MARS-KS system code simulations of ATLAS facility mid-loop tests

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1. Introduction

Mid-loop operation tests were conducted at ATLAS facility to investigate the scaled down APR1400 model's behavior under various pressures and non-condensable gas presence. Experimental results were compared to MARS-KS system code results to evaluate software capabilities predicting such phenomena as peak cladding temperature (PCT) and reflux condensation.

2. Experiments and MARS-KS preparations

Three initial-boundary condition sets were established preliminary with various pressures and core powers to cover as wide as possible operational range.

2.1 ML01 experiment

Mid-Loop-01 test was conducted under atmospheric pressure (primary and secondary system open to environment) with a 129 kW core power which is the maximum capacity of the ATLAS reactor heat removal system (RHR). After stabilizing steady state System Blackout (SBO) protocol was initiated shutting down main coolant pumps (MCP) and disabling all active components of the system. No safety mitigation was applied during the transient, only the reflux condensation's cooling capability was tested.

2.2 ML02 experiment

For the Mid-Loop-02 boundary conditions were adjusted from the previous test although the core power was reduced to 100 kW thus the influence of decay heat decrease could be investigated.

2.3 ML03 experiment

The Mid-Loop-03 test was performed at 27.4 bar primary and secondary pressure simulating a shut-down transient. The primary system was completely sealed while the secondary system was partially open to atmosphere via main system isolation valves (MSIVs). The core power was kept at 288 kW.

2.3 MARS-KS input for mid-loop operation tests

The basic input deck of ATLAS facility was customized for each case to highlight the advantages and discrepancies of the system code related to the investigated phenomena. Before initializing the calculation, the water level of the primary system was set to the hot leg (HL) centerline and the remaining space was filled with vapor-air mixture (99% air mass fraction). One can anticipate multi-phase multi-component flows in the primary system thus flow regimes of certain control volumes (CV) were observed closely.

3. Comparison of experiment and calculation

Comparing test data and MARS-KS result one can see differences in the sequence of events. Although temperature and pressure tendencies are similar the calculation predicted PCT ~3000 s earlier than the experiment.

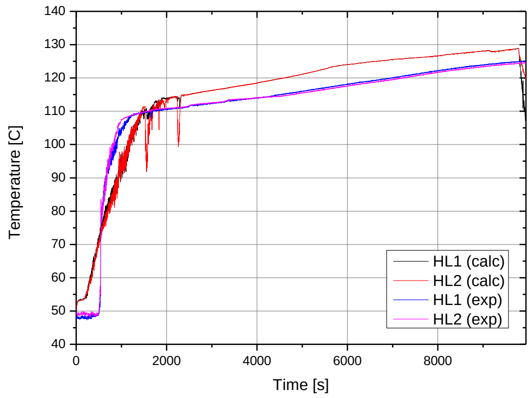

Fig. 1. Hot leg fluid temperatures

Despite of the previous anomalies the secondary system showed relatively good agreement which indicated that heat transfer rates governed by reflux condensation are not capable enough to such distortion.

Looking at the pressurizer (PRZ) collapsed level the system code showed entirely different fill-up tendency, while gradual refill was observed during experiment MARS showed a rapid-total PRZ fill up. Since there was no coolant injection on the PRZ and the HL dried down at 4500 s the behavior can be explained by unphysical void fraction calculation.

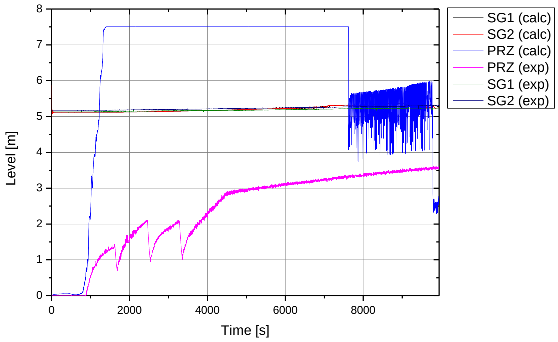

Fig. 3. PRZ and SG levels in ML01

The system code uses a flow regime map to evaluate certain properties in the CV depending on the inlet-outlet conditions. According to Fig. 3. the PRZ is filled up, vertical stratified/bubbly flow could be expected. Aforementioned maps were based on horizontal flow data, thus applying them to vertical CVs (PRZ 40x vertical CV) numerical issues can be expected. In order to verify which type of flow was present during the transient the flow regime numbers are shown in Fig. 4.

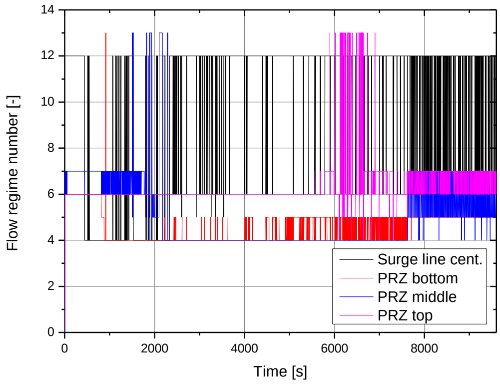

Fig. 4. Flow regime numbers in ML01 (4=bubbly, 5=slug, 6=annular-mist, 7=mist-pre-CHF, 12=horizontal stratified, 13=vertical stratified)

One can see that slug flow appeared frequently in the vertical volumes while the horizontal surge line showed horizontal stratification. As the pressurizer blocks the steam release the primary pressure was increased thus indirectly the dry-down process gained speed enhancing heat transfer coefficients in the core and in the U-tube assembly.

ML02 showed very similar characteristics to ML01 however the sequence of events was also distorted in the MARS calculations while the experiment showed a much slower transient according to reduced core power. PRZ fill up was rapid compared to experiment while SG levels were in good agreement with actual test.

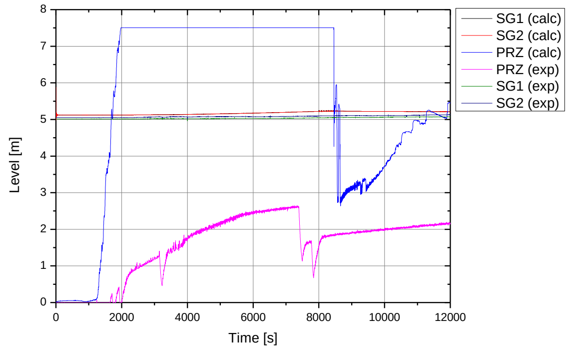

Fig. 5. SG and PRZ collapsed water levels in ML02

The explanation could be the same as for the ML01 case for such level curves in Fig. 5. which is inappropriate flow regime map implementation. To validate the theory one can discuss the flow regime numbers in Fig. 6.

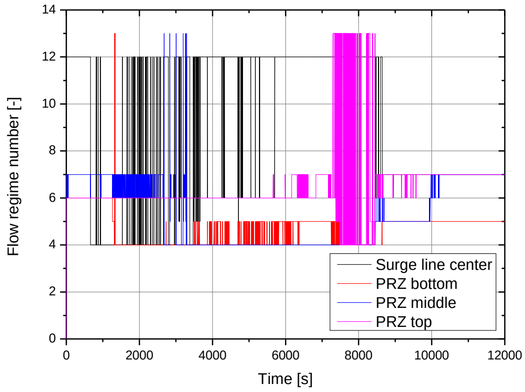

Fig. 6. Flow regime numbers in ML02 (4=bubbly, 5=slug, 6=annular-mist, 7=mist-pre-CHF, 12=horizontal stratified, 13=vertical stratified)

The same water plug built up in the PRZ as before as result of slug and bubbly flow which appeared to be an even bigger resistance to the steam flow because of the lower core power. Flow regimes show that in the horizontal center of the surge line bubbly-slug and stratified flow appeared, the PRZ bottom showed similar regimes to surge line while the middle section was altering between slug-annular-mist and pre-CHF which is non-physical under given circumstances. As one can see the top volume oscillating from bubbly regime to horizontal stratified the rapid fill up can be explained.

ML03 showed different tendencies compared to previous cases. The PRZ behavior significantly differed, the PRZ and the surge line was governed by bubbly flow and the top was alternating between bubbly and vertical stratified flow. Since there was no heat loss applied to the PRZ there was no condensation inside however despite of this practice the pressure did not rise similarly to test data (Fig. 7).

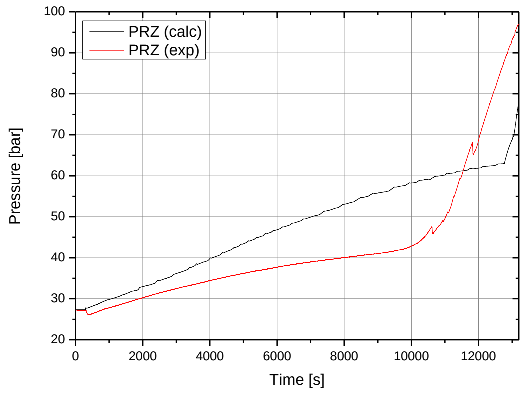

Fig. 7. Pressurizer pressure comparison

Hot leg temperatures showed the same behavior, also the void fraction did not decrease under 0.8 in the HL center according to MARS. In Fig. 8 one can see the difference in the SG main steam isolation valve flow rates, calculation does not show the flow decrease (consequence of SG dry-out).

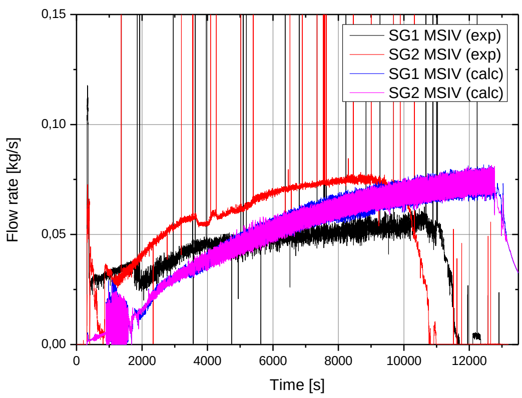

Fig. 8. SG MSIV flow rates

Nevertheless, the gradients were similar in steam flow curves and the valve position was well simulated the offset in steam flow rate and SG level variables can be explained by reduced heat transfer rates in the SGs (Fig. 9.). Since NC agent (air) is present in the U-tube volumes the reflux condensation cannot provide the required condensate flow rates for core wetting on primary and awaited steam flow rates on secondary side. This observation highlights the limits of the current condensation models, the high pressure and temperature region of such condensation is yet to be investigated in the presence of NC gases as well.

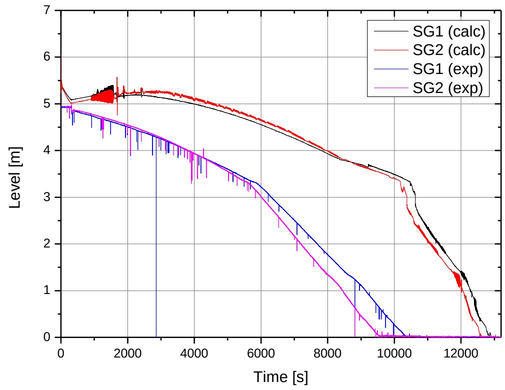

Fig. 9. SG levels in ML03

3. Conclusions

The MARS-KS system code capabilities were tested against mid-loop operation experimental data. The negative non-condensable gas effect on condensation was prevailed by hydraulical issues corrupting proper reflux condensation simulation. Inappropriate method of the flow regime map implementation was found under various boundary conditions. Condensation model development in high pressure and temperature conditions with various non-condensable agents (air, N_2, He, H_2).