# Modeling of Aggressive Cool Down in a PSA with a Procedural Change

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## INTRODUCTION

A risk-informed application based on probabilistic safety assessment (PSA) information requires a PSA model assuring its technical adequacy. One of issues that need to be further investigated to improve the quality of a reference PSA was the modeling of an aggressive cool down (ACD) operation [1].

The paper describes (1) the difference between the modeling of ACD in the PSA of a reference plant and its actual operational response, and (2) its impact on the plant risk after revising the modeling of ACD with a procedural change.

## ACD MODELING ISSUE IN A PSA

ACD is an emergency strategy forcedly cooling down a reactor coolant system (RCS) at the maximum cooling rate in a pressurized water reactor (PWR) type nuclear power plant (NPP), which is required when a small break loss of coolant accident (SLOCA) or a steam generator tube rupture (SGTR) event occurs with a failure of the high-pressure safety injection (HPSI) system [1].

An RCS cooling operation through the secondary side generally limits the cooling rate as less than 56C/h to prevent the RCS from thermal shock, which is known as an ordinary cool down operation for a power cutback or reactor shut down during normal operation. On the other hand, ACD is an emergency response strategy to prevent core damage by opening the SG atmospheric dump valves (ADVs) manually to cool down the RCS as rapidly as possible with the maximum cooling rate.

The ACD operation is explicitly described in the emergency operating procedures (EOPs) of a Westinghouse type NPP. However, in the EOP of the reference plant [2], there is no explicit instruction for an ACD operation. Therefore, we examined the feasibility of ACD modeling in the reference plant's PSA and proposed a new procedural instruction for adapting the ACD strategy. To verify the feasibility of the ACD, a comprehensive TH analysis is performed using the MARS code, and crew's performance time (PT) taken for ACD are generated using simulator data to support its human reliability analysis (HRA). Based on these supporting analyses, we design a procedural path for ACD and show its impact on the plant risk using a sensitivity analysis [3].

## SUPPORTING ANALYSES FOR ACD

For ACD operation, operators should open the SG ADVs to cool down and depressurize the RCS within an allowable time to prevent core damage. To define the success criteria for a human failure event (HFE) of an ACD, we perform two supporting analyses: (1) a MARS analysis to find the allowable time window and cooling rate for ACD, and (2) a time analysis to estimate the PTs taken for operators to initiate an ACD based on the simulator data.

### MARS Analysis

A thermal hydraulic analysis is conducted using the MARS code (ver. KS1.1), which is one of the best-estimate TH codes developed by KAERI [4]. We run MARS code along with varying SLOCA sizes without HPSI to find the allowable time for an ACD operation. The RCS cooling rate determined by the operator is considered an important variable affecting the starting point of the ACD. From the TH analysis, we can understand the plant behaviors and the changes to the key safety parameters in various combinations of break size, cooling rate, and ACD starting time. For example, Fig. 1 shows the PCT behaviors in the case of a 1.5 inch break, 65 min as the start time, and various cooling rates.

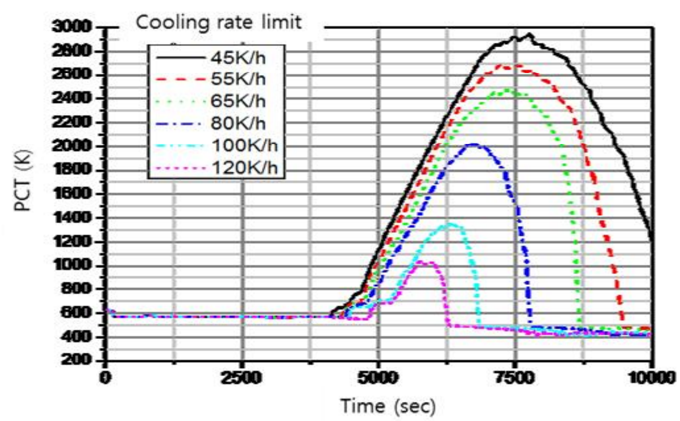


Fig. 1. PCT (1.5" break, ACD at 65 min after Rx trips).

### Performance Time Analysis

Regarding operators' PT of a set of emergency tasks, we have collected and analyzed simulator records secured from training simulators of the reference plant. The task to be analyzed here is 'a crew diagnosis of the occurring event, LOCA with HPSI failure, making a decision to preform ACD, and initiating an ACD by opening the SG ADVs.' To estimate PT to initiate an ACD, we use PT data generated from a previous study conducted by KAERI [5]. TABLE I shows a part of the PTs in the case of the LOCA scenario.

TABLE I. A Part of Operators' PTs [5]

| Procedure: Task | PT (seconds) | |
|---|---|---|
| | Mean | Std.dev |
| SPTA: average of all events | 196.2 | 72.8 |
| DA: average of all events | 149.9 | 79.5 |
| E-2: delivery of a sufficient SI flow | 195.9 | 106.7 |
| E-2: checking criteria for RCP stoppage | 182.4 | 72.4 |
| E-2: isolating break location | 137.2 | 89.8 |
| E-2: securing the integrity of a containment | 106.7 | 39.9 |
| E-2: cooling down RCS | 101.3 | 55.3 |

## NEW PROCEDURAL PATH FOR ACD

The PT of ACD can be varied depending on the procedural paths of EOP taken by control room operators in the event scenario of LOCA with an HPSI failure. As previously mentioned, however, EOPs of the reference plant do not describe any instruction for ACD. We designed an instruction for ACD so that operators could cool down the RCS without any limitation regarding cooling rate. Then, three different paths can be possible as an anticipated operator response for ACD operation. Among them, a new procedural path we proposed for ACD is shown in Fig. 2.

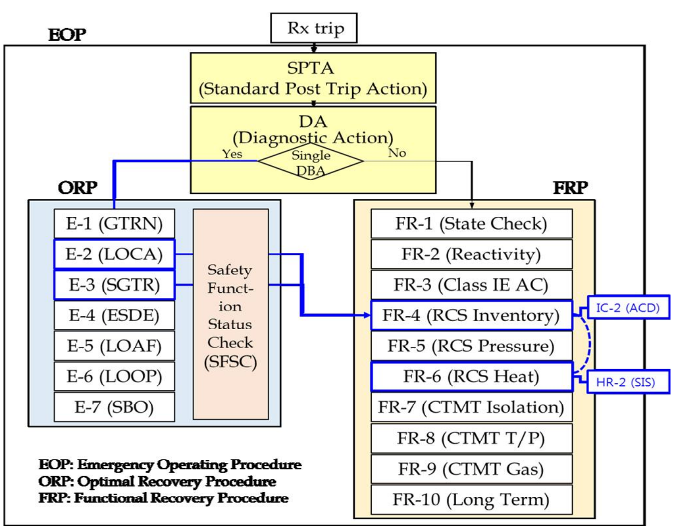


Fig. 2. New procedural path for ACD operation.

## RISK IMPACT ANALYSIS OF ACD

The modeling of ACD in the reference PSA is revised using the success criteria that are newly defined based on the supporting analyses described in the previous section. TABLE II outlines the major changes of the PSA model with regard to three options for ACD. Human error probability (HEP) of ACD in each option is evaluated using the K-HRA method [6] with relevant inputs including the allowable time and average PT for ACD.

Fig. 3 shows the core damage frequencies (CDFs) of relevant initiating events comparatively in three options of ACD modeling. The CDF of Option-3, a new procedural path for ACD, is about 50% lower than that of the original model (Option-1).

TABLE II. Changes in Modeling of ACD

| Case | Success Criteria | HEP of ACD |
|---|---|---|
| Option-1 | ACD starting = 15min,<br>Cooling rate = 56C/hr,<br>PT = 25~60min | 1.0 |
| Option-2 | ACD starting = 35min,<br>Cooling rate = no limitation,<br>PT = 25~40min | 0.8 |
| Option-3 | ACD starting = 35min,<br>Cooling rate = no limitation,<br>PT = 20~30min | 0.35 |

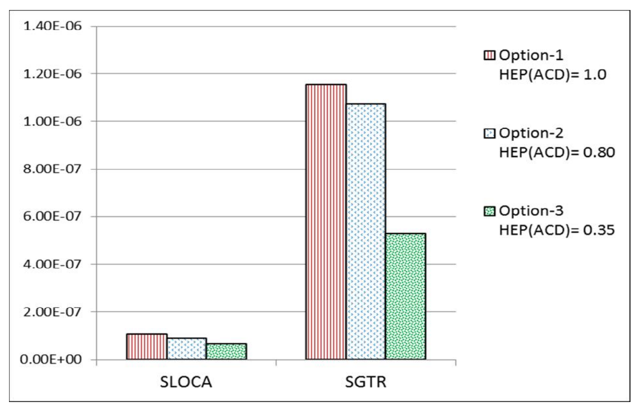


Fig. 3. Risk impact of ACD modeling.

## CONCLUSION

This paper summarized a study on the modeling of ACD operation and its impact on the risk of an NPP. It noted that the model of the ACD in the reference PSA did not reflect the plant's behavior or the operators' PT exactly. We performed comprehensive supporting analyses and revised the PSA model using the newly defined success criteria. In addition, a new procedural path for ACD was proposed to initiate an RCS cool down more quickly. The sensitivity analysis showed that the risk of the revised model was much lower than that of the original model.

## ACKNOWLEDGMENT

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