Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH

Nuclear Rules and Regulations for SMR

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KIVI-NNS

Arnhem, April 20, 2018

GLOBAL RESEARCH FOR SAFETY.

Outline

- Introduction
  - Personal Introduction
  - Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
  - Division Reactor Safety Research and its Nuclear Simulation Chain
- Changed political Framework in Germany
  - Germany’s and GRS’ interest in SMRs
  - GRS study on *Safety and International Development of SMRs*
- Licensing, nuclear rules and regulations
  - necessary effort for licensing
  - regulatory pyramid and harmonization activities
  - definitions of Passive Safety Systems
  - currently open questions and evidence for Passive Safety Systems
  - challenges for evidence tools
- Summary

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Personal Introduction

Name: **Dr.-Ing. Anne Krüssenberg**

Actual Position: since 2013: Technical expert at GRS
since 2018: editor of journal *KERNTECHNIK (Hanser Publishing House)*

Selected Competences: (gained at various employers – see logos)

- system code (COCOSYS, ATHLET) model development, validation and application
- operation mode and performance of passive safety systems (e.g. emergency and building condensers, passive pressure pulse transmitters, flooding lines, heat pipes, …)
- CFD code application
- lead of national and international projects
- nuclear licensing- and supervisory procedures for PWR and BWR
- safety of fusion reactors

Gesellschaft für Anlagen und Reaktorsicherheit (GRS) gGmbH

- **GRS** = **G**esellschaft für Anlagen- und **R**eaktor**S**icherheit **g**GmbH *(free translated Society for Plant and Reactor Safety)*
- **independent non-profit organization** (indicated by the small g in gGmbH – legal form: common to public interest)
- **funded entirely by projects, annual turnover 60 mio. €**
- **Shareholders:**
  - **Federal Republic of Germany** (46.15%)
  - **Technical Inspection Agencies** (TÜV) (together 46.15%)
  - Free State of Bavaria and Federal State of North Rhine-Westphalia (each 3.85%)
- over **450 staff members** at **4 sites** thereof **350 scientific-technical experts**
- areas of expertise are e.g. nuclear, process and mechanical engineering, physics, computer science, …
- 1 subsidary: RISKAUDIT (headquarters in Paris)

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH

- the main **Technical Support Organization (TSO)** in **nuclear safety** for the **German federal government:**
  - **BMUB** (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
  - **AA** (Federal Ministry of Foreign Affairs)
- **major research organization** in **nuclear safety** funded by:
  - **BMWi** (Federal Ministry of Economic Affairs and Energy),
  - **BMUB** and
  - **BMBF** (Federal Ministry for Education and Research)
- traditionally involved in **numerous international activities**
  - e.g. **IAEA**, **OECD / NEA** and **EC** (DG Energy, DG RTD, DG DevCo)

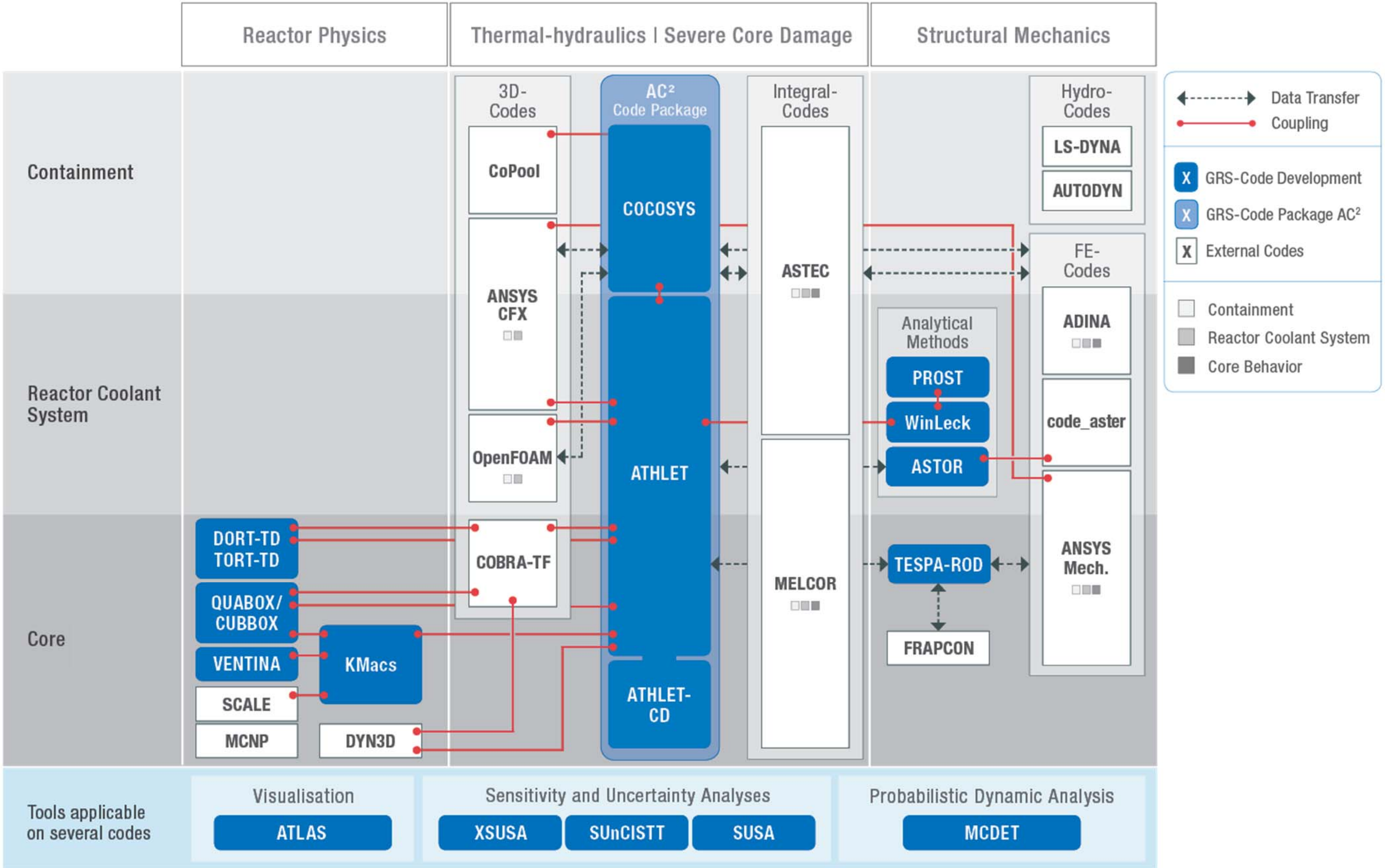
Division Safety Research

- division consists of 3 departments (with approx. 75 employees): *Nuclear Fuel*, *Cooling Circuit*, *Barrier Effectiveness,* which perform generic reactor safety research
- our products are
  - **scientific codes** for the analyses of operational states, incidents, accidents, severe accidents in NPP

    → the codes represent the **current state-of-the-art *science and technology***

    → all codes together form the **nuclear simulation chain** (see next slide)
  - **publications** in scientific journals and conferences
- historically, GRS has developed own codes in several areas
  - this approach leads to improved understanding of physical phenomena
  - widely independent of others
- currently we are co-operating with research organizations in Germany and abroad
  - forward-looking strategy to cope with current limited resources
  - to share development efforts by using results and models developed in research alliances and networks
- co-operate with other organizations (e.g. TÜV, TSO, regulators esp. in Eastern Europe) by transferring our codes and conducting training programs

Division Safety Research



 https://www.grs.de/projekte-der-grs-der-reaktorsicherheitsforschung

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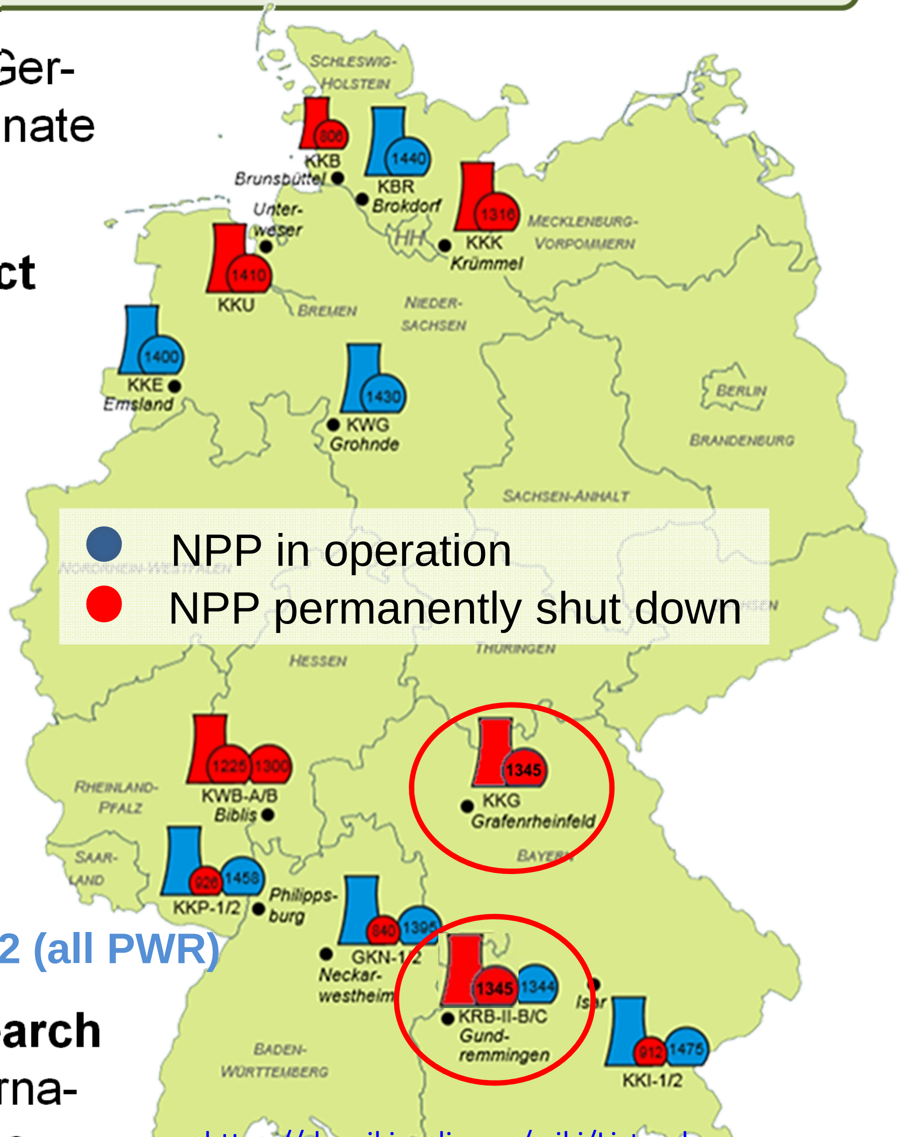
Changed Political Framework in Germany (1)

- after the Fukushima nuclear disaster the German Federal government decided to terminate the use of nuclear energy latest in 2022
- 13th Amendment of the **Atomic Energy Act** came into force on August 6th 2011
  - licenses of the 7 oldest NPPs and of the Krümmel NPP expired
  - stepwise shutdown of the remaining 9 NPPs until 2022

2015: Grafenrheinfeld (PWR)
2017: Gundremmingen B (BWR)
2019: Philipsburg 2 (PWR)
2021: Brokdorf, Grohnde (both PWR)
Gundremmingen C (BWR)
2022: Emsland, Isar 2, Neckarwestheim 2 (all PWR)

➢ but no “phase out” of **nuclear safety research in Germany:** in line with national and international framework conditions and obligations



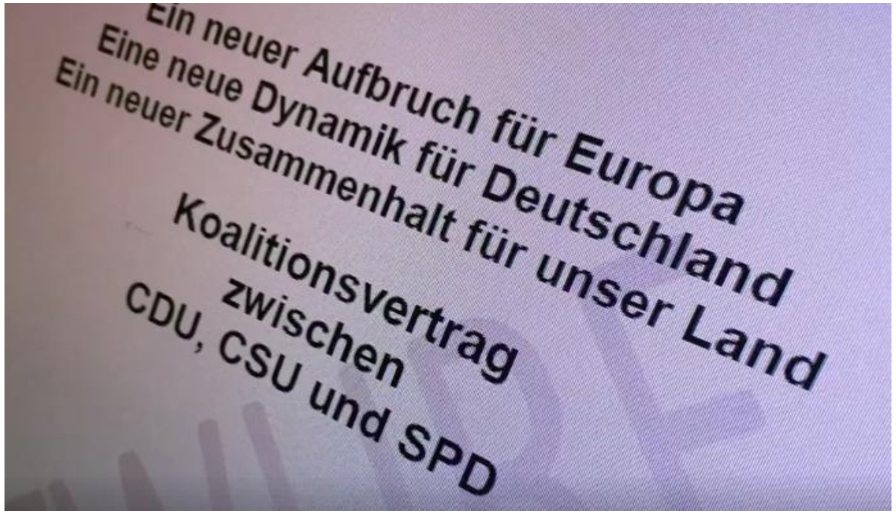
https://de.wikipedia.org/wiki/Liste_der_Kernreaktoren_in_Deutschland

Changed Political Framework in Germany (2)

Coalition Agreement of March 18, 2018 (analogous translation):

- Even after phasing out of the national use of nuclear energy **Germany should have a permanent influence on reactor safety in Europe**.
- Several neighbouring countries continue to use nuclear energy.
- Germany continues to promote comprehensive safety reviews, ambitious binding safety targets in the EU and a system of mutual control with continued national responsibility for the security.
- To be further involved in nuclear safety issues **this requires necessarily an appropriate knowledge**. For this a preservation of nuclear know-how is indespensable.

https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/koalitionsvertrag-inhaltsverzeichnis.html



A new rise for Europe
A new dynamic for Germany
A new team spirit for our country

GRS' interest in SMRs – overview (1)

- GRS continuously reviews these new builds and the reactor concepts
- most of them are advanced or innovative designs with **new (passive) safety features**

GRS' interest:

- extension of the **GRS evidence tools such as ATHLET, COCOSYS** (applied in nuclear licensing procedures) in such a way, that they can be applied for safety analyses for these **advanced** and **innovative designs**

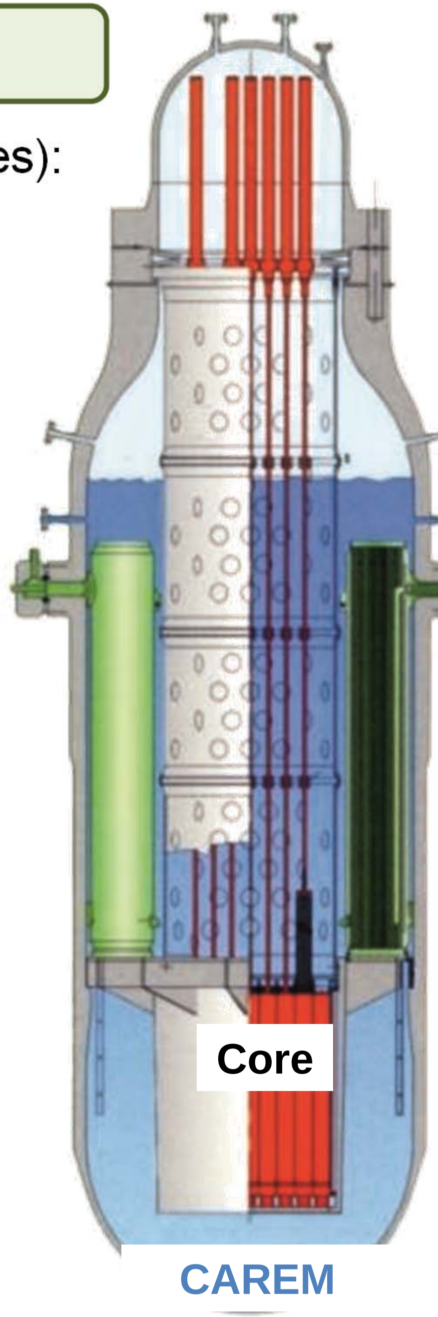
GRS' course of action:

- Can SMRs in principle be successful on the market → screening under consideration of safety aspects and competitiveness
- Identification of SMRs with best success chances to be built?
- What are the modelling gaps in the evidence tools? Which priorities shall be set for closure? → GRS Study on *Safety and International Development of SMRs (GRS 376)*

GRS' interest in SMRs – screening results safety (1)

- selected screening results (based on developers' messages):
  - **SMR could be – if proven – among the safest nuclear equipment ever made**

    (a) **core cooling**
    - reactor core with lower power density (up to -50 % compared to current operated LWR)
    - low positioning of the core inside the RPV
    - high water coverage, even for a break of the largest line connected at pressure vessel no core exposure
    - up to an electrical power of roughly 200 MW the decay heat can be safely removed
      → **core melt is excluded**
    - improved heat removal compared to (A)LWR due to
      - larger RPV surface to volume ratio
      - smaller distances of the core from the wall
      - smaller thermal resistance because the required wall thickness of the RPV decreases with the curvature

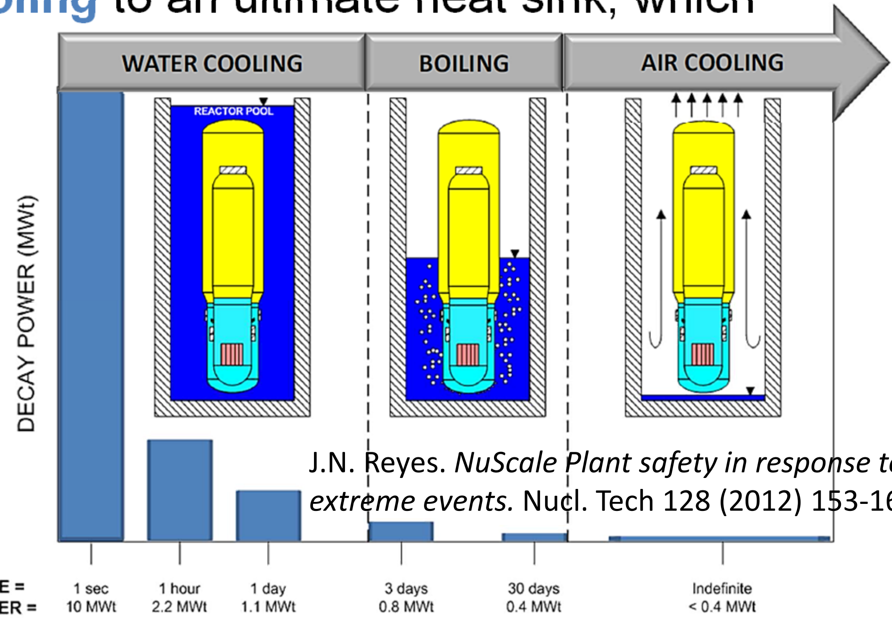


CNEA / INVAP. CAREM - 'A Safe Innovative Small Nuclear Power Plant, broshure, Buenos Aires (Argentinia), 1994)

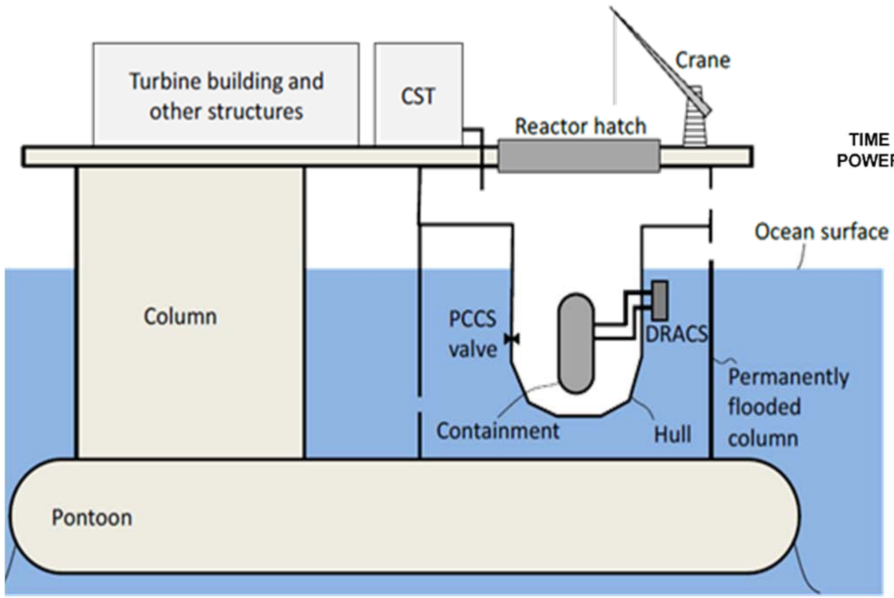
GRS’ interest in SMRs – screening results safety (2)

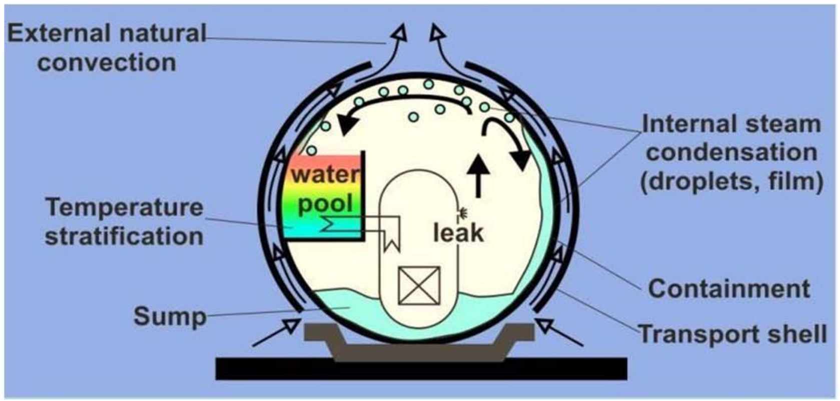
(b) **infinite passive containment cooling** to an ultimate heat sink, which could be either air or water

- horizontally, vertically arranged containments in water pools
- subsea-based containments
- floating containments
- heat pipes



J.N. Reyes. *NuScale Plant safety in response to extreme events.* Nucl. Tech 128 (2012) 153-163





J. Buongiorno et al. *Offshore small modular reactor (OSMR): An innovative plant design for societally acceptable and economically attractive nuclear energy in a post-Fukushima, Post-9/11 world*. Proceedings of the ASME 2014 Small Modular Reactors Symposium, SMR2014, April 15-17, 2014, Washington, DC, USA

GRS' interest in SMRs – screening results competetiveness (4)

- **SMR can be** (under certain assumptions) **competitive compared to (A)LWR**
  - disadvantage the **economy of scale**
  - **but various advantages**
    - large application spectrum (electricity and heat production)
    - SMRs require less capital costs for construction
    - risk of delays is eliminated, after transportation to the site the modules can be immediately connected to grid
    - a production unit can be extended module by module
    - SMRs require less maintenance and have longer operating cycles
    - easier disposal (complete module can be transported back to the factory and could be dismantled there)
  - **different studies indicate a significant market potential**
    - in the medium term competitive to gas power plants (< 8 Cent pro kWh)
    - **but** the economic feasibility is not proven and is based on assumptions:
      - all entry barriers have been overcome
      - series production in a factory
      - **efficient <u>transnational</u> licensing procedures** have been established

GRS' interest in SMRs – screening results (6)

- the first 2 screening steps indicate that **SMR can be**
  - (if proven) **among the safest nuclear equipment ever made**
  - (under certain assumptions) **competitive compared to (A)LWR**
- roughly **70 SMR concepts** were under construction / in development → Which SMRs shall be further considered by GRS?

  First approach: GRS shall focus on SMRs
  - which shall be built in the direct neighborhood of Germany,
  - where our clients have a special interest or
  - which will be constructed in a large number of units worldwide
  - ➢ difficult to identify the SMRs which will ultimately be built → generic approach
- first step GRS reviews all SMR concepts, allocation in groups concerning
  - **stage of deployment** (SMRs (a) in operation, (b) in construction, (c) in development with concrete projects for construction (≈ 10), (d) in development without plans to build (≈ 60))
  - **coolant** (32 LWR, 2 HWR, 22 LMR, 9 GCR, 4 MSR)
  - place of **erection** (onshore, offshore, subsea-based)

GRS' interest in SMRs – screening results (7)

- ***Defence-in-depth concept*** *(simplified representation)*

NPP state	level	objective	features
normal operation	1	prevention of abnormal operation and failure	conservative design and quality
anticipated opera-tional occurencies	2	control of abnormal operation and detection of failures	control, limiting, protection systems
DBA	3	control DBA	safety systems
BDA	4	control of severe plant conditions	accident mana-gement measures

→ compile the features for each safety level, which are imple-mented in the SMRs

→ check, if these features can be simulated with our simula-tion tools

- Identification of modelling gaps in the evidence tools and de-velopment of a strategy for closure, results are published in

Safety and International Development of SMRs (GRS 376)


Studie zur Sicherheit und zu internationalen Entwicklungen von Small Modular Reactors (SMR)

GRS - 376

https://www.grs.de/node/2594

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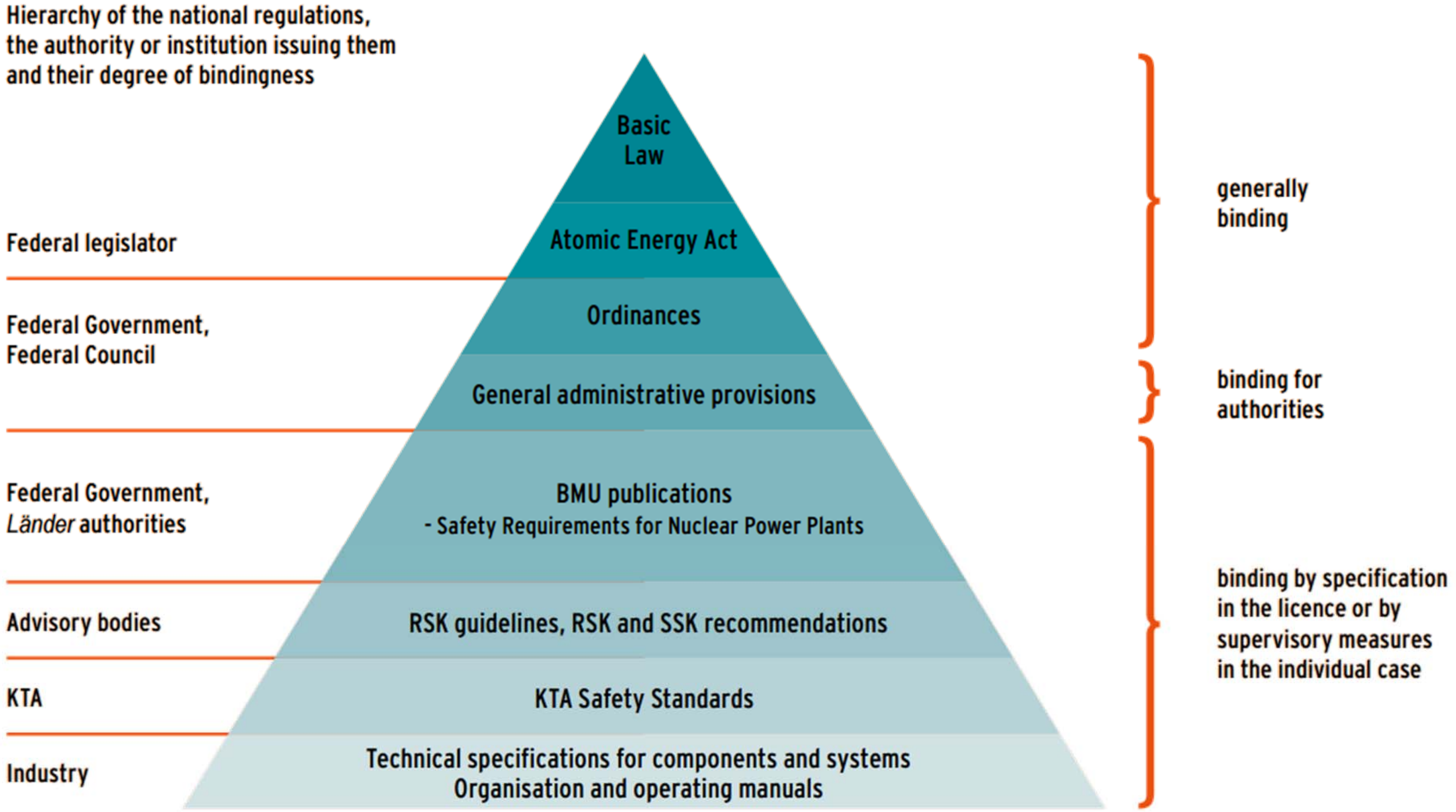
Licensing, Nuclear Rules and Regulations - Requests

- **great efforts for licensing are necessary**
  - cost efficiency of SMR requires the construction of a large number (> 100) of identical units → one design for different countries
  - for construction of large numbers it is necessary to **simplify** the **licensing procedure**
    - **type licensing** → if a further module is added to a production unit no new licensing procedure should be necessary,
    - **licenses / certificates** should be internationally recognized
    - **harmonization** of definitions (e.g. for passive safety systems), rules and regulations (e.g. for experimental and analytical evidence)
  - according to our opinion, SMR based on LWR technology offer advantages
    - due to the experiences of the nuclear stakeholder (especially of the regulators) with LWR technology collected in the last decades
    - build / licensed SMR are (compared to SMR under development) in advance since a licensing process requires several years
    - design assessments were successfully performed e.g. for SMR based on LWR technology e.g. for CAREM (ARN, 2010) and SMART (KINS, 2012)

Licensing, Nuclear Rules and Regulations - Regulatory Pyramid (1)

- **Do SMR require new rules and regulations – national aspect?**

Example: German Regulatory Pyramid

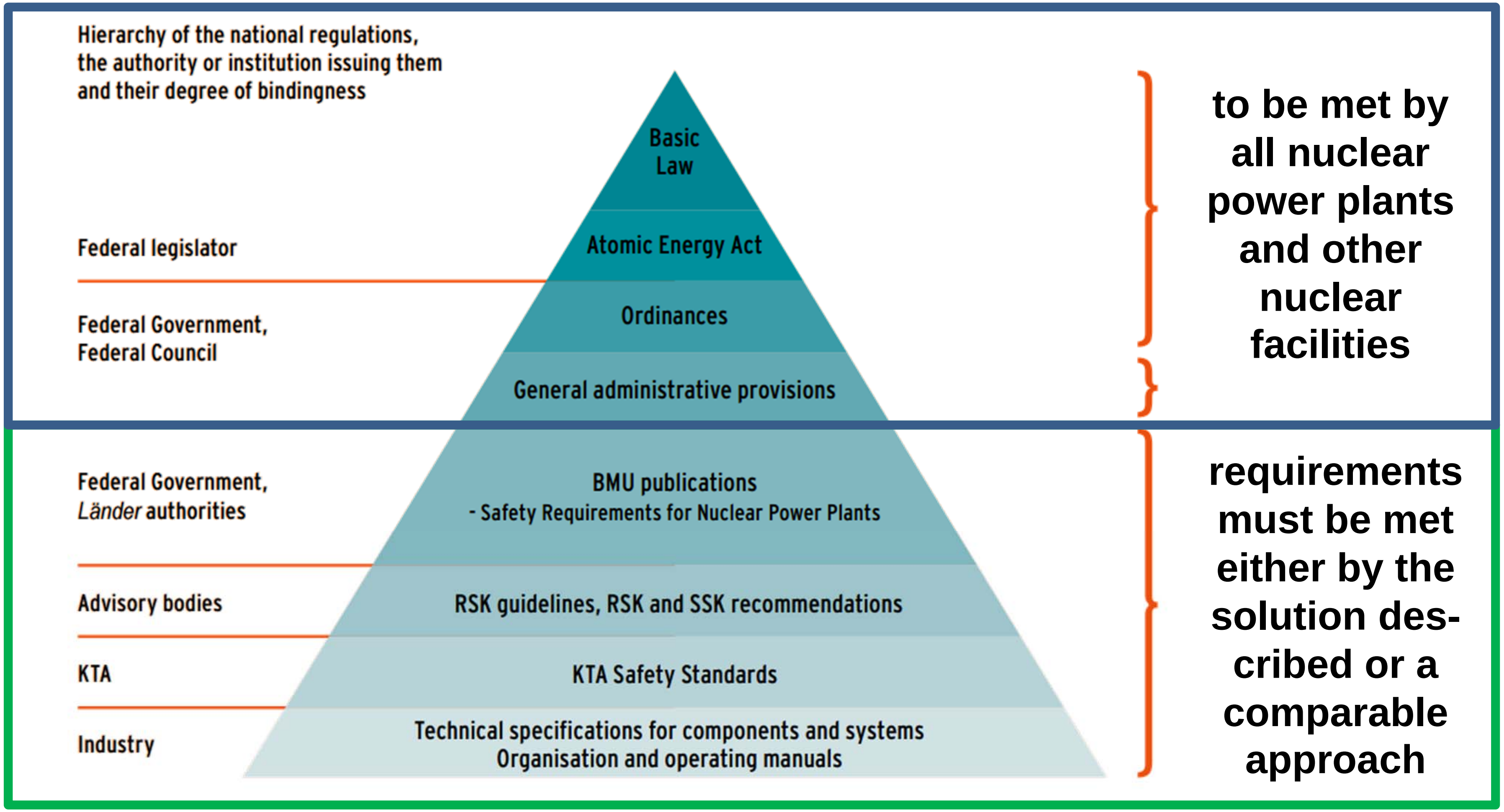


http://regelwerk.grs.de/en/node/120

Licensing, Nuclear Rules and Regulations - Regulatory Pyramid (1a)

- **Do SMR require an own set of rules and regulations – national aspect?**

Example: German Regulatory Pyramid



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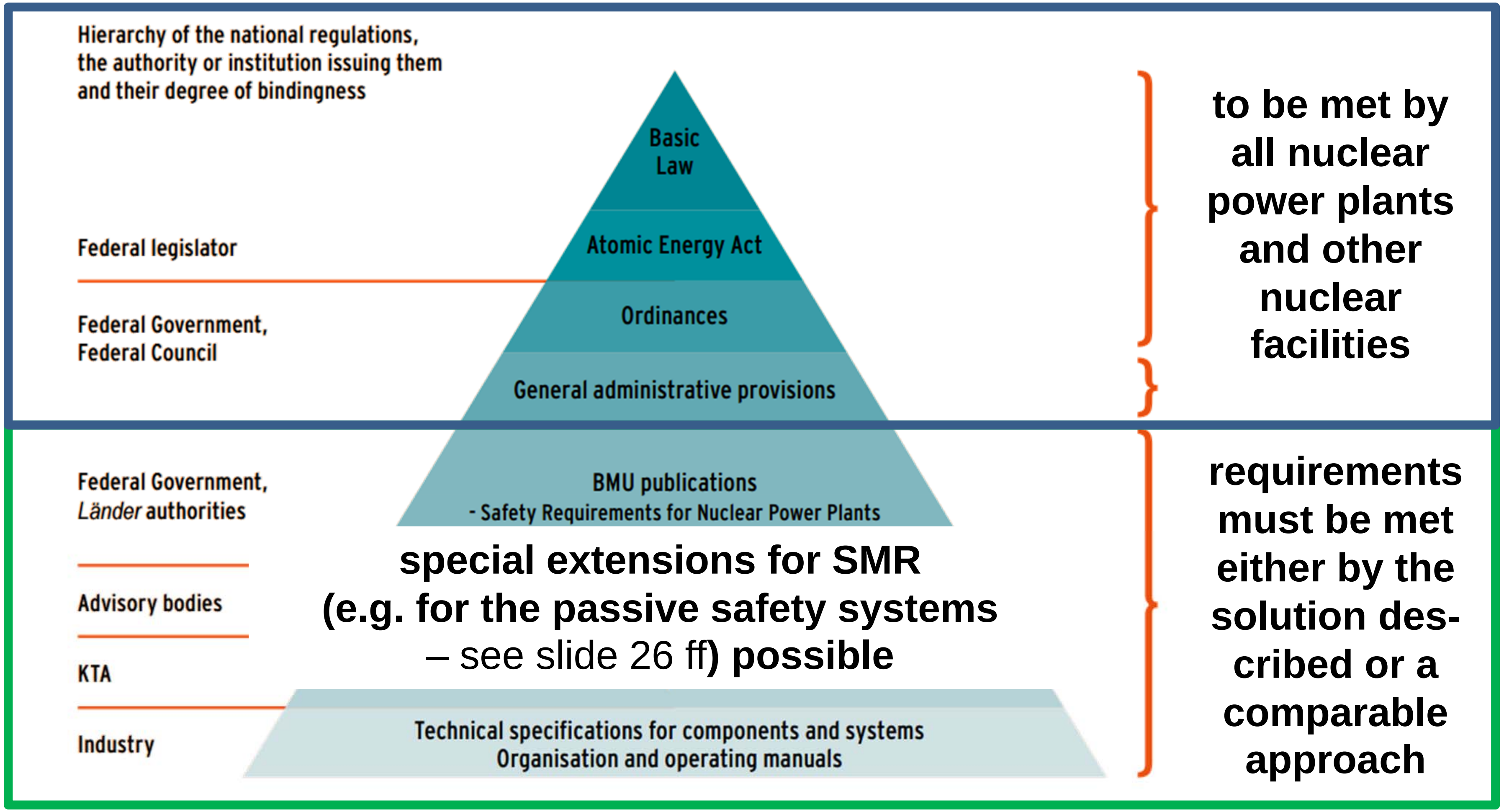
Licensing, Nuclear Rules and Regulations - Regulatory Pyramid (1b)

- **Do SMR require an own set of rules and regulations – national aspect?**

Example: German Regulatory Pyramid



http://regelwerk.grs.de/en/node/120

Licensing, Nuclear Rules and Regulations - Status (1)

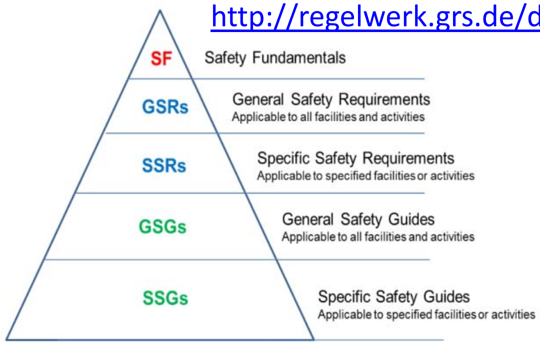
- **Is there a common international understanding of the legally binding part of the regulatory pyramid?**
  - countries (e.g. GER, CH, UK) with **unlimited operational licenses with-out** or **with licensing requirements**
    - *The German atomic act (Art. 7) demands a precaution in the light of the **current state-of-the-art science and technology (S&T)** to prevent damages resulting from the erection and operation of a nuclear installation.*
      - o ***S&T**: advanced methods, equipment and operating modes which leading ex-perts (such as the German Reactor Safety Commission (RSK)) expect to be required - in this connection economic considerations play no role*
      - o ***current**: the state-of-the-art S&T is continuously developing*
      - o *common understanding in Germany, that in the remaining operating time of the German NPP (until 2022) the **high safety standard** shall be **maintained** and **further improved**.*
    - positive assessed (deterministic / probabilistic) safety analyses, security analysis
  - countries (e.g. USA) with time limited operational licenses (e.g. 40 years), ob-ligation to maintain the safety level, before expire the operator may request an extension
  - ➢ big differences concerning **approval period**, **time development of safety level**

Licensing, Nuclear Rules and Regulations - Status (2)

- **numerous harmonization activities, e.g.**
  - Department of Nuclear Safety and Security of **IAEA** defines the international state of the art in science and technology as a guideline for development of nuclear regulatory frameworks which was adopted by consensus of the Member states

    provision of the IAEA *Safety Standards Series*

    http://regelwerk.grs.de/de/iaeo



  - **WENRA** activities are triggered by the necessity to develop a common position concerning the safety of nuclear power plants in EU applicant countries states for accession negotiations, today WENRA become a network of nuclear safety regulators in Europe exchanging experience and discussing significant safety issues relating to the operation of nuclear installations
  - **EU** Safety Directive **Community framework** in order to maintain and promote the continuous improvement of nuclear safety and its regulation and to ensure that Member States shall **provide appropriate national arrangements** for a high level of nuclear safety to protect workers and the general public against the dangers arising from ionizing radiations from nuclear installations

Licensing, Nuclear Rules and Regulations - Status (3)

- **EU** Safety Directive (continued)

Chapter 2: **Obligations**

Section 1: **General obligations:** Legislative, regulatory and organizational frame-work, competent regulatory authority, license holders, expertise and skills in nuclear safety, transparency)

Section 2: **Specific obligations (2014)**

Article 8a: **Safety objective for nuclear installations** (prevent of (severe) accidents, mitigate their consequences)
Article 8b: Implementation of the nuclear safety objective for nuclear installations (**defence-in-depth**; **safety culture**)
Article 8c: Initial assessment and **periodic safety reviews**
Article 8d: **On-site emergency preparedness and response**

Chapter 2a: **Peer Reviews and Reporting**

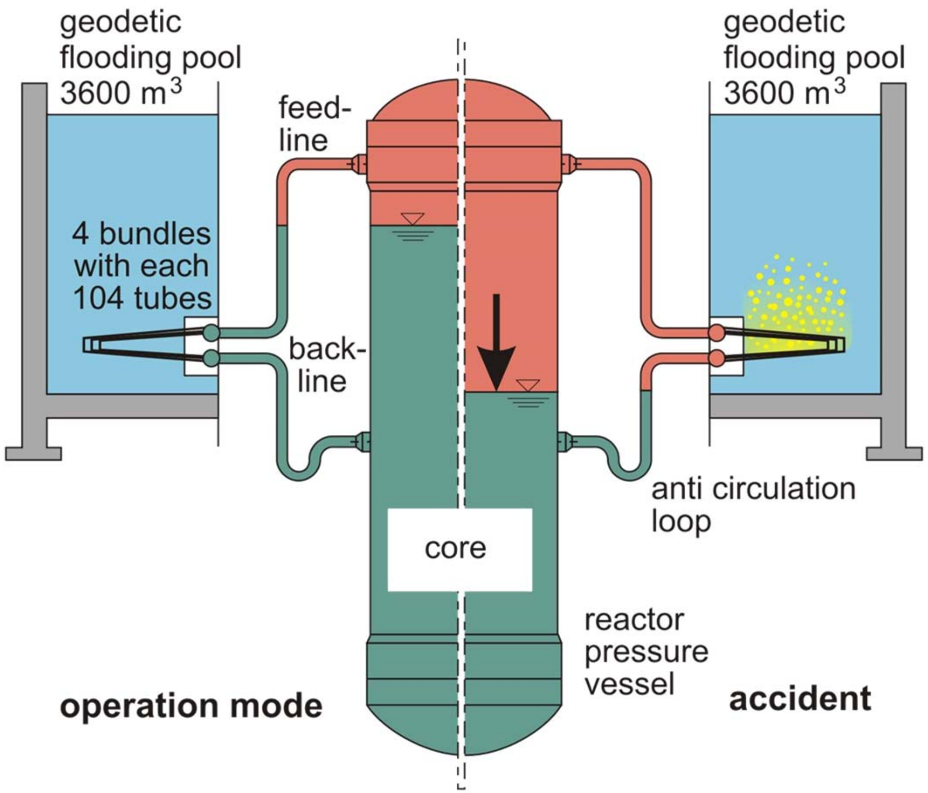
Chapter 3: **Final Provisions**

Article 10: **Transportations**
Member States shall bring into force the laws, regulations and adminis-trative provisions necessary to comply with this Directive…..

- All three approaches describe basic, high level procedures but **don't regulate details.**

Licensing, Nuclear Rules and Regulations – Example new PSS (1)

- the advanced or innovative (SMR) designs have **new safety features → passive safety systems (PSS)**
- **passive safety systems** have a great potential to control DBA and BDA (in Gen. III+ PSS solely control accidents)
- **operation mode is based on laws of nature** (free convection, conden-sation, evaporation) with usually small driving pressure and high tem-perature differences
- due to the **lack of operating expe-rience** there are, however concerns regarding the application
- different definitions (IAEA, EPRI, Ger-man safety requirements) of PSS e.g. with an influence on **the degree of redundancy**
- no accepted methods for the assess-ment of the performance and reliability



A. Schaffrath, „Experimentelle und analytische Untersuchungen des Notkondensators des SWR600/1000," Forschungszentrum Jülich GmbH, Juel-3326, 1996.

Definition of *Passive Safety System* (1)

- Definition according to **IAEA TECDOC 626 *Safety Related Terms for Advanced NPP*** are based on different categories (grade of passivity and different activation mechanisms)

excitation mechanisms

criterion	category - decreasing grade of passivity			
	A	B	C	D
moving media	-	x	x	x
moving parts	-	-	x	x
signals	-	-	-	x
external energy support	-	-	-	batteries, pressure suppression tank
example	physical barrier, like pipe, fuel rod cladding, bio. shield	natural heat transfer, as in emergency condensers	geo. flooding systems with a check valve	SCRAM (pressure tanks)

Supplement to passive D:
- active activation is allowed only with energy from batteries or pressurized media
- no (hand) measures by operators
- no rotating machines

Definition of *Passive Safety System* (2)

- ***Advanced Light Water Reactor*** *(ALWR)* ***Utility Requirement Document*** of **EPRI**

  A passive system is a system that ***primarily relies on passive principles*** *to perform important safety functions.*

  The use of active components is limited to valves for initiation, monitoring and instrumentation (i.e. no use of AC or rotating machinery).

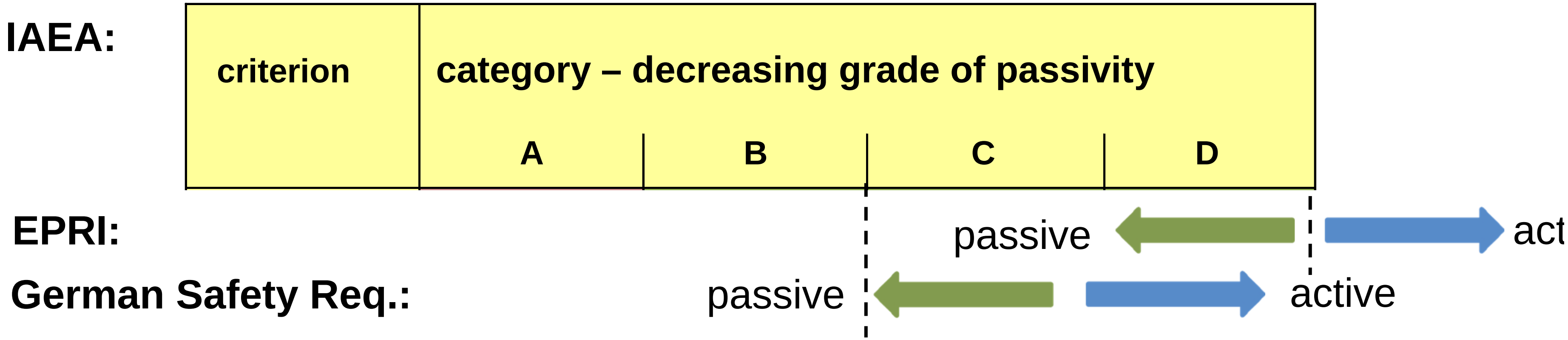
- ***German Safety Requirements for Nuclear Power Plants*** (as well as *Begriffe-Sammlung des kerntechnischen Ausschusses* (free translated *KTA Collection of terms)*

  A component is passive, if it needs no active activation for function. (Passive components are z.B. pipes, tanks, fuel rod cladding, heat exchanger or biological shield).

  Automatic components *are to be regarded as passive if* ***the position is not changed within the sequence.***

  example: a safety valve or check valve which opens during an accident sequence is an active component

Definition of *Passive Safety System* (3)



- the definitions of IAEA expresses a first international consensus
- requirements for the degree of redundancy
  - active system: n + 2 — failure of a train due to individual faults as well as due to maintenance / repair
  - passive system: n + 1 — failure of a string due to maintenance / repair

➢ The (different) definitions of passive safety system have a strong influence on the required redundancy of trains of safety systems!

Currently open questions for the assessment *Passive Safety System*

- Which definition of PSS is used?
- Which initial and boundary conditions do PSSs require for their operation?
- Is it ensured that these conditions will be present in case of a request?
- Are damages leading to failure of a PSS detected reliably?
- How to test PSSs? How to evaluate its reliability, if the PSS cannot be inspected or periodically tested after installation?
- Which redundancies do PSSs require?
- How to assess the elimination of human actions?

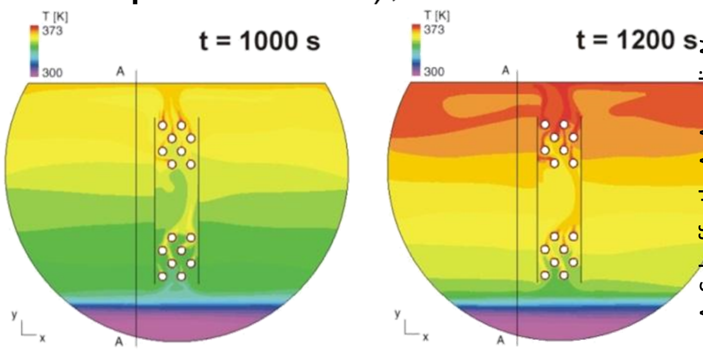
  On the one hand human errors are excluded. On the other hand PSSs cannot be used for accident management measures.
- How to evaluate ageing materials?
- How do PSSs behave under deviating conditions? Are there cliff-edge effects?
- Are all failure possibilites (e.g. functional failures due to the collection of non-condensables) of a PSS considered?

Evidences for *Passive Safety System*

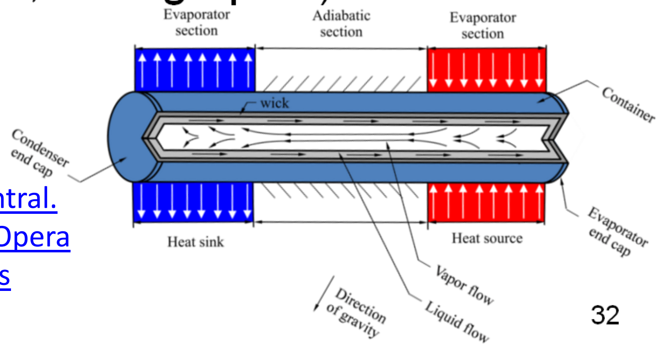
- (phenomenological) understanding and description of all relevant physical phenomena
- **experiments** with
  - original geometries / materials
  - reactor typical initial / boundary conditions and beyond design initial / boundary conditions to avoid cliff-edge effects
  - component tests
  - integral tests for understanding of PSSs' mutual interactions of different trains of one passive safe systems and different passive safe systems
  - if scaled experiments are performed a proof of the scaling concept is required
  - evaluation of experimental and analytical sensitivities and uncertainties
  - proof of reproducibility of experiments
- (blind pre- and post-test) **calculations** of the experiments with at least **one validated code** (see next slide) and determination of analytical sensitivities and uncertainties
- comparison of experimental and analytical results, (plausibility) checks with other experiments and / or calculations

Challenge for the evidence tools (1)

- **light water cooled SMR**
  - cores longer cycles with higher burn-ups, more burnable poisons and diffe-rent core geometries, advanced loading pattern
  - free convection flow with (very) small driving forces (uncertainties which are in the order of magnitude of the respective flow parameters), flow instabili-ties and phase exchange
  - behavior of water pools with thermal stra-tification
  - heat transfer outside large heat exchan-ger bundle in free convection, sub-cooled or saturated boiling conditions
  - decay heat removal with compact and high performance innovative heat exchangers (helical coiled, bayonnette tubes, plate heat exchanger, heat pipes (e.g. for cooling of the core, the core catcher, storage pool)
    - complex 3D flow fields
    - near vacuum conditions (heat pipes)
    - flow induced vibrations
    - new working fluids



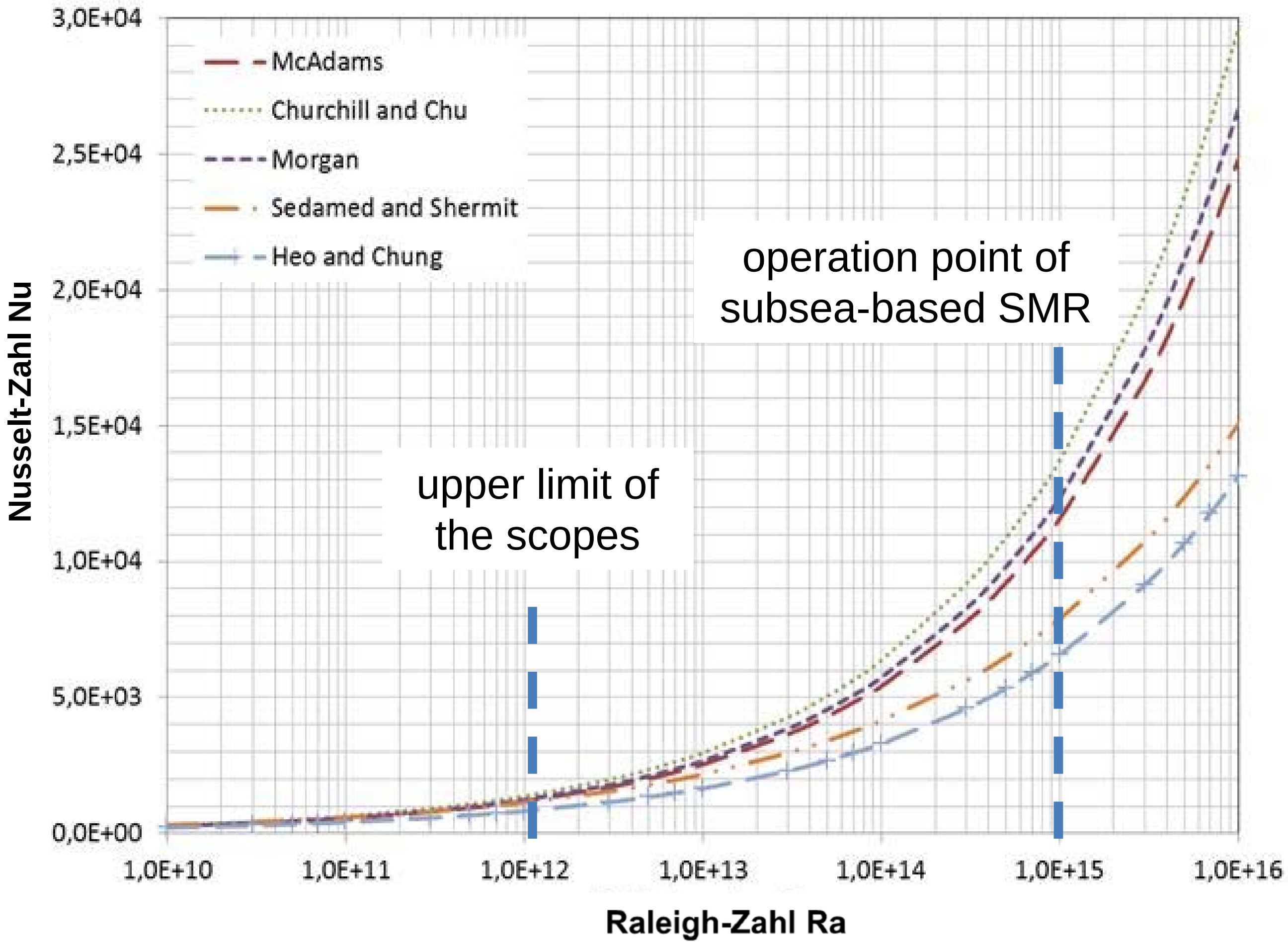
E. Krepper, A. Schaffrath, A. Aszodi. *Numerical Simulation of the Emergency Condenser of the SWR1000*. Nuclear Science and Engineering 135 (2000) 267-279



https://www.thermalfluidscentral.org/encyclopedia/index.php/Operation_Principles_of_Heat_Pipes

Challenge for the evidence tools (3)

- **cooling of the containment**: free convection around large horizontal cylinder, additionally influence of seawater, mussel growth well-known from ships water



Challenge for the evidence tools (4)

- **SMR with fast neutron spectra**
  - validation of neutron kinetic codes for fast neutron spectra
  - uncertainties of the nuclear data libraries
  - implementation of **properties** for working fluids for subcritical and heavy water, helium, liquid metals (sodium, lead, lead-bismut), gases (helium, nitrogen, CO_2) and molten salts)
  - validation of correlations for friction, heat and mass transfer

Summary (1)

- despite Germany's phase out from nuclear energy there is a national consensus to continue reactor safety research e.g. for
  - independent safety assessments of NPP currently operating, under construction in our neighborhood
  - influencing international developments of reactor safety
- Germany therefore funds research for advanced and innovative reactor concepts (e.g. the GRS development of scientific codes for the analyses of operational states, incidents, accidents, severe accidents in NPP)
- the division reactor safety research in future GRS will have the necessary staff, competences, know-how and validated evidence tools for safety assessments also for SMRs

- SMR can be an interesting option for new builts – SMR could be – if proven – among the safest nuclear equipment and (under certain assumptions) compe-titive to A(LWR)
- however there are currently numerous different designs and it is not possible to predict which design will ultimately be successful
- a prerequisite for success are greats progress for licensing (type licensing, int. recognition of licenses, harmonization of definitions, rules and regulations

Summary (2)

- currently licensing is in the responsibility of the countries, in which a SMR shall be operated
- the licensing procedures (unlimited operational licenses without or with licen-sing requirements or time limited licenses) differ despite numerous efforts to harmonize nuclear rules and regulations

- a new safety feature of SMR is the application of passive safety systems (PSS)
- currently various definitions (IAEA, EPRI, KTA Standards) are used in parallel
- depending on these definitions there is a different understanding, whether a system is active or passive and which redundancy level (n+1 or n+2) it requires

- currently there are numerous open questions for PSS (elimination of human influence, aging, cliff-edge effects, ….)
- GRS view for experimental / analytical evidences
- selected challenges for codes applied in nuclear approval procedures