Institute of Safety and Risk Sciences

Licensing of Small, Modular Reactors (SMRs)

Overview - Licensing of SMRs

What regulatory approaches exist?
Can current safety standards be applied?

Not all SMRs are the same....

- Power: 10 kWe - 300 MWe (Factor 30.000!)
- Intended use: remote small scale units - centralized large scale units
- single unit vs. multi unit sites
- LWR vs. all other nuclear reactor designs

SMRs - Two Examples

NuScale VoYGR Plant

- 12/6/4 Modules
- 77 MWe each
- LWR technology

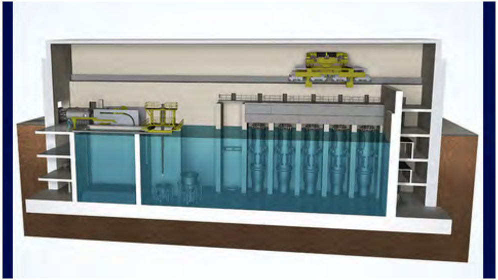


Image: NuScale

eVinci Microreactor

- 5-13MWt
- No emergency planning zone
- TRISO fuel

Image: Westinghouse

Genehmigungsansätze

Prescriptive Regulatory Approach I

Comprehensive regulatory guides prescribing detailed acceptance criteria to meet regulatory requirements. (NRC)

Development:

- Severe Accidents
- Extensive Research (more initiating events, consideration for plant states beyond design basis, design extension conditions - core damage, accident management)
- development of computer codes (accident spectrum, experiments, identification of physical phenomena)

Prescriptive Regulatory Approach II

- Licensing framework developed together with technology
- High level principles apply to very different reactor designs
- Derived technological acceptance criteria and analysis framework strongly tied to LWR
- SMR based on LWR might meet close time targets - easy for licensee & regulator
- for Non-LWR: the same path will take time

Applied in most countries

Performance-Based Regulation (PBR)

PBR is a regulatory practice that establishes performance and results as the primary bases for decision-making. (NRC)

Must have the following attributes NRC Strategic Plan (NUREG-1614, Vol. 3):

- parameters exist to monitor performance
- objective criteria exist/can be developed
- licensees decide how to meet performance criteria
- failing to meet one performance criterion will not result in an immediate safety concern

Example: Regulation USA

For LWR:

- prescriptive regulatory approach
- Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-800) $\rightarrow$ cook book

For other reactors:

- Draft Part 53 rule making: voluntary, performance-based alternative regulatory framework for future commercial nuclear power plants
- applicable for Non-LWR and SMR

Goal-Setting Approach (UK)

Outcome-focussed & goal setting:

- broad regulatory requirements
- licensee determines and justifies how to achieve them
- licensee can be innovative and adopt practices that meet their particular circumstances

International Atomic Energy Agency (IAEA)

The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.

→ ten associated safety principles
→ safety standards, safety guides, ...

- international safety rules & regulation
- must be transferred into national regulation
- self-commitment of most countries to meet IAEA standards

Selected SMR-related IAEA Activities

Nuclear Safety Standards Committee (NUSSC)

SMR Regulator's Forum

Nuclear Harmonization and Standardization Group (NHSI)

Themes of Novelty - IAEA NUSSC

Questionnaire for SMR vendors to identify areas of novelty

Examples:

- New hazards (water and air ingress; chemical attack; sodium leaks; graphite dust) and new features for coping
- Novel approaches to O&M: remote operation, walk away safe concepts, sealed cores

Image: EFNEnvironmentalists for Nuclear Energy

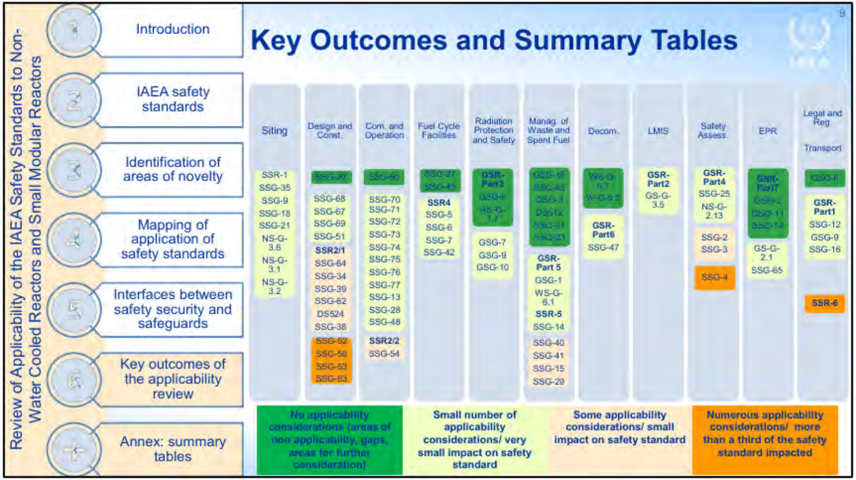
IAEA - Evolutionary & Innovative Designs (EIDs)

Safety Report on Applicability of Safety Standards to Non-Water-Cooled Reactors and Small Modular Reactors (IAEA Preprint 2022)

Goals:

- Documenting areas of novelty
- Assessing the impact of novelty on applicability and completeness of standards
- Identifying gaps (areas of novelty not covered by standards)
- Listing areas for additional consideration

Key Outcomes IAEA Report



Design

Fundamental safety functions:

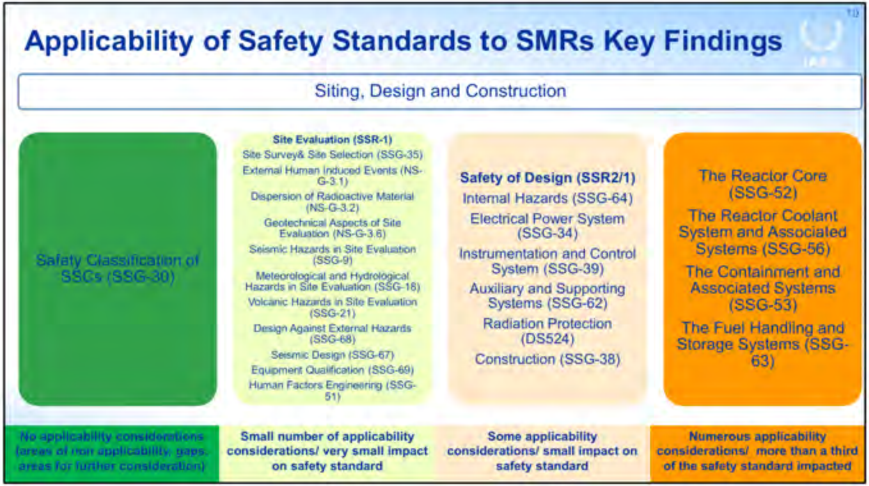
- Criticality control
- Cooling
- Prevention of radioactive releases

Image: Garcia 2013, ISBN 978-85-99141-05-2

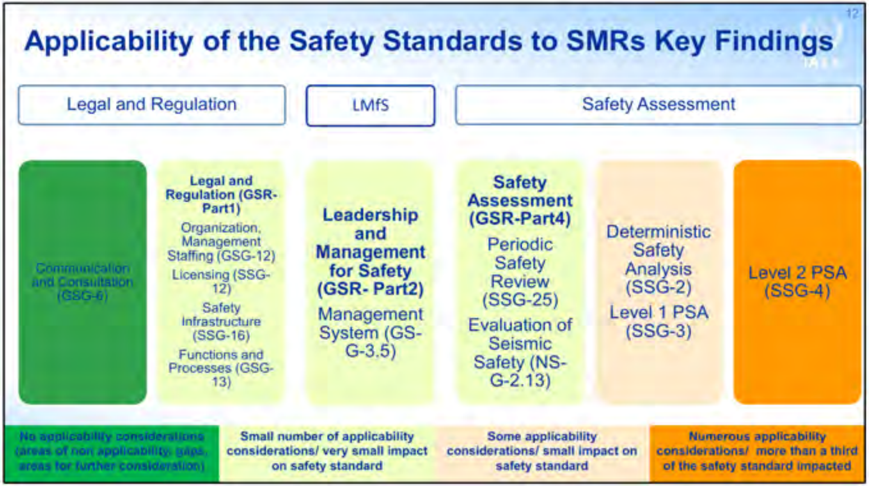
Image: Lori Thermal

Image: ORNL, U.S. Dept. of Energy

Applicability of SS to SMRs - Design & Construction



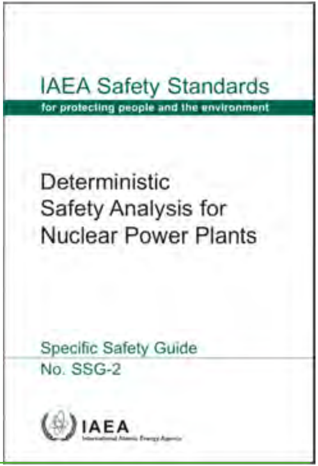
Application of SS - Safety Assessment



Deterministic Safety Assessment

Facility is tolerant to identified faults/hazards within design basis:

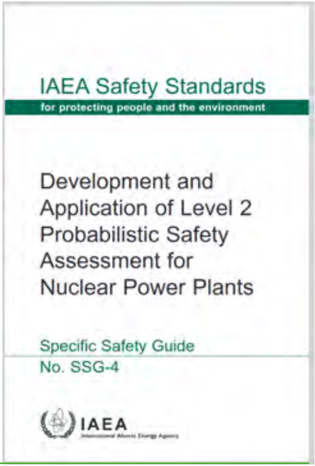
- list of postulated initiating events (PIE)
- depending on the probability, consequences might be less or more severe
  $\rightarrow$ goals that must be met
- ALL PIEs must be managed according to the goals
- conservative calculations (single failure criterion)
- limits of safe operation



Probabilistic Safety Assessment

Realistic estimate of the risk presented by the facility.

- List of initiating events (PIE)
- For each PIE: Even tree
- for each component (e.g. HPIS): Fault Tree
- Level 1 PSA: core damage frequency
- Level 2 PSA: Large and early release frequency
- Cumulative probability - some leverage possible

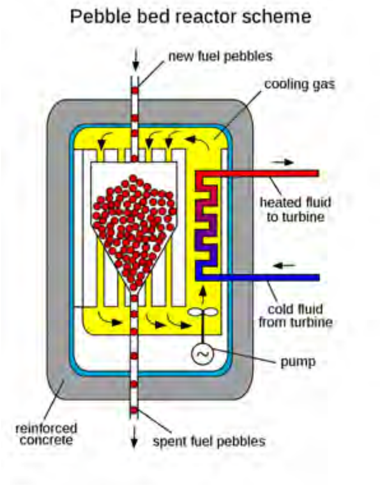


Key issues for Safety Analysis

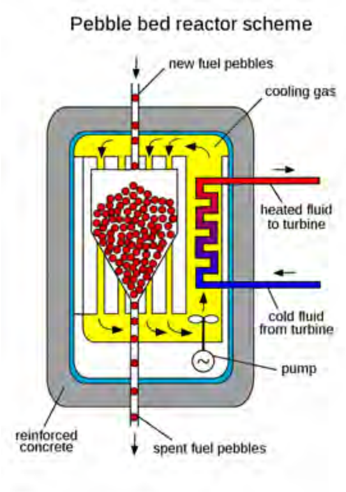
- limited knowledge of physical phenomena
- scarcity of experimental and operational data
- difficulty in addressing uncertainties (limited experience, FOAK designs)
- Interpretation of terms like DBA, DEC, ...

Gaps related to design:
SSC "review" of the safety standard can be initiated when information is obtained.

High Temperature Pebble Bed Reactor I



High Temperature Pebble Bed Reactor II



Nr.	Title	LW-SMRs (Appendix I)	HTG-SMRs (Appendix II)
	Safety analysis		
42	Safety analysis of the plant design (5.71–5.76)	As is	Change
	6. DESIGN OF SPECIFIC PLANT SYSTEMS		
	Reactor core and associated features		
43	Performance of fuel elements and assemblies (6.1–6.3)	As is	Change
44	Structural capability of the reactor core	As is	Change
45	Control of the reactor core (6.4–6.6)	As is	Change
46	Reactor shutdown (6.7–6.12)	As is	Change
	Reactor coolant systems		
47	Design of reactor coolant systems (6.13–6.16)	As is	Change
48	Overpressure protection of the reactor coolant pressure boundary	As is	Change
49	Inventory of reactor coolant	As is	As is
50	Cleanup of reactor coolant (6.17)	As is	Change
51	Removal of residual heat from the reactor core	As is	As is
52	Emergency cooling of the reactor core (6.18–6.19)	As is	Change
53	Heat transfer to an ultimate heat sink (6.19A–6.19B)	As is	As is
	Containment structure and containment system		
54	Containment system for the reactor	As is	Change
55	Control of radioactive releases from the containment (6.20–6.21)	As is	Change
56	Isolation of the containment (6.22–6.24)	As is	Change
57	Access to the containment (6.25–6.26)	Interpretation	Change
58	Control of containment conditions (6.27–6.30)	As is	Change

Small Modular Reactor Regulators' Forum

Created in March 2015, expected results are

- Positions statements on regulatory issues
- Suggestions for revisions to or new IAEA documents
- Information to help regulators enhance regulatory frameworks
- Reports on regulatory challenges with discussion on paths forward
- Suggestions for changes to international codes and standards

Example: working paper on emergency planning zones
2022: officially joined NHSI to lead process

Strong Push for Hamonization

→ Nuclear Harmonization and Standardization Initiative (NHSI)

- Announced begin of 2022 by IAEA Director General Rafael Grossi
- Goal: Facilitate the safe and secure deployment of SMRs and Advanced Reactors
  - increase regulatory collaboration
  - establish common positions on technical and policy issues
  - pave the way to greater harmonization, one standard for technical details

Limitation of NHSI II

Members: industry, regulators, operators from selected countries

- “Consider nuclear as a global fleet”
- “same safety standards everywhere”

But:

→ who chose the members?

→ who decides on the safety level?

→ why should other IAEA members follow?

Consequences

Time Schedule SMR Deployment

Czech Republic:

- SMR build in Temelín announced 2022
- supposed to be finished between 2032 and 2035

USA NuScale (50 MWe):

- Design process started $\approx$ 2000 (state funded)
- certification process started in February 2008
- 50 MWe certified 2023
- operational 2030?

Example Great Britain

Source: Office for Nuclear Regulation 2022

- Nuclear share 15% of electricity (2022)
- All but one NPP shut down until 2030
- SMR competition launched March 2023 → final investment decision on two new build projects between 2025-2029

Time Schedule Rolls-Royce SMR

Generic Design Assessment (GDA) - online 2029?

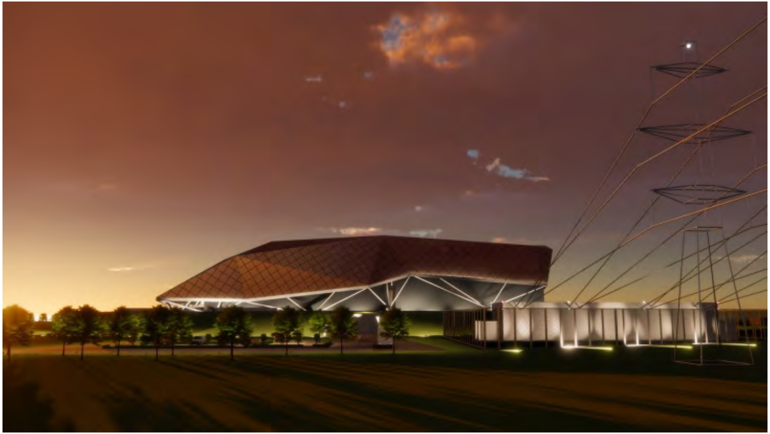


Image: Rolls-Royce

Consequences for Regulation

Situation:

- Several new-builds to meet Netzero Goal by 2050
- Pressure on regulatory bodies for fast procedures
- “small” designs $\rightarrow$ less need for safety provisions?
- legitimate wish graded approach

But:

- several SMRs at one site still small?
- Difficulties to decide which safety provisions can be downgraded
- especially for FoaK licensing might take even longer

Conclusions

IAEA safety standards largely applicable to SMRs / advanced reactors

- but: Standards for the key areas design and safety analysis require more design information
- Defining standards as currently used for LWR takes (a lot of) time
- Fast licensing needs different approach
  - $\rightarrow$ definition of only high-level safety goals
  - $\rightarrow$ performance-based approach

WENRA - Summary

The label “SMR” in itself does not justify changes in safety requirements. Each design and application needs to be considered individually, taking into account the case specific characteristics.

Western European Nuclear Regulators Association (WENRA):
Conclusion 2021: Safety Objectives for new NPPs are applicable to SMR designs.

Backup

Overview Regulatory Approaches

	Rules-Based Regulation (RBR)	Goals-Based Regulation (GBR)
Focus	Prescribed actions	Objectives
Demonstrate compliance	Adherence to prescribed actions	Achievement of results, assurance mechanisms
Rules & standards	Particularistic and detailed	Goal-orientated outcomes
Advantages	Precision, certainty, less discretion, regulator ultimately accountable	Flexible, regulatees more responsible, adaptable to changes
Disadvantages	Prescriptive, inflexible, stifle innovation	Imprecise, greater uncertainty for regulatees

Table adapted from Peter J. May, "Performance-based Regulation", Jerusalem Papers in Regulation & Governance, Working Paper No. 2 (April 2010).