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Study of Safety and International Development of SMR

GRS

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General Information (1)

- Two Definitions
  - IAEA: Small (P_{el} < 300 MW) and Medium (P_{el} < 600 MW) Sized Reactors
  - US: Small Modular Reactors
- 1950 construction start of SMR (use as engines for nuclear ice breakers and submarines)
- Up to now app. 130 SMR are built worldwide (IAEA definition)

General Information (2)

- Examples for SMR in operation
  - India: 4 PHWR
  - Pakistan: CANDU-137 & 2 CNP-300
- Examples for SMR under construction:
  - Russia: Akademik Lomonosov (KLT-40S)
  - Argentina: CAREM
  - China: HTR-PM

Situation in Germany and at GRS

- German government decided to phase out from use of nuclear technology for commercial electricity generation

- **Why we do have a focus on SMR in Germany and at GRS?**

  - Energy Research Program of German government:
    → Conveys acknowledgement to observe current nuclear developments especially in foreign countries (e.g. SMR)

  - GRS is the key Technical Safety Organization (TSO) for German government

Current work at GRS on SMR (1)

- Study on SMR: 2013 – 2014, funded by German Federal Ministry for Economic Affairs and Energy (BMWi)
  - Setting up a sound overview on 69 SMR concepts (light & heavy water, liquid metal and gas cooled reactors as well as molten salt reactors)

    → Based on open access literature
  - Identifying safety relevant issues of the concepts by using German safety requirements for nuclear power plants and the fundamental safety functions
  - Identification of needs for adaptation for system codes of GRS used in reactor safety research

Current work at GRS on SMR (2)

- Prioritization of essential issues for GRS Reactor Safety Research in 2014 & 2015
- Treating of issues with highest prioritization for adaptation of system codes by national and international projects → First started in 2015
- National project on integral behaviour of operation of different passive safety systems (like emergency condenser, containment cooling condenser, water pools, etc.) during Design Basis Accidents (DBA) scenarios (LOCA, SBO)

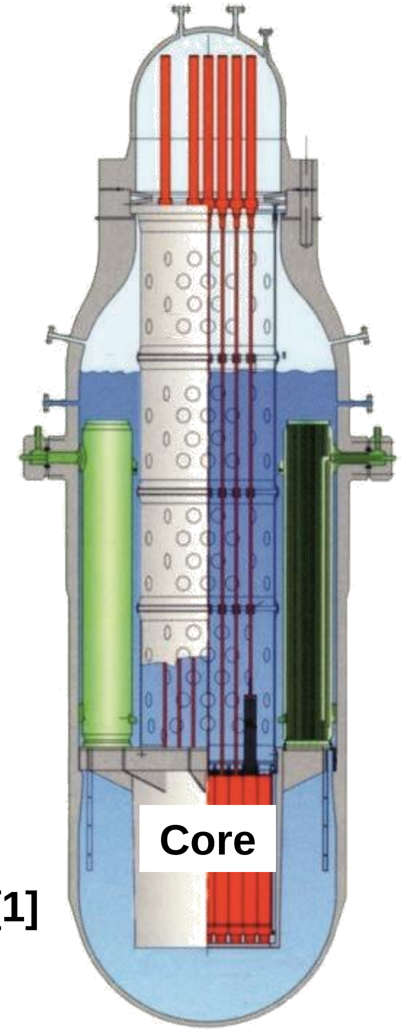
  → Start in 2015

Study on SMR development (1)

- In literature about 100 different SMR designs
- Intense work on 69
- Difference in working fluid:
  - Light Water (e.g. CAREM, NuScale, mPower, etc.)
  - Heavy Water (e.g. EC6, PHWR-220, etc.)
  - Liquid Metal such as Pb, Na (e.g. CEFR, HPM, SSTAR, 4S, etc.)
  - Molten Salt (e.g. FUJI)
  - Gas (e.g. HTR-10, EM^2, GT-MHR, etc.)
- Following selected results focus on light water cooled SMR

Study on SMR development (2): Core Characteristics

- Core is often located at low elevation
- High water column above the core
- Better heat removal due to (with respect to current PWR):
  - Reduced power density
  - Smaller distance between RPV wall and core
  - Larger curvature of RPV wall, but same pressures → smaller wall thickness
  - Larger surface to volume ratio
  - When using no pumps → No decreased cooling capability during blackout
- Boron free core → no deboration issues



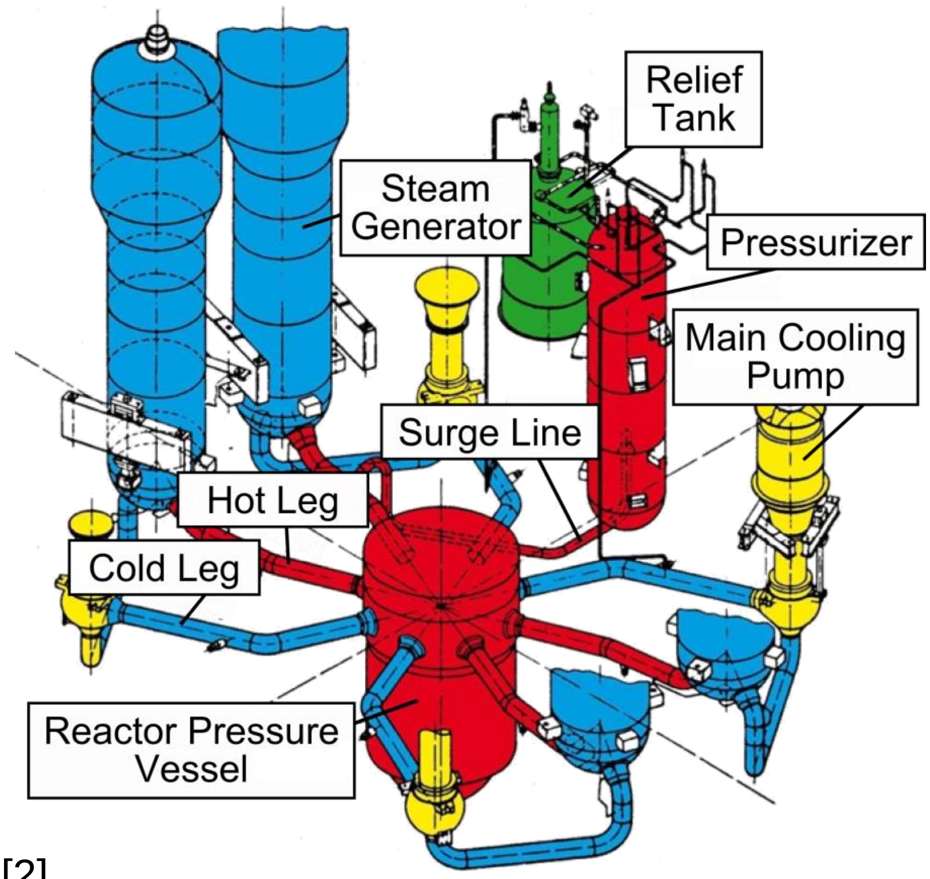
CAREM [1]

Study on SMR development (3): Integral design

- Integral Design → no activated coolant pipes
  - Elimination of Large Break Loss of Coolant Accident (LBLOCA)
    - PWR double end break of reactor coolant line (RCL) DN800 → 1 m^2
    - CAREM main steam line (MSL) DN30 → 0.001 m^2)
  - Minimizing number of connected pipes on Reactor Pressure Vessel (RPV)
  - Connecting nozzles mainly on the upper part of RPV

→ Easier mitigation of LOCA

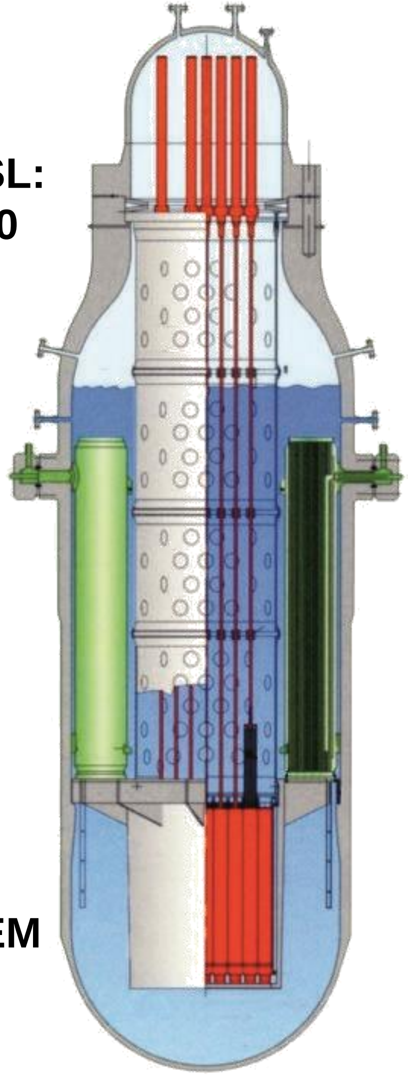
Study on SMR development (3): Integral design



[2]

4 RCL: DN800

12 MSL: DN30

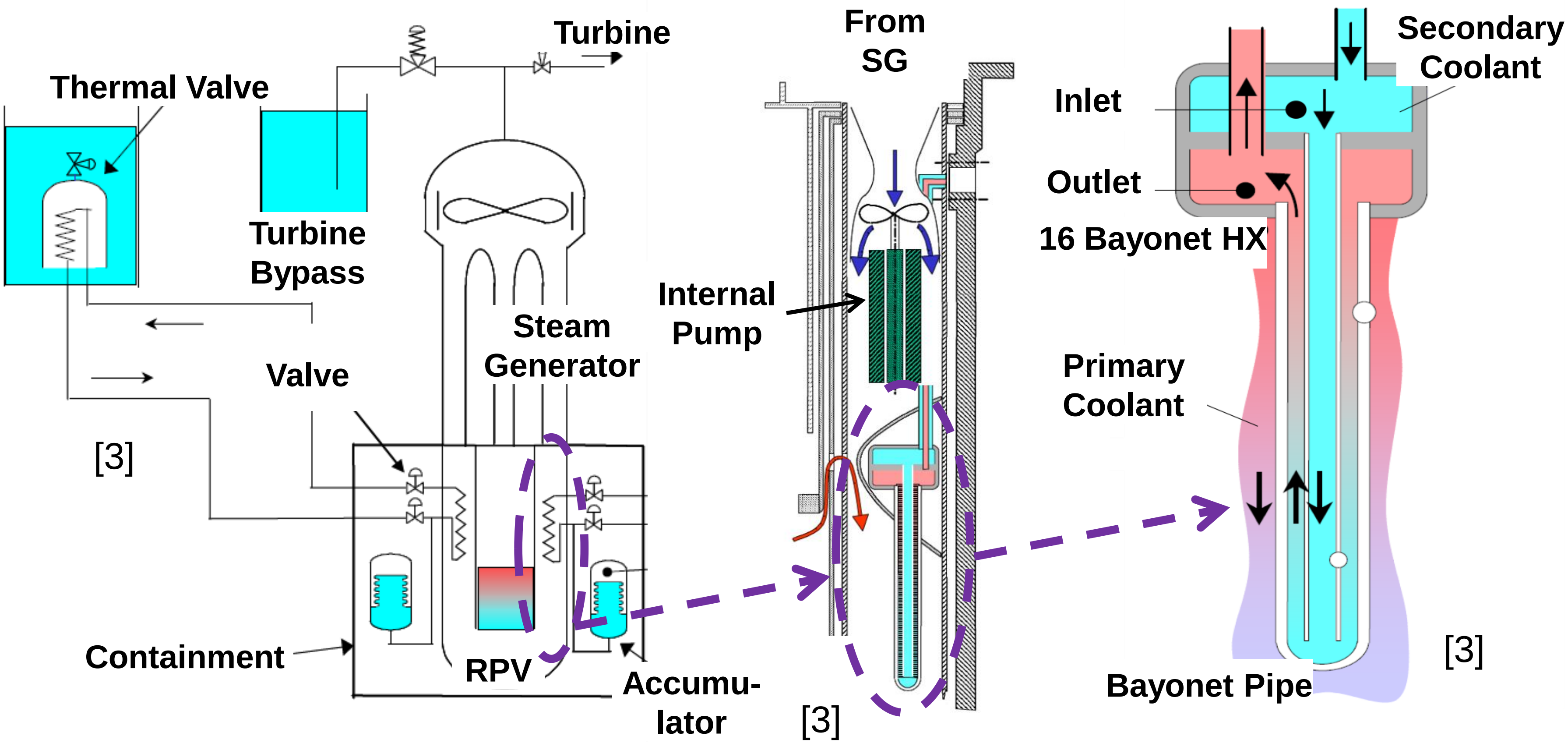


CAREM

Study on SMR development (4): (Passive) safety systems

- Passive safety features (based on natural principles e.g. convection, condensation, gravity, etc.)
- Example for passive safety system of SCOR (**R**esidual heat **R**emoval on **P**rimary Circuit RRP)

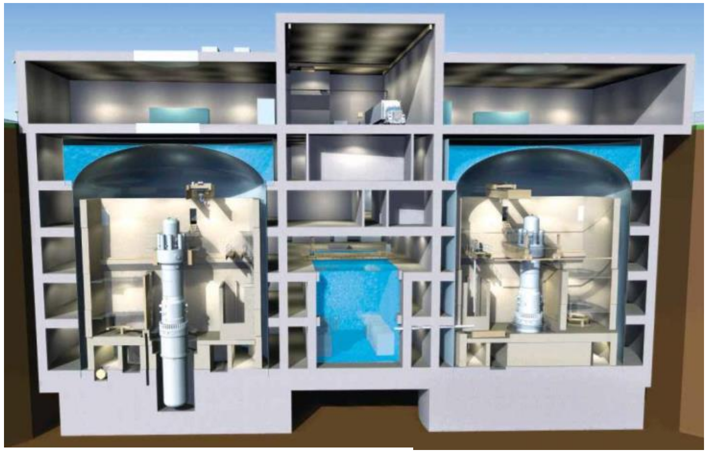
Study on SMR development (4): (Passive) safety systems



Study on SMR development (5): External Impacts

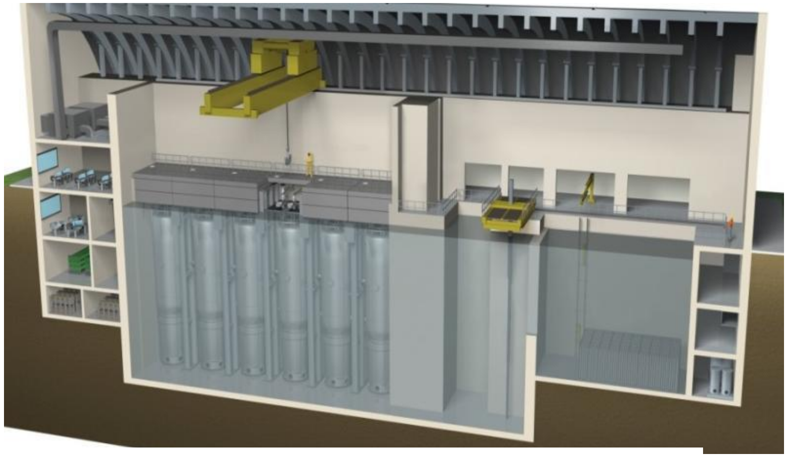
Three different solutions for mitigation of external impacts (e.g. earth quakes, explosions, air plane crash, flooding, etc.)

- Reactor placed in (water filled) caverns under the earth (retention of radioactive material inside water pool)



mPower (B&W) [5]

Note: Only the upper part of the containment of the mPower is floated



NuScale (NuScale Power Inc.) [4]

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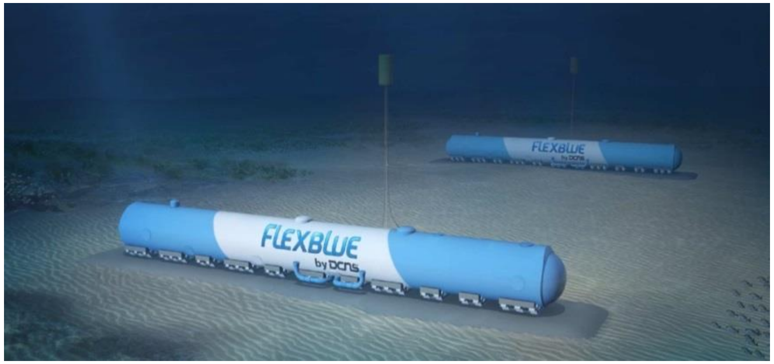
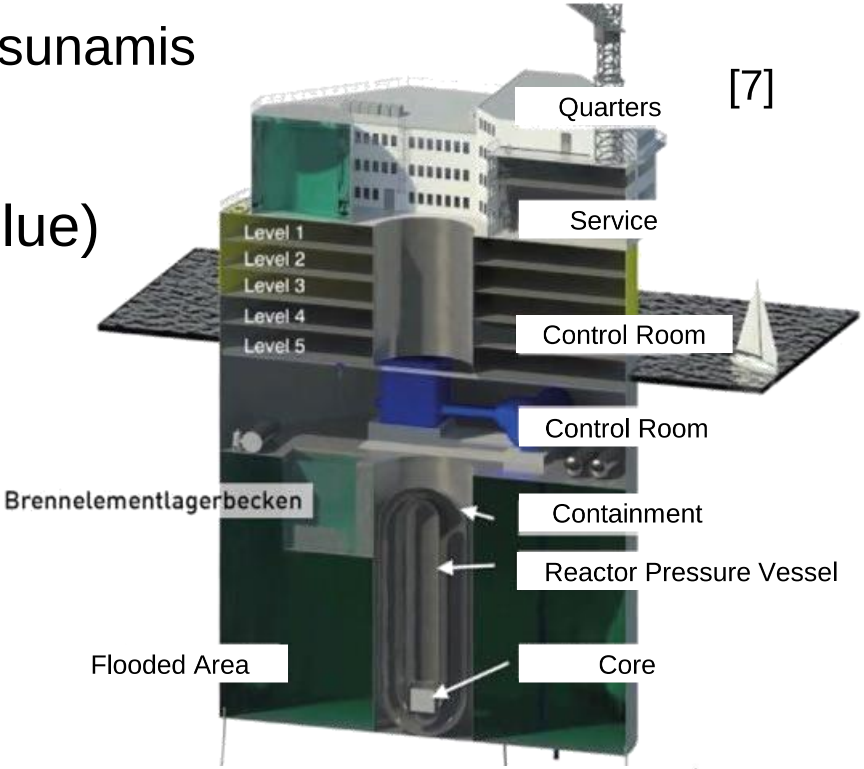
Study on SMR development (6): External Impacts

- Swimming SMR several km from coast with depths of approximately 100 m
  - Design like off shore oil platforms
  - No impact of earth quakes and tsunamis
  - Sea is infinite heat sink
- SMR on sea bottom (e.g. Flexblue)
  - 100 – 150 m long hull, Ø 15 m
  - Controlling on shore
  - Sea is infinite heat sink



[6]



[7]

Study on SMR development (7): Code Development & Validation Needs

- Several code improvements / validation work for system codes (e.g. ATHLET, COCOSYS) and neutron kinetic codes (e.g. QUABOX/CUBBOX) used at GRS are needed, for example:
  - Implementation/Validation of new **working fluids** (e.g. Air, Nitrogen, CO_2, Molten salt, Lead, LBE, etc.) including **corresponding correlations** (e.g. heat transfer, etc.)
  - Adaptation of **heat transfer correlations** for new **heat exchanger geometries** (e.g. helical pipes, plates, horizontal inclined pipes, bayonet pipes)
  - Completion/Validation of **2D/3D model for ATHLET** for calculation of phenomena in large water pools (e.g. stratification, 3D flows)

Study on SMR development (8): Code Development & Validation Needs

- Several code improvements / validation are needed, for example (cont.):
  - Implementation/Validation of **new components** (e.g. special check valves, venturi)
  - Validation for **integral behaviour of passive safety systems**
  - Analysis of **uncertainties of nuclear basic data** (e.g. in ENDF-VII, JEFF 3.1, etc.) for new materials
  - Validation of **complete code chain** for new reactor concepts

Conclusions

- New reactor concepts due to SMR development are of high interest for GRS (TSO for German government)
- Study on SMR
  - Screening of SMR concepts currently under development
  - Identifying safety relevant issues
    - Core
    - Integral design → elimination of LBLOCA
    - Passive decay heat removal systems
    - Improved protection against external impacts
  - Identification of development and validation needs of GRS codes
- Proposed or even currently running projects

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