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# Validation of the CATHARE 1-D and 3-D reflood models against FEBA and ACHILLES experimental tests

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## HIGHLIGHTS

- We used CATHARE2 and CATHARE3 codes to simulate scenarios featuring reflood conditions.
- Both the 1-D and 3-D features of the CATHARE2 code have been adopted to simulate the experiments.
- The quantitative analysis shows a systematic underprediction of the PCT and faster quenching in the majority of FEBA and ACHILLES tests.
- The best agreement with experiment among the tested models is achieved using the 3-D model.
- CATHARE2 has a tendency to improve the PCT prediction with increase of the bundle pressure and when increasing the inlet liquid velocity.

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## ABSTRACT

This paper presents results of a code validation activity that has been carried out at the University of Pisa within the EC-funded NURESAFE project, aimed to assess CATHARE2 v2.5_3 Mod3.1 code capabilities to simulate scenarios featuring reflood conditions. For such purpose, experimental data available from FEBA and ACHILLES separate-effect test facilities was used.

In order to set-up a reference calculation model, rigorous sensitivity studies have been performed for each of the selected experimental test facilities. Quantitative analysis of the results has been carried out for all of the considered tests, using the Fast Fourier Transform Based Method (FFTBM) for accuracy quantification of code predictions.

The calculations of experimental tests of ACHILLES facility have been performed with CATHARE2 v2.5_3 mod 3.1 using both 1-D and 3-D models. The non-regression of the results predicted by such code was successfully checked through qualitative and quantitative comparison with results obtained by the one of previous code versions: CATHARE2 v2.5_2 mod 7.1.

An assessment of the capabilities of the new CATHARE3 v1.3.13 code to simulate reflood phenomena using both two- and three-field 1-D models has then been carried out, based on the same ACHILLES tests. Simulations by CATHARE3 (three-field) exhibit faster quenching than CATHARE2, mainly due to the presence of the droplet field enhancing the heat exchange from the fuel rod simulators.

The performed qualitative analysis has shown the ability of CATHARE2 code to capture the main features of the reflood phenomena using appropriate modeling. Nonetheless, the quantitative analysis shows a systematic underprediction of the peak cladding temperature and faster quenching in the majority of FEBA and ACHILLES tests.



## 1. Introduction

The rewetting characteristics of the overheated core after the Loss Of Coolant Accident (LOCA) was one of the most interesting research topics in 70's and still has a significant influence on acceptance criteria in licensing and probabilistic safety analyses. Large break scenarios involve a very rapid depressurization with significant emptying of the primary system and core uncovering. When the primary system pressure falls below the injection pressure of the various Emergency Core Cooling Systems (ECCS), borated coolant enters the primary system and flows through the available paths to refill the lower-plenum and then to reflood and finally recover the core.

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The CATHARE developing strategy comprises qualification process, which is based on: Code Verification, Validation procedure on separate-effect and integral test facilities. Experimental data covering a wide range of operation parameters during reflood phase is available from FEBA and ACHILLES separate-effect test facilities and is an excellent exercise for code qualification, based on peak cladding temperature (PCT) and quench front motion predictions on the level of fuel assemblies with a typical Pressurized Water Reactor (PWR) power and fluid conditions.

In current work, different models of FEBA and ACHILLES experimental test bundle have been developed using CATHARE2 and CATHARE3. The capability of codes to represent complex phenomena during reflood at different experimental conditions has been assessed, comparison of the results with measured data has been carried out and accuracy of code predictions was quantified.

## 2. CATHARE2 and CATHARE3 codes general overview

CATHARE2 (Lavialle et al., 2012) is being developed in Grenoble by the Commissariat à l'Energie Atomique (CEA), Electricité de France (EDF), AREVA and Institut de Radioprotection et de Sûreté Nucléaire (IRSN) to perform best-estimate calculations of pressurized water reactor accidents. It is based on a two-fluid six-equation model with a unique set of constitutive laws. Several modules (e.g. volumes (0-D), pipes (1-D) or vessels (3-D)) can be assembled to represent the primary and secondary circuits of any reactor design or test facility. The code space discretization adopts the staggered mesh and the donor cell principle. The time discretization of all terms of the equations is fully implicit in 1-D and 0-D modules and semi-implicit in 3-D elements including inter-phase exchange, pressure and convection terms, and the resulting nonlinear equations are solved using classical Newton-Raphson iterative method.

CATHARE3 (Emonot et al., 2009) is an advanced system code developed by CEA within the NEPTUNE multiscale thermal-hydraulic platform (Guelfi et al., 2007). In addition to the two-fluid, 6-equation model already used in CATHARE2, a new three-field model has been implemented in CATHARE3, including a liquid droplet field, a continuous liquid field and a gas field. This advanced model has been developed in order to improve the flow simulation when liquid droplets and continuous liquid flow are at significantly different velocities. Specific closure relations are implemented in CATHARE3 to describe a droplet field: droplet entrainment flux, droplet deposition flux, interfacial friction for droplets, heat transfer between droplets and wall and heat transfer between droplets and gas field, droplet diameter correlations and flow regime transitions (Valette et al., 2011). The numerical calculation scheme used by CATHARE3 is similar to the one employed in the CATHARE2 code (Barré et al., 1993). The set of conservation equations and closure relations is discretized using a finite difference scheme with staggered spatial meshings and the donor-cell method.

## 3. Validation of CATHARE against FEBA reflooding Experiments

### 3.1. Description of FEBA test facility

The FEBA (Flooding Experiments with Blocked Array) program has been performed at KfK Karlsruhe, Germany (Kfk Karlsruhe, 1984). This Separate-Effect Test Facility (SETF) was designed for the reflooding tests with possibility of maintaining constant flooding rates and constant back pressure. The test section consists of a full-length 5 × 5 rod bundle of PWR fuel rod dimensions (Fig. 1) utilizing electrically heated rods with a cosine power profile (Nichrome 80/20 is used for the heater element and cladding, whereas magnesium oxide – for the filler and insulator) with a cosine power profile. The rod bundle is placed in housing made of stainless steel and insulated to reduce heat losses to environment.

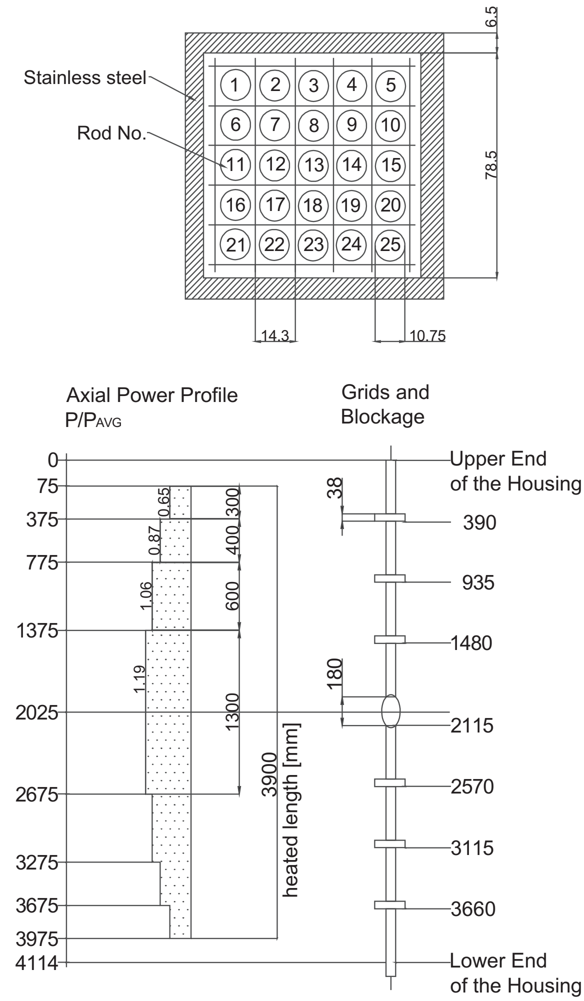


**Fig. 1.** FEBA rod bundle – cross-section view and axial power profile distribution.

### 3.2. Modeling of FEBA with CATHARE2

The FEBA test assembly has been modeled by CATHARE2 V2.5_3 mod 3.1 code by one single 1-D component representing the core bundle (heated part, 3900 mm) with only 1 heat rod element, inlet and outlet boundary conditions (Fig. 2). The 1-D component is composed of 39 vertical meshes in the core (length of 1 mesh is 0.1 m). The thick-wall housing is modeled (adiabatic wall with a thickness of 6.5 mm), whereas unheated part of FEBA rods, lower and upper plenum are not represented. The CATHARE reflood correlations (REFLCHAR) are used for both the heater rods to fluid and housing to fluid heat transfers (Lavialle et al., 2012).

Spacer grids have been taken into account during the nodalization set-up and the proper singular pressure loss coefficient $K_{loss}$ has been allocated at corresponding junctions in order to simulate the pressure loss due to flow restriction. No flow area reduction or change in hydraulic diameter has been modeled at locations of the spacer grids. The main model features are summarized in Table 1. It should be also noted that the reference model has been developed using the available description of FEBA facility and experimental measurements of test 216. However, no special tuning has been applied to get the best possible agreement with experi-

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