-6 shows the various times which were to calculate the HEPs. Column three gives the calculated times before boiling (case a), and core damage (case b), or the total time available for allocation. Columns 4 and 5 show the results of the allocation. Enough time is allocated to post-diagnostic actions, so that there is sufficient time for recovery of human errors, even if the required action must take place outside the control room.

19QB.4.4 Results and Conclusions

The results of this HRA study are documented in Tables 19QB-3 and 19QB-4. It is concluded that the operator has adequate instrumentation and alarms to diagnose the event. Adequate procedures and operator training will assure proper response to the loss of RHR event.

19QB.5 Decay Heat Removal Capability of CUW and FPC

The purpose of the following heat removal calculations is to determine heat removal capabilities of FPC and CUW after flooding the cavity as a function of time following shutdown. In Modes 3 and 4, FPC cannot be used but CUW, which is conservatively modeled as only a single pump available, is able to remove the decay heat because of increased capacity at higher temperatures. The results show that the CUW System alone is capable of removing the decay heat 8 days after shutdown because it keeps the RPV temperature below 373 K (212°F) within 24 h. The FPC System can be used 10 days after shutdown to keep the temperature below 339 K (150°F), which is the design limit for the FPC pumps. To perform these calculations, initial RPV temperatures of 333 K (140°F) and 325 K (125°F) were assumed for the CUW and the FPC, respectively an initial temperature of 333 K (140°F) and 325 K (125°F) was assumed for the CUW to account for the time that it takes to initiate the CUW System manually, because one FPC pump is working all the time, it takes a negligible amount of time to initiate the second pump.

19QB.6 References

19QB-1 Swain, A.D., “Accident Sequence Evaluation Program Human Reliability Analysis Procedure”, Sandia National Laboratories, NUREG /CR-4772, U.S. Nuclear Regulatory Commission, Washington, D.C., February 1987.

19QB-2 Interlock Block Diagram, IBD, 137C8326, Sh. 18, Rev. 2.

19QB-3 “ABWR Shutdown Risk Evaluation,” Toshiba UTLR-0013.

Table 19QB-1 Time to Boiling for the RPV and RPV Plus SFP

Mode	Days after Shutdown	Decay Heat (watts)	Decay Heat (Btu/h)	Mass of Water (kg)	Mass of Water (lbs)	Time to Reach Boiling (h)
4	2	$2.0x10^7$	$6.8x10^7$	$5.0x10^5$	$1.1x10^6$	1.2
5	3	$1.7x10^7$	$5.9x10^7$	$5.0x10^5$	$1.1x10^6$	1.3
5	3	$1.7x10^7$	$5.9x10^7$	$5.4x10^6$	$1.2x10^7$	15
5	14	$9.4x10^6$	$3.2x10^7$	$5.4x10^6$	$1.2x10^7$	27

Table 19QB-2 Time for RPV Water Level to Reach TAF

Mode	After Shutdown	Decay Heat (watts)	Decay Heat (Btu/h)	Mass of Water (kg)	Mass of Water (lbs)	Time to Reach TAF
3	4 hrs	$4.19x10^7$	$1.43x10^8$	$4.4x10^5$	$9.8x10^5$	6.4 h
4	2 days	$2.0x10^7$	$6.8x10^7$	$4.4x10^5$	$9.8x10^5$	13 h
5	3 days	$1.7x10^7$	$5.9x10^7$	$4.4x10^5$	$9.8x10^5$	15 h
5	3 days	$1.7x10^7$	$5.9x10^7$	$5.4x10^6$	$1.2x10^7$	7.8 days
5	14 days	$9.4x10^6$	$3.2x10^7$	$5.4x10^6$	$1.2x10^7$	14.5 days

Table 19QB-3 Probability of Failure to Diagnose

Case	Mode	Time After Shutdown	Prob. (Fail to Diagnose) Calculated	Prob. (Fail to Diagnose) Used in PRA
a	5	2 - 3 days	*	*
a	5	>3 days	*	*
b	3,4, and 5 (prior to flooding reactor cavity)	Any time After Shutdown	*	*
b	5 (after flooding reactor cavity)	Any Time	*	*

* Not a part of DCD (Refer to Reference 19QB-3, Table 8).

Table 19QB-4 Probability of Failure to Start a Specified "Minimum-Set" System

Case	Mode	Prob. (Fail to Diagnose) Calculated	Prob. (Fail to Diagnose) Used in PRA
a	All	*	*
b	All	*	*

* Not a part of DCD (Refer to Reference 19QB-3, Table 10).

Table 19QB-5 Control Room Alarms and Indications Aiding Diagnosis of "One RHR Lost"

RHR Specific	RPV Parameters
1. Pump discharge pressure high	1. Temperature
2. Pump motor over current	2. Pressure
3. RHR loop power failure	3. Water level
4. RHR loop logic failure	
5. RHR pump motor trip	
6. RCW outlet temperature high	

Table 19QB-6 Times Available (in Hours)

Case	Mode	Total Time To Event	Allocated Diagnosis Time (TD)	Time for Post-Diagnosis Actions (T_A)
a	5 (Days 2 to 3)	1.2	0.5	0.7
a	5 (after 3 days)	≥14	12	≥ 2
b	All	≥ 6.4	≥ 2.4	≥ 4