OECD/NEA SERENA Project for a Resolution of Ex-vessel Steam Explosion Risks

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has conducted the TROI (Test for Real cOrium Interaction with water) program for a study on a fuel-coolant interaction (FCI) since 2001. More than 50 experiments using several prototypic materials have been carried out so far. SERENA phase 2 project which has been conducting since 1st Oct. 2007 is aimed a 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 instrumentations to clarify the nature of a prototypic material with mild steam explosion characteristics and to provide innovative experimental data for a computer code validation.

2. 2. OECD/NEA SERENA Project

2.1. Scope of SERENA project

From SERENA Phase 1 which was completed in 2005, the experts reached a consensus on major FCI phenomena where uncertainties impact the predictability of a dynamic loading for reactor structures. 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 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. Only a global void fraction is available from level-swell measurements. The other major uncertainty is the explosion behaviour of corium melts. What is the very reason why corium melts exhibit low energeticis.

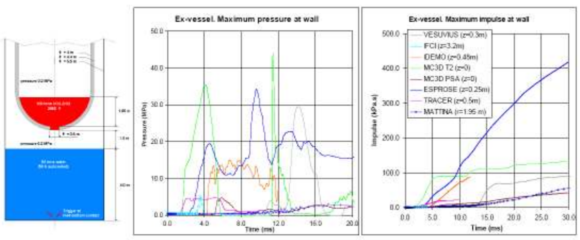

Fig. 1 Loads to Standard Ex-Vessel Conditions

SERENA phase 2 is carrying out confirmatory research required to reduce the uncertainties on these phenomena to an acceptable level for risk assessment. This is the first joint exercise on a steam explosion applied to a reactor case.

2.2 Safety significance of ex-vessel SE

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 be able 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 a 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 will be used. KROTOS is to investigate the FCI characteristics of prototypical corium melts in a one-dimensional geometry. It 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. It is more suitable for validating the capability of the computer codes in reactor-like situations

2.4.1. Test facilities

Fig. 2 shows the KROTOS and TROI test facilities. The strength of using both KROTOS and TROI is to check on the key effects in experiments with an increasing complexity and to check on whether a consistent interpretation of both KROTOS and TROI with identical modelling approaches is possible Once this is achieved, it means that codes validated by KROTOS will capable of calculating more reactor-oriented situations in TROI. Two test results will strengthen confidence in the code applicability for reactor FCI scenarios

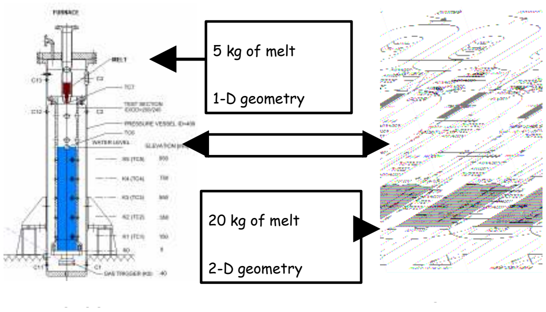

Fig. 2 KROTOS and TROI test facilities

2.4.2 Choice of test conditions

The configurations and melt compositions are tentatively selected such that they reflect most relevant accident scenarios for an ex-vessel FCI of four different melt compositions, pressure(0.5MPa) and subcooled water (~50 K). A series of twelve complementary tests is proposed (6 in KROTOS and 6 in TROI). The first test will be performed in realistic conditions that are expected to exacerbate an FCI. The other tests will investigate the geometry and material effects. Table 1 shows the phase 2 tentative test matrix.

Table 1. Phase 2 tentative test matrix.

		KROTOS	TROI
1	**Challenging conditions (to be finalised through discussion with the partners)**	Standard geometrical conditions High melt superheat High system pressure (0.5 MPa)	High system pressure (0.5 MPa) Reduced free fall (Melt jet velocity) and thick melt jet
		Mat: to be decided	
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	**Material effect** Oxidic composition	Standard conditions	Large jet at penetration (5 cm)
		Mat 2: 80%UO_2-20%ZrO_2	
4	**Material effect** Oxidation/composition	Standard conditions	Large jet at penetration (5 cm)
		Mat 3: 70%UO_2-30%ZrO_2 +steel +Zr	
5	**Material effect** Large solidus/liquidus ΔT	Standard conditions. Effect of fission product: higher melt superheat	Large jet at penetration (5 cm). Failure at the bottom, considering layer inversion.
		Mat 4: 70%UO_2-30%ZrO_2 +FP+iron oxide+absorber materials	
6	**Reproducibility tests**	Idem Test 3 or 4	Idem Test 3 or 4

2.5 Analytical work programme in Phase 2

An analytical working group (AWG) is established. The main aim is increasing 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 a purpose, and for a safety analysis and elaboration of the major effects which reduce the explosion strength. The group will include the proposing organisations (CEA, IRSN, KAERI and KINS) and those partners in the experimental programme with calculating capabilities.

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 with Phase-1 (in particular for reducing the scattering of the predictions) by repeating the “ex-vessel reactor exercise”.

2.6 Innovative features of KROTOS and TROI

Melt release conditions have improved in both KROTOS and TROI. Advanced measurement techniques for determining a component distribution in a pre-mixing will be applied with high energy X-rays in KROTOS and electrical tomography in TROI. The electrical tomography technology which will be applied to TROI is developing at Han-Dong University. Physical and chemical analysis of debris to identify the “material effect” is improved by investigating the physico-chemical behaviour of the materials.

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 ex-vessel steam explosion to acceptable limits for a risk evaluation of a containment failure by improving a 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 a risk assessment of a containment failure due to an ex-vessel steam explosion.

ACKNOWLEGEMENTS

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REFERENCES

[1] OECD/NEA, Agreement on the OECD/NEA SERENA Project; to address remaining issues on fuel-coolant interaction mechanisms and their effect on Ex-vessel steam explosion energetics, 2008.12.