Current Status of the OECD-SERENA Project for the Resolution of Ex-vessel Steam Explosion Risks

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1. Introduction

The OECD/NEA SERENA project, which has been in progress since 1st Oct. 2007, is aimed at the resolution of the uncertainties on the void fraction and the melt composition effect by performing a limited number of well-designed tests with advanced instrumentation. This will clarify the nature of a prototypic material with mild steam explosion characteristics and provide innovative experimental data for FCI computer code validation. KAERI has been participating in the SERENA project with CEA as one of the operating agents. This paper focuses on the current status of the SERENA project.

2. OECD/NEA SERENA Project

2.1. Background of SERENA project

From OECD/NEA SERENA Phase 1, which was completed in 2005, the experts reached a consensus on major FCI phenomena where uncertainties impact on the predictability of a dynamic loading for reactor structures. The main conclusion of phase 1 is that, in the absence of pre-existing loads, an in-vessel steam explosion would not challenge the integrity of the vessel, and some damage to the cavity is to be expected for an ex-vessel explosion because the level of the loads cannot be predicted due to a large scattering of the results (Fig. 1). One major uncertainty that does not allow for a convergence towards consistent predictions is that there is no data on the component distribution in a pre-mixture at the time of the explosion, especially the level of a void. The other major uncertainty is the explosion behavior of corium melts.

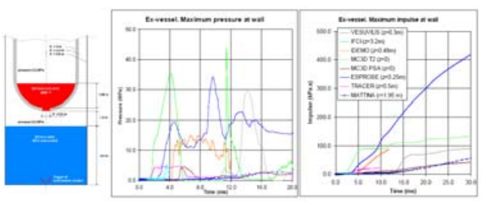

Fig. 1 Loads to Standard Ex-Vessel Conditions

SERENA phase 2 is to carry out the confirmatory research required to reduce the uncertainties on FCI phenomena to an acceptable level for risk assessment.

2.2 Safety significance of ex-vessel SE

The flooding of a reactor cavity is considered as SAM measures for new PWRs like APR-1400 and AP1000 to assure the IVR of a core melt. Flooding of a reactor cavity is not considered for existing PWRs as a SAM strategy. However, the presence of water in the reactor cavity, caused by the use of a spray and/or by a primary circuit rupture, cannot be excluded. Consequently, there is a need to establish containment safety margins to an ex-vessel explosion.

2.3 Objective of Phase 2

Objective of Phase 2 is to reduce the scattering of the predictions in order to be able to put safety margins to a containment failure (1) by providing the missing data on the key phenomena for a code validation from the spatial distribution of a fuel and void during a premixing and at the time of an explosion in various conditions, and the explosion behavior of a large spectrum of corium melts representative of accident scenarios; (2) by improving the modeling on the basis of the new data so that consistent predictions of a cavity loading by an ex-vessel steam explosion are obtained.

2.4 Experimental work program of Phase 2

The complementary and innovative features of KROTOS (CEA) and TROI (KAERI) facilities have been used. KROTOS is to investigate the FCI characteristics of prototypical corium melts in a one-dimensional geometry and is suitable for a computer code model improvement. TROI is to investigate the FCI behaviour in reactor-like conditions by greater mass and multi-dimensional melt water interaction geometry and is more suitable for validating the capability of the computer codes in reactor-like situations. Fig. 2 shows the KROTOS and TROI test facilities.

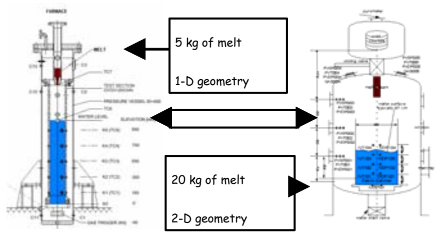

Fig. 2 KROTOS and TROI test facilities

2.4.1 Choice of test conditions

The configurations and the melt compositions selected are such that they reflect the most relevant accident scenarios for an ex-vessel FCI of four different melt compositions, pressure and subcooled water. A series of twelve complementary tests is proposed (6 in KROTOS and 6 in TROI).

Table 1. Phase 2 test matrix

		KROTOS	TROI
1	Challenging conditions	High melt superheat High system pressure (0.4 MPa, Room water temp.)	High system pressure (0.4 MPa) Reduced free fall (Melt jet velocity) and thick melt jet (Room water T.)
		Mat 1: 70%UO_2-30%ZrO_2	
2	Geometry effect Effect of geometry by comparison between KROTOS and TROI	Standard conditions: jet of diameter 3 cm	Large jet at penetration (5 cm)
		Mat 1: 70%UO_2-30%ZrO_2	
3	Reproducibility tests	Idem Test 2	Idem Test 2
4	Material effect Oxidic composition	Standard conditions	Large jet at penetration (5 cm)
		Mat 2: 80%UO_2-20%ZrO_2	
5	Material effect Oxidation/composition	Standard conditions	Large jet at penetration (5 cm)
		Mat 3: 70%UO_2-30%ZrO_2 +steel +Zr	
6		Standard conditions	Large jet at penetration (5 cm)
		Not finally decided	

2.4.2 Test results

KAERI has performed 4 tests from the first to the 4th test. In the four tests, triggering steam explosions were observed, but, the explosion load was much less than it was by ZrO2 and Al2O3. The test results also show similar results to the previous TROI test results. The conversion ratio is less than 0.4% in maximum. The volume average void fraction for three spans, which is the most important factor to induce uncertainty for code validation, has been provided. In addition, KAERI also performed the visualization test to have very important information by request of the members of the SERENA project. From the visualization test, KAERI have provided melt jet behavior, mixing zone size and the void fraction and melt bottom contact time which are have not been provided until now, as shown in Fig.3. This is the first test which has provided useful information for code validation. CEA have provided the information for the image of mixture using X-ray. This kind work is the first attempted work for code validation.

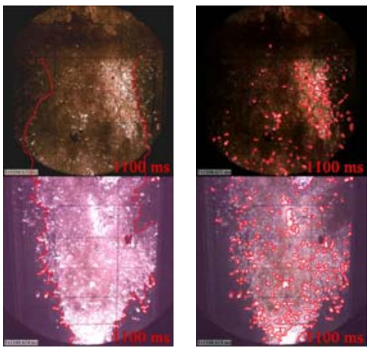

Fig. 3 Mixing zone and particle distribution

2.5 Analytical work

An analytical working group (AWG) has been established to increase the capabilities of the FCI models/codes for use in reactor analyses by complementing the work performed in Phase-1. The work is oriented to fitting for the purpose, and for a safety analysis and elaboration of the major effects which reduce the explosion strength. The main tasks of the group are ; (1) Performing pre-, post-test calculations in support of a test specification and analysis, (2) Improving the common understanding of those key phenomena that are believed to have a major influence on an FCI process, (3) Addressing the scaling effect and application to a reactor case, (4) Demonstrating the progress made in SERENA Phase-2 as compared to Phase-1 by repeating the “ex-vessel reactor exercise”. The four topics of jet break-up, melt mass and void in the mixture, solidification of the melt during premixing and explosion are very important to code validation. The leaders for the four topics have been designated and are writing outcome reports. The typical conditions of BWR and PWR for FCI analysis have simultaneously been defined and the preliminary calculation has been performed. At the moment, several limitations for the application of the FCI codes to the reactor conditions have been found and these limitations will finally be reflected in the FCI codes.

3. Conclusions and Recommendations

SERENA-2 is designed (1) to remove uncertainties on a void distribution by providing detailed data of an internal structure of a pre-mixing and (2) to confirm a low explosivity of corium by using a large spectrum of corium melts and conditions in the KROTOS and TROI facilities and 3) to bring the scattering of the predictions for an ex-vessel steam explosion to within acceptable limits for the risk evaluation of a containment failure by improving the modeling and code performance on the basis of the new data. SERENA-2 should allow us to resolve the FCI issue from the perspective of the risk assessment of a containment failure due to an ex-vessel steam explosion.

ACKNOWLEGEMENTS

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