Reactor Vessel failures, vapour Explosions and Spent fuel Pool Accidents (VESPA)

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Introduction

This project brings together three different fields of nuclear safety research: structural integrity, steam explosions and spent fuel pool (SFP) accidents. In order to analyse containment loadings that are determined by discharging core melt, the timing and the place of reactor vessel rupture have to be defined accurately. If the core melt is discharged to a water pool a risk of steam explosion to occur is induced. The accident at the Fukushima Dai-ichi nuclear power plant has highlighted the vulnerability of nuclear fuels that are in SFPs. The related phenomena differ from reactor applications.

Benchmarking Abaqus against PASULA

The first objective of the project was to investigate the applicability of a commercial code Abaqus for modelling reactor pressure vessel lower head deformations at high temperatures. This is done by comparing the simulation results with suitable experimental data as well as with results obtained with the specific code PASULA developed at VTT.

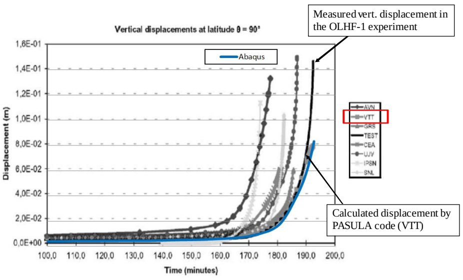
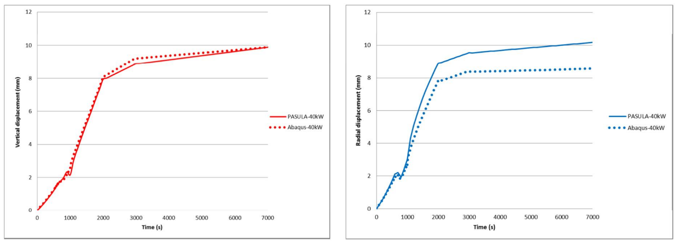


Figure 1. *Estimated vertical displacement at the bottom of the vessel by the Sandia OLHF-1 experiment benchmark participants and the result obtained with Abaqus.*



a) b)

Figure 2. *(a) Vertical and (b) radial displacement obtained by Abaqus 3D section model from the bottom of the vessel at* θ *= 18° and comparison to PASULA results in simulating the FOREVER-C2 experiment.*

Analysing steam explosions with MC3D

The second objective of the project was to become acquainted with phenomena related to steam explosions and to learn to use MC3D code developed by French IRSN and CEA.

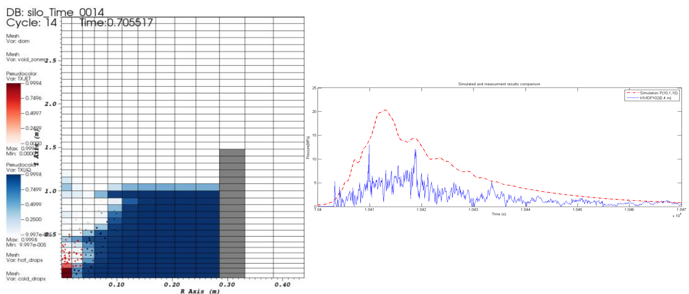


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Figure 3. *(a) Premixing conditions just before the triggering and (b) pressure on the test vessel wall according to the MC3D simulation and as measured in the TROI-TS4 experiment.*

Table 1. *The effect of premixing parameters on explosion probability and strength.*

Property		Explosion probability	Explosion strength
Amount of melt	↑	↑	↑
Melt temperature	↑	↑	↑
Melt density	↓	↑	↑
Hydrogen production	↑	↑	↓
Void fraction	↑	↑	↓
Ambient pressure (< 0.8 MPa)	↑	↑	↑
Ambient pressure (> 0.8 MPa)	↑	↓	↑
Coolant temperature	↓	↓	↑

Developing PANAMA computing model

The third objective of the project was to analyse thoroughly phenomena related to SFP accidents. Numerical CFD type calculation methods and a computer program called PANAMA (Polttoainealtaiden ANAlyysi ja MAllinnus) were developed for simulating heating of water-cooled interim spent fuel storage in loss of coolant. Next complicated phenomena, from the numerical CFD point of view, are programmed into PANAMA:

1. Water level between the fuel rods descends continuously.
2. Hot vapour flows vertically between the fuel rods and with varying velocity out from the fuel elements.
3. Multidimensional heat conduction and vapour flow above the fuel elements transport heat upwards.
4. Thermal radiation emitted from the hot end of fuel elements absorbs to a varying vapour depth.

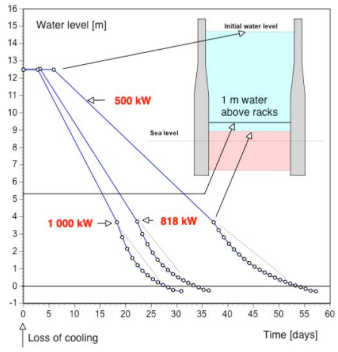

Figure 4. *Water level decrease with different average decay heat levels.*

Coolant losses in SFPs were also analysed with the integral code MELCOR. These analyses confirmed the result obtained also with PANAMA: when the water level in the pool is above the lower end of fuel racks, air is not able to flow down to cool the structures due to strong steam flow upwards.

Conclusions

Both Abaqus and PASULA can be utilised in analysing vessel deformations and possible failure under severe accident circumstances. The amount of uncertainties related to steam explosions is large and specialised know-how is needed to be able to analyse in which conditions steam explosions might be triggered. When studying SFP accidents, most attention should be paid on phenomena occurring on the level of the upper end of fuel elements. Heat removal from this interface has an essential effect on the evolution of maximum temperature in the fuel.

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