Qualification of System Codes for New Builts - Code Requirements and Model Improvement

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Background
Background

- Nuclear new builds in Europe in the medium term will be focused mainly on Gen III/III+ LWR designs including LWR SMRs.
- In the long term, Gen IV reactor concepts might play a role.
- These new designs pose specific challenges for the development but also for the verification and validation (V&V) of system thermal-hydraulics codes (STH), which often are legacy codes.
- STH will be the working horse to support the safety demonstration of a new built for the foreseeable future.
- For using STH in licensing, these codes need to be properly qualified. Relevant good practice for V&V is given e.g. in IAEA SSG-2 and several regulatory guides. Expectations on a robust V&V of STH for new challenges from new builds 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.
- Extension of validation matrices with specific validation for passive safety systems and innovative safety features
Overview of AC²
Motivation for the Development of AC²

New reactor concepts (Gen III/III+, SMRs, ADS, …) impose new **challenges**:

- **Passive safety** systems, including large water pools
- **Innovative** components (e.g. compact heat exchanger, heat pipes)
- **New working fluids** (e.g. LBE, sodium, helium, ….)
- Require partially coupled (multi-physics) simulations of phenomena in the core, cooling circuit, containment and fuel pool

AC² takes up these challenge by:

- Coupling ATHLET/ATHLET-CD und COCOSYS for the **integral co-simulation** of flow phenomena in cooling circuit and containment
- Specific models for **passive safety systems** and innovative components
- Extension to new **working fluids**, homogenization of material values
- **Integral validation** of the overall system
- Coupling interfaces for **multi-physics/multiscale analyses** (CFD, CSM, subchannel codes, 3D neutronics)
AC² 2019 – Architecture and Main Codes

GUI for results visualisation and interactive control

ATLAS

ATHLET

 Cooling circuit thermal hydraulics

Thermal hydraulics

Core geometry

Energy and H₂-generation

Fission products

ATHLET-CD

Core degradation and fission product transport

AC² Driver

Run control

Containment thermal hydraulics and fission product transport

Mass, Energy, Pressure,
Temperature, Void, NC gases

Fission products core melt

COCOSYS
General Validation Strategy of AC^2
Overview of validation activities (I)

- QM Guidelines for computer programs
- Separation of Development and Verification and Validation
  - Verification: check whether models are implemented correctly
  - Validation: check whether physical phenomena are described by the correct models
    - Phenomena orientated validation matrix
    - Single effect tests (SET): selected effects, clearly defined initial and boundary conditions, high instrumentation density and quality
    - Integral tests: interaction of different effects, normally scaled test facilities, common special instrumentation
Overview of validation activities (II) – AC²/ATHLET –

- **PWR**: 105 relevant Experiments / Transients → 75 % calculated
- **BWR**: 18 relevant Experiments / Transients → 100 % calculated
- **WWER**: 37 relevant Experiments / Transients → 98 % calculated
- **Gen. III/III+, IV, SMR** extensive number of new phenomena large new test matrices → big effort
- Work performed also with the help of external partners
Specific Validation of ATHLET for Passive Systems
Extension of Validation Matrices for Passive Systems

The extension of validation matrices is ongoing

- Identification of relevant phenomena of passive systems especially those less relevant for or not applicable in active systems (for safety demonstration)
- Identification of experiments investigating passive systems and considering the phenomena relevant for passive systems, e.g.:
  - Emergency condenser of INKA
  - Emergency condenser Jülich
  - UPTF TRAM A6
  - Selected experiments of the ATLAS test series considering passives systems
  - PKL SACO (part of EC PASTELS project)
  - Selected experiments identified in EC ELSMOR project
  - PERSEO Test No. 7 (OECD Benchmark) and No. 9
Simulation of PERSEO Test No. 7

Scope of the experiment

- Test 7 is a full pressure test (7 MPa) and investigates the system stability and the system operation (long term cooling capability)

- The test consists of two parts:
  - Part 1: to verify the behavior of the system with two different water levels
  - Part 2: to verify the long term cooling capability of the system
Simulation of PERSEO Test No. 7

– Results –

Application of ATHLET including additional correlations for condensation heat transfer within vertical tubes

- Underestimation of transferred power of approx. 5 – 10 %
  - Differences to ATHLET standard version: up to 20 %
  - Correlations will be included in future ATHLET versions
Simulation of PERSEO Test No. 7
– Results Part 1 (I) –

HX Pool collapsed water level

Overall Pool collapsed water level

HX Pool relative pressure

Power IC

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Simulation of PERSEO Test No. 7
– Results Part 1 (II) –

Overall pool top and bottom

Heat exchanger pipe wall temperature

Primary side steam mass flow rate

Primary side condensate mass flow rate

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Simulation of PERSEO Test No. 7  
– Results Part 2 (I) –

**HX Pool collapsed water level**
- L_VQ_Exp
- L_VQ_AC2

**HX Pool relative pressure**
- P-Q001_Exp
- P-Q001_AC2

**Overall Pool collapsed water level**
- L_VP_Exp
- L_VP_AC2

**Power IC**
- W_IC_Exp
- W_IC_AC2
Simulation of PERSEO Test No. 7  
– Results Part 2 (II) –

Overall pool top and bottom

Heat exchanger pipe wall temperature

Primary side steam mass flow rate

Primary side condensate mass flow rate
Conclusions and Outlook (I)

- The results of the validation simulations show that the AC$^2$ module ATHLET can be successfully applied for thermal-hydraulics of LWR Gen II, III including **passive systems** by application on selected experiments and plants.

- The V&V of the AC$^2$ modules ATHLET and ATHLET-CD will be continued to assure the capability and predictability of the modules. Intensive validation by
  - Systematically increasing verification and validation cases
  - Increased use of a CI server as basis for evaluation and expert judgement
  - (Re-)Calculation of Single Effect Tests

- Extended validation of AC$^2$ with coupled ATHLET(-CD)/COCOSYS scenarios

- Participation in international activities, especially OECD/NEA activities and EC sponsored projects
  - For code usage and experimental data exchange
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Thank you very much for your attention!