*Transactions of the Korean Nuclear Society Autumn Meeting*
*Jeju, Korea, October 21-22, 2010*

# An Evaluation of Operator's Action Time for Core Cooling Recovery Operation in a loss of Component Cooling Water

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## 1. Introduction

Operator's action time in the success criteria of a Probabilistic Safety Assessment (PSA) is generally derived from Thermal-Hydraulic (T-H) analyses. It serves as a type of input in Human Reliability Analyses (HRA) which eventually impacts PSA.

For the successful implementation of risk-informed application, more realistic T-H analyses in PSA are necessary [1]. In existing PSA of KHNP, T-H analyses are conducted using the MAAP4 code. However, the results of MAAP4 analysis are too conservative to perform a realistic PSA, because it is simplified simulation code. Also, ASME PRA standard recommends the use of best-estimate code to improve PSA quality [2].

The MARS code is more useful for realistic and plant specific analyses, as it provides best-estimate results for the thermal hydraulic behavior of a Nuclear Steam Supply System (NSSS).

In this paper, under a loss of component cooling water, equivalent break size depending on four cases of RCP leakage rate are calculated and corresponding operator's action times to mitigate accidents are evaluated. Consequently, the Human Error Probability (HEP) and Core Damage Frequency (CDF) are compared with previous results.

## 2. Analysis and Results

### *2.1 Identification of Event Sequence*

The event tree for a loss of Component Cooling Water (CCW) contains an operator action for a core cooling recovery related to a RCP seal failure, as shown in Fig. 1. When a loss of CCW occurs and all RCPs stop, the reactor is tripped and the Motor-Driven Auxiliary Feed Water Pump (MD-AFWP) starts by Steam Generator (SG) low-low level. When the RCP seal failure results from a loss of CCW, operators should open two steam dump valves to the condenser or two SG PORVs to the atmosphere in order to drop the pressure of RCS rapidly for safety injection, according to the emergency operating procedures [3, 4]. A safety injection tank and a Low Pressure Safety Injection (LPSI) should follow this action. If the water level of Refueling Water Storage Tank (RWST) reaches the low-low level, operators convert to low-pressure cold leg recirculation for continuous cool-down of the core. With the success of this action, a containment heat removal procedure is required.

### *2.2 RCP seal failure Model*

RCP seal leakage events are classified into four cases, depending on amount of leakage rate, 57gpm, 76gpm, 182gpm, or 480gpm per RCP.

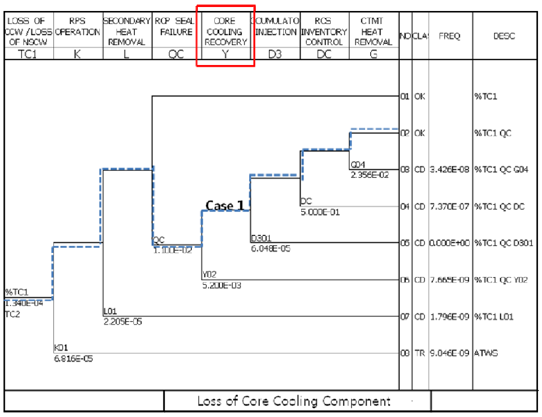


Fig. 1. Case 1 (Sequence no. 2) contains the core cooling recovery operation in the loss of CCW event tree.

To achieve each RCP leakage rate, a break in the cold leg at the same location as a RCP is assumed. Because the pressure of each part in the RCS is identical, this assumption is reasonable. The desired leakage rate is achieved by trial and error. When the liquid fraction of the broken cold leg is maintained at 1.0, that is, only the liquid in the RCS is released to containment, the accumulated flow rates divided times are considered as the total RCP leakage rate. Table I shows the equivalent break sizes corresponding to the RCP seal leakage rate. All RCP seal failure areas are included within the small break LOCA range.

Table I: Equivalent break size with RCP seal leakage rates

| RCP seal leakage rate (gpm) | Break size ($m^2$) | Remark |
|---|---|---|
| 57x3 | 0.000089467 | About 0.4 inch |
| 76x3 | 0.000119390 | About 0.5 inch |
| 182x3 | 0.000289000 | About 0.75 inch |
| 480x3 | 0.000840265 | About 1.3 inch |

### *2.3 Modeling Assumption*

The criterion for core damage is 2200℉(1477K) for the MARS code [1]. The time window for a core cooling recovery is defined as the time which the SI signal is generated to the time when the core exit gas temperature reaches 700˚F. The following assumptions related to an accident mitigation system are used to model the selected sequences.

- A MD-AFWP is actuated and delivers the flow to the two SGs when the SG narrow-range level is decreased to the low-low level, i.e., 17%.
- A MD-AFWP is actuated with 50min of the delay time, considering the restricted recovery time of the start-up feed water pump.
- For the core cooling recovery action, operators start to open two SG PORVs by maintaining the cool-down rate at 100˚F/hr when the core exit gas temperature reaches 700˚F. They fully open two SG PORVs without considering the cool-down rate when the core exit gas temperature reaches 1200˚F.
- One out of two LPSI pumps delivers the SI flow into a cold leg.
- Two Safety Injection Tanks (SITs) are available.
- When the total amount of the flow accumulated from the LPSI pump becomes 1219.9m$^3$, the RWST level is considered to be 39%, that is, at a low-low level. When the cumulated SI flow is 1755m$^3$, this is considered to be the state of RWST depletion [5].
- When the temperature of the SI flow sucked from the sump after RWST depletion is constant, containment heat removal is possible.

*2.4 Analysis Results*

The operator's action times for the core cooling recovery operation calculated by the MARS code range from 67.8 min for 480gpm to 614.5 min for 57gpm as shown in Table II and III. The RCP seal leakage at 480gpm case is the most conservative case. The operator's action time for 480gpm was used to estimate the HEP.

Table II: MARS analysis results of the core cooling recovery operation with four RCP leakage rates

| Event/Time(min) | 57gpm | 76gpm | 182gpm | 480gpm |
|---|---|---|---|---|
| Event begins | 0.0 | 0.0 | 0.0 | 0.0 |
| Reactor trip | 0.2 | 0.2 | 0.2 | 0.2 |
| RCP seal failure occurs | 40.0 | 40.0 | 40.0 | 40.0 |
| MD-AFWP starts | 50.2 | 50.2 | 50.2 | 50.2 |
| **SIAS on** | **78.7** | **73.1** | **61.2** | **53.5** |
| **Core cooling recovery starts** | **693.2** | **526.3** | **230.8** | **121.3** |
| SIT injection | 699.3 | 532.3 | 238.0 | 134.3 |
| LPSI condition | 715.7 | 549.3 | 256.7 | 159.5 |
| RWST low-low level | - | - | - | 1047.3 |
| RWST depletion | - | - | - | - |
| Core uncover | 548.3 | 421.7 | 186.7 | 136.7 |
| $T_{CET*}$ > 700˚F | 692.7 | 525.3 | 230.8 | 121.3 |
| $T_{CET}$ > 1200˚F | - | - | - | - |
| PCT** > 2200˚F | - | - | - | - |
| End | 1440.0 | 1440.0 | 1440.0 | 1440.0 |

*CET (Core Exit Temperature)
**PCT (Peak Cladding Temperature)

Table III shows that MARS analysis provides a larger time window compared to the MAAP4 analysis. Although the MAAP4 analysis also adopts the same definition of a time window for a core cooling recovery action, the characteristics of the two code results in different time windows.

Table III: Comparison of operator's action time between the MARS analysis and the MAAP4 analysis

| RCP leakage rate (gpm) | MAAP4 | MARS |
|---|---|---|
| 57x3 | 390.5 min | 614.5 min (=693.2-78.7) |
| 76x3 | 287.5 min | 453.2 min (=526.3-73.1) |
| 182x3 | 118.6 min | 169.6 min (=230.8-61.2) |
| 480x3 | 47.7 min | 67.8 min (=121.3-53.5) |

*2.5 PSA Effects*

This section analyzes the impact of the time window for this action on HRA and PSA. The Korean Standard HRA method [6] is used to estimate the HEPs. Table IV shows the re-estimated HEPs and CDF change rate based on the MARS analysis and the MAAP4 analysis. The total HEP is reduced by 47% compared to that of the MAAP4 analysis for a conservative case. The change in the CDF is reduced by 1.65% for the same RCP leakage rate, that is, 480gpm.

Table IV: Re-estimated operator's action time, HEP, and CDF compared to previous results

| HEP /CDF | MAAP4 | MARS |
|---|---|---|
| Time (min) | 47 | 67 |
| Diagnosis Failure Prob. | 3.62E-3 | 1.36E-3 |
| Execution Failure Prob. | 1.00E-2 | 5.00E-3 |
| Total HEP | 1.36E-2 | 6.36E-3 |
| CDF change rate (%) | 0.0 | -1.65 |

## 3. Conclusions

We assessed the operator's action time for a core cooling recovery operation in a loss of CCW event tree using the MARS code. The impact of the analysis on PSA was investigated and compared with the MAAP4 results. It was found that the MARS analysis provides a better margin for the same operator action and decreases CDF by 1.65%. For a more realistic approach, MARS code can be used instead of MAAP4 code in PSA success criteria.

## REFERENCES

[1] ASME/ANS RA-Sa-2009, "Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications", Feb. 2, 2009.
[2] Han, S. J., Lim, H.G., & Yang, J. E., "An estimation of an operator's action time by using the MARS code in a small break LOCA without a HPSI for a PWR", Nuclear Engineering and Design, 237, 749-760, 2007.
[3] KHNP, "Emergency Operating Procedure ER-C.1 Response to Degraded Core Cooling", Rev. 6. Nov. 21, 2006.
[4] KHNP, "Emergency Operating Procedure ER-C.2 Response to Inadequate Core Cooling, Rev. 6, Nov. 21, 2006.
[5] KHNP, "Emergency Operating Procedure Supplement-1.3 Switch to Cold leg Recirculation", Rev.6, No. 21, 2006.
[6] Jung, W. D., Kang, D. I., Kim, J. H., "Development of a Standard Method for Human Reliability Analysis (HRA) of Nuclear Power Plants-Level 1 PSA Full Power internal HRA", KAERI/TR-2961/2005, December, 2005.