

A Nodalization Study of Phebus FPT-1 Experiment in MELCOR 2.2

Tomas Cerny¹ and Michal Ptacek¹

¹Department of Electrical Power Engineering, Brno University of Technology, Technicka 12, 61600 Brno, Czech Republic

E-mail: xcerny67@vut.cz, ptacekm@vut.cz

Abstract—Phebus, an integral experimental facility located in France, is scaled down version of a French 900 MWe pressurized water reactor (PWR) by a ratio of 1/5000. The goal of the facility is to study phenomena occurring during light water reactor severe accidents and validate models and computer codes used for calculation of sever accidents. The aim of this paper is to compare different modelling approaches in MELCOR 2.2 computer code and the influence on thermal hydraulic behavior and core degradation in comparison with experimental results.

Keywords—MELCOR, Phebus, FPT-1, ISP-46, nodalization, thermal-hydraulics

1. INTRODUCTION

The Phebus FPT (Fission Product Tests) programme was carried out by IRSN, a French nuclear regulatory, between 1988 and 2010. Five integral experiments were conducted to study severe accident related phenomena with focus on core degradation, release, transport and deposition of fission products. Another objective of these experiments was to assess the capability of computer models and codes to simulate accident progression. Due to the broad phenomena focus, the Phebus tests are considered as one of the most essential experiments dedicated to severe accident research [1]. In this paper, the MELCOR code was selected to model these severe accident phenomena.

Based on [2], MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactor nuclear power plants (NPPs). MELCOR was developed at Sandia National Laboratories for U.S. NRC as a second-generation plant risk assessment tool. A broad spectrum of severe accident phenomena in both boiling and pressurized water reactors is treated in MELCOR. These include thermal-hydraulic response in the reactor coolant system, reactor cavity, containment building; core heat-up, degradation and relocation; core-concrete interaction; hydrogen production, transport and combustion; fission product release and transport behaviour. MELCOR applications include estimation of severe accident source terms and their sensitivities and uncertainties in a variety of applications. Each of the above mentioned process is handled by a specific package (CVH, FL, COR, etc.). The packages communicate with each other on a specific basis. The MELCOR code is designed as highly parametric code. Most of the models in each package and their parameters can be modified by sensitivity coefficients and sensitivity study is thus easily feasible.

2. FACILITY AND EXPERIMENT DESCRIPTION

The Phebus facility, depicted in Fig. 1, is described using references [1,3]. The facility contains a driver core, which provides a fission power to a test fuel bundle, a cooling circuit and a containment vessel. The test bundle contains 20 fresh fuel rods laid on a zircaloy support plate and held in place by two zircaloy spacer grids. In the centre of the bundle, there is an absorber rod containing Ag-In-Cd. The test bundle is insulated from the driver core by zirconia shroud with inner ZrO₂ or ThO₂ layer, external ZrO₂ layer and an Inconel pressure tube with inner ZrO₂ coating. The test bundle is cooled by a mass flow of steam imposed at the core inlet. The experimental circuit made of Inconel-600 connects core exit with containment and simulates the thermal-hydraulic conditions of hot leg, steam generator and cold leg. The containment vessel collects the coolant, aerosols and gases transferred through the experimental circuit and simulates a PWR containment building.

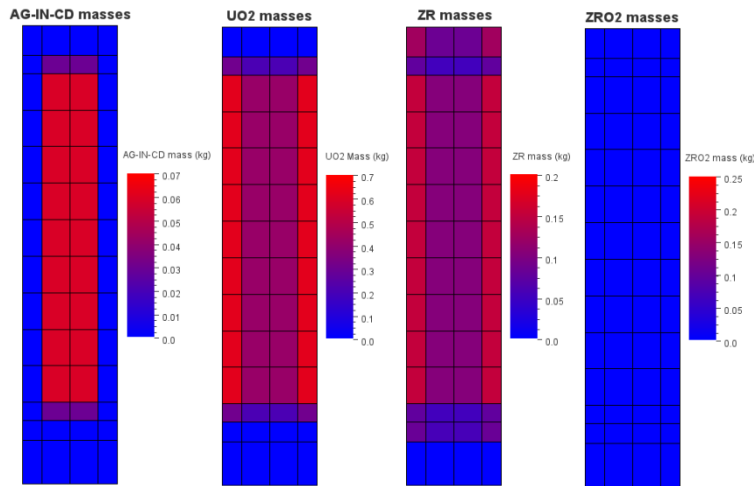


Figure 3: Medium mesh (14 axial and 2 radial levels) initial mass distribution

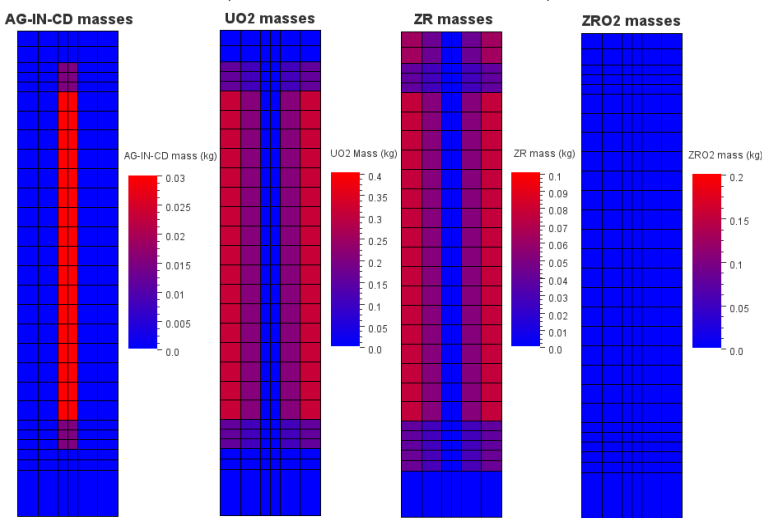


Figure 4: Fine mesh (28 axial and 3 radial levels) initial mass distribution

4. COMPARISON OF RESULTS

To evaluate the influence of medium and fine mesh MELCOR nodalization on thermal-hydraulic behavior, five parameters were selected for comparison with experimental measurements from FPT-1 test and are presented in following Fig. 5, Fig. 6 and Fig. 7 including the evaluation of the total amount of generated hydrogen, respectively. Fig. 8 and Fig. 9 display the final state of fuel bundle damage.

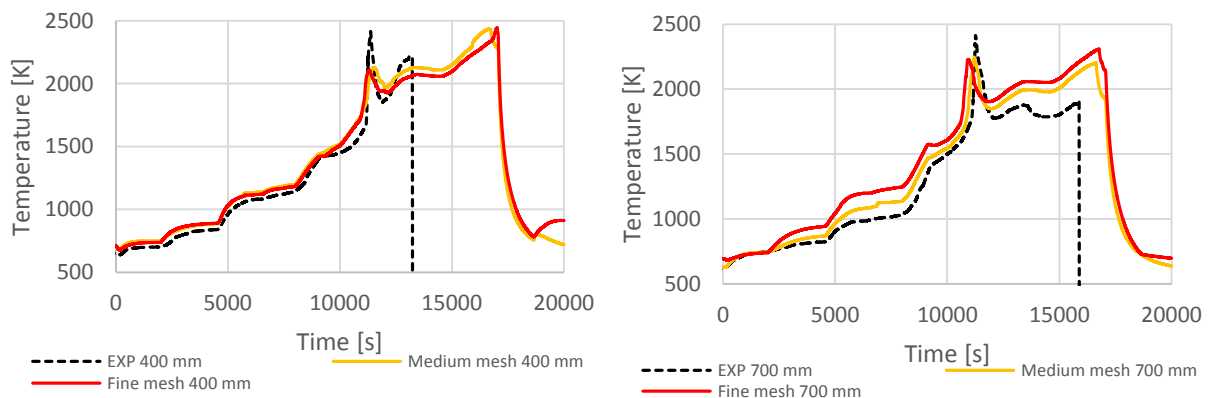


Figure 5: a) Temperature of outer fuel rods

b) Cladding temperature of outer rods

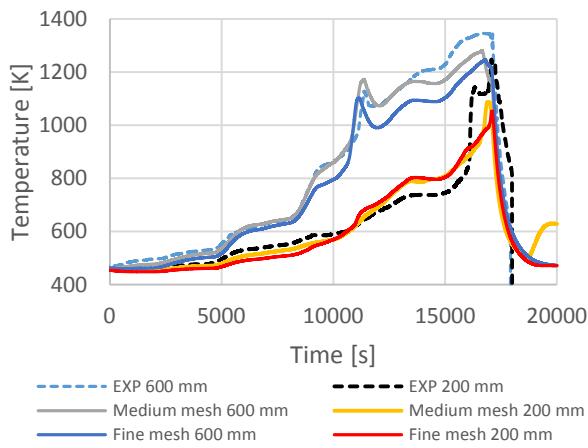
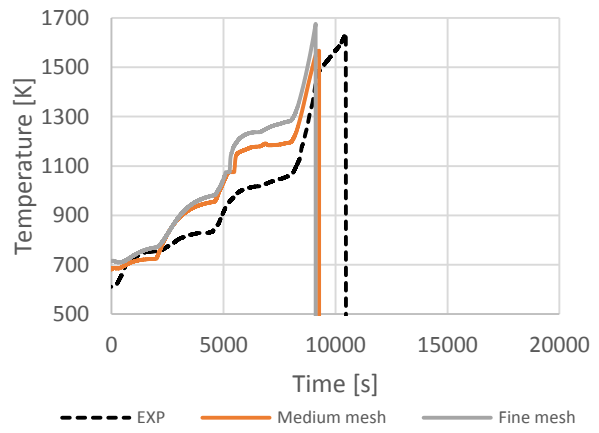


Figure 6: a) Temperatures inside core shroud



b) Temperatures of control rod at 700 mm

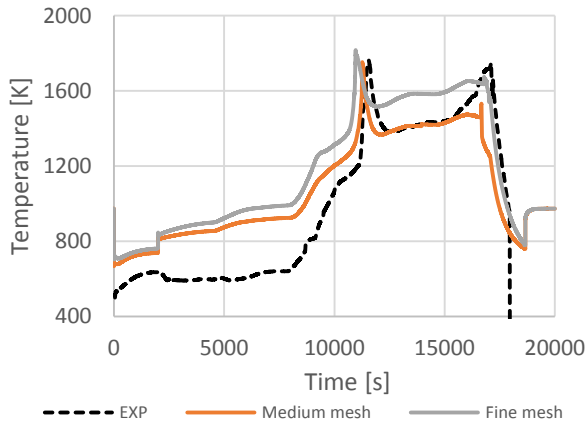
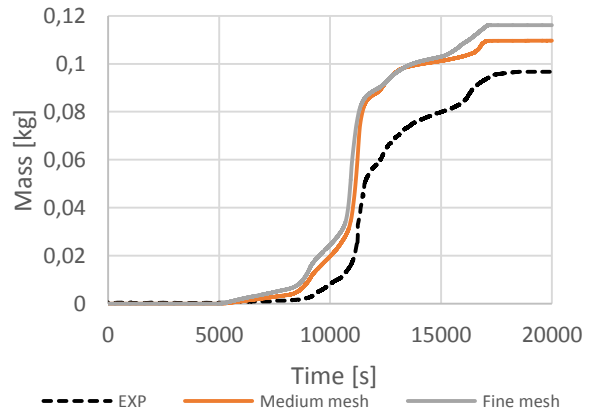


Figure 7: a) Temperature of coolant at core exit



b) Total amount of generated hydrogen

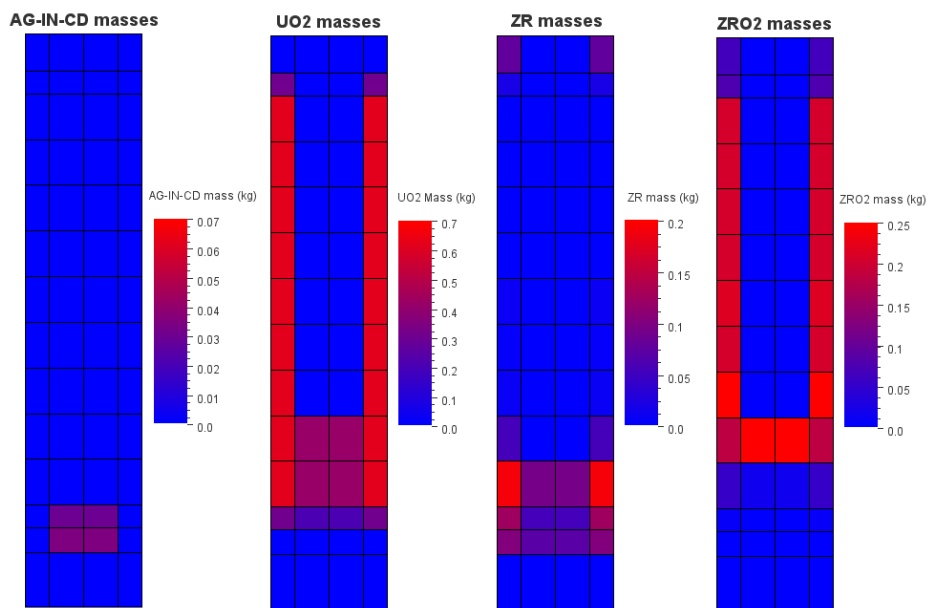


Figure 8: Medium mesh post-test mass distribution

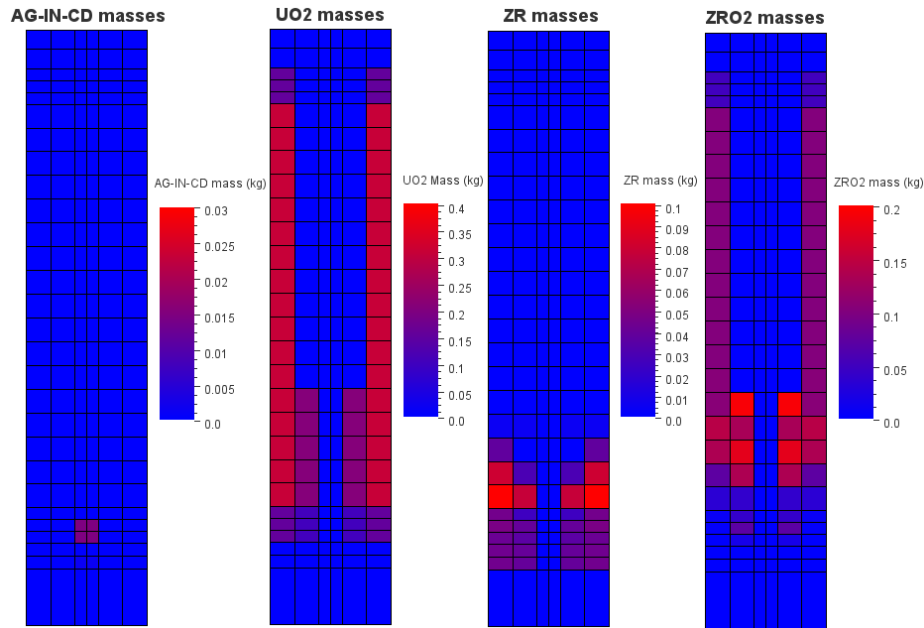


Figure 9: Fine mesh post-test mass distribution

5. CONCLUSION

In this paper, a nodalization study of Phebus FPT-1 experiment in MELCOR 2.2 code has been performed. The study evaluates two nodalization meshes of the fuel bundle, one using 2 radial rings and 14 axial levels and the second one using 3 radial rings and 28 axial levels. An attempt to calculate a nodalization using 1 radial ring and 6 axial level was not successful since the code was crashing immediately causing an unknown error, therefore this nodalization was not taken into account. The masses of the fuel bundle (see Fig. 1 description) were accordingly distributed into mesh cells and the initial mass distribution at the start of the experiment is depicted in Fig. 3 and Fig. 4.

After MELCOR calculations of both nodalizations, the selected thermal-hydraulic parameters are compared with experimental measurements (dashed black lines) in Fig. 5, Fig. 6 and Fig. 7 a). The total amount of generated hydrogen is compared in Fig. 7 b), since it is a good indicator of a cladding oxidation process. From figures it can be conducted, that both nodalizations produce over-estimated results in comparison to experiment. However, the medium mesh nodalization provides more accurate results compared to experimental values for all of the evaluated parameters. Figures 8 and 9 show the mass distribution at the end of calculation. In both cases, the inner fuel rod ring was mostly destroyed, while the outer fuel rods remained intact. MELCOR calculations also revealed that almost all of the zirconium present in cladding underwent oxidation and transformed into ZrO_2 . Similar core damage was found to be present after examination of the experimental fuel bundle using an X-ray image. The inner fuel rods were completely destroyed above the elevation of the first spacer grid located at 0,25 m from the bottom of the fuel bundle.

The MELCOR nodalization study revealed that the medium mesh provides a better overall calculation results in comparison with experiment than a fine mesh nodalization. The main advantage of the fine mesh is that it allows to model core damage more precisely. However, the code user has to bear in mind, that finer mesh strongly influences the calculation time. In case of medium mesh, the calculation took 9 minutes 32 seconds, while for fine mesh, the calculation took 28 minutes 9 seconds to complete (a 295 % increase). Since MELCOR is designed to calculate severe accidents in NPPs and the FPT-1 experiment has just one fuel bundle, the effect of nodalization on calculation time is therefore multiplied significantly for NPP calculation.

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