Current Challenges in Nuclear Safety R&D especially Code Development

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Challenges Faced by Technical and Scientific Support Organizations (TSOs) in Enhancing Nuclear Safety and Security

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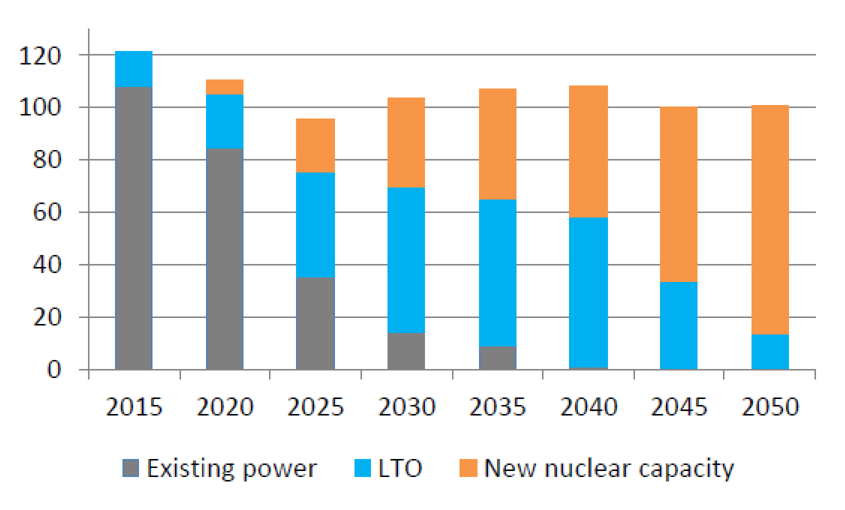
Introduction – Nuclear Illustrative Programme (PINC) of the EU [1)]

- Communication of PINC is a requirement under Article 40 of the Euratom Treaty
- Overview of planned investments for next steps of the nuclear lifecycle until 2050
- Nuclear energy is part of the energy mix of half of the EU Member States: 27.5% nuclear, 29.2% renewable sources within the EU [1)]
  - *EU requires: Member States need to apply the highest standards of safety, security, waste management and non-proliferation as well as diversify nuclear fuel supplies. It will help to achieve the objectives of the 2030 climate and energy framework.*
- Decline in nuclear generation at EU level up to 2025 due to Member States phase out
- Trend would be reversed by 2030 as new reactors are predicted to be connected
- Capacity replacement up to 2050 will most likely be by advanced reactors: EPR, AP 1000, VVER 1200, ACR 1000, ABWR
  - *Challenges in Nuclear Safety R&D / Code Development.*



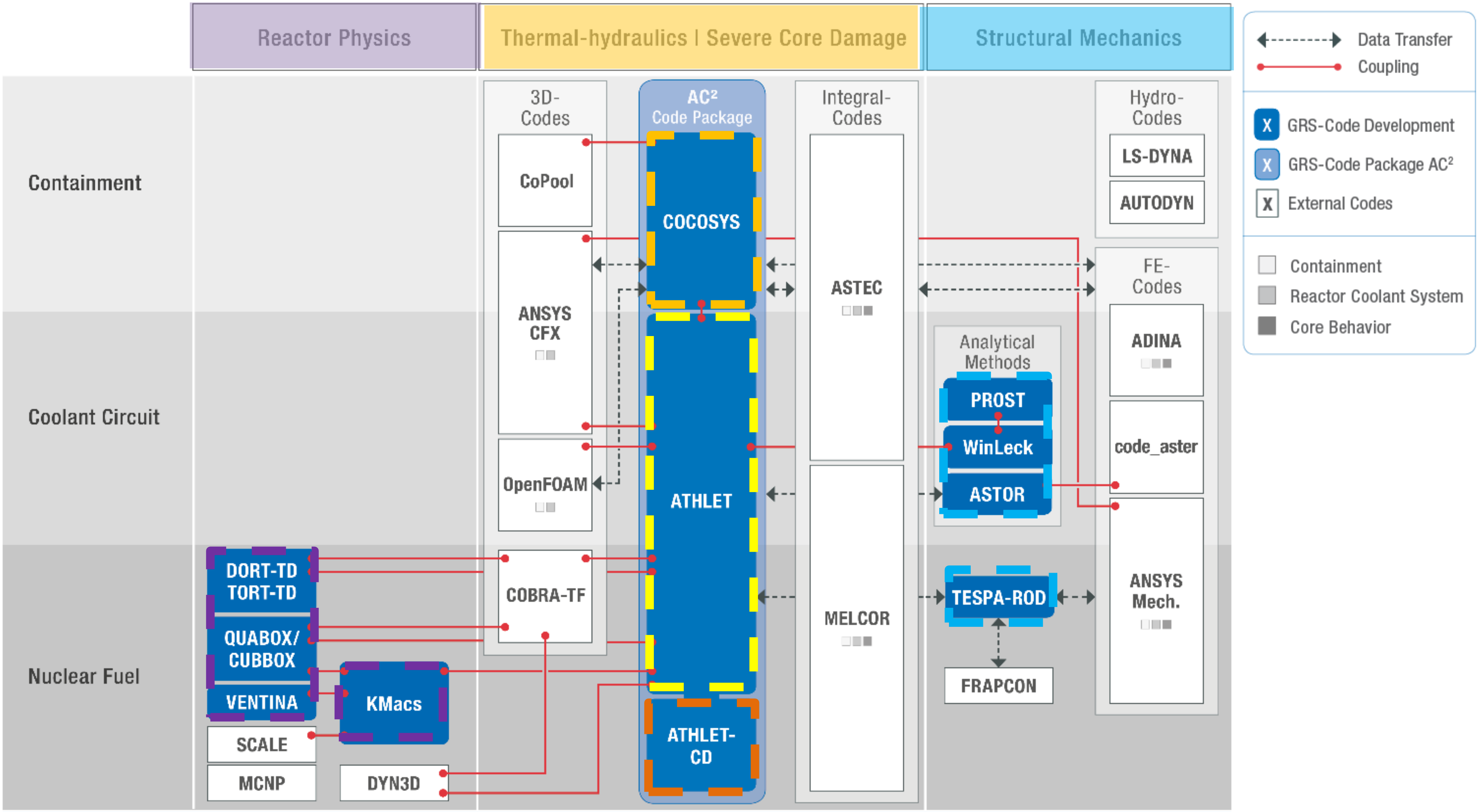
1) - https://ec.europa.eu/energy/sites/ener/files/documents/nuclear_illustrative_programme_pinc_-_may_2017_en.pdf

Introduction – GRS, main German TSO & ETSON member

- **GRS** is the main **Technical Support Organization (TSO)** in nuclear safety for German federal government and a major research organization
- GRS is an independent non-profit organization and a Member of ETSON
- GRS is traditionally involved in numerous int. activities e.g. IAEA, OECD/NEA, EU
- Research Tasks and Safety Analyses at GRS are done to provide technical support to different German ministries: BMU, BMWi, AA, BMBF
- GRS as the main German TSO will retain its function in supporting the German government even after phase out of Nuclear Energy production
- **Reactor Safety Research at GRS**:
  - Scientific codes *(Nuclear Code Chain)* – developed, validated and applied for the analyses of operational states, accidents and severe accidents in various NPPs, other facilities, spent fuel storage, etc.
  - GRS Codes represent the current state of science and technology
  - Participation in experimental projects is done to improve understanding of fundamental safety phenomena and to get reliable data for code/model validation (no experimental facilities are operated at GRS)

➢ ***Challenges:*** *GRS Activities should follow international / EU trends in Nuclear Energy.*

Introduction – GRS‘ Nuclear Code Chain



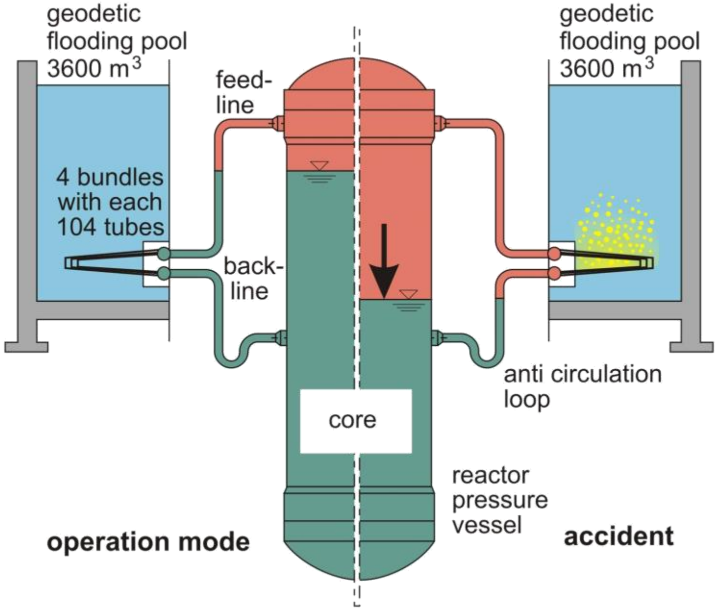
➢ ***Challenges:*** *Further development / validation of Nuclear Code Chain, so that it can be applied for safety analyses of existing / advanced / innovative NPPs & SMR.*

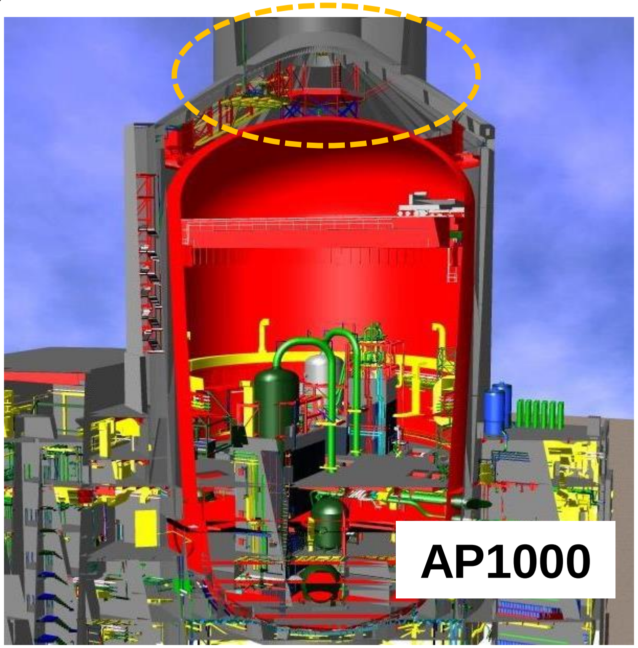
Challenges in Code Development – Thermal Hydraulics

- GRS TH code chain was originally developed for Gen. II reactors

> ***Challenges:*** *Application for Gen. III/III+ and Advanced Designs:*
> - *Passive cooling systems (convection and condensation phenomena, inter-actions cooling circuit – containment, etc.), ultimate heat sink (heat pipes etc.)*
> - *Material properties, specific correlations and models relevant for Accelerator Driven Systems and Gen. IV (near vacuum, supercritical water, liquid metals e.g. sodium or lead-bismuth, etc.)*

Passive cooling systems

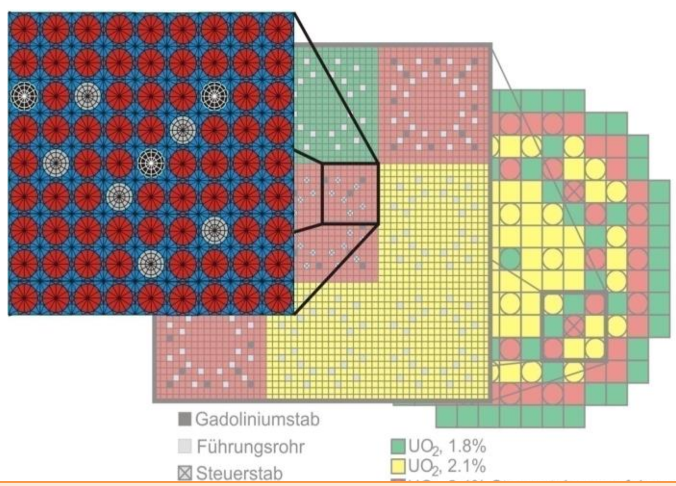




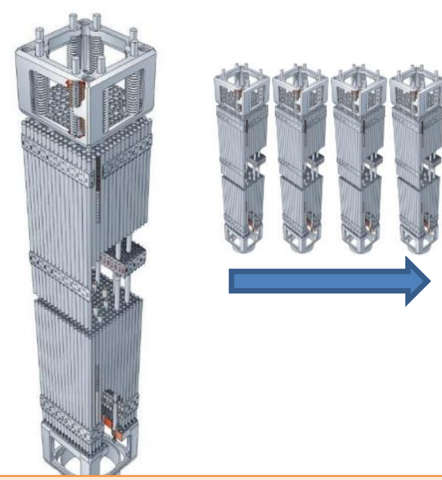
Challenges in Code Development – Reactor Physics

- Different core simulators have been developed:
  - **Assembly wise Core Simulator** (nodal) for calculation of power distribution (QUABOX/CUBBOX using diffusion approximation)
  - **Pin-by-pin Core Simulator** for improved calculation of rod wise power distribution (DORT-TD/TORT-TD – multigroup transport), especially to describe dedicated phenomena in innovative reactor systems
  - New **Core Simulator KMacs** for detailed operation cycle calculations, applied for western-type PWR

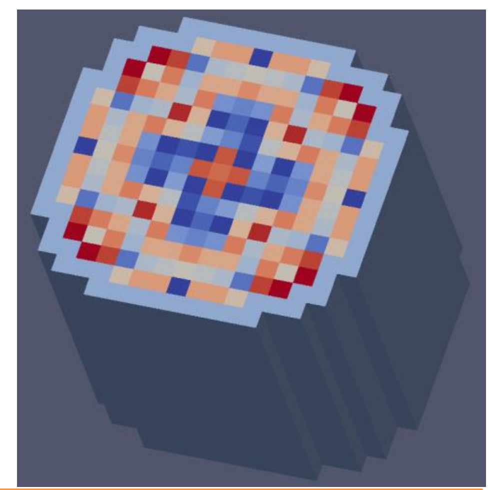
Transition from Coarse-Mesh to Pin-by-Pin



Cross-Section Generation



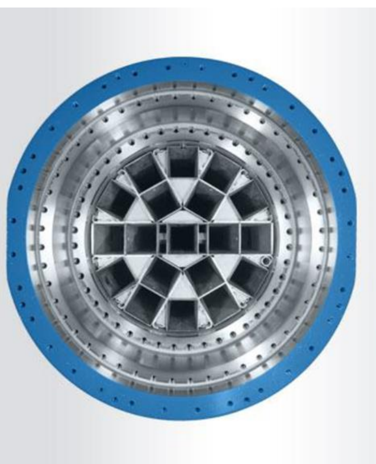
Cycle Calculation

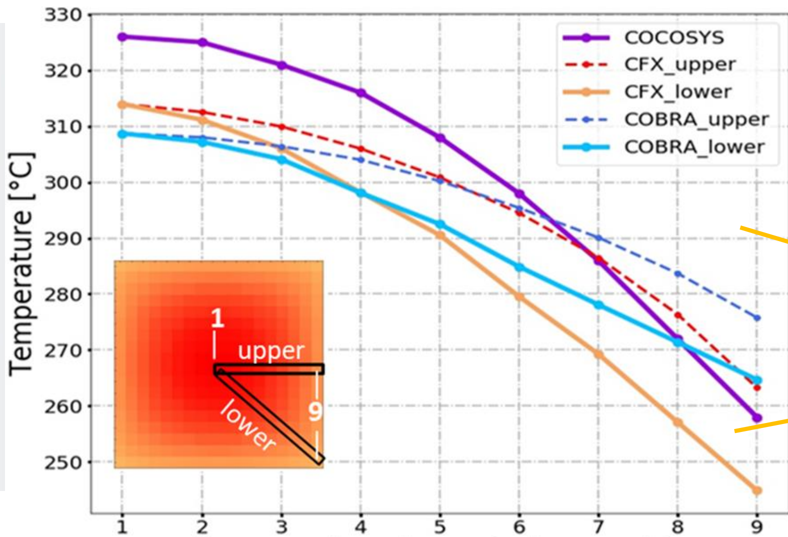


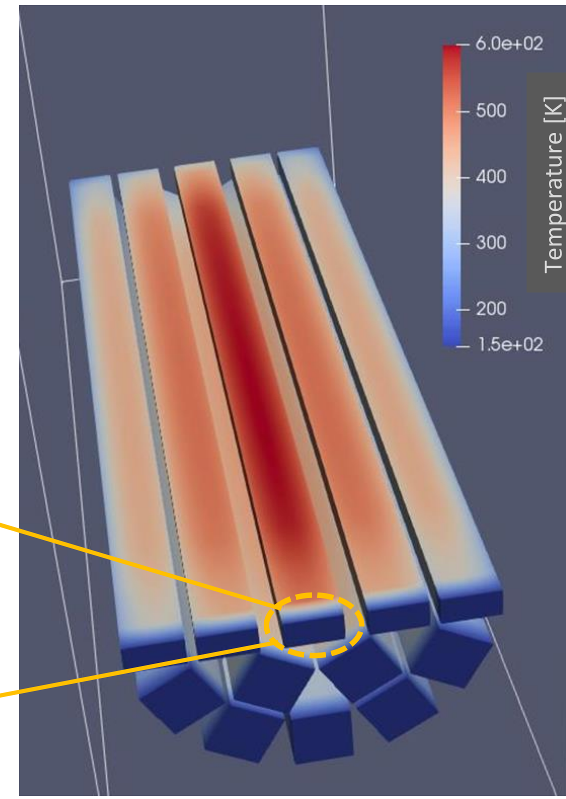
> ➢ ***Challenges:** Extension of core simulators for other fuel assembly geometries and multi-physics / multi-scale code coupling in the field of neutron kinetics.*

Challenges in Code Development – Fuel behaviour / storage

- Spent fuel dry cask interim storages are currently commissioned for ~40 years
- Extended long-term operation of such dry storage facilities is expected
- 3D temperature field of a loaded cask was analysed using different codes: COBRA-SFS, COCOSYS, ANSYS CFX
  - Large variations of the cladding temperatures can be observed in both horizontal and vertical directions
  - The temperature results are used to predict the thermo-mechanical cladding behaviour



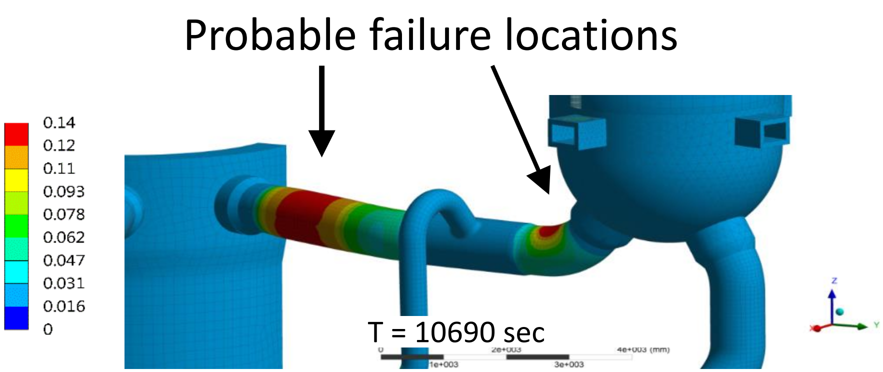


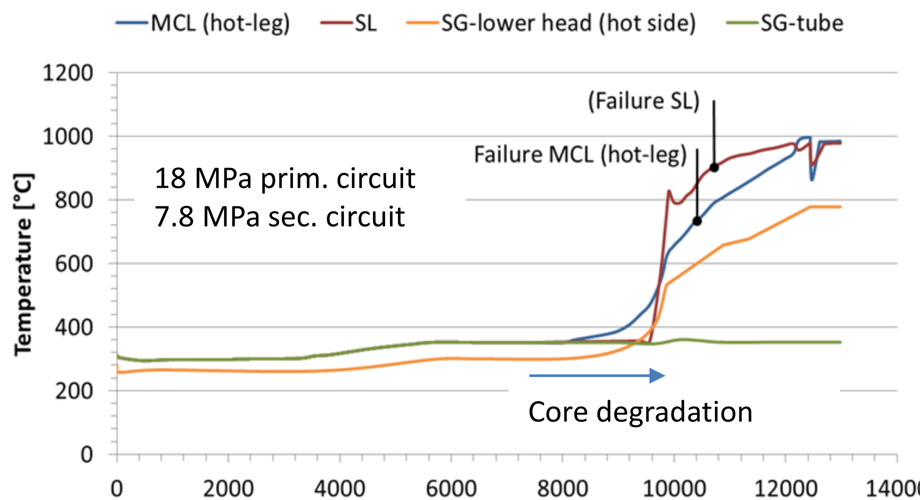


➢ ***Challenges:** Additional knowledge and data about material and component performance in conjunction with predominant conditions are necessary, etc.*

Challenges in Code Development – Component behaviour

- Development / Validation / Application of Structural Mechanics codes for analyses of component behaviour under severe accident loads – coolant circuit & containment
- Calculation of component failure time with ASTOR, ANSYS Mechanical
- Example: Station-Blackout-Scenario with core melt in a PWR
  - Progressive failure process
  - Strong increase of temperature leads to radial deformations and strains within short time up to failure due to plastic instability
  - First failure: Main Coolant Line (hot-leg)





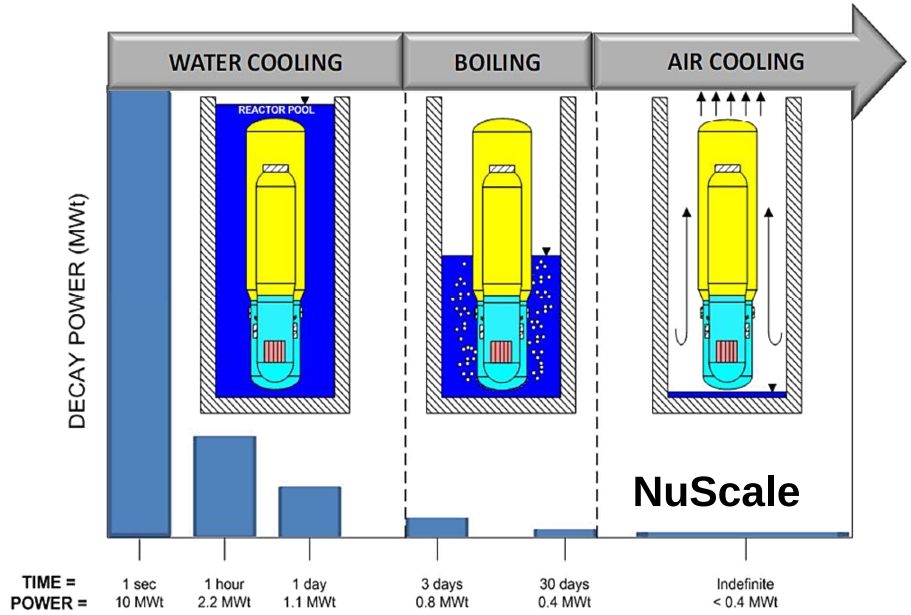
➢ ***Challenges:** Improvement of methods / codes related to material conditions under high temperature / pressure, consideration of local effects, asymmetric loads in combination with determination of finite leak size, etc.*

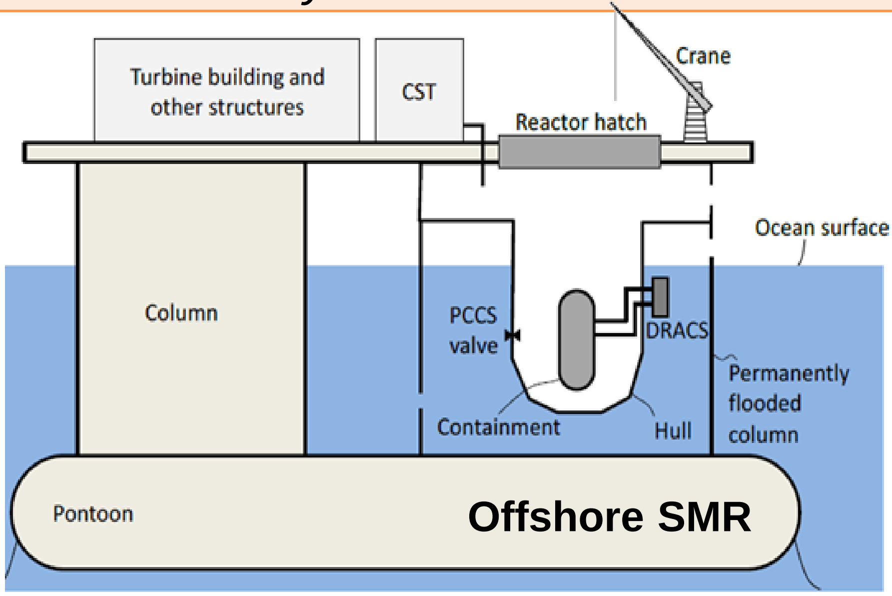
Challenges in Code Development – Small Modular Reactors (SMR)

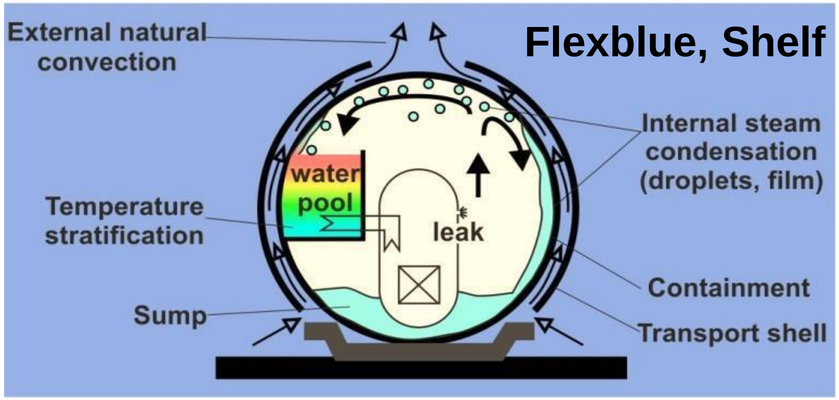
>130 SMRs are running, >100 new SMR concepts are under development:

- Various containment concepts are realized
- Integrated, often self-pressurized passive cooling systems with innovative heat exchanger designs (heat pipes, etc.)

> **Challenges:** *SMR require updates in the simulation of new physical phenomena and systems in the code chain.*







Conclusions and Outlook

- The German government decided to terminate the use of nuclear energy production by the End of 2022.
- Renewable energy production is an increasing factor in Germany.
- GRS as the main German TSO will retain its function in supporting the German government in all relevant issues on nuclear safety and radioactive waste management in Germany and abroad.
- Research at GRS in reactor safety so far was and will be focused on code development and validation for existing / advanced / innovative NPPs and SMR.
- Various *Challenges* have been identified; some examples have been discussed.
- Other *big Challenges* are
  - the conservation and transfer of “nuclear knowledge” to the next generation of nuclear engineers and physicists and
  - the restructuring / modernisation of our “legacy codes”.

➢ *GRS will have the necessary staff, competences, know-how and validated tools for safety assessments for Advanced NPPs and SMR in future as well.*

Thank you very much for your attention!

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