PAUL SCHERRER INSTITUT

Horst-Michael Prasser

Labor of Thermal Hydraulics

NES Infotag, 24.10.2017

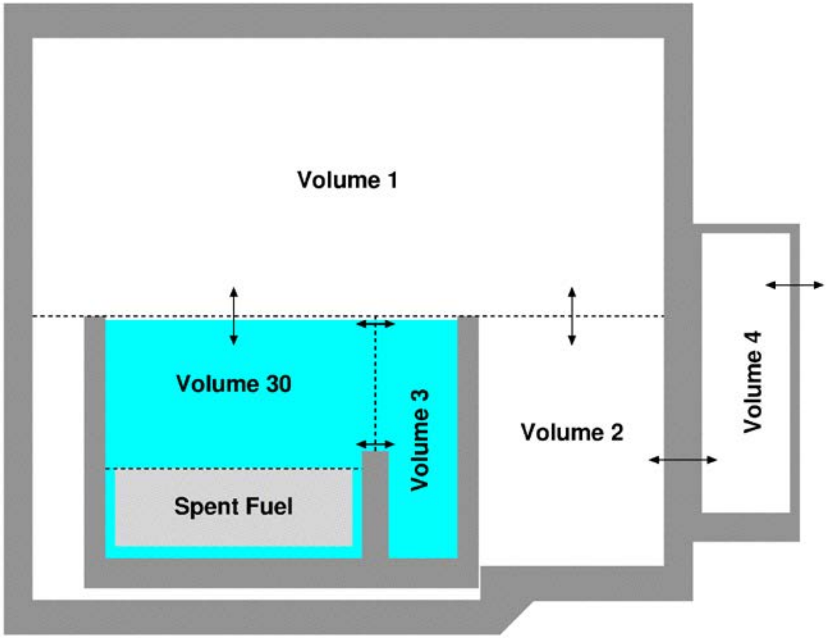
Laboratory of Thermal Hydrailics

Content:

- Severe accident research
  - Spent fuel pool behavior during a loss of coolant
  - Hydrogen deflagration simulations
  - Simulation of hydrogen removal by Passive Autocatalytic Recombiners
  - Iodine retention in wet scrubbers and pools
  - Fukushima benchmark – simulation of fission product release
- DNB prediction by fundamental boiling simulations
- Containment thermal hydraulics
  - New OECD project HYMERES 2
    - Flow impacting obstructions and containment internals
    - Thermal radiation driven flow phenomena
    - Suppression pressure pool and BWR systems behavior
    - Performance of safety components
  - Partners and link to NEST initiative of NEA/OECD
- Imaging with fast neutrons
  - Massive objects
  - Source performance tuning
  - Energy selective imaging

Spent fuel storage Loss-of-Cooling #1

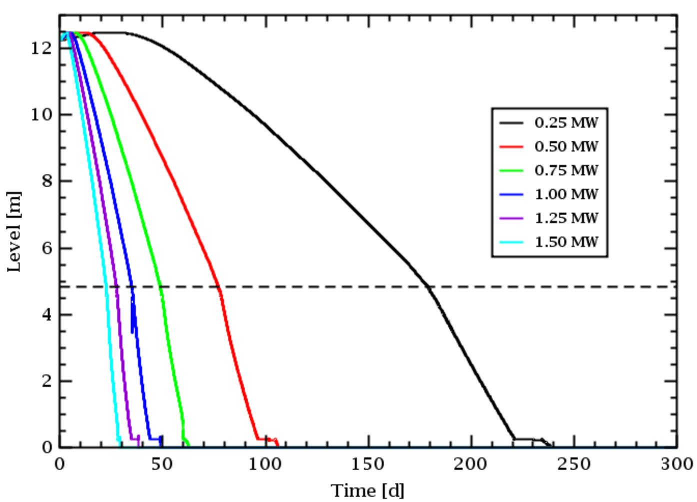
- Wet pool for intermediate storage of spent fuel
- Loss-of-Cooling, all safety systems failed
- Sequence analysis with integral severe accident code MELCOR2.1
- Analyse:
  - Accident progression with different heat loads in the pool
  - Time available for accident management measures



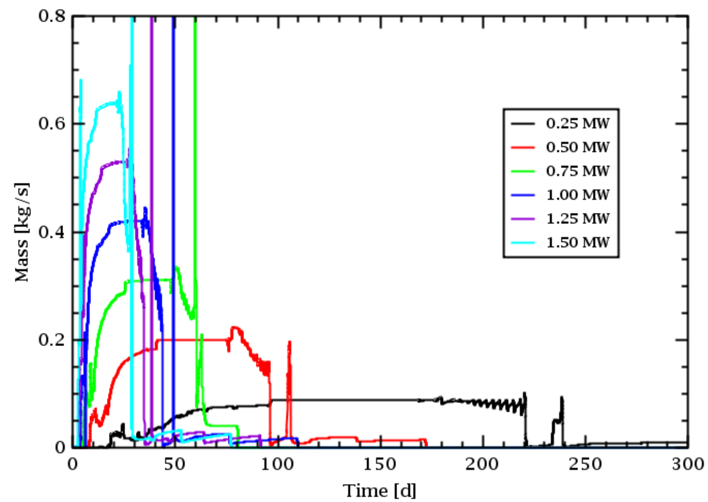
Spent fuel storage Loss-of-Cooling #2

- Accident progression slow even at the highest heat load
  - More than 24 days for fuel to heat-up above boiling
- Less than 0.7 kg/s cooling water enough to keep the water level constant
  - Easily delivered by a single fire water pump

Power/Event	Onset of Boiling	7 m	Water loss at boil down	Water at top of rack	Top of active fuel
0.50 MW	13.5 d	62 d	0.20 kg/s	76 d	80 d
1.00 MW	6.1 d	28 d	0.42 kg/s	35 d	36 d
1.50 MW	3.8 d	17.9 d	0.64 kg/s	22.4 d	23.3 d



Water level in the pool



Coolant injection

Hydrogen deflagration #1

- ETSON benchmark
- ENACCEF facility with obstacles for challenging geometry
- CFD FLUENT used with two combustion models
  - The Turbulent Flame speed Closure model (TFC-Zimont)
  - The Eddy Dissipation Model (EDM)

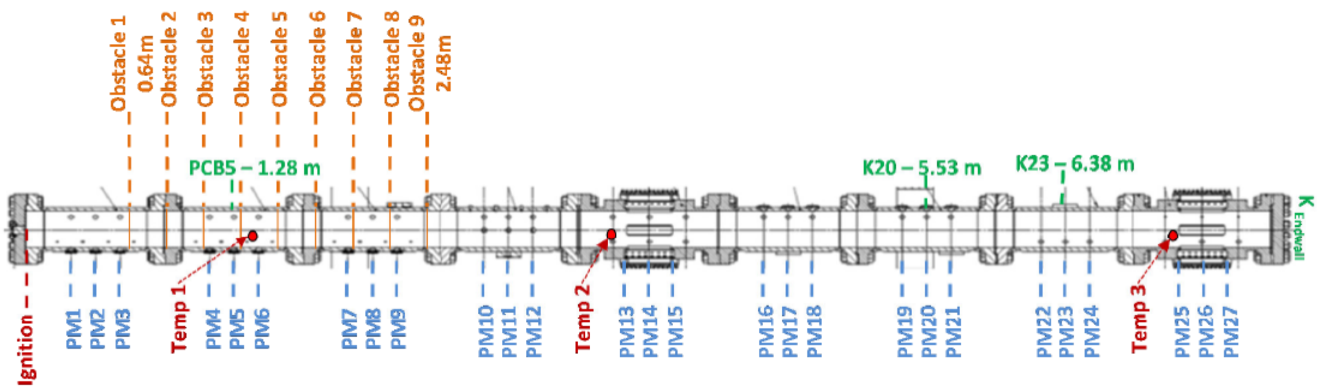
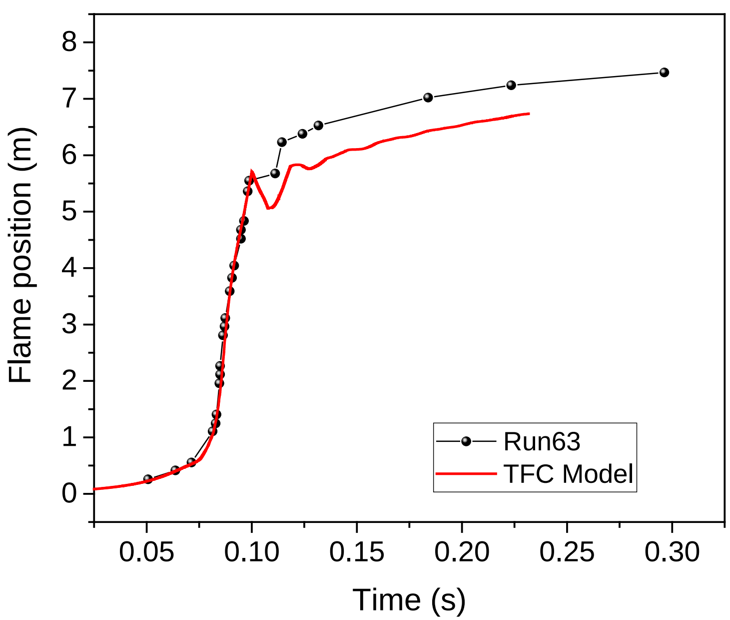
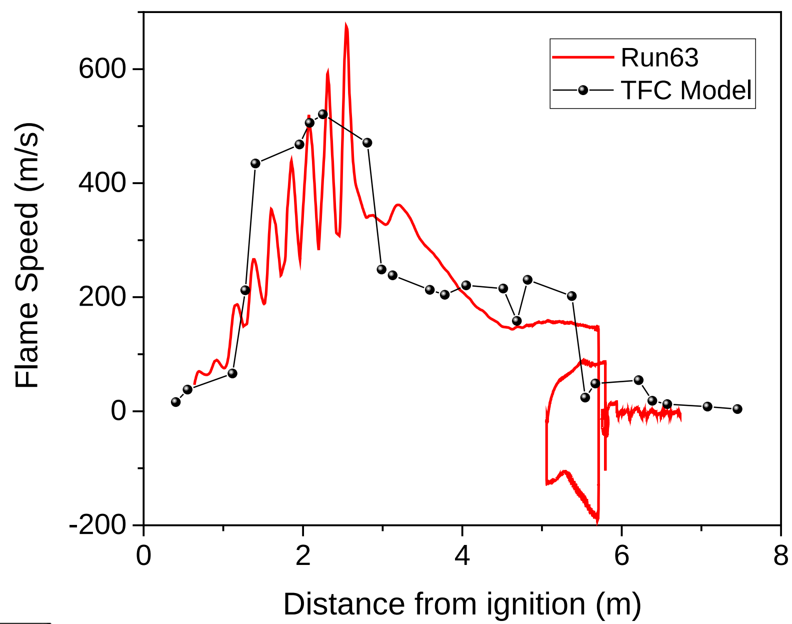


Figure 6: ENACCEF II Facility- diagnostics and obstacles location. The depicted configuration corresponds to this benchmark work.

Hydrogen deflagration #2

- TFC results used for the benchmark
  - Flame stops propagation forward at some point then goes back at position 5.5 m
  - Flame speed confirms this by showing some negative values after 5.5 m
- Reasonable agreement of the flame acceleration (baffle area), but reflection of flame shown only in simulation
- Pressure peaks reasonable, but highest peak (end wall) not captured

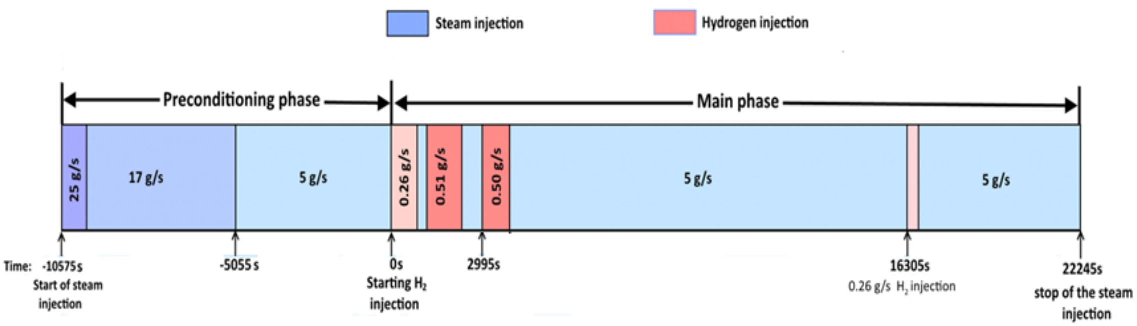


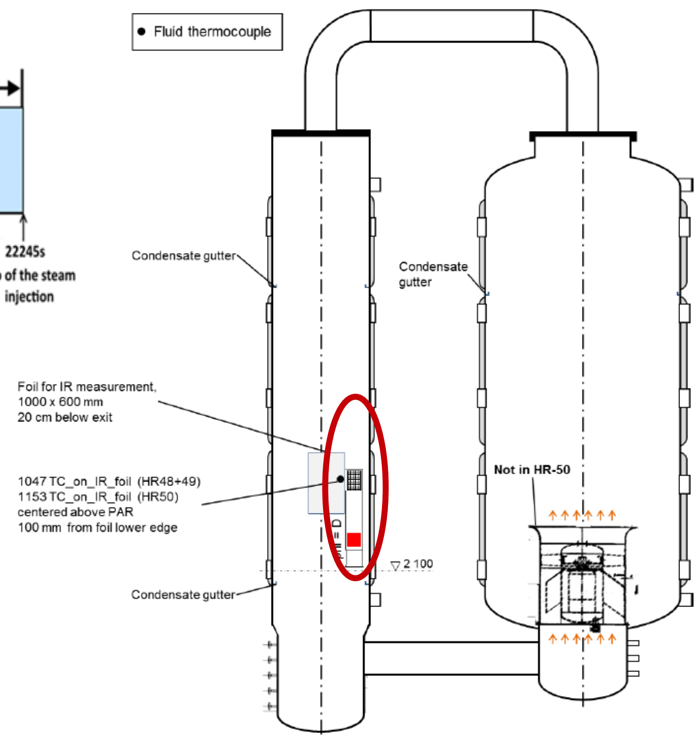


Run63-PregressC.mp4

Hydrogen PAR #1

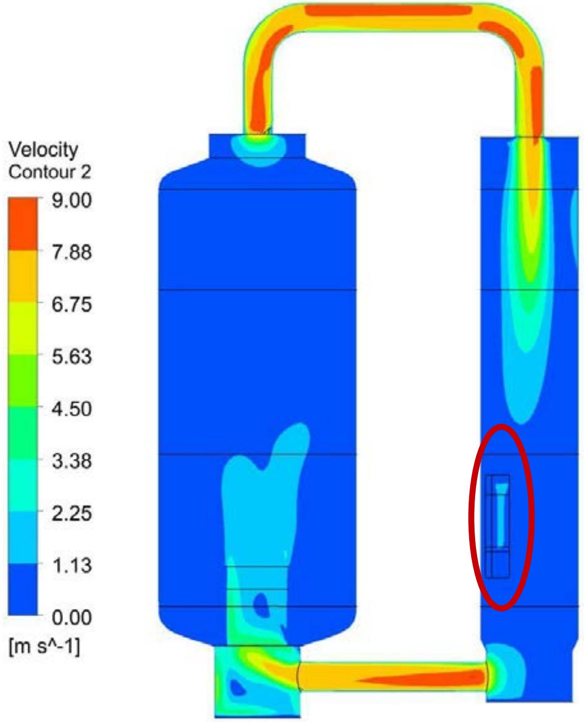
- Blind THAI benchmark for Counter-Current PAR test using CFD Fluent
  - Turbulence: k-ε model incl. buoyancy terms
  - PAR recombination: AREVA correlation
- Pre-conditioning phase with steam injection to reach given initial conditions (3 bar, 60% vol. steam and wall/gas temperature)
- Main phase with several H2 injections

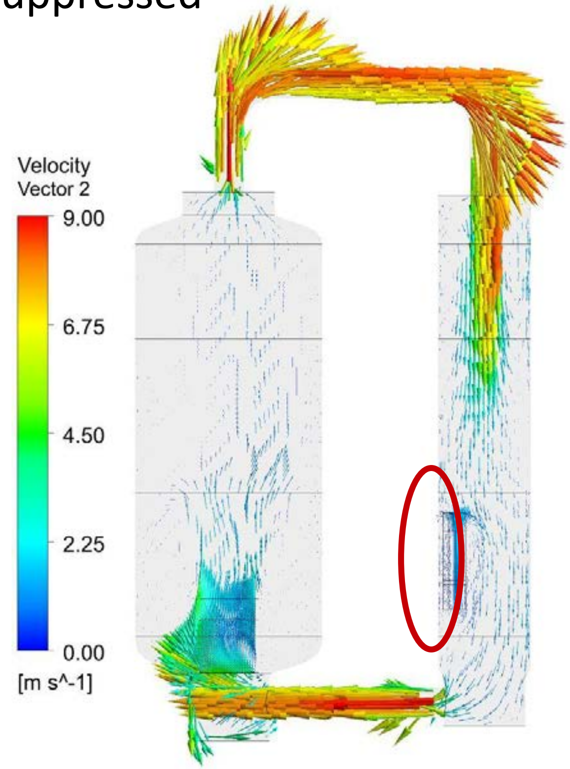




Hydrogen PAR #2

- Results show very good agreement with initial released data
  - Pressure trace
  - Recombination rate
- Temperature plume exiting PAR compressed compared to usual due to effect of downward flow
- Flow out of PAR compressed by not suppressed





Iodine retention in water #1

- Experimental investigation of iodine retention in water, e.g.:
  - Filtered containment venting systems (FCVS)
  - Suppression pools
  - Fuel handling incidents
- Experiments in 1.5 m high test facility
- The effect of flow regime, chemistry, temperature

Mass flow = 3.0 kg/h
Volume flux = 0.02 m/s

Mass flow = 22.5 kg/h
Volume flux = 0.16 m/s

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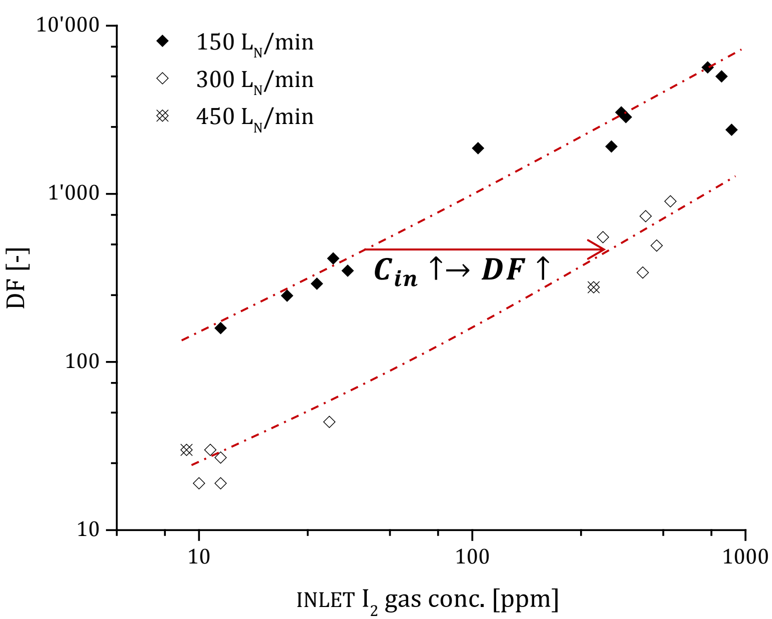
Iodine retention in water #2

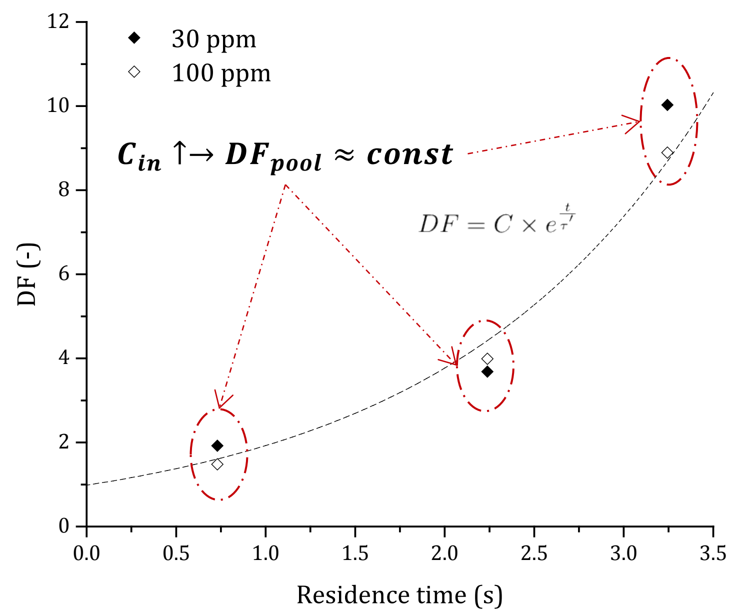
- Efficiency depends strongly on the flow regime
- Increasing retention with high iodine content due to nozzle dynamics
- The iodine retention in the bubble-rise zone in the scrubber pool is well described by the two film theory → linearity:

$$DF = \frac{M_{in}}{M_{out}}$$

Injection region + pool



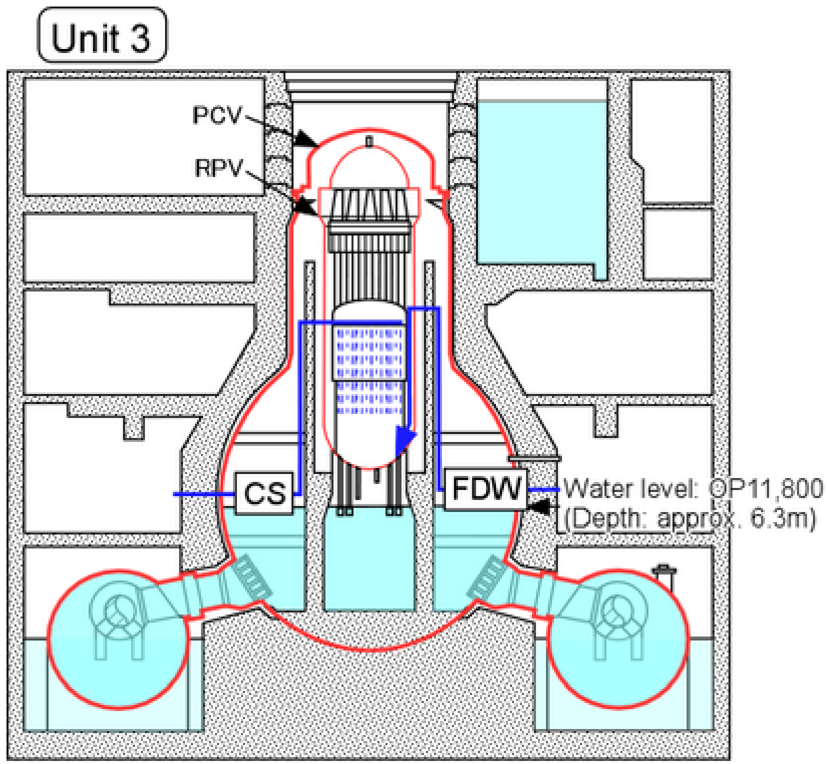
Pool alone



- High relevance of **injection region** → highest sensibility for optimization
- Experiments with **high iodine concentrations** may **not** be **conservative**

Fukushima analysis #1

- Benchmark project of Fukushima accidents BSAF, OECD/NEA
- PSI analysis for Unit 3 with MELCOR2.1
- Phase-2:
  - Fission product distribution and release
  - Analysis for 20 days

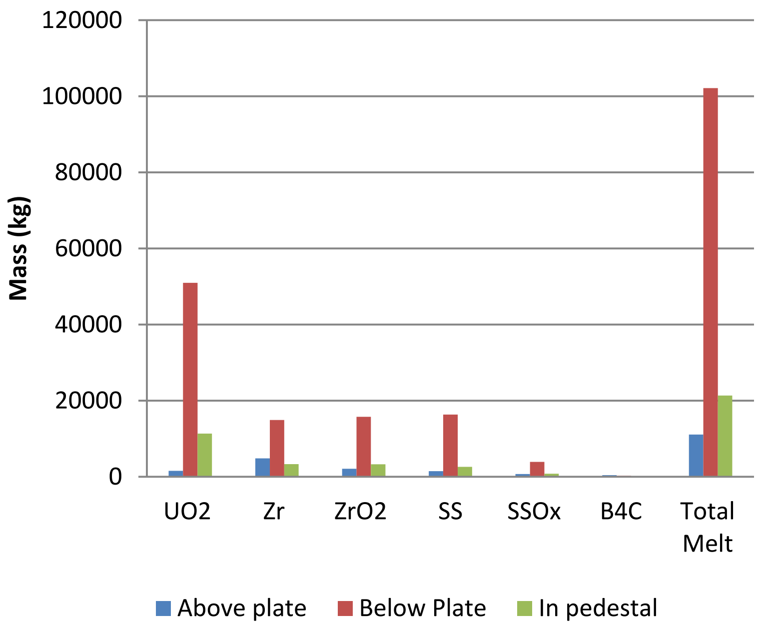


Fukushima analysis #2

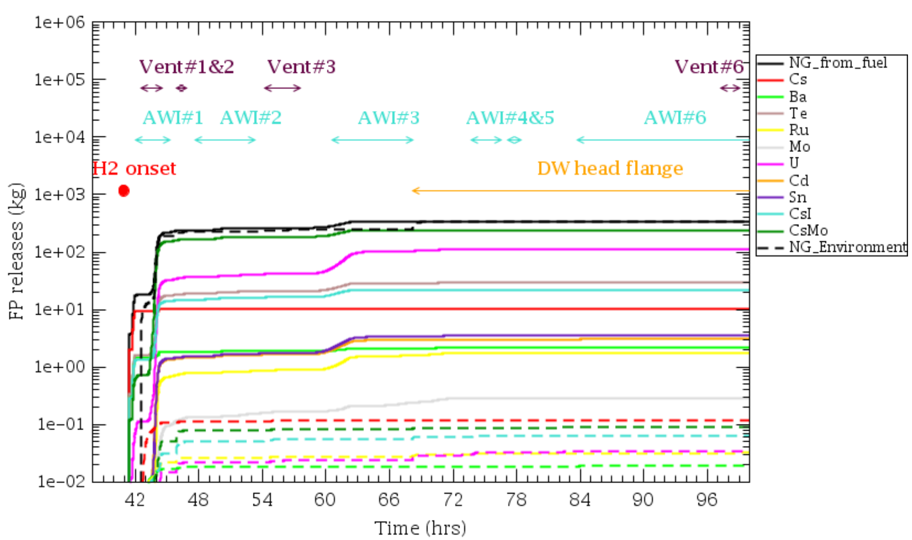
- Analysis for 20 days => until end of March, 2011
- A fraction of debris on the pedestal under the reactor pressure vessel
- 1300 kg hydrogen generated
- Release to the environment:
  - direct atmospheric release of 0.1 % of Cs and 0.2 % of iodine
  - But: approximately 25% of I-131 in the water outside of containment => release ***from the water to the gas phase*** not considered bv most of the severe accident codes

Unit 3

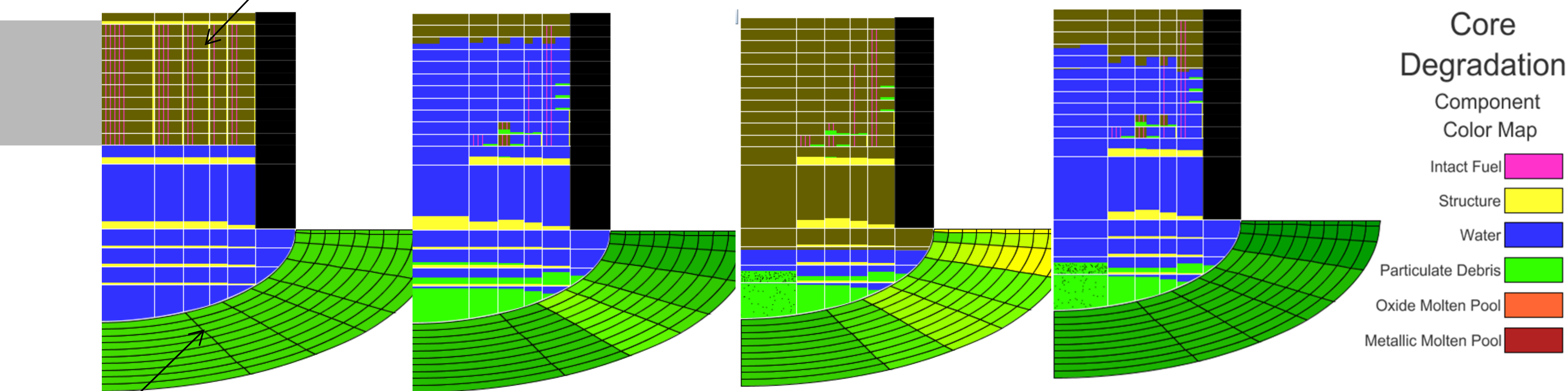
Corium after 20 days



Fission product release to the environment



Fukushima analysis #3

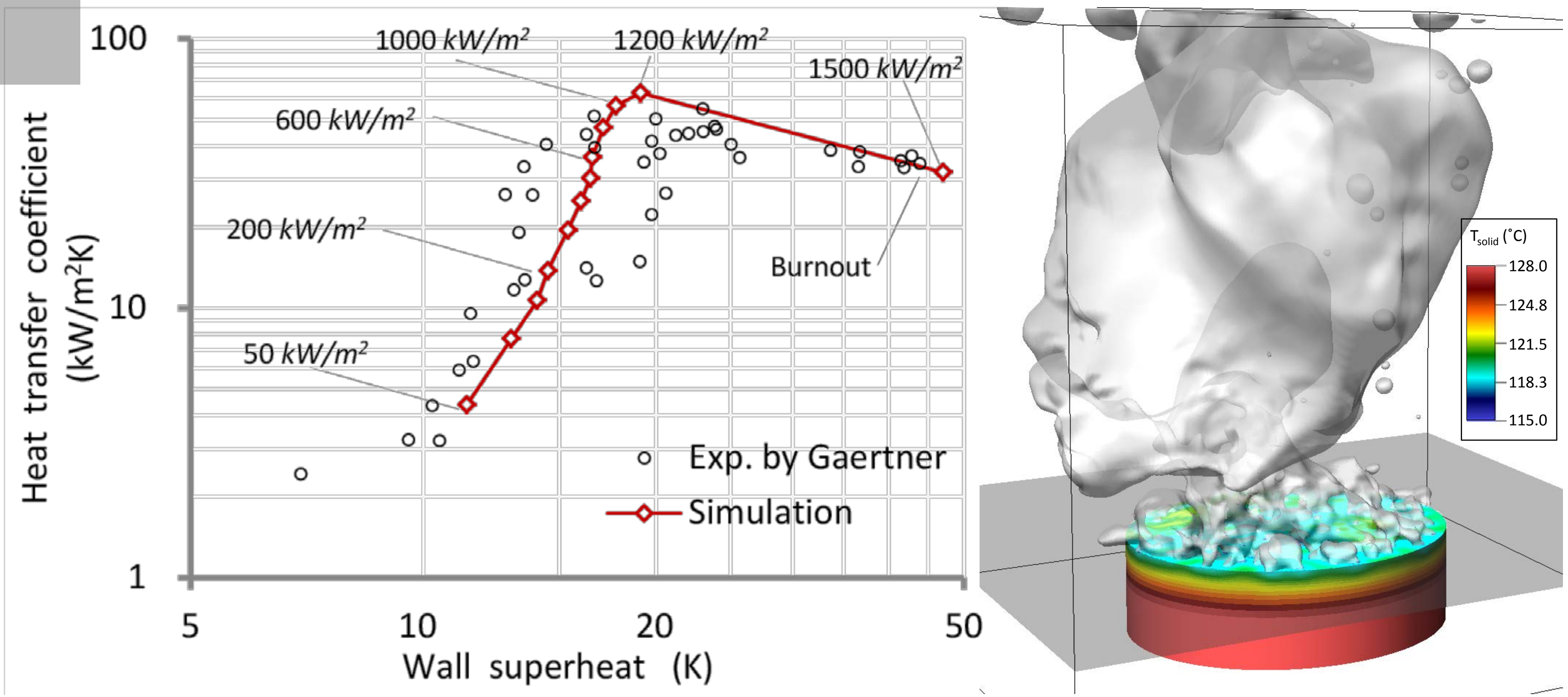


H2 generation onset	**41 hours**
Debris relocation to lower head	**70 hours**
Vessel failure (penetration)	**73 hours**
Debris out of RPV	**79 hours**

Unit 3

- At the end of calculation at 350 hours (code is still running):
  - Decay heat not very high
  - Debris hot but not hot enough to melt the lower head
  - Core not stable, modification in coolant injection could further uncover it

DNB simulated by fundamental CFD approach



Validation of heat transfer coefficient at experiment (Gaertner R.F., J. Heat Trans., 87 (1965) 17-27)

OECD/NEA HYMERES phase 2

Acronym:

- Hydrogen Mitigation Experiments for Reactor Safety

Objective:

- to improve the knowledge on containment safety in order to enhance its modeling in support of safety assessment that will be performed for current and new nuclear power plants.

OECD/NEA NEST initiative:

- Nuclear Education, Skills & Technology
- The HYMERES phase 2 project is a pilot project (the first) for NEST
- Students and young professionals from participating Countries will visit PSI and take part at the experimental and analytical activities in the HYMERES-2 project

PANDA Facility at PSI will be used for the HYMERES-2 Experiments

OECD/NEA HYMERES phase 2

The participating Organizations/Countries of the project are:

- Paul Scherrer Institute (PSI), **Switzerland**
- UJV Rez, a.s., **Czech Republic**
- Teknologian tutkimuskeskus (VTT), **Finland**
- Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), **Germany**
- Nuclear Regulatory Authority (NRA), **Japan**
- Korea Atomic Energy Research Institute (KAERI), **Korea**
- Russian Academy of Sciences Nuclear Safety Institute (IBRAE) together with the State Atomic Energy Corporation (ROSATOM), **Russian Federation**
- Consejo de Seguridad Nuclear (CSN), **Spain**
- State Power Investment Corporation Research Institute (SPICRI) together with the China Nuclear Power Technology Research Institute Co. Ltd. (CNPRI), **China**
- United States Nuclear Regulatory Commission (NRC), **USA**

Discussions are ongoing with other Countries

Period: 1st July 2017 – 30th June 2021

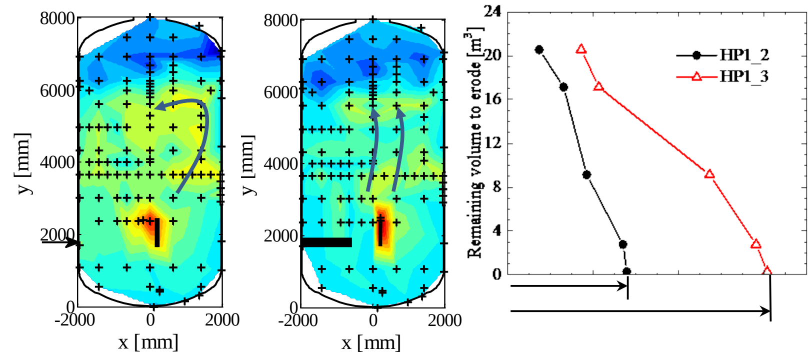
Budget: 4.84 M€

Kick-off meeting: Held on the 5th -6th October 2017 at PSI ***(new)***

HYMERES-2

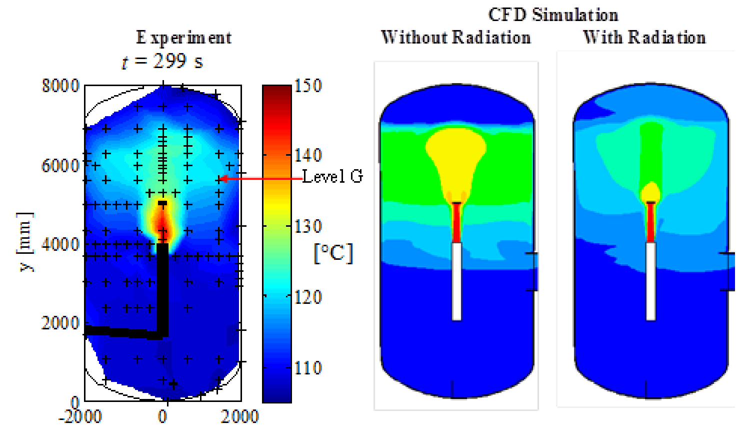
- ***Topic 1:***

Flow impacting obstructions and containment internals



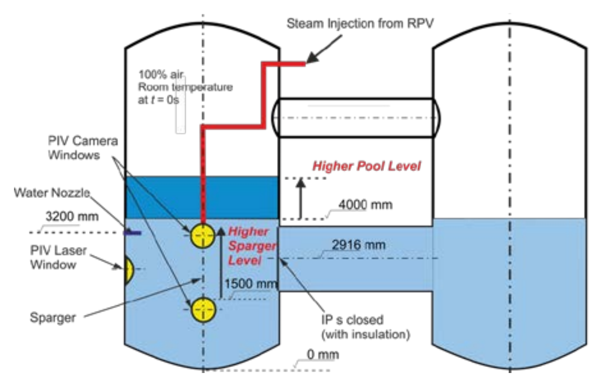
- ***Topic 2:***

Thermal radiation driven flow phenomena



- ***Topic 3:***

Suppression pressure pool and BWR systems behavior



- ***Topic 4: Performance of safety components***
  → *next slide*

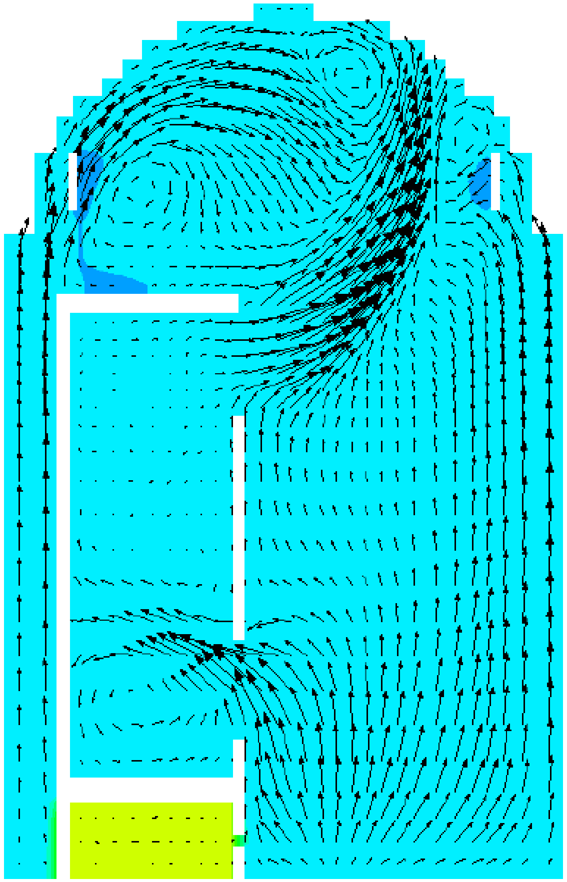
The HYMERES-2 test series…

Analysis of a real plant containment under DBA or BDBA conditions

HYMERES-2 Topic 4: extend the database on the performance of safety component operation

Tests address needs of regulators, vendors and utilities on:

- *Active and passive components for safety backfitting*
- *Novel safety system concepts of Gen-III reactors (e.g. APR1400, EPR, VVER-1200, LAES-2)*
- *Examples: spray systems, active an passive containment coolers, two-room containments, etc.*
- *Tests to be defined according to current needs of project partners*



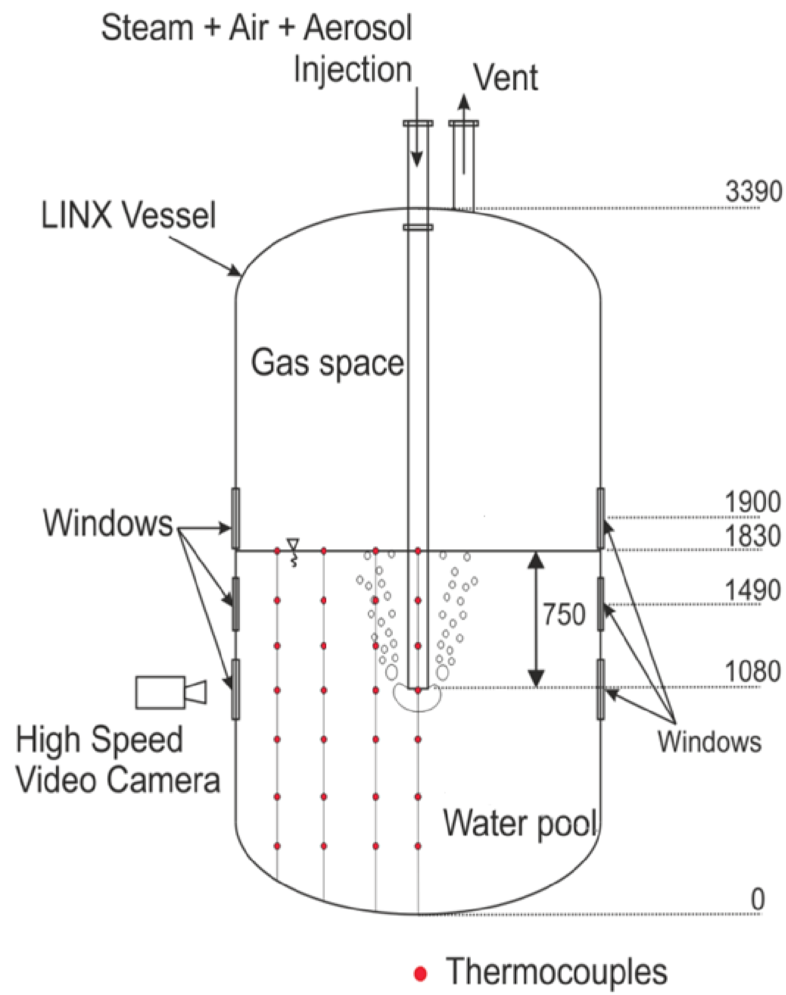
Flow pattern analyzed with GOTHIC in the HYMIX K2 cooler analytical test (IBRAE, Russia).

Pool Scrubbing Experiments in LINX

Proposed additional experimental program

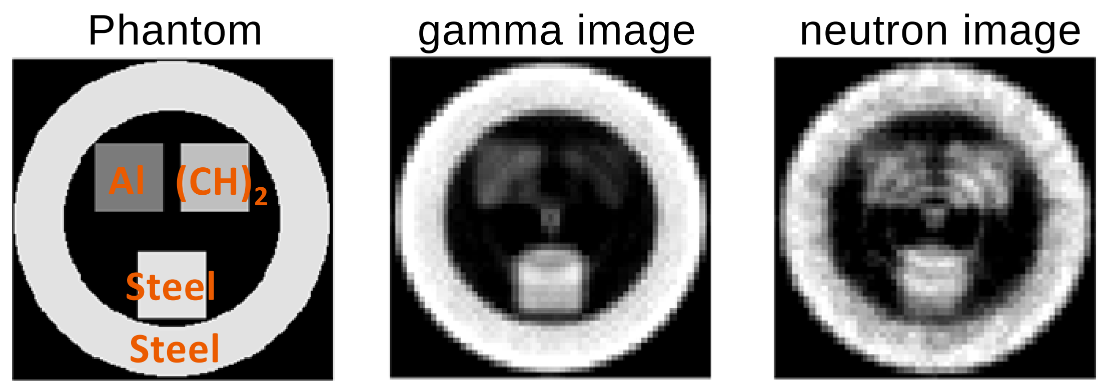
- **Background:**
  - Transport of aerosols in LWR containments during BDBA
  - Scrubbing of aerosols in water pools
  - Hydrodynamics of aerosol scrubbing

- **Specific objectives:**
  - Study of two-phase Flow Regimes
  - Study of the large scale circulation induced in the pool and its impact on aerosol removal
  - Dependence of Decontamination Factor on initial and boundary conditions
  - Validation of hydrodynamic models in pool scrubbing codes (e.g. SPARC, BUSCA)

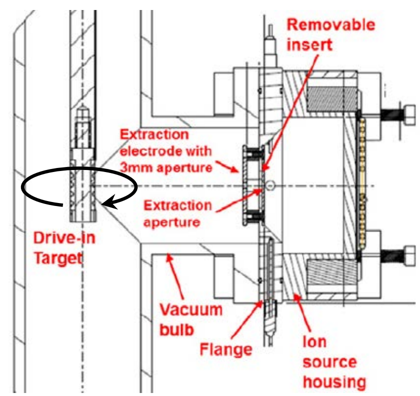


Imaging with fast neutrons

- Tomographic imaging of a heavy object
  - o Light material in 3 cm thick steel canister
  - o fast neutrons provide better contrast for hydrocarbons

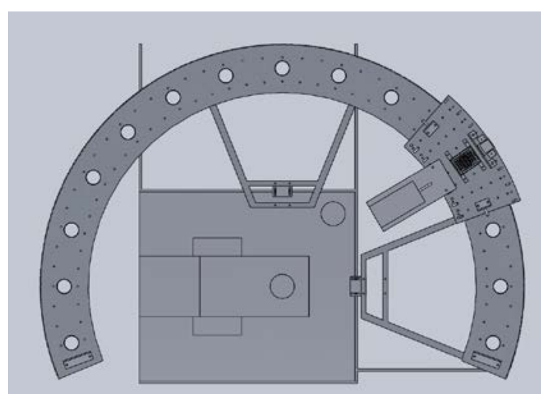


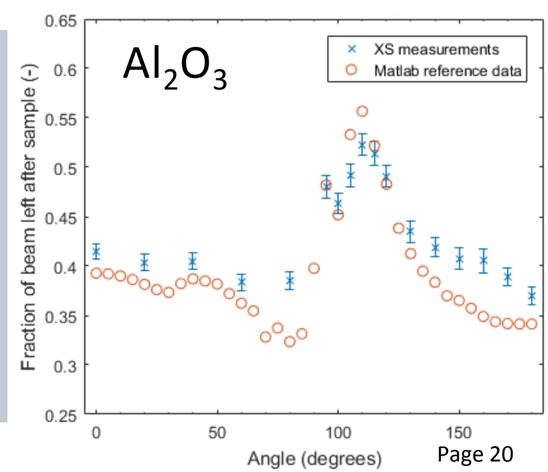
- Enhancement of output
  - o Rotating target allows higher D2 accumulation in Ti target
  - o Higher D-D fusion reaction rate



Beam heating of target distributed around circumference → lower temperature → higher deuterium doting

- Energy selective imaging
  - o Angular energy dependency of D-D neutrons
  - o Measurement of energy dependent attenuation
  - o Basis for energy dependent imaging





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Summary: Tools of LTH

Laboratory of Thermal Hydraulics
Head: Prof. Dr. H.-M. Prasser
Deputy head: B. Jäckel

Secretary
A. Mohr

Group Experimental Thermal Hydraulics
Leader: Dr. D. Paladino

- PANDA
- LINX
- GEMIX
- HOMER/GAMILO
- SUBFLOW
- FLORIS
- Neutron Tomo
- MCNP

Group Modeling and Simulation
Leader: Dr. B. Niceno

- PSI-Boil
- FLUENT
- STAR-CCM+
- GOTHIC
- Multi-scale mod.

Group Severe Accidents
Leader: Dr. Terttallisa Lind

- VEFITA
- MiniVefita (Iodine)
- Aerosol tests
- MELCOR
- ASTEC
- Eul.-Lagr. CFD
- H_2 deflagration CFD

Thank you for the attention