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Qualification of system code AC^2/ATHLET for New Builts

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1. Introduction

Nuclear new builts in Europe in the short to medium term will be Gen III/III+ LWR designs including LWR SMRs. In the longer term, Gen IV reactor concepts might play a role. All of these new designs pose specific challenges for model development but also for the verification and validation (V&V) of system thermal-hydraulics codes (STH), which often are legacy codes. STH will remain the working horse to support the safety demonstrations of reactors for the foreseeable future. Therefore, STH codes need to be properly qualified to be used in licensing. Relevant good practice for V&V is given e.g. in IAEA SSG-2 and several regulatory guides. Expectations on robust V&V of STH for new simulation challenges like passive safety systems with small driving forces, innovative components or new materials require to enhance internal procedures and processes, including use of continuous integration techniques. For the STH codes package AC^2 developed by GRS the approach how the meet all of these challenges is discussed and exemplary simulation results for ATHLET as part of AC^2 are discussed.

2. Methodology

The AC^2 best-estimate system code package consisting of ATHLET for cooling circuit thermal-hydraulics, ATHLET-CD for severe accidents in-vessel, and COCOSYS for the containment is developed by GRS for the analysis of nuclear reactors at normal operation, anticipated operational occurrences and design basis accidents up to severe accident conditions with radionuclide releases from the containment [1]. The AC^2 code development process follows an internal quality management process considering requirements in IAEA SSG-2, Rev. 1, [2] and other regulatory guidance as well as industry standards, which also includes verification and validation. Here, verification is understood as checking the correct implementation of specific models including code reviews, unit testing and comparing code output against theoretical predictions and selected separate effect test results as well as doing regression testing against previous versions. For validation, GRS uses well-balanced validation matrices with separate effect tests and integral tests derived from the OECD/CNSI validation matrices, e.g. for ATHLET based on [3] and [4], and extended by more recent test series [5]. This is complemented by selected plant transient and postulated fault condition simulations, which are checked against available data or for plausibility. In the last 30 years, the ATHLET validation has covered 70% of the 80 single effect tests, 76% of the PWR experiments, 100% of the BWR experiments and 90% of the WWER experiments with a least one successful simulation [1].

For future applications, ATHLET needs to be qualified for the specific challenges posed by SMR and passive safety systems. GRS has identified relevant phenomena for LW-SMR and passive systems, especially those of less relevance for active systems, for which ATHLET needs to be qualified [6]. Based on that, GRS has identified suitable and available experiments for extending the validation matrices [7]. Moreover, GRS is involved in national, EC supported and OECD/NEA projects generating new validation data for STH and participates in international working groups like the OECD/NEA WGAMA and in IAEA activities on these topics [8]. Thereby, the AC² code ATHLET could be improved and validated against several tests relevant to SMRs and passive safety systems.

3. Results and Discussion

In the following, two exemplary results from the extended ATHLET validation matrix are discussed.

PERSEO

Passive residual heat removal via a closed 2-phase natural circulation loop, where a condenser heat exchanger is placed in a large (in- or ex-containment) water pool is foreseen in several recent NPP and SMR designs as a passive safety system [6] and is present in some BWR designs as an isolation condenser. During operation, steam from the reactor or steam generator is condensed in vertical tubes (straight, C-shaped and more complex forms are considered), while the condensate flows back via a return line due to the hydrostatic head from the elevation of the heat exchanger. On the outside, there is free convection in a large pool, which is slowly heated up and eventually starts to boil off. There are different means for activating such a system, often at least one valve in the return line has to be opened, in order to drain the sub-cooled water from the tubes, which fills them during stand-by.

The PERSEO test facility includes a straight-tube heat-exchanger for closed loop 2-phase natural circulation. However, the activiation is a little different to the above-mentioned sequence: In PERSEO, two water pools exist. The heat exchanger is located in a closed heat exchanger pool (HX pool), which is initially filled with air and vapour. Since also tubes are not filled with water but with vapour initially, heat losses are minimised when the condenser is not working. The large overall pool is connected to the heat-exchanger pool via a connection line with a valve blocked at their bottom level. A second pipe directs steam generated in the HX pool vessel via an immersed conical injector into the overall pool, which is open to the atmosphere. The system is activated by opening the valve in the bottom connection line, so that the smaller HX pool gets fill and steam in the straight tubes starts to condense [9]. For the validation of ATHLET three test sequences were investigated, the main results of Test 7, Phase 2 are discussed below.

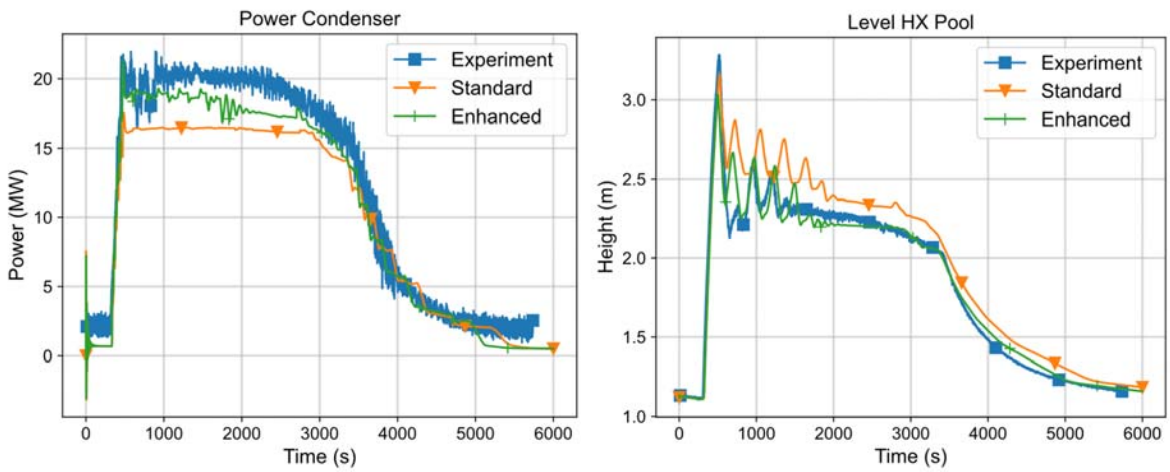

Figure 1: Measured and calculated condenser power as well as HX water level of PERSEO Test No. 7, Phase 2.

The results of the simulation with ATHLET 3.3 for Test 7 Part 2 are shown in Figure 1. In this test, the valve in the connection line between the pools is opened only once but longer than in Part 1 (not shown here). With opening the valve at 300 s, the liquid level in the HX pool is rising and oscillating. Power of the condenser follows the liquid level in the HX pool and reaches 20 MW but declines with decreasing pool level after closing the valve at 3338 s. With the standard version of ATHLET, steady-state HX power results were underestimated by ~20%. Consequently, a new correlation proposed by Papini and Cammi for heat transfer in vertical pipes [10]was implemented in a developer version of ATHLET, which reduced the underestimation to 5-10%, marked as "Enhanced" in Figure 1. This change also led to a better agreement of the predicted water level in the HX pool with the measured data.

ATLAS

One main contribution for the validation of ATHLET for passive systems was the participation in the OECD/NEA joint project ATLAS [11]. It provided valuable experimental data for investigating LWR thermal-hydraulic safety issues related to multiple high-risk failures by using the ATLAS (Advanced Thermal-Hydraulic Test loop for Accident Simulation) facility. ATLAS is an integral test facility operated by KAERI (Korea Atomic Energy Research Institute) and designed according to the three-level scaling methodology by Ishii and Kataoka. It has a geometrical scaling ratio of 1/2 in length, 1/144 in area and 1/288 in volume with respect to its reference NPP APR1400 and it is scaled for full system pressure and temperature [12].

Two tests of the OECD/NEA joint project ATLAS studied the behaviour of the Passive Auxiliary Feedwater System (PAFS) under station blackout (SBO) conditions, both tests with asymmetric secondary side cooling via one steam generator (SG) as the envisaged accident management (AM) action:

- Test A1.2: feedwater supply via PAFS to SG in loop 2 at low SG secondary side level;
- Test A2.1: SBO with additionally coolant pump seal failure in loop 2, with feedwater supply via PAFS in loop 2 at very low SG secondary side level as foreseen AM action.

The main results of the post-test calculation of Test A2.1 are depicted in Figure 2. ATHLET 3.2.1 can reproduce adequately the main phenomena observed in the experiment, including pressure and temperature evolutions as well as the coolant distribution in the primary system. The PAFS natural circulation flow rates for Test A2.1 were well predicted by the code. For the whole transient duration, the code calculates a small sub-cooling at the outlet plenum of SG-2, showing the effectiveness of the PAFS actuation, even under reflux-condenser conditions in the primary circuit, as observed in the later phases of the experiment.

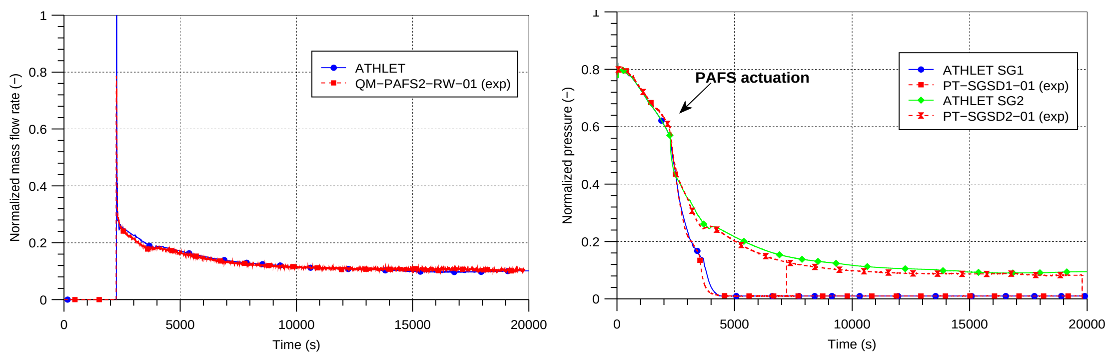

Figure 2 : Normalized measured and calculated secondary side pressures and mass flow rates of the PAFS int experiment ATLAS A2.1.

4. Conclusions

System codes for the simulation of new reactor designs like Gen III/III+ or SMR, which rely on passive safety systems, need to be validated for the relevant phenomena and condition to be used for safety analyses in support of a licensing process. Therefore, a separate validation matrix is set up for the thermal-hydraulic code

ATHLET. This validation matrix addresses the phenomena, which are relevant in passive safety systems and for LW-SMRs, and identifies experiments which cover these phenomena. The results of validation calculations against two of these experiments show that ATHLET can predict the behavior of these systems both for separate effect tests like PERSEO and for an integral facility like ATLAS. During the validation process, potentials for code improvement could be identified and new models were implemented, which significantly increase the predictive capabilities of ATHLET. The V&V of the AC^2 codes will be continued as part of the ongoing developed at GRS Intensive validation will be done by a) systematically increasing verification and validation cases, b) increased use of a CI server as basis for evaluation and expert judgement, c) (re-)calculation of single effect tests.

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