VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Thermal Hydraulics of Severe Accidents (TERMOSAN)

SAFIR2014 Final Seminar
19–20 March, 2015, Espoo, Finland

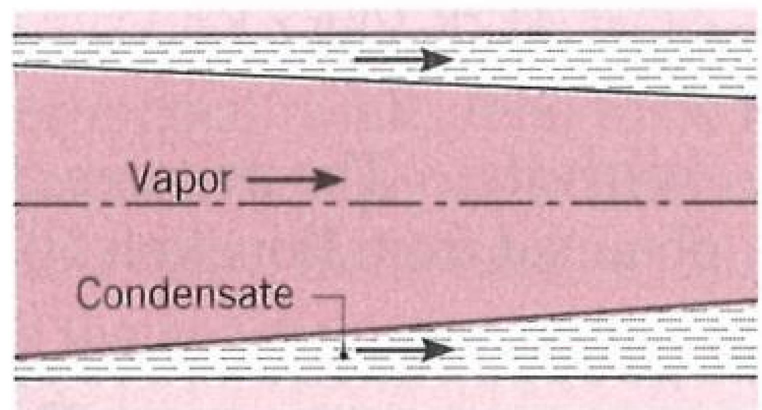
Tuomo Sevón, Anna Nieminen,
Veikko Taivassalo, Karri Penttilä

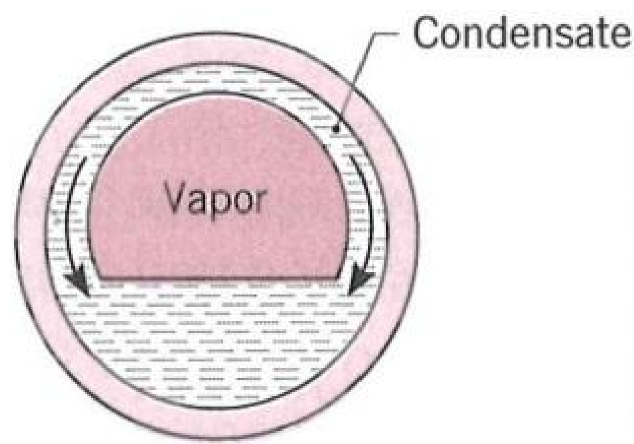
Introduction

- Objective: improve modeling capabilities on thermal hydraulics of severe accidents
- Passive containment cooling system experiments calculated with MELCOR and ASTEC codes
- Participated international OECD THAI-2 research program
  - Developed CFD models of hydrogen combustion experiments during spray operation
- In-vessel melt retention at VVER-440 analyzed with ChemSheet and ASTEC codes
- Models of the Fukushima accident developed with MELCOR code

Modeling of Passive Containment Cooling Systems (PCCS)

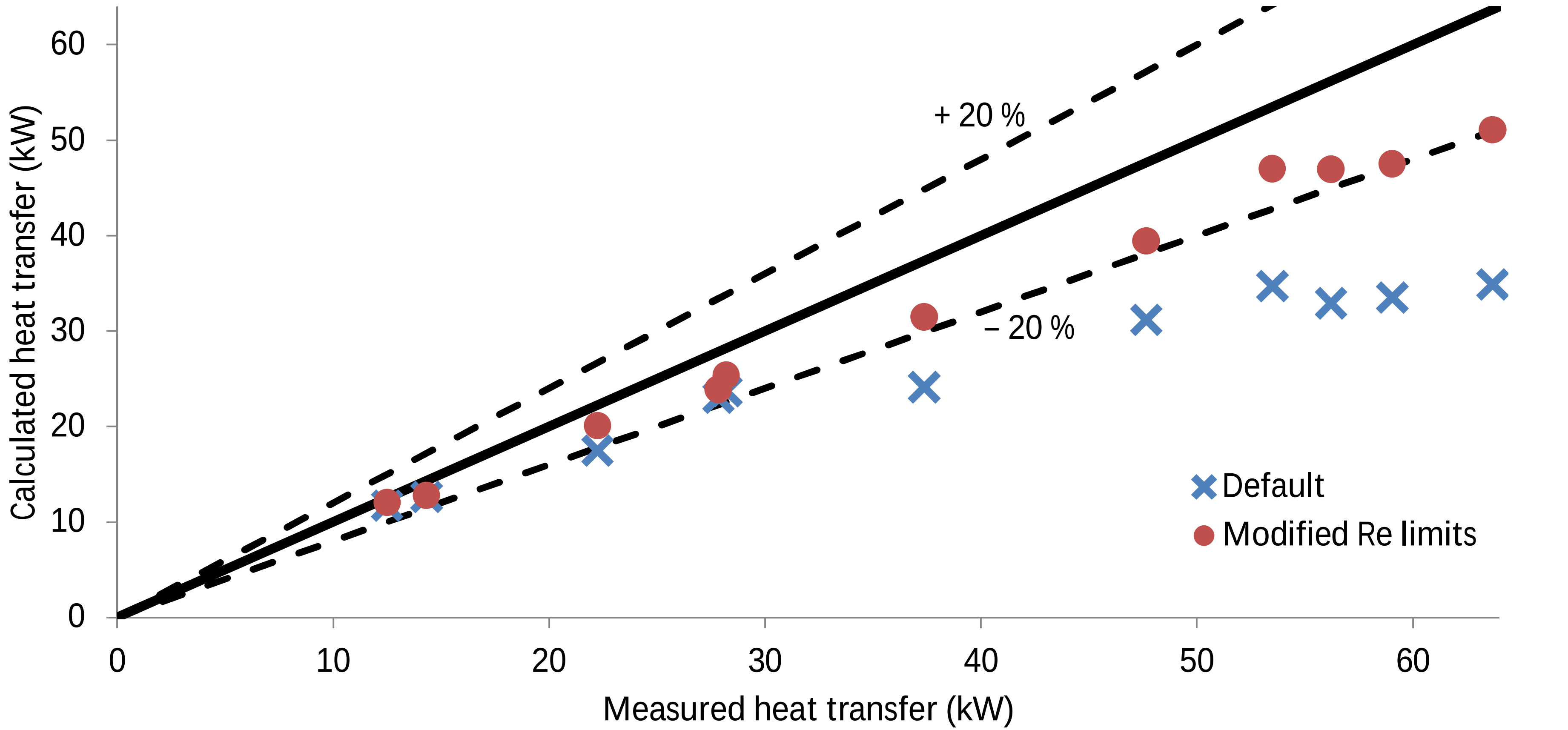
- Earlier: developed MELCOR models of vertical PCCS
  - Obtained very good results, better than 10 % accuracy
- ABWR reactor type has PCCS with horizontal tubes
- Condensation in horizontal tubes more challenging to calculate
  - Cylinder symmetry is lost
  - Condensate film thicker at bottom of tube





Figures: Incropera & DeWitt:
Fundamentals of heat and mass transfer

MELCOR Calculation of Steady-State Condensation in a Horizontal Tube

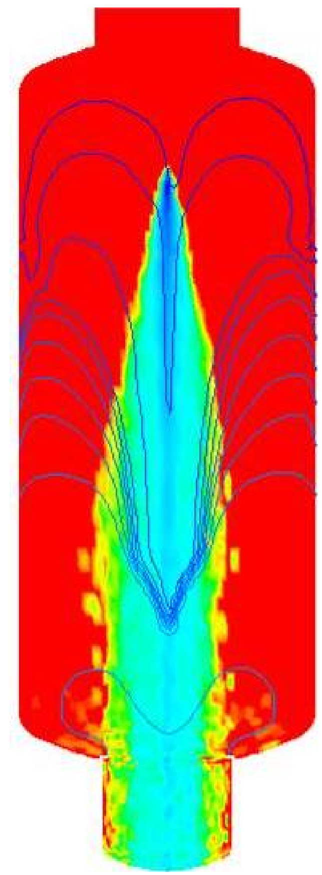


Calculation of Lappeenranta University of Technology PCCS Test

- Transient experiments with U-shaped tubes made in PCCS project in SAFIR
- VTT calculated PCC-06 test with MELCOR and ASTEC in TERMOSAN project
- Both codes underestimated condensation by about 50 %
- Slightly better results with Apros in ESA project
- Reason for poor results unknown
- Work should continue, but did not get funding in SAFIR2018

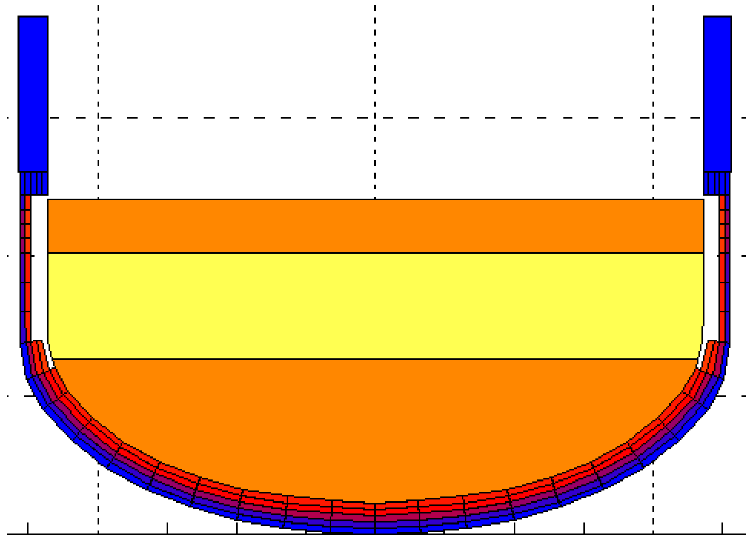
Behavior of Hydrogen and Iodine: OECD THAI-2 Research Program

- Finland participated THAI-2 in the frame of TERMOSAN project
- Test facility located in Eschborn, Germany
- Experiments made on:
  - Interaction between gaseous iodine and aerosol particles
  - Hydrogen recombiners
  - Hydrogen deflagration during containment spray operation
- Veikko Taivassalo calculated deflagration experiments with Fluent CFD code



In-Vessel Melt Retention

- Loviisa: retention of molten corium in RPV by external cooling
- Heat flux depends on melt layering
- Methods for modeling a three-layer melt pool were developed in TERMOSAN project
- Chemical equilibrium was calculated with ChemSheet by Karri Penttilä
  - Fortum has used these results in their own safety analyses
- Heat transfer was calculated with ASTEC by Anna Nieminen



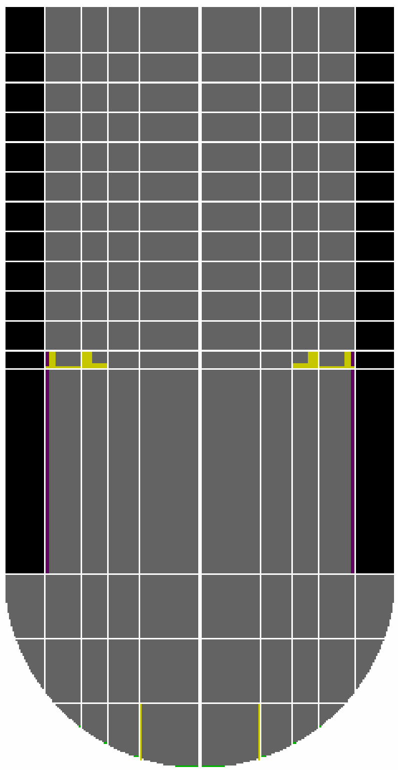
Analysis of Fukushima Accident

- Accidents at Fukushima Units 1, 2, and 3 calculated with MELCOR code in TERMOSAN project
- Calculation models developed from scratch, using publicly available plant data
- Objectives:
  1. Improving expertise in severe accident modeling
  2. Gaining better understanding of events during the accident
  3. Getting insights into capabilities and weaknesses of MELCOR

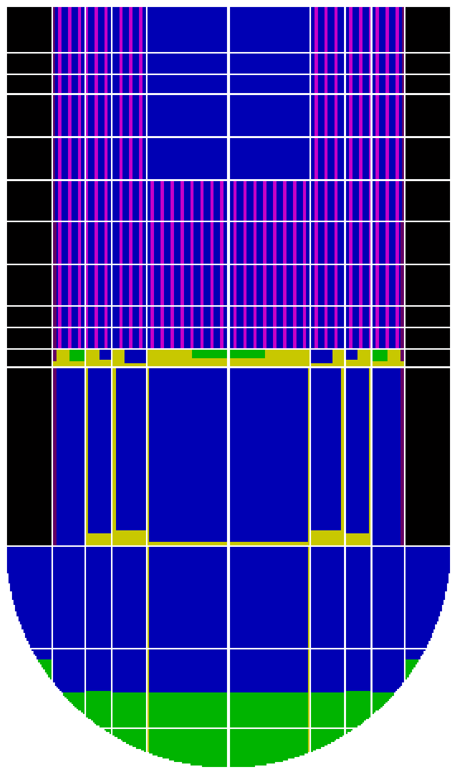
Accident Progression at Fukushima Reactors

- Unit 1:
  - Cooled by isolation condenser until tsunami arrival
    - All cooling failed when AC and DC power was lost
  - Core uncovery started less than 3 hours after earthquake
- Unit 2:
  - Cooled by turbine-driven pump for 66 hours
    - Surprisingly long operation without AC and DC power
  - Core uncovery started about 75 hours after earthquake
- Unit 3:
  - Cooled by turbine-driven pumps for about 35 hours
    - DC power was available from batteries
  - Core uncovery started about 36 hours after earthquake

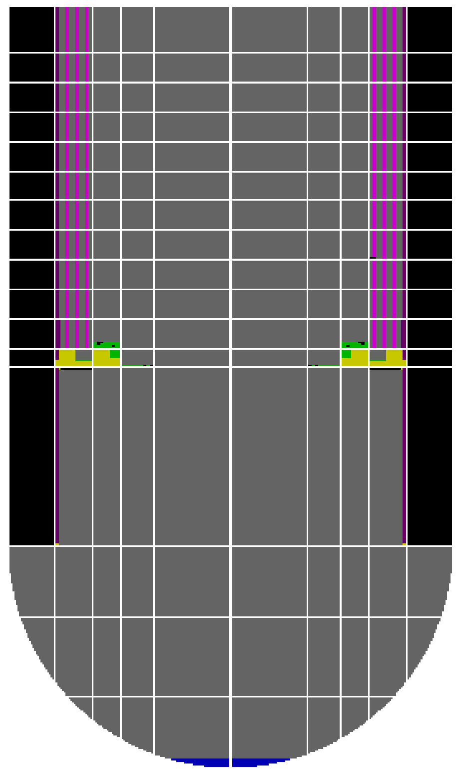
Calculated Final State of Fukushima Reactors



Unit 1: RPV failed, all fuel discharged to containment



Unit 2: RPV not failed, 13 % of fuel relocated to bottom of RPV

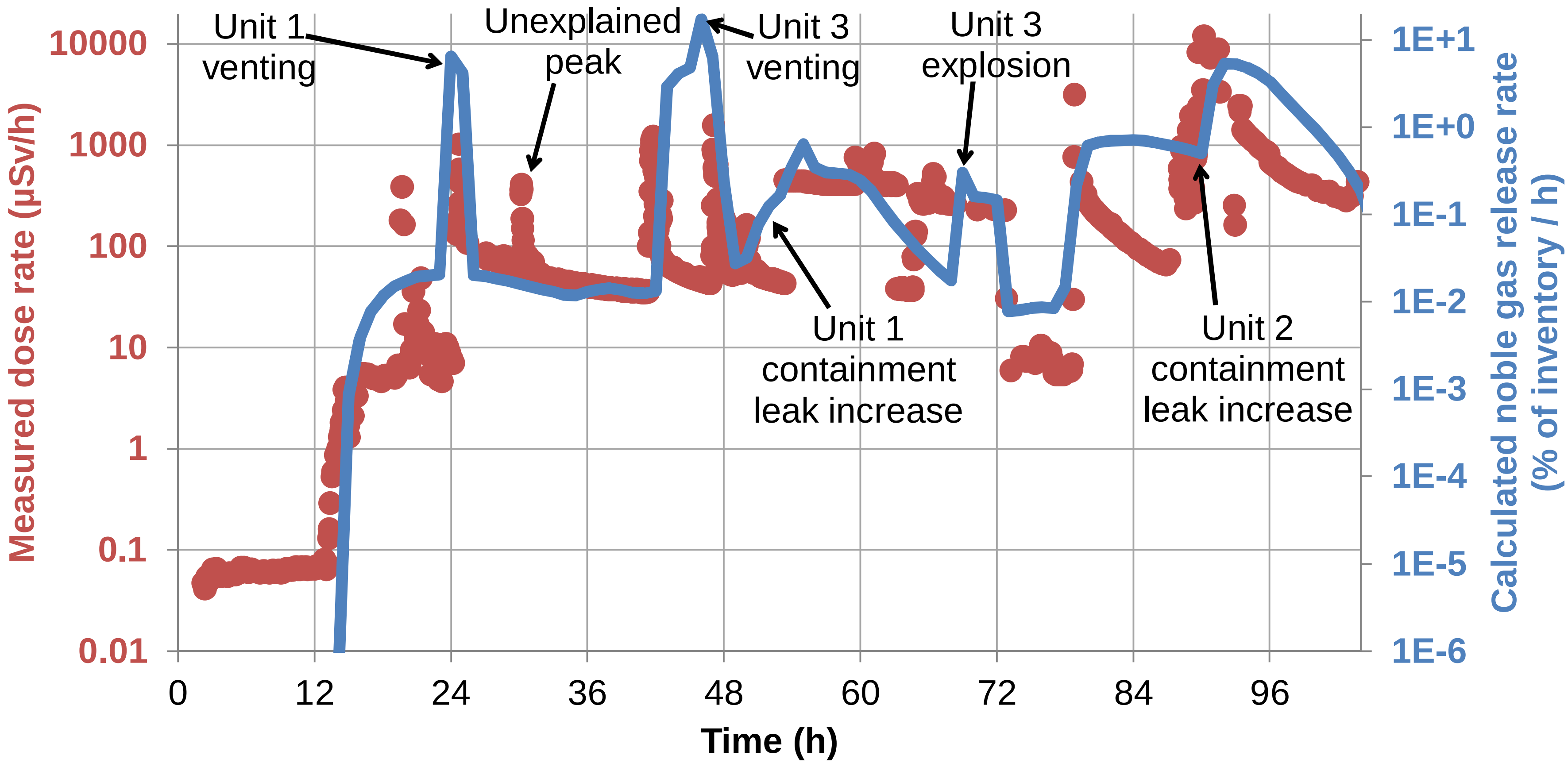


Unit 3: RPV failed, 70 % of fuel discharged to containment

Calculated Radioactive Release to Environment at Fukushima

- Noble gas inventory almost completely released at all three units
- Calculated cesium release:
  0.05 % from Unit 1, 0.08 % from Unit 2, 0.95 % from Unit 3
- Largest release from Unit 3 because of early containment venting, no time for deposition of aerosols
  - Containment venting systems not equipped with filters
- Hydrogen explosions in reactor buildings had only small effect on release to environment
- Still large uncertainties in calculated releases
- Models will be updated when more information becomes available

Calculated Timing of Releases to Environment, Compared with Timing of Measured Dose Rate



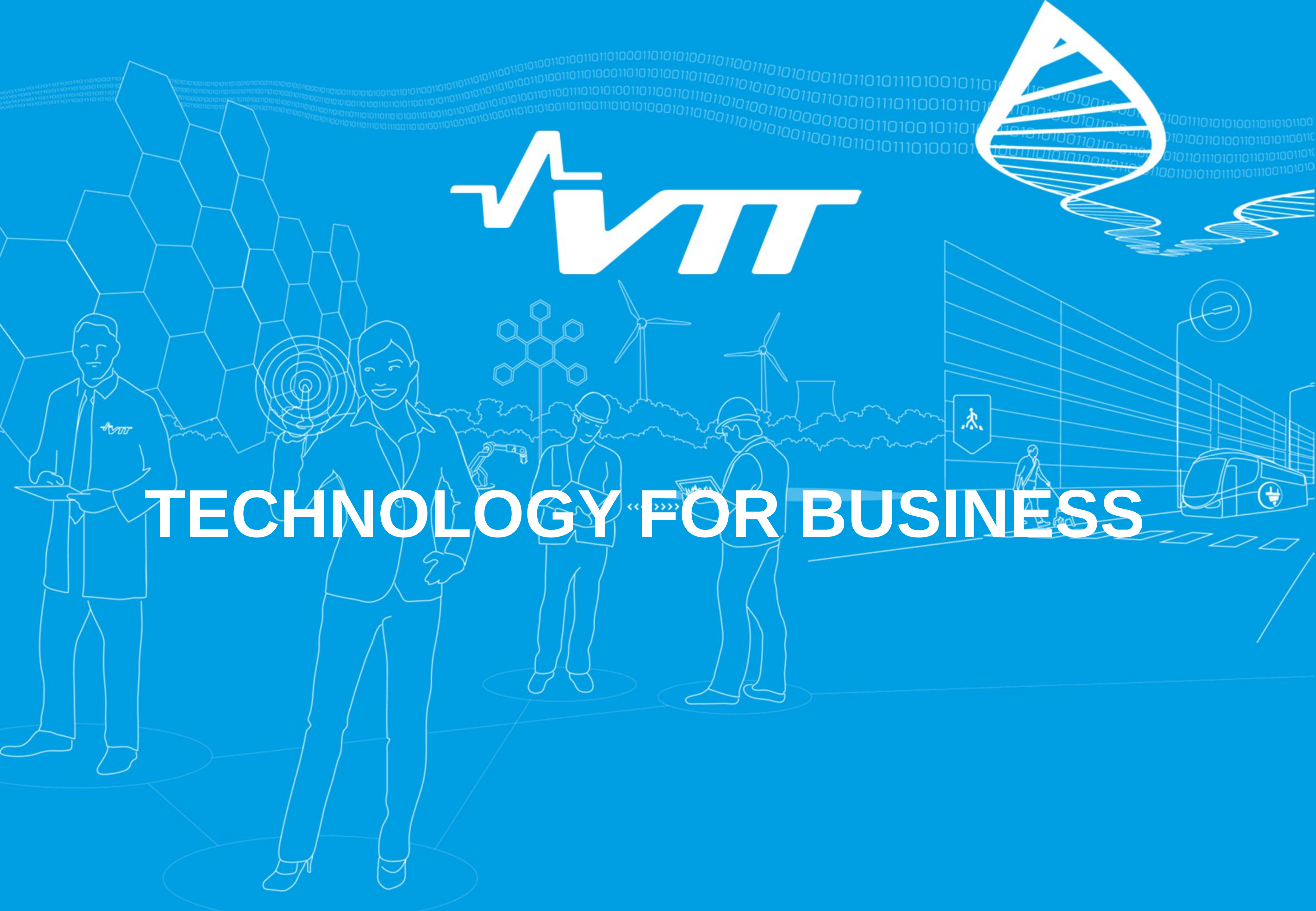
Conclusions from Fukushima Calculations

- Units 1 and 3: Molten fuel probably discharged to containment
- Unit 2: All fuel probably still inside reactor
- Unverified because camera inspection of reactors not yet possible
- Largest release to environment from Unit 3 because unfiltered venting made at early phase
- Calculated timing of release corresponds well to measured peaks of radiation dose rate at plant area
- Stratification of wetwell water has large effect on containment pressure but difficult to calculate
- Behavior of safety systems outside their design conditions difficult to predict

Participated on Fukushima Plant Tour

How TERMOSAN Project Has Developed Expertise for Solving Safety Issues

- TERMOSAN project pays Finland's annual MELCOR license fee
  - Provides MELCOR license for VTT, TVO, Fortum, and Fennovoima
- Developed analysis methods for horizontal passive containment cooling systems (similar to ABWR)
  - Results not yet satisfactory, more work needed
- Better knowledge of hydrogen and iodine behavior from OECD THAI-2 experiments and their CFD calculations
- Methods for in-vessel melt retention analysis
  - Fortum has used these results in safety analyses of Loviisa
- Expertise in severe accident modeling significantly improved by developing models of three real accidents at Fukushima


TECHNOLOGY FOR BUSINESS