

Thesis Abstract

This thesis has been performed under co-tutelle supervision between Charles University in Prague (Czech Republic) and Strasbourg University (France). It also profited from the background and cooperation of Institute of Inorganic Chemistry Academy of Science of the Czech Republic and French Commission for Atomic and Alternative energies (CEA Cadarache, France). Results of the work contribute to the OECD/NEA project Serena 2 (Program on Steam Explosion Resolution for Nuclear Applications).

Presented thesis can be classed in the scientific field of nuclear safety and material science. It is aimed on the so-called “molten nuclear Fuel – Coolant Interaction” (FCI) that belongs among the recent issues of the nuclear reactor severe accident R&D. During the nuclear reactor melt down accident the melted reactor load can interact with the coolant (light water). This interaction can be located inside the vessel or outside in the case of vessel break-up. These two scenarios are commonly called in- and ex-vessel FCI and they differ in the conditions such as initial pressure of the system, water sub-cooling etc. The Molten fuel – coolant interaction can progress into thermal detonation called also “steam explosion” that can challenge the reactor or containment integrity.

Recent experiments have shown that the melt composition has a major effect on the occurrence and yield of such explosion. In particular, different behaviors have been observed between simulant material (alumina), which has important explosion efficiency, and some prototypic corium compositions (80 w. % UO₂, 20% w. % ZrO₂). This “material effect” has launched a new interest in the post-test analyses of FCI debris in order to estimate the processes occurring during these extremely rapid phenomena.

The thesis is organized in nine chapters.

The chapter 1 gives the general introduction and context of the nuclear reactor severe accident. Major nuclear accidents (Three Miles Island 1979, Chernobyl 1986 and Fukushima 2011) are briefly described.

The chapter 2 summarizes the theoretical aspects of the fuel – coolant interaction. It is divided in four thematic fields according to the FCI progression in four stages:

- i) Premixing – hot melt is poured in water and fragmented in coarse droplets surrounded by steam film
- ii) Triggering – steam film around melt droplets is destabilized allowing fine fragmentation
- iii) Propagation – the fine fragmentation propagate through the premixture increasing the melt – water interface area, which leads to large steam production
- iv) Expansion (explosion) – Thermal energy transferred from the melt to water is changed into mechanical work of the steam

The chapter 3 summarizes the research conducted in recent experimental facilities using non-radioactive simulant or radioactive prototypic materials

The chapter 4 shows the results of thermodynamic calculations, by which the possible chemical reactions between melts and water/steam at high temperatures were modeled. Second part presents the results of 1D calculations of radiation heat transfer from FCI materials to water/steam.

The chapter 5 describes the material analyses of non-radioactive simulant debris coming from MISTEE (KTH, Sweden) and PREMIX, ECO (FZK, Germany) experimental research programs.

The chapters 6 to 8 describe the material analyses of radioactive prototypic debris coming from KROTOS research program (CEA, France). The KROTOS KS2 test used melt composition: 1) 70 w. % UO_2 and 30 w. % ZrO_2 ; 2) 80 w. % UO_2 and 20 w. % ZrO_2 ; 3) sub-oxidized melt 80.1 w. % UO_2 , 11.4 w. % ZrO_2 and 8.5 w. % metallic Zr.

The chapter 9 concludes the work and presents future perspectives.