

MARS-KS Assessment of the OECD/NEA ATLAS C4.2 Shutdown-Cooling LOCA Test and the Effect of the PAFS Configuration

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1. Introduction

A loss-of-coolant accident (LOCA) initiated during shutdown cooling is hard to manage: the decay heat is still appreciable, the automatic safety injection actuation signal is normally bypassed, and mitigation rests on manual operator action [1]. Integral data for this scenario were produced as the C4.2 test of the third phase of the OECD/NEA ATLAS joint project (OECD-ATLAS3): a 50 % direct vessel injection (DVI) line break during shutdown cooling of the APR1400, with two operator actions, actuation of the passive auxiliary feedwater system (PAFS) on one steam generator after a 30-minute grace period and manual safety injection on a cladding temperature setpoint.

The measured behavior was reported previously [2]: loop seal clearing and reformation developed asymmetrically, only the PAFS-cooled loop reforming its loop seal, and the core uncovered nonetheless. Left open was whether a system analysis code reproduces the transient, since the scenario evolves at low pressure and low subcooling, where closure models for critical flow, condensation, and loop seal clearing are largely unvalidated. This paper assesses MARS-KS against the C4.2 data and asks, through a sensitivity study on the PAFS configuration, whether passive cooling alone can prevent the core heat-up.

2. MARS-KS Analysis Model

The test was analyzed with MARS-KS version 2.0, the best-estimate system analysis code maintained for regulatory application in Korea, which solves a one-dimensional two-fluid, six-equation formulation of two-phase flow [3]. The ATLAS input model nodalizes the primary system with two hot legs and four cold legs, the downcomer and core, the pressurizer, the four DVI lines with the safety injection tanks and pump, the two steam generators with their secondary sides, and the PAFS steam-supply line, condensation heat exchanger, and return-water line [4,5]. Wall structures are passive heat structures, reproducing the measured steam generator heat loss; break discharge uses the Henry-Fauske critical-flow model with a discharge coefficient of 0.85 and thermal non-equilibrium constant of 0.14.

The steady shutdown cooling state was matched to the measured initial conditions of 265.3 kW core power, 2.74 MPa primary pressure, and 177 °C core exit temperature. Three calculations were then run on the

event schedule of the test: without PAFS, with a single train actuated 1273 seconds after the break, which is the test configuration, and with both trains. The safety injection pump is not credited, so that the calculations isolate the core heat-up driven by the loop seal and passive-cooling behavior; comparisons are therefore confined to the pre-injection window, $t^* < 4.72$. Data are normalized under the confidentiality rules of OECD-ATLAS3.

3. Results and Discussion

3.1. Assessment against the C4.2 data

The calculated initial pressures reproduce the measured values within a few percent, and the calculated collapsed levels follow the early inventory depletion and the hold-up of the downcomer level at the DVI nozzle elevation. Fig. 1 compares the integrated break mass: up to safety injection the calculation lies within about 12 % of the data, so the break-flow integral is reproduced through the inventory-depletion phase. The divergence afterwards reflects the injected water discharged through the break in the test, which the calculation does not credit.

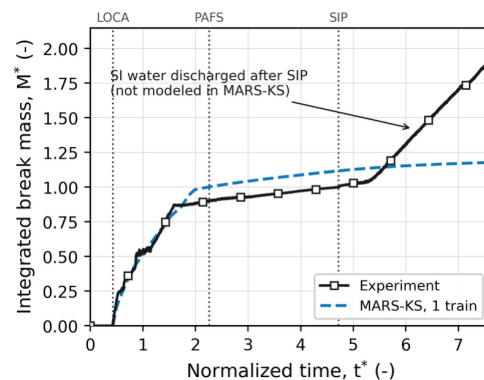


Fig. 1. Integrated break mass, experiment and MARS-KS (single train), normalized by the measured value at safety injection.

The passive cooling is also reproduced, the time-averaged natural circulation flow of PAFS falling within about 27 % of the measured steady value. The calculated flow oscillates while the measured flow is smooth, as is characteristic of system-code analyses of gravity-driven two-phase condenser loops, but the

gravity head fixes the time-averaged return and the mean value stands.

The most safety-relevant comparison is the maximum cladding temperature. MARS-KS reproduces the prolonged covered period and places the onset of the excursion at $t^* = 4.66$ against the measured $t^* = 4.72$, capturing the timing of core uncover to within about 1.3 % and slightly on the conservative side.

3.2. Effect of the PAFS configuration

Fig. 2 compares the three configurations. In every one of them the cladding temperature ultimately undergoes an excursion, so passive cooling delays the core heat-up but does not prevent it. The onset times are non-monotonic in the number of trains, at $t^* = 4.29$ without PAFS, 4.56 with two trains, and 4.66 with one train, the two PAFS-equipped cases differing by only about 0.1 in normalized time. With two trains the core inventory is transiently lower during the onset window, plausibly because condensate is retained in both loop seals rather than one.

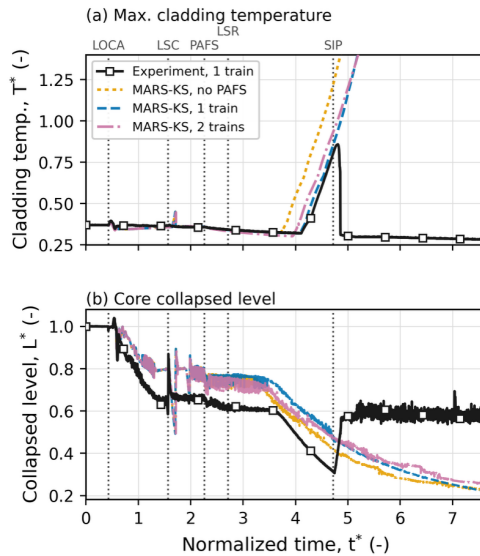


Fig. 2. Effect of the PAFS configuration: (a) maximum cladding temperature and (b) core collapsed level. The experiment corresponds to one train.

These differences are small and non-monotonic, and the numerical uncertainty has not been quantified, so they should not be over-interpreted. What the comparison does show is that once the loop seals have cleared, the core heat-up is governed mainly by the boil-off and the break flow rather than by the passive-cooling configuration. A symmetric, both-loop reformation neither delivers coolant to the core nor averts the heat-up, so the asymmetry reported in [2] conditions the inter-loop pressure distribution but does not by itself decide recoverability.

4. Conclusions

(1) Over the pre-injection window MARS-KS reproduces the event sequence, the system pressures, the inventory depletion, the break mass to within about

12 %, and the time-averaged PAFS return flow to within about 27 %, and places the cladding excursion at $t^* = 4.66$ against the measured 4.72.

(2) In all three passive-cooling configurations the cladding temperature ultimately undergoes an excursion, so timely manual safety injection remains necessary when the actuation signal is bypassed during shutdown.

(3) The assessment compares global variables only and does not yet address the asymmetric loop seal behavior; a nodalization sensitivity study and uncertainty quantification remain follow-on work. Subject to these limitations, the C4.2 database is a useful benchmark in a regime where closure models are largely unvalidated.

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