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Benchmark exercise on SBLOCA experiment of PWR PACTEL facility

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ABSTRACT

The PWR PACTEL benchmark exercise was organized in Lappeenranta, Finland by Lappeenranta University of Technology. The benchmark consisted of two phases, i.e. a blind and an open calculation task. Seven organizations from the Czech Republic, Germany, Italy, Sweden and Finland participated in the benchmark exercise, and four system codes were utilized in the benchmark simulation tasks. Two workshops were organized for launching and concluding the benchmark, the latter of which involved presentations of the calculation results as well as discussions on the related modeling issues.

The chosen experiment for the benchmark was a small break loss of coolant accident experiment which was performed to study the natural circulation behavior over a continuous range of primary side coolant inventories. For the blind calculation task, the detailed facility descriptions, the measured pressure and heat losses as well as the results of a short characterizing transient were provided. For the open calculation task part, the experiment results were released.

According to the simulation results, the benchmark experiment was quite challenging to model. Several improvements were found and utilized especially for the open calculation case. The issues concerned model construction, heat and pressure losses impact, interpreting measured and calculated data, non-condensable gas effect, testing several condensation and CCFL correlations, sensitivity studies, as well as break modeling. There is a clear need for user guidelines or for a collection of best practices in modeling for every code.

The benchmark offered a unique opportunity to test the best practices and solutions in modeling and analyzing tasks as well as a possibility to increase knowledge about the interpretation of test results. The benchmark exercise served as a practical and rewarding forum to discuss the needs, problems and possibilities in the analysis and in producing useful data with an experiment facility. The workshops provided an advantageous site for interaction of the code users and the experimenters.

1. Introduction

At Lappeenranta University of Technology (LUT), experimental thermal–hydraulic studies have been conducted on various safety issues of nuclear power plants (NPPs) already since 1976. Over the years, several experiment facilities have been constructed and utilized at LUT for studies on the behavior of light water reactors (Purhonen, 2007). As the new European Pressurized Reactor (EPR) type NPP is under construction in Olkiluoto in Finland, national research activities related to pressurized water reactors (PWRs) are being intensified. Hence, also the PWR PACTEL facility was introduced in order to stimulate research activities on PWR and EPR specifics (Kouhia et al., 2012; Rantakaulio et al., 2010).

The PWR PACTEL benchmark exercise was organized in Lappeenranta, Finland by LUT in 2010–2011. The exercise was launched in order to give a unique opportunity for the thermal–hydraulic

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system code users to model a new PWR PACTEL facility configuration as well as to simulate a yet unpublished facility experiment. The objective of the benchmark was to provide a framework where the participants could test the capabilities of the computer codes and modeling practices with blind and open calculation cases. The benchmark workshops were set as common sites to share views and ideas in the benchmark workshops. A benchmark type exercise on a new facility design serves as a fresh discussion forum where code users and facility operators can exchange perspectives on generating and utilizing useful experimental validation data.

This article introduces shortly the design, main characteristics and experimental program of the PWR PACTEL facility. Then, the PWR PACTEL benchmark exercise frames are presented along with the description of the experiment procedure. The blind and open calculation tasks are discussed and few examples of the open calculation results are presented. Finally, the focus in the article is pointed to more general aspects in modeling practices and approaches considered within the benchmark tasks; i.e. problems found and solutions tested as well as issues dealing with the interaction between the experiment and calculations.

2. PWR PACTEL facility

The PWR PACTEL test facility is designed and constructed to be utilized in the safety studies, especially related to the thermal–hydraulics of PWRs with EPR type vertical steam generators (Kouhia et al., 2012; Rantakaulio et al., 2010). PWR PACTEL consists of a reactor pressure vessel model, two loops with vertical steam generators, a pressurizer and emergency core cooling systems (ECCSs), see Fig. 1. A significant design and construction basis of the facility is the utilization of some parts of the original PACTEL facility (Purhonen et al., 2006; Tuunanen et al., 1998), i.e. the pressure vessel model, pressurizer and ECCS. Hence, the facility core parts are not direct models of the reference EPR core. The new loops and steam generators of EPR style construction enable the PWR and EPR related experimental research. Table 1 lists some of the main characteristics of the facility. Detailed description of the facility can be found in the report of Riikonen et al. (2009).

The pressure vessel model in PWR PACTEL comprises a U-tube construction modeling the downcomer, lower plenum, core and upper plenum. The core rod bundle consists of 144 electrically heated fuel rod simulators arranged in three parallel channels. The core can be powered by a maximum of 1 MW electric power supply. The ECCS of PWR PACTEL includes high and low pressure pumps and two separate accumulators for the injection of water to the system.

The main focus with the PWR PACTEL design is set on the new construction of the primary loops and steam generators. The set-up is designed to allow the simulation of the main PWR and EPR features and the studying of loop and steam generator behavior in particular. Both primary loops simulate one reference EPR loop. The heat transfer area of the steam generator U-tube bundles and the primary side volume of each steam generator are scaled down with a ratio of 1/400 compared to the reference steam generator. The inner diameter of the steam generator U-tubes in PWR PACTEL is the same as in the EPR steam generator. The secondary sides of the steam generators include a downcomer, a riser and steam dome volumes as well as feed water injection systems. The riser and downcomer parts are also divided into hot and cold sides. There are altogether about 250 temperature, pressure and differential pressure measurement transducers especially attached to allow deeper analysis of the steam generators. A view of the steam generator model is presented in Fig. 2 and some characteristics can be found in Table 1.

The first set of PWR PACTEL experiments during the first operational years included system and characterizing tests to obtain the representative characteristics data of the facility. With these tests pressure and heat losses (Riikonen, 2009) as well as natural circulation and steam generator secondary side behavior (Riikonen, 2010) were studied. The natural circulation experiments included step-wise inventory reduction and small break loss of coolant (SBLOCA) tests of which the latter was chosen to be the subject for the PWR PACTEL benchmark exercise. More recently the PWR PACTEL experiments have focused on additional low pressure studies, investigation of reversed flow in vertical steam generator U-tubes and loop seal clearing behavior (Riikonen and Kouhia, 2011c; Riikonen et al., 2011). Some experiment data has been generated particularly for CFD code model development purposes (Pättikangas et al., 2011). Some PWR PACTEL experiments are set to be performed under the OECD-NEA PKL Phase 3 project (OECD/NEA, 2013).

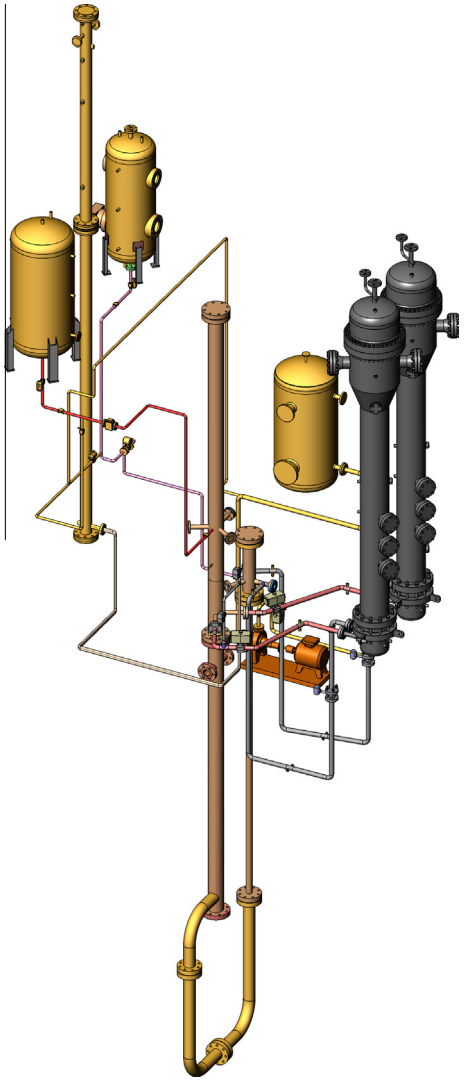

Fig. 1. PWR PACTEL facility.

3. Benchmark exercise

3.1. Introduction

The PWR PACTEL benchmark exercise was launched in October 2010 in the first workshop at LUT, in Lappeenranta, Finland. The benchmark process consisted of a blind and an open calculation phase. The simulation task was to model the PWR PACTEL facility