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European SMR Pre-Partnership – R&D Needs & Technical Issues of the Nuclear Steam Supply Systems

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Overview of Technical Issues

- Regulatory framework, applicable nuclear codes & standards (NC&S)
- Reactor internal hydraulics (incl. Vibrations)
- Reactor structural materials and coolant chemistry control for LFRs
- Specific Reactor Components
- Advanced Manufacturing
- In-Service Inspection
- …

Regulatory Framework incl. NC&S

- 3 levels for harmonisation in principle:

1. Legal framework (country legislators, very challenging)
2. Licensing & regulation (nuclear regulators, challenging, but aim of WS2)
3. NC&S (mainly industry, manageable)

- Expectation that common NC&S (ASME, AFCEN, …) also applied to SMRs, requiring some adaption & extensions.
- Alternative proposal: Start from PED (valid in whole EU, but not applicable to nuclear components) + extend to cover nuclear components.

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Reactor Internal Hydraulics – water-cooled SMRs

- Thermal hydraulics (TH) of water-cooled SMRs basically the same than large LWRs. However some differences due to different component size and scale & importance of relevant phenomena (e.g. sub-cooled boiling, CHF onset, flow instabilities, induced vibrations, …).
- Existing computational codes for TH analysis largely applicable to water-cooled SMRs, but may require separate validation or addition of modules for 1-phase or 2-phase or pressure drops in complex geometries (e.g. microchannels). (**R&D need**)
- Wherever crucial safety-relevant phenomena (e.g. fuel rod dryout) are investigated or passive safety systems are exploited (e.g. natural recirculation in accident scenarios), experiments are required. (**R&D need**)

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Reactor Internal Hydraulics – Fast SMRs

- Key topic in design and safety analysis of FRs
- 3 areas of TH challenges: Core TH, pool TH, system TH, distinguishing normal reactor operation, off-normal conditions and severe accidents for each area
- 7 basic phenomena that are at basis of above challenges and thus require investigation: turbulent heat transfer, thermal fluctuations, mechanical fluctuations, mass transfer, bubble transport, particle transport and solidification.
- Safety demonstration of FRs relies to large extent on numerical analysis of various transients of interest.
- **R&D needs**: Numerical analysis codes need to be validated against exhaustive experimental databases and uncertainties associated with analysis results need to be quantified.

Flow-induced Vibration (FIV)

- Causes fatigue and wear of components and can lead to substantial damage.
- Affected LWR components: fuel rods, heat exchangers, steam generators, canned motor reactor coolant pumps
- SMRs (iPW-SMRs, LFRs) rely on innovative compact component designs, e.g. heat exchangers / steam generators, coolant pumps, … that lack data and qualified heuristic methods to predict FIV.
- **R&D needs**: Development of numerical tools (FE/CFD-based) for FIV prediction and analysis, including their validation via experiments.

Reactor Structural Materials & Chemistry Control for LFR

- Corrosion & liquid metal embrittlement (LME) are critical factors for structural materials selection of reactor vessel and internals.
- SS 316L promising reactor material, but its corrosion in lead depends upon temperature and dissolved O2 content of lead coolant.
- Alumina-forming Alloys or alumina-coated steels are candidate structural materials, but require testing & qualification.
- **R&D needs**:
  - Materials for reactor coolant pump impeller
  - Demonstration of structural materials and O2 control strategies for corrosion control under operational conditions for an engineering-scale demonstrator LFR.
  - Development & qualification of advanced structural materials in high-temperature lead and irradiation conditions
  - Development of design codes or code cases for corrosion resistant materials or coatings.

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Specific Reactor Components

- Very high temperature components (HTG-SMRs) made of high-T materials (e.g. Inconel 617, Hastelloy, …)
- Immersed vs. conventional CRDM for iPWRs
- Pump designs (canned motor pumps vs. other)
- Compact steam generators
- Diffusion bonded heat exchanger
- **R&D needs**: all the above have specific R&D needs.

Advanced Manufacturing

- Advanced manufacturing covers relatively novel manufacturing technologies: additive manufacturing (3D printing), diode laser cladding, electron beam welding (EBW), …
- These have unique advantages compared to conventional manufacturing methods, e.g. add. Manufacturing allows rapid manufacturing of complex geometry components, EBW generates welds with virtually no HAZ, …
- To use them to produce safety-related structures & components they need to be incorporated into NC&S or comply with them, which requires stable & qualified processes with reproducible output.
- **R&D needs**: R&D projects to incorporate advanced manufacturing technologies into NC&S, similar to ongoing Euratom project NUCOBAM for additive manufacturing.

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In-Service Inspection (ISI)

- Assumption that current ISI rules for large LWRs, e.g. ASME Sec. XI, RSE-M, also apply to SMRs, with some possible additions / adaptions (e.g. new ASME Sec. XI Div. 2 addressing ISI for non-water-cooled SMRs).
- Like for large LWRs NDT systems for SMRs need to be qualified, either PDI-type or ENIQ-type inspection qualification.
- Depending upon the operating temperature and coolant new NDT technology needs to be developed.
- We may also see large deployment of SHM systems in-lieu of ISI performed by humans.
- **R&D needs**:
  - Development of inspection strategies for various SMRs
  - Development of NDT technologies for high temperature and non-water environments
  - Investigation on use of SHM systems in-lieu of inspections performed by humans.

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