Review of doctoral thesis

"Material effect in the nuclear Fuel-Coolant Interaction: Structural characterization of the steam explosion debris and solidification mechanism"

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The submitted doctoral thesis of Mr. Vaclav Tyrpekl deals with very important subject, namely with interaction of molten nuclear fuel material, corium, with water coolant (FCI interaction). It is well known, that this interaction can cause steam explosion and consequently severe accidents of nuclear power plants. Thesis focuses on material part of this interaction, i.e. on effects of materials taking part in it, thermodynamic calculations of chemical equilibrium at it , energy exchange between fuel and coolant. However, the main part of thesis deals with morphology of debris produced in this interaction. It presents shapes, dimensions, porosity, composition of fractions formed during fuel-coolant interaction and presents quantitative criteria for determination of part of produced debris originated from steam explosion.

Thesis is divided into nine chapters. First chapter gives general context of the thesis subject by reporting on several accidents of nuclear power plants over the world including those in Chernobyl, Fukushima-Daiichi, and Three Mile Island. This part also presents four stages of fuel-coolant interaction. They are, premixing, triggering, propagation and expansion (explosion). General objectives of thesis are presented at the end of this chapter, namely understanding to material effects in FCI and proposal of mechanisms describing behaviour of different materials in different stages of FCI.

Second chapter summarizes state of art of fuel-coolant interaction for each of the above mentioned four steps. It shows close similarity of this interaction with processes in volcanology related to lava-water interaction.

Third chapter thesis describes and discusses some research results obtained in several research facilities, particularly in FARO facility (Italy), Troi facility (South Korea), Krotos facility (Cardache, France), MISTEE facility (Sweeden). PREMIX and ECO facilities (Germany). On the basis of these results material aspects of FCI interaction are specified.

Fourth chapter deals with calculations of chemical equilibrium at systems containing water and Al_2O_3, ZrO_2, UO_2-ZrO_2 or Fe at high temperatures. A model describing radiation

heat transfer between selected and water steam is presented in this chapter. Results of modelling effects of emissivity values on steam generation at three temperatures by the MC3D computer code are presented at the end of this chapter.

In fifth chapter results of analysis of debris samples obtained from MISTEE, PREMIX and ECO experiments are presented. On these samples methodology of debris analysis used in thesis is described. This methodology includes SEM/EDS micrographs, IR absorption spectra, thermogravimetric measurements, X-ray diffraction, image analysis applied to SEM micrographs.

Next three chapters deals with description and results of four tests KS2-KS5 performed in the framework of this thesis on KROTOS facility. In each chapter the steam explosion efficiency is calculated, debris size distribution, SEM/EDS micrographs, chemical composition and results of image analysis, X-ray diffraction and ICP/MS measurements (Auger measurements for KS4 debris), amount of hydrogen produced and oxygen-over stoichiometry. In chapter sixth two criteria are proposed for classification of debris part produced at steam explosion. These criteria employ the circularity and solidity of debris pieces obtained from image analysis of SEM debris micrographs .

The last chapter summarizes thesis results from the point of view of phenomenological aspects, chemical aspects, and physical aspects of FCI.

Generally, I can say that thesis presents an remarkable set of experimental results which are used for describing and discussion material-water interaction at high temperatures. Especially, I appreciate the employment of image analysis for characterisation of debris fractions on the basis of SEM miccrographs. The proposal and development of criteria making possible to distinguish part of debris being produced by steam explosion I consider to be very valuable. I can state that the thesis have been fulfilled. Thesis shows all attributes and steps of scientific work, i.e. the identification of a new research subject, choice of suitable approaches and tools for doing the research, explanation and interpretation of obtained results and drawing conclusions.

I have the following questions to thesis:

1. Can be results of thermodynamic calculations used for explanation of experimentl results from KS2-KS5 experiments?
2. What values of the circularity and solidity can be proposed for characterisation of debris produced in steam explosion on the basis of KS2-KS5 experiments?

3. How can be local extremes in the size distributions explained (e.g. KS2 test) and what repeatability of such extremes can be expected?

4. Is there any effect of debris piece position on results of its image analysis?

In conclusion, I have the pleasure to propose to the Defence Jury at the University of , Strasbourg to accept thesis of Mr. Vaclav Tyrpekl as a basis for obtaining the degree "Docteur".

Prague, June 11, 2012

Dr. Vlastimil Matejec