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Review

Investigation of molten core–concrete interaction reactor benchmark test for VVER 1000

A. Stefanova [a,*], R. Gencheva [a], P. Groudev [a], M. Cranga [b], C. Spengler [c], I. Ivanov [d], J. Foit [e], P. Kostka [f]

[a] Institute for Nuclear Research and Nuclear Energy (INRNE), Tzarigradsko shaussee 72, 1784 Sofia, Bulgaria
[b] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), CE de Cadarache BP 3, 13115 St-Paul-Lez-Durance Cedex, France
[c] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Schwertnergasse 1, 50667 Cologne, Germany
[d] Technical University of Sofia (TUS), Kliment Ohridski 8, 1000 Sofia, Bulgaria
[e] Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany
[f] Nukleáris Biztonsági Kutatóintézet (NUBIKI), Konkoly-Thege Miklós út 29-33, 1121 Budapest, Hungary

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ABSTRACT

This paper presents the results from molten core–concrete interaction (MCCI) reactor benchmark test cases, performed in the frame of European Severe Accident Research Network of Excellence (SARNET2). VVER-1000 nuclear power plant at Kozloduy site was chosen as a reference for the benchmark test-cases. The initial conditions for MCCI calculations were taken from a Station Blackout (SBO) scenario calculated with severe accident computer code ASTEC version 1.3R2 by INRNE.

Six participants from different countries (INRNE, Bulgaria; TUS, Bulgaria; GRS, Germany; KIT, Germany; IRSN, France; NUBIKI, Hungary) were involved in this project. Two different computer codes were used to perform two independent calculations: ASTEC and WECHSL, each one representing the main phenomena arising during the interaction between the corium and the reactor pit concrete in dry conditions and in case of corium reflooding.

The purpose of the analysis is to compare results obtained by the different computer codes in the reactor test cases as well as to compare modeling and the best-estimate assumptions in the models used in the available MCCI codes. The other purpose is to synthesize conclusions on the major uncertainties in the models used in these codes.

Contents

1. Introduction

This benchmark work was done in view of enriching the scientific knowledge concerning molten core–concrete interactions, which could happen in the hypothetical case of a severe accident at the nuclear reactors. In case of a postulated severe accident the reactor core could be overheated and a molten pool called

Abbreviations: ASTEC, Severe accident computer code; GEMINI2, Code for physico-chemistry calculation; MCCI, Molten core–concrete interaction; MEDICIS, Molten core–concrete interaction computer code; NUCLEA 09, Thermo-dynamic database; SARNET2, Severe accident research European network of excellence – 2; SBO, Station Blackout; VVER 1000, Water–water energy reactor; WECHSL, Molten core–concrete interaction computer code.

* Corresponding author. Tel.: +359 29795583; fax: +359 29753619.
E-mail address: antoanet@inrne.bas.bg (A. Stefanova).

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corium could be generated at the bottom of the reactor vessel. This molten pool will consist mainly of uranium oxides, zirconium oxides, steel oxides and fission products. If the reactor vessel failure occurs this corium will enter the containment basemat and will start to interact with the reactor pit concrete. That is why it is very important to study the process of concrete ablation in real nuclear power plants because the concrete is the last barrier, which preserves FP release to the environment.

This benchmark has been organized in the frame of European Severe Accident Research Network of Excellence (SARNET2) work programme to discuss notable issues concerning MCCI test cases for real VVER1000 reactor type with and without water injection. The VVER-1000 at Kozloduy NPP was chosen for the SARNET2 benchmark MCCI test-cases.

Beforehand a SBO scenario calculation for VVER1000 (Kozloduy NPP design) with ASTECv1.3 (Allelein et al., 2003; Allelein et al., 2005) has been done to determine the initial conditions for the MCCI benchmark test cases. Based on this calculation a "Benchmark Definition report of reactor test-cases" (Stefanova et al., 2010) has been prepared to specify the obligatory parameters for the benchmark comparison. The definition report also summarizes the VVER1000 geometry of the reactor core, cavity and concrete basemat. It was decided to perform the MCCI test calculations with and without water injection to evaluate clearly the possible impact of corium quenching on ablation kinetics.

Different codes like MEDICIS/ASTECv2 (Cranga et al., 2005; Cranga et al., 2008; Duval et al., 2008) and WECHSL (Foit et al., 1995) have been used to describe the main phenomena during the interaction between real concrete material from the reactor pit and the corium. Many scientific organizations have been involved to recalculate and explain pool/concrete interface behavior.

2. Input data for reactor test cases

The geometry of the initial concrete cavity is cylindrical with a height of 2.35 m, radius of 2.906 m, and basemat axial thickness of 3.6 m. It means that the real cavity floor area of cylindrical part has to be 26.53 m^2. The cavity flow area in the calculations is assumed to be 31.47 m^2 because it is included to this area of cylindrical pit and a corridor to the isolating steel door. In this way the radius assumed in the calculations is 3.16 m. The radial thickness of the cavity is assumed to be 6 m in all the calculations due to the main interest being focused on the downward basemat melt-through, which leads to fission products release to the environment.

The concrete composition and other features are presented in Table 1 and Table 2 (Stefanova et al., 2010).

As seen in Table 1 the type of concrete is siliceous with a rather low content of H_2O (chemically bounded and free water is 4.8%) and CO_2 (6.8%). The iron fraction in the VVER1000 reactor pit concrete (16.2%) is considerably higher compared with PWR reactor types (around 6.15%).

Table 1
Concrete composition.

Concrete composition	Content (%)
H_2O (chemically bound)	1.775
CO_2	6.761
SiO_2	47.36
Fe_2O_3	2.01
Al_2O_3	1.755
CaO	20.03
MgO	1.135
Fe	16.17
H_2O (free water)	3.0

Table 2
Concrete features.

Density, kg/m^3	2600.0
Solidus temperature (K)	1420.0
Liquidus temperature (K)	1820.0
Radiation emissivity	0.8
Ablation temperature (K)	1570.0
Ablation enthalpy, J/kg	$1.815 * 10^6$

Table 3
Initial mass of oxides and metals in kilograms.

Oxides and metals in corium						
UO_2	ZrO_2	FeO	Zr	Fe	Cr	Ni
74,294	1700	11.2	12,143	30,000	4520	2620

During the preliminary SBO calculation with ASTECv1.3 the total mass of 125 288 kg corium slump transferred to the cavity is observed at 21,897 s (6.08 h). It is accepted that corium consists of oxide and metal phase. The initial corium inventory and composition for MCCI VVER1000 test cases are presented in Table 3.

The initial temperature of the ejected corium in MCCI VVER 1000 test cases is evaluated as 2879 K. After a discussion it was decided that more accurate initial temperatures for both the oxide and the metal layers would be 2673 K. Some of the participants in the benchmark have used the higher value. In spite of the different initial temperature chosen by the participants the impact on the long term behavior is small. It only results in a small delay in melt-through times due to the different initial energies stored in the oxide and metal which are consumed in the first transient phase. After this short phase the processes are ruled by the decay heat.

The other assumption is that the decay heat power is generated at 100% from the oxide phase in all MEDICIS calculations except the GRS where it is assumed 10% of the decay power to be released in the metal layer. The decay power evolution after MCCI onset is presented in Table 4.

The pressure in the containment and respectively in the cavity during the MCCI is assumed to be constant: 1.5 bar. The calculations stop when the axial basemat with thickness 3.6 m fails and fission products release in the environment appears.

3. Main modeling assumptions

Model assumptions are similar to those used in MEDICIS calculations for the other SARNET reactor benchmarks (Cranga, 2010; Spindler, 2008). In all MEDICIS calculations excluding GRS calculation BALI correlations were used to calculate heat transfer

Table 4
Decay heat power evolution.

Decay heat power after vessel failure	
Time, s	Power, W
0 E+04	2.70E+07
0.7 E+04	2.25E+07
1.5 E+04	2.10E+07
6.48 E+04	1.50E+07
1.514 E+05	1.17E+07
3.244 E+05	1.05E+07
4.964 E+05	7.50E+06
6.649 E+05	6.60E+06
8.424 E+05	5.40E+05