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Belgian Nuclear Research Centre

MYRRHA

HLM research

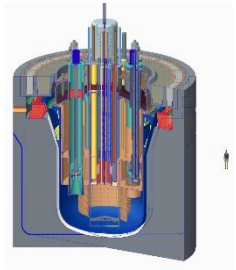
Paul Schuurmans – 04/02/2021

SNETP forum TS7

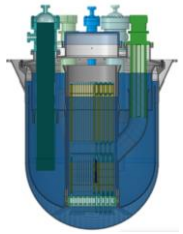
HLM systems : why and how

- SNETP "provide real industrial solutions"
- ESNII Vision statement : Safe performing fast neutron reactors with a closed fuel cycle competitive energy production

- MYRRHA : the R&D machine



- ALFRED : the demo



- fuel development & qualification
- materials development & qualification
- coolant behaviour, TH and chemistry control
- component design and testing
- instrumentation and control
- safety assessment & code validation
- fuel handling technology & fuel-coolant interaction
- robust decay heat removal systems
- development of out-of-pile and in-pile mock-ups and demonstrators

HLM research : advantages and challenges

- Significant synergy between Pb (LFR systems) and Lead-Bismuth (MYRRHA)
  - If it works for LBE it will work for Pb
  - Major difference in temperature
- Use of MYRRHA as a development tool for LFR
  - Test machine (irradiation tests)
  - Pilot plant
  - Step-wise approach
- We are reaching the licensing phase
  - A lot more focus on procedures and QA
  - All issues need to be addresses (not just most of them)
  - Importance of building a knowledge database

Focus & boundary conditions

- R&D exists to support the development of the reactor system
  - Input for design
    - How to's : e.g. corrosion tests
    - "Suitability" limits : materials exposure limits
    - Confirmation of design : component tests
  - Input for Safety :
    - How to's : e.g. release of radionuclei from the HLM coolant
    - Deviations/accidents, e.g. heat transfer in a blocked FA, sloshing
  - Input for modelling
    - Model building
    - Simulation **validation**

Input for (pre)License

HLM research

Technical content

- Topics
  - Driver fuel
  - Materials
  - Thermal hydraulics and component tests
  - Coolant Chemistry control
  - Instrumentation and reactor control

  - Code validation runs across all topics

- Work embedded in
  - EU programmes (past & present)
  - National programmes with different partners

Driver fuel

- Standardise use of fuel
  - Pelleted MOX
- Make separation between fuel side and coolant side
- Use existing database wherever possible
  - 15-15Ti cladding (but LFR needs coating)
- Re-establish manufacturing
  - Fuel clad/spacer/wrapper/assembly production to specifications
  - MOX production
- Do new experiments when needed
  - Cladding : Materials programme
  - Fuel-coolant interactions
  - Transient tests
- Strengthen knowledge base (see also TS3)
  - MOX and MA bearing fuel
- Innovative fuels for the second phase

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Materials

- Assessment of materials properties and materials qualification steps needed
  - Basic mechanical characterization
  - Test procedure development & QA
  - Identified materials issues and related R&D
    - Liquid metal Corrosion
    - HLM LBE effect on mechanical properties
    - Irradiation effects
    - Synergetic effects
  - Irradiation experiments
- Mitigation when materials qualification fails (see TS4)
  - Coatings
  - New materials

GEMMA

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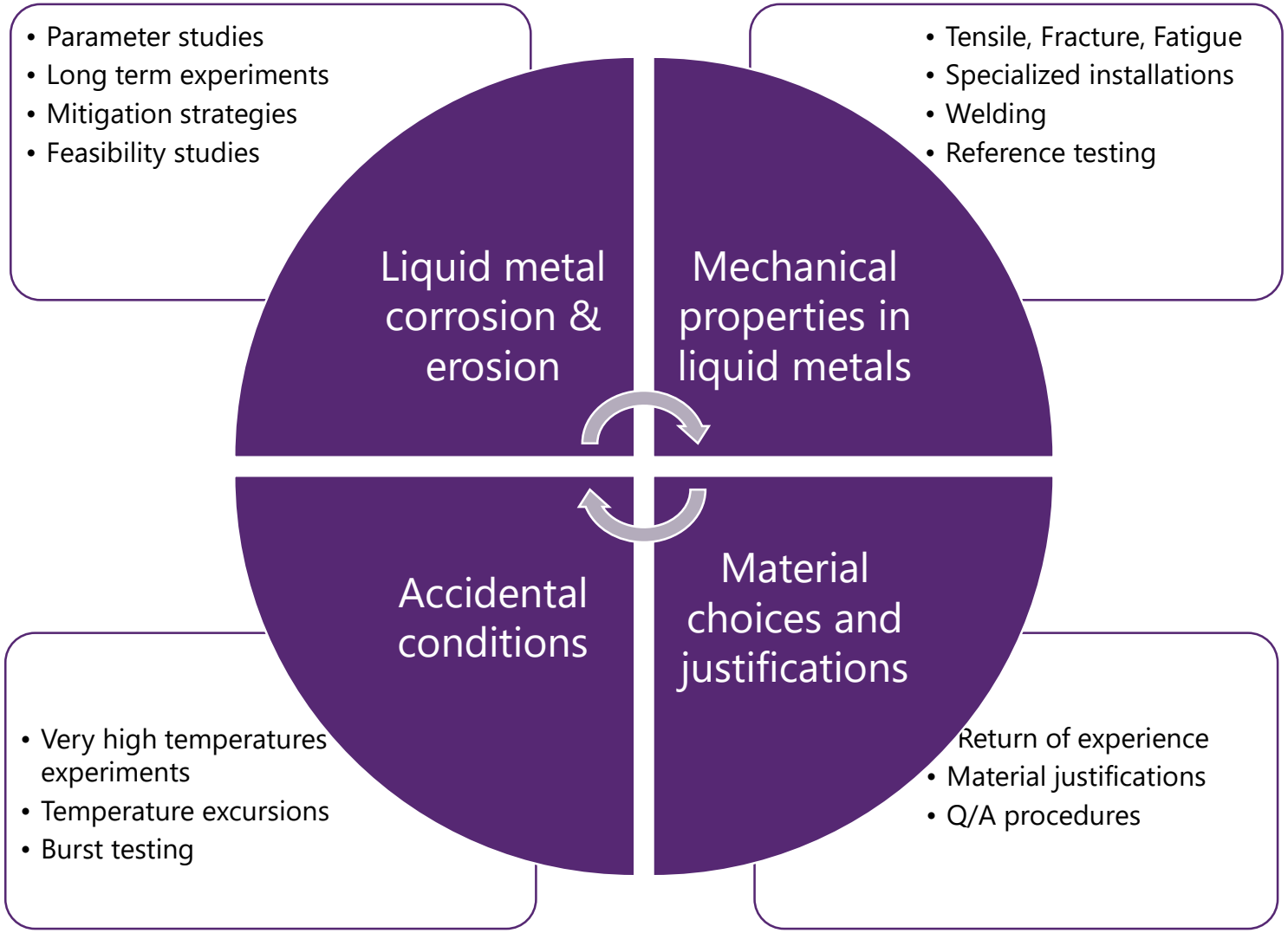
Material R&D is not linear



Thermal-hydraulics (T-H) topics

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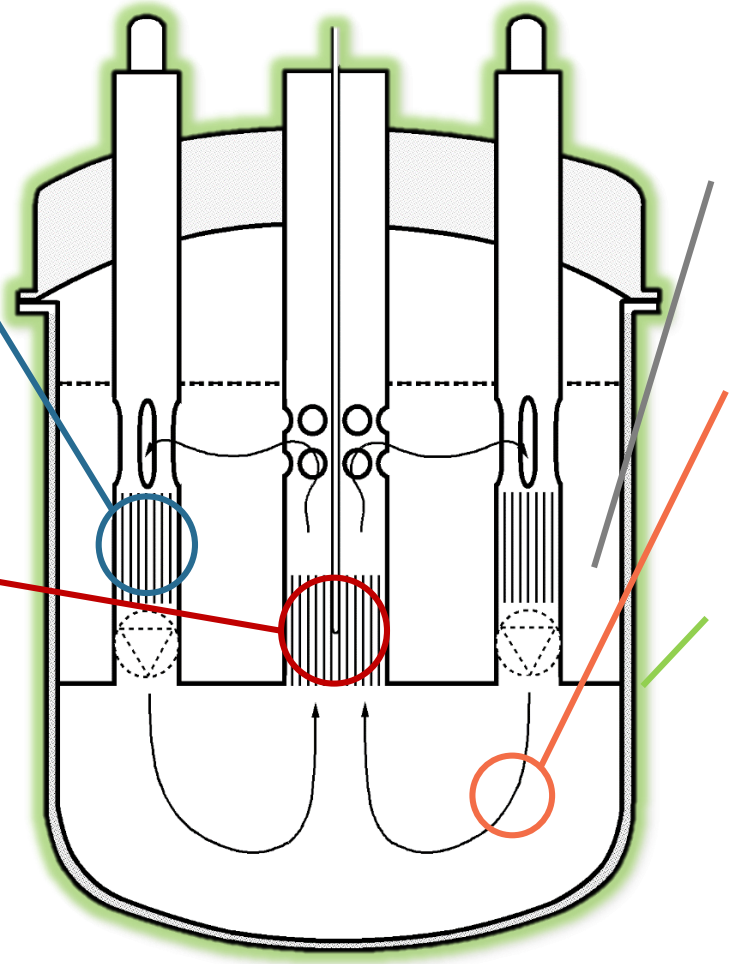
Primary heat exchanger validation

- HEX tube performance evaluation
- Fouling effects

Fuel assembly & core thermal-hydraulics

- Fuel assembly velocity & temperature field
- Blockage effects & initiation
- Deformed FA
- Flow-induced vibration
- Fouling effects
- Inter-wrapper flow



Liquid Metal (LM) fundamentals

- LM heat transfer

Pool thermal-hydraulics

- Mixing & stratification
- Flow patterns
- Solidification

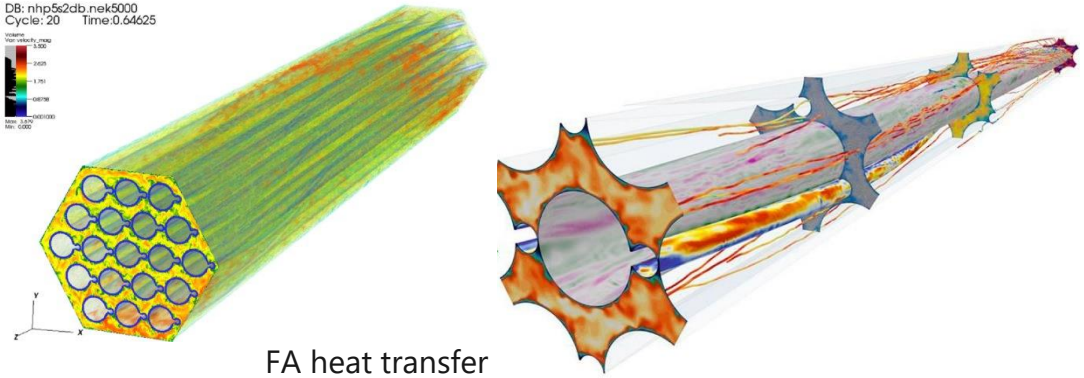
System thermal-hydraulics

- Passive heat removal
- Flow transients
- Asymmetric behaviour

Seismic sloshing

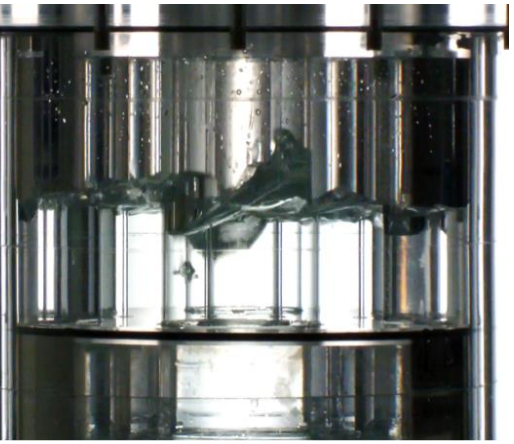
- Forces on vessel & components
- Reactor coolability

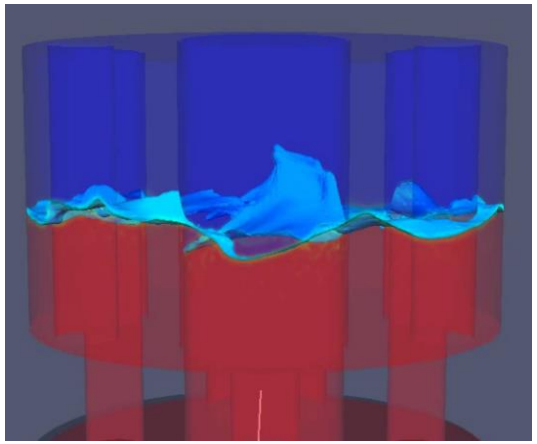
Thermal-hydraulics (T-H) topics



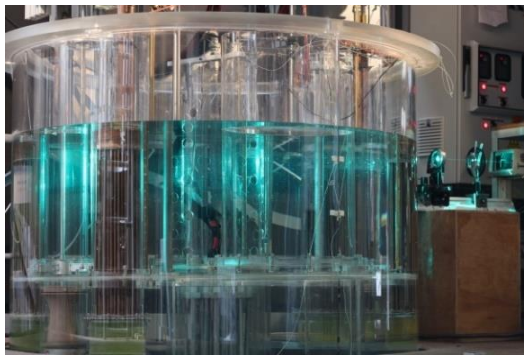
FA heat transfer

Pool TH





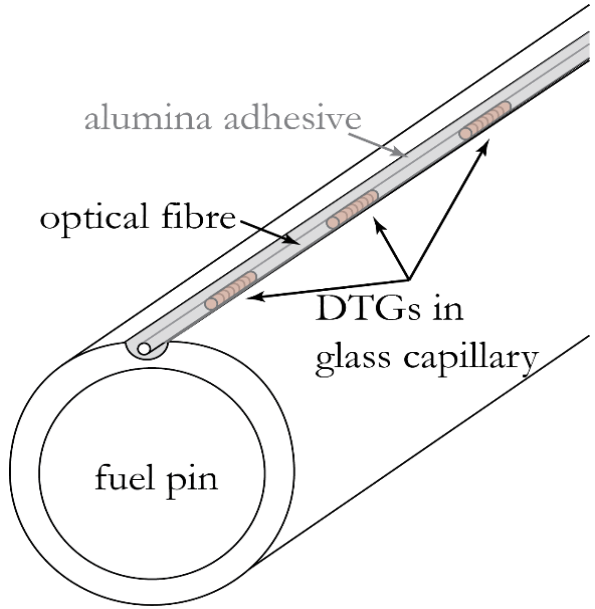
Sloshing

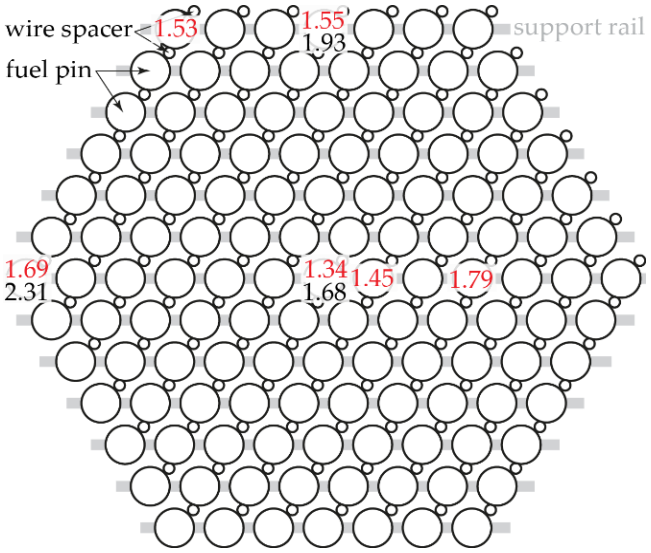


Flow induced vibration experiment

Fuel assembly thermal hydraulics : flow induced vibration

- Fuel assembly hydraulics: **flow-induced vibration (FIV)**
  - Full-scale 127-pin fuel assembly instrumented with optical fibre FBG sensors for FIV monitoring
  - 16 instrumented pins, 21 fibre optics (Ø200µm)
  - 226 FBGs in total (1 kHz sample rate)
  - **No fatigue damage expected** based on exp. results





Maximum vibration strain (µε)

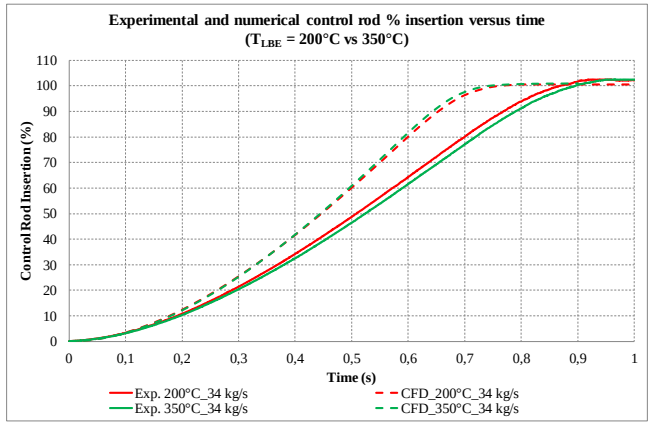
Thermal hydraulics

- Very high similarity between Pb and LBE
- Mainly design differences
  - wire spaced vs grid spaced FA
  - HEX design
  - …
- Thermal hydraulic analyses of full reactor needs simulation
- Model validation is crucial
  - TH experiments need to be supported by numerical analyses
- Intermixing with component tests
  - Component tests used for TH purposes

Component tests

Design validation of essential components

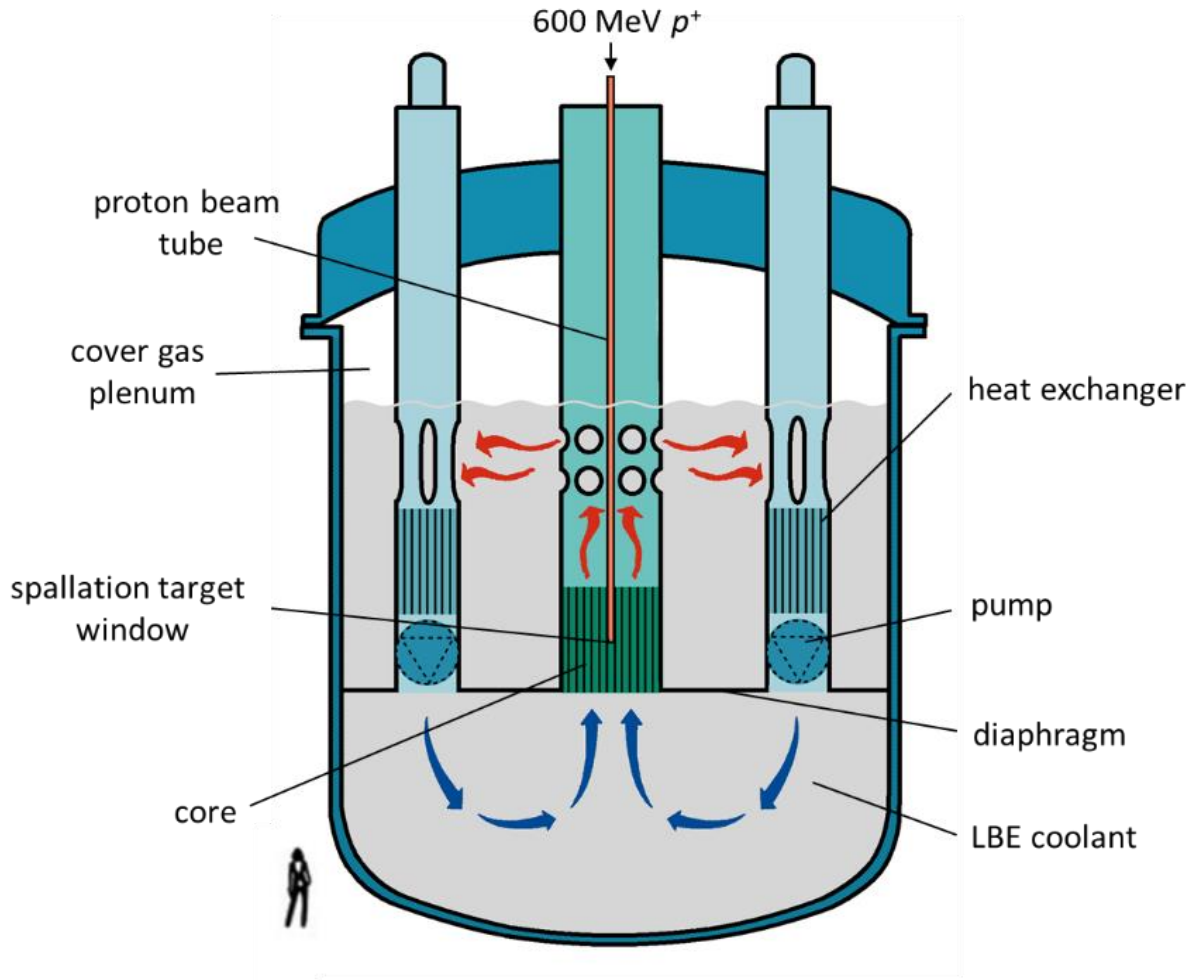
- Fuel assembly
- Primary HEX
- Control rod system
  - Proof of principle
  - reliability
  - Seismic tests
- Safety rod system
- HLM pump
  - Hydraulic design
  - Bearings
  - Impeller
- In-vessel fuel handler



Chemistry control : topics

- Keep the HLM in the right condition
  - Oxygen monitoring and control
  - Impurity effects and purification
  - Radionuclide release
  - Component cleaning

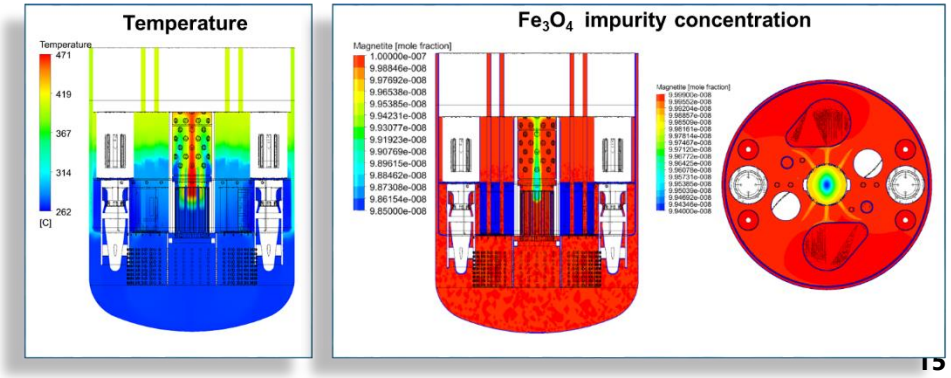
- Pb ⊂ LBE
- Reactor ⊂ ADS



Chemistry control

- Oxygen control
  - Sensors
  - Control methods
  - REX large experiments
- Impurity effects and purification
  - Thermodynamics of oxygen and impurities in HLM
  - Formation /dissolution/deposition kinetics
  - Development of chemical-thermal-hydraulic simulation methods & tools
    - Mass transfer, nucleation, growth, dissolution, deposition, particle transport
    - Where does nucleation & growth occur, where do particles accumulate ?
  - Long term safe state
  - Purification strategy
    - Filters
    - Cold trap
    - Surface cleaning
    - Electrochemical impurity sensor development

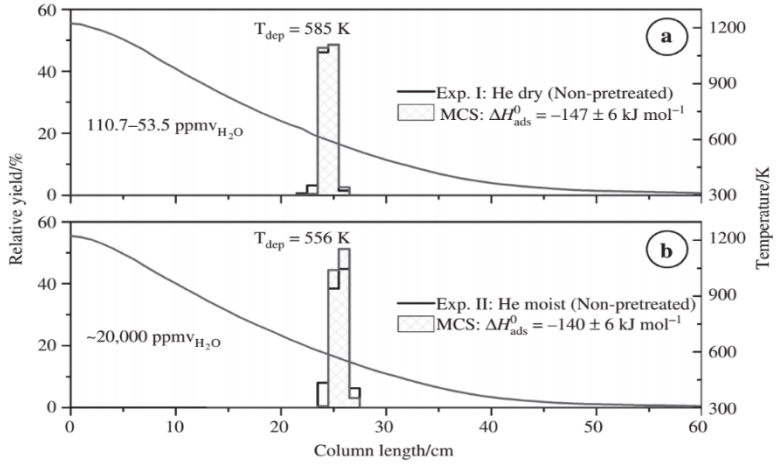
Plugged pipe by Bi-Ni of CORRIDA (KIT)



Chemistry control

Radiological release : study of safety critical radionuclides

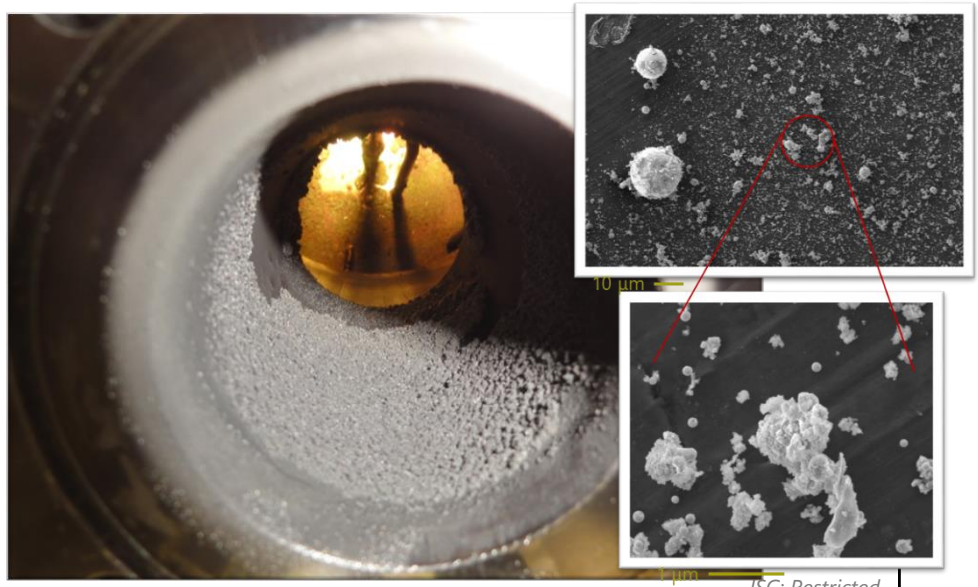
- Radionuclide inventory (spallation, coolant activation, fission products)
- Hg release & gettering
- Po release studies
  - Normal operation & accident conditions
    - Enhanced release in presence of water vapour
    - Po strongly absorbed on stainless steel in humid cover gas
  - Filter/getter design to be optimized
  - Po release in vacuum studies (window break) in preparation
  - Window leak detection experiment planned at JRC Karlsruhe



Chemistry control

Radiological release : study of safety critical radionuclides

- Fission product release to LBE
  - JOG (Joined oxide Gain) interaction with LBE
    - Retention of FP in JOG vs diffusion to HLM
    - LBE/JOG/Clad interaction 500°C-1000°C
- Fission & spallation product release studies from HLM and gas phase deposition
  - Experiments, literature data, thermodynamic modelling
  - MEGAPIE feedback
  - Determination of retention factors ongoing
  - Characterisation by MBMS
- Aerosol formation
  - Potential transport mechanism for radionuclides (HeliosIII)
    - Formation mechanism, source term assessment
    - Experimental programme for code validation & numerical modelling



Chemistry control

Component cleaning and decontamination

- Investigation focused on HLM removal
  - After HLM removal, existing decontamination can be used if needed
- Potential methods
  - Chemical cleaning
    - Ethanol/acetic acid/hydrogenperoxide
    - REX on large scale components from CIRCE experiments
  - Mechanical cleaning
    - Solid CO2 blasting
- Focus on REX
- Waste stream optimization

Instrumentation & reactor control

- Reactor control experiments (Guinevere at VENUS)
  - Experiments completed
  - Analyses ongoing
- Instrumentation development
  - REX from experiments
- In-service inspection tools & strategy
  - Demonstration that US inspection works in a HLM system

Guinevere & VENUS

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Summary

- HLM R&D is about risk reduction
  - supports design and safety
- Programme needs to be complete
  - “Basic” information generation
  - Design confirmation (qualification)
  - Off-normal and accident scenarios
- Required :
  - Efficiency in resources
  - International collaboration
  - Optimised use of simulations

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