Economical risks in licensing and available tools for safety analysis

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JAAKKO LEPPÄNEN, ATTE HELMINEN, VILLE TULKKI

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- Part I: Economical risks in licensing:
  - Objectives
  - Licensing costs

- Part II: Available tools for safety analysis:
  - Safety analyses related to licensing, example case: LDR-50
  - Core physics and system-scale analyses
  - Challenges and next steps

Part I: Economical risks in licensing

Content and objective of the study

- Collection of suitable references
- Definition of licensing and what is included in the licensing costs
- Estimation of licensing costs for a 100 MWth nuclear heating plant:
  - **Top-down approach:** Scaling down from conventional (large) LWR
  - **Bottom-up approach:** Adding up estimated costs for each component
  - Comparison of the results from two approaches
- Discussion and further research identification

Definition of licensing costs

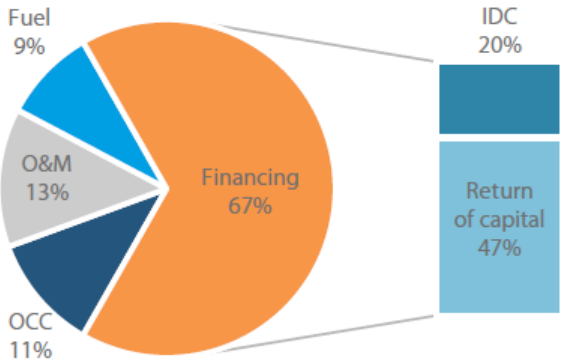
- Covers the construction or operating licence for a nuclear power plant
- In the licensing process, the safety authority will review and assess:
  - Design basis of the plant
  - Requirement specifications
  - Analyses substantiating the fulfilment of safety criteria
  - Implementation of defence-in-depth concept and safety functions

Definition of licensing costs

- Challenges:
  - Process is closely connected to plant design -- difficult to specify exactly what is included in the licensing costs
  - The licensing costs are often listed under the category of owner costs
  - How comparable are the overall costs of large power reactors to the overall costs of SMR?
  - How comparable is the percentage share of SMR licensing to a large power reactor's licensing?
  - Passive safety functions involve new technology without prior licensing experience
- Not possible to make accurate top-down or bottom-up estimates based on publicly available data.

Cost breakdown structure of nuclear power

- Various cost categories: construction, operation, decomissioning, financing, …
- Licensing costs are typically listed under owner costs (15-20% share)
- Owner costs listed under overnight construction costs (11% share)



Note: Calculations based on OCC of USD 4 500 per kilowatt of electrical capacity (/kW_e), a load factor of 85%, 60-year lifetime and 7-year construction time at a real discount rate of 9%.

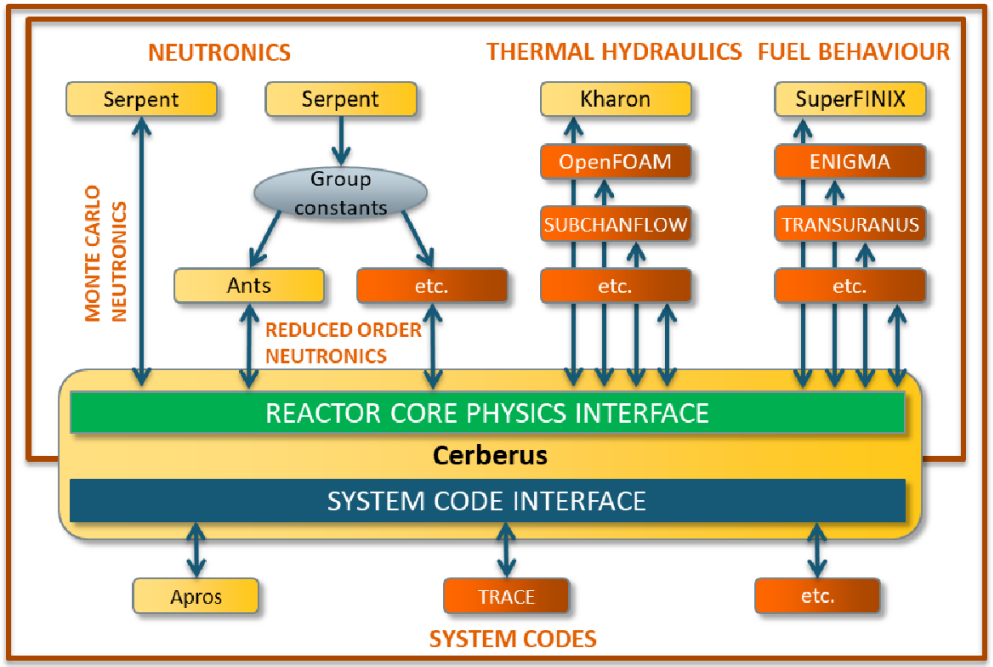
Part II: Tools for safety analyses

Safety analyses related to licensing

- Analyses for different systems at multiple levels:
  - Various scales: reactor core, system-scale, plant level, …
  - Normal operation, transients, accidents
  - Deterministic and probabilistic methods
  - Different phenomena: neutronics, thermal hydraulics, material behavior, external threats, severe accidents, dispersion of emissions, …
  - Not only technical: human factors, security, …
- Example case: conceptual design of VTT's LDR-50 district heating reactor

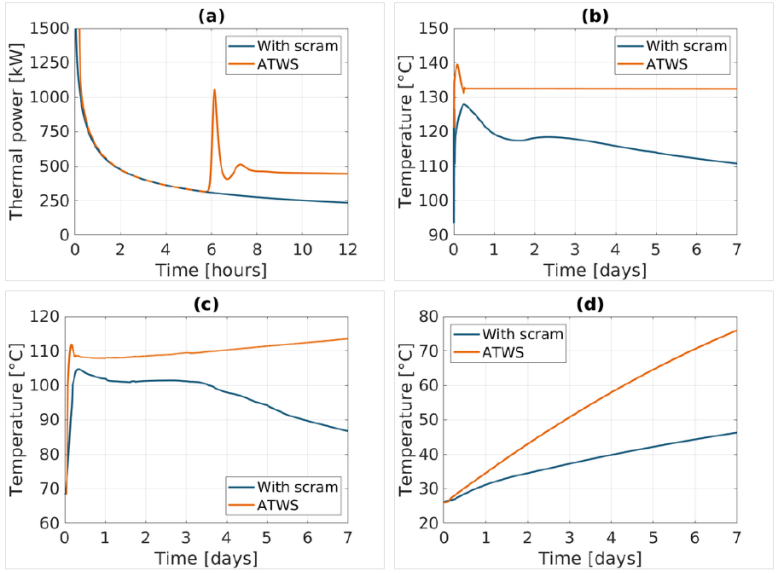
Core physics

- Coupled problem between neutronics, thermal hydraulics and fuel behavior
- Fuel cycle simulations: ensuring that the reactor operates within a safe regime
- Transient analyses: behavior in transients
- Source terms for other analyses: accidents, radiation protection, final disposal
- Separate analyses: criticality safety, etc.
- Codes used at VTT: Serpent, Kraken



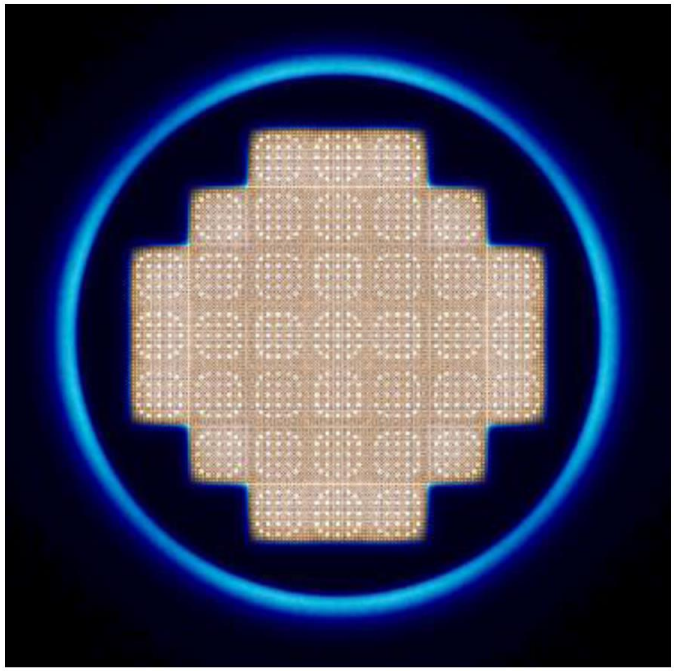
System-scale analyses

- Core-level calculations are coupled to system-scale analyses via boundary conditions
- Time-dependent neutronics in reactivity transients, but most initiating events lead to reactor scram
- Long time-scale, requires models for primary circuit and connected systems
- Examples of safety analyses: SBO, small-break LOCA, etc.
- Codes used at VTT: Apros

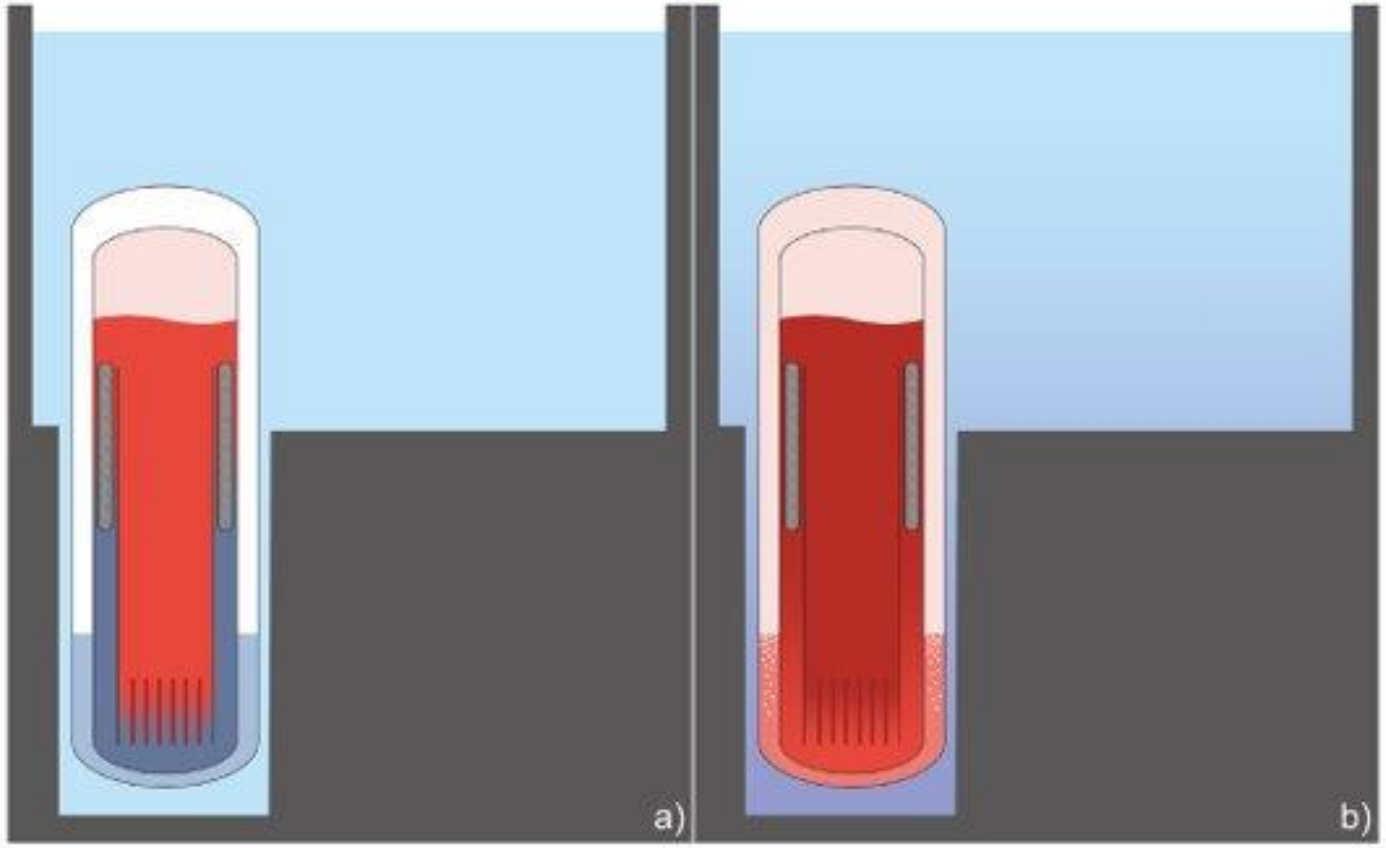


Challenges and next steps

- SMR cores are neutronically compact and challenging for reduced-order methods (nodal diffusion)
- Modelling natural circulation requires full system-scale calculations
- Heat transfer at low temperature and pressure requires experimental confirmation
- Passive decay heat removal function in LDR-50 is robust, but modelling long-term behaviour is challenging



Challenges and next steps



Challenges and next steps

- Example tasks planned for the next development stage:
  - Deterministic safety analyses to be accompanied by PRA
  - New severe accident model under development in Apros
  - Dispersion of radioactive emissions in urban environment
  - Complementary CFD analyses for reactor vessel and pool
  - Improvements in heat transfer models in Apros
- Computational safety analyses must accompanied by experimental work, e.g. component- and system-scale TH experiments.

Eco SMR

Summary and conclusions

- Different approaches can be taken in the evaluation of licensing costs
- Estimates are complicated by the lack of available data and new safety philosophies applied to SMRs
- Existing computational tools and methods are for the most part applicable to LWR-type SMRs
- New challenges related to passive safety functions, urban siting, etc.