Webinar Series
on the Small Modular Reactor (SMR) Regulators' Forum
Phase 3 Reports

Design and Safety Analysis (DSA) Working Group

3 May 2024

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Q&A instructions

- The questions will be addressed after the presentations have been delivered. During the presentations, the participants are invited to post their questions in the chat.
- When posting a question in the chat, please kindly indicated the speaker you wish to address your question.
- After the presentations, the Moderator will start the Q&A session by selecting the questions to be addressed, from the chat first.
- Once all the questions from the chat have been answered, the Moderator will give the floor to the participants to ask questions directly by raising their virtual hand. This part of the session will proceed in the order in which the participants have raised their hands.
- When the Moderator gives the floor to a participant, the participant is kindly requested to turn on the video, identify themselves and indicate the speaker they are addressing, and then proceed by asking a clear and concise question. Please kindly mute your microphone while the speaker is providing their answer.
- The participants are encouraged to courteously react to one another's questions and/or remarks by using the chat. This will help the Moderator identify topics that interest the audience the most.
- Please keep in mind that the Moderator will set a time limit for each question to keep things on track and to maintain a good pace.

PLEASE KINDLY NOTE THAT THIS WEBINAR IS BEING RECORDED

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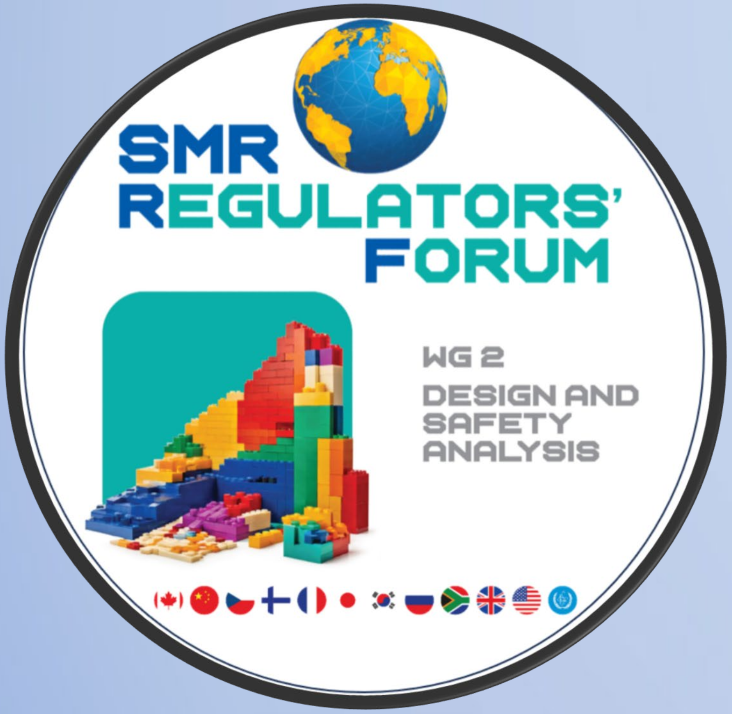
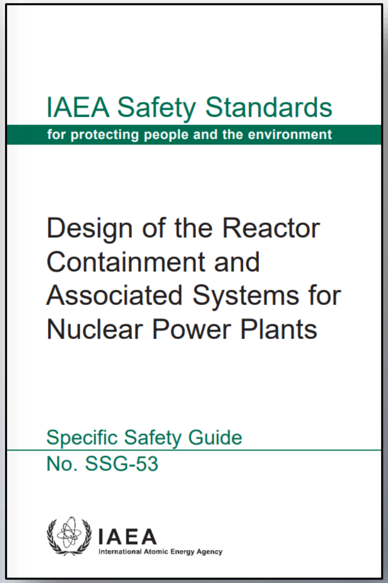
SMR Regulators' Forum Webinar Series



Introduction to the topic

- The current practice is to design a NPP in alignment with SSR2/1, this includes two important topics:
  - ✓ A requirement to consider the interfaces between safety, security, and safeguards. On the other hand, most of the IAEA guidance documents address these three topics independently
  - ✓ Reliance on a containment structure as the principal barrier to radionuclide release, requirements and recommendations on how to design the containment and associated systems are provided in SSR2/1 and SSG-53



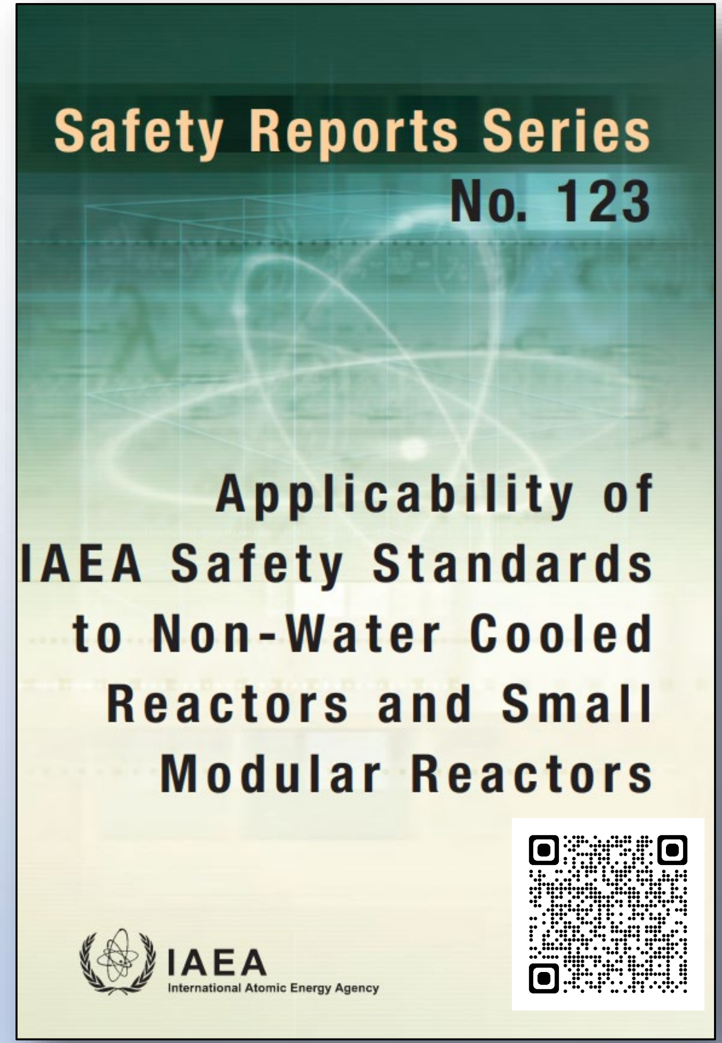
Introduction to the topic

SMRs bring new approaches:

- The consideration of security and safeguards after the design stage may need design modifications or compromise the envisaged deployment models
- For non-water cooled SMRs, the function of confinement of radionuclide release may be achieved via subsequent barriers that are different from the ones used in current operating reactors

How to practically apply the 3S concept for SMRs?

What are the alternative approaches to meet containment safety objectives and how they can be considered by regulatory bodies?



Contents

Introduction: SMR Regulators' Forum (SMR RF)

Mr Brian W. Smith (US NRC), SMR RF Chairperson

Part 1. Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach

Ms Sanja Simic (CNSC), SMR RF DSA WG Chair

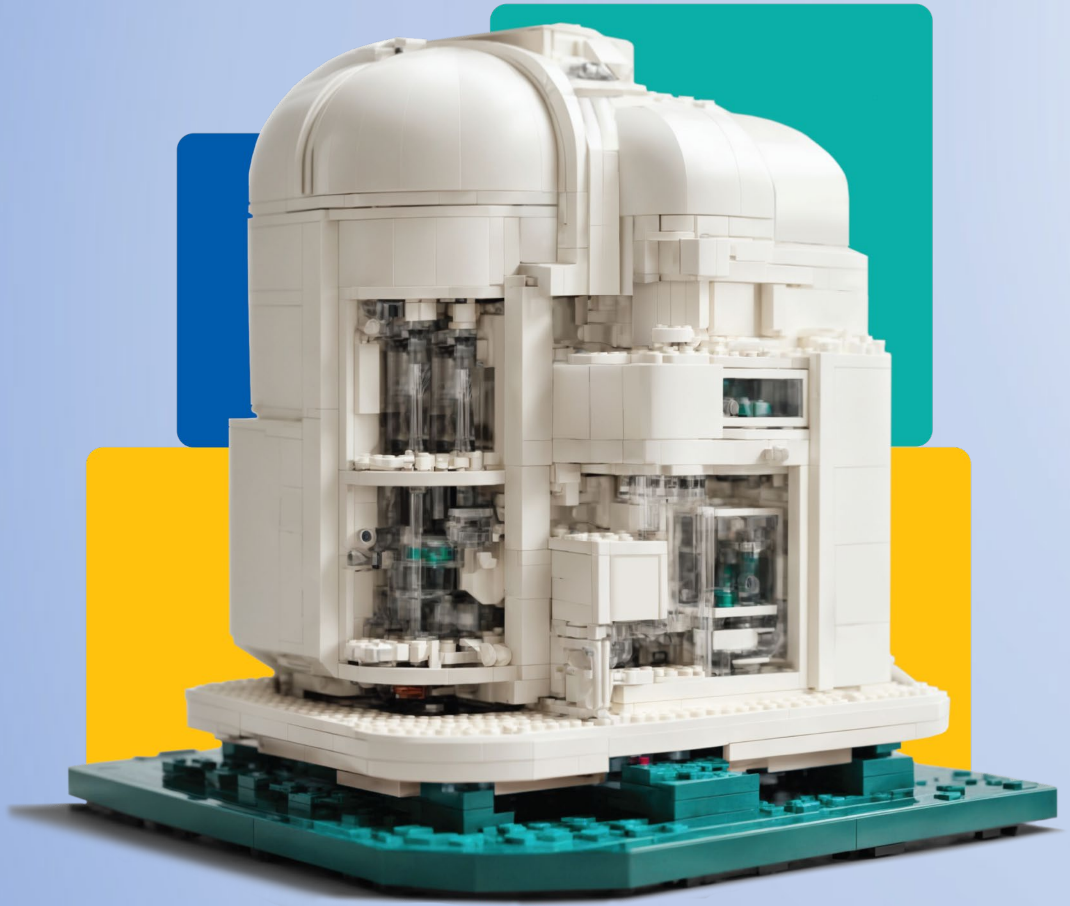
Mr Shahen Poghosyan, Safety Assessment Section (SAS), IAEA

Part 2. Confinement/ containment systems for non-water cooled SMRs

Mr Sébastien Israel (IRSN), SMR RF DSA WG member

Questions and Answers

Ms Paula Calle Vives (IAEA)



Introduction to the Small Modular Reactor Regulators' Forum (SMR RF)

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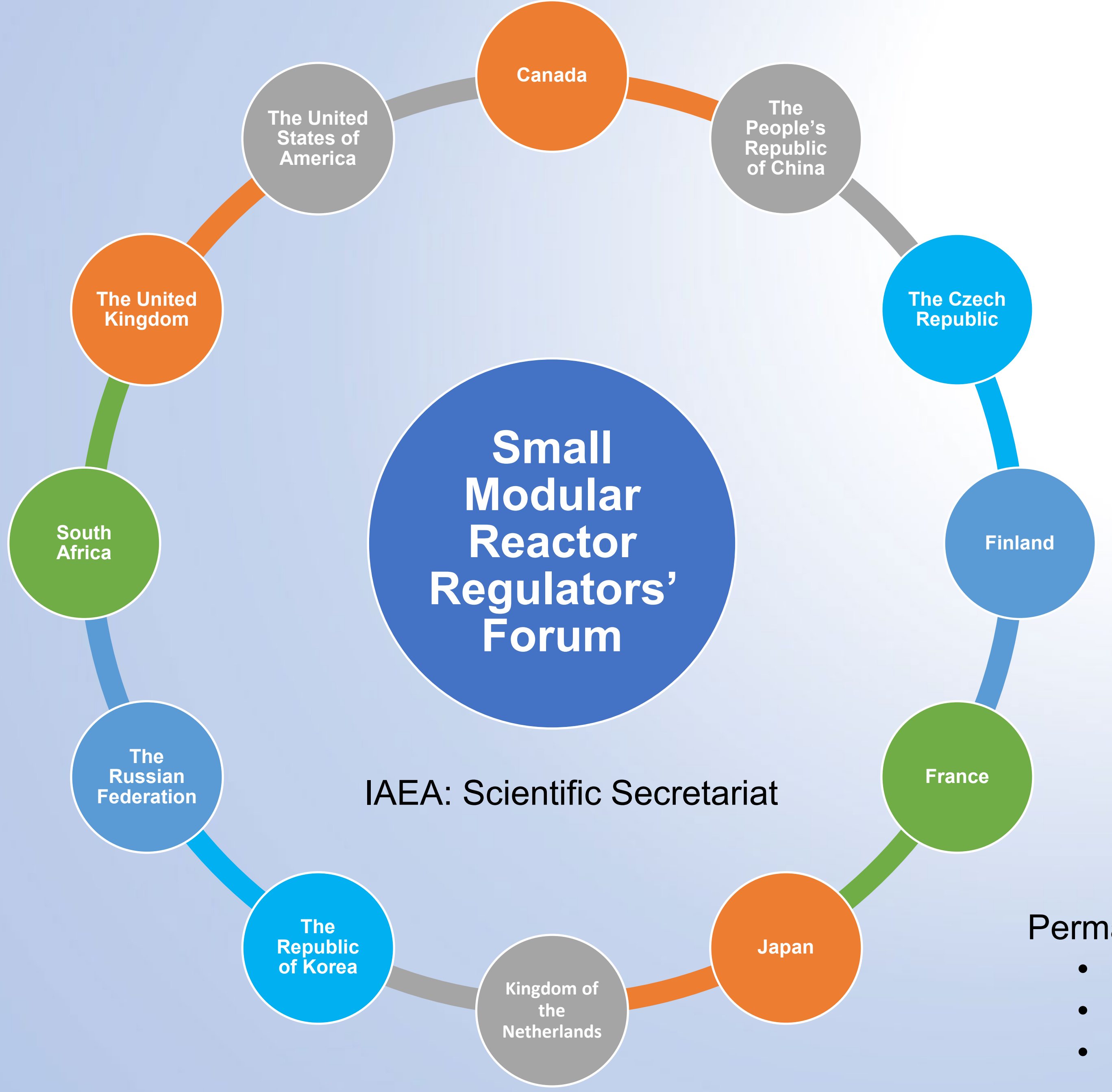
SMR REGULATORS' FORUM



Permanent Observers:

- European Commission
- OECD NEA
- WNA-CORDEL

Objectives and Outcomes

- Share regulatory experience among the Members to:
  - ✓ facilitate efficient, robust, and thorough regulatory decisions;
  - ✓ encourage enhanced nuclear safety and security;
  - ✓ facilitate international cooperation among regulators performing SMR-related assessments.

Generation and sharing of information that regulators can use to enhance their regulatory frameworks and activities

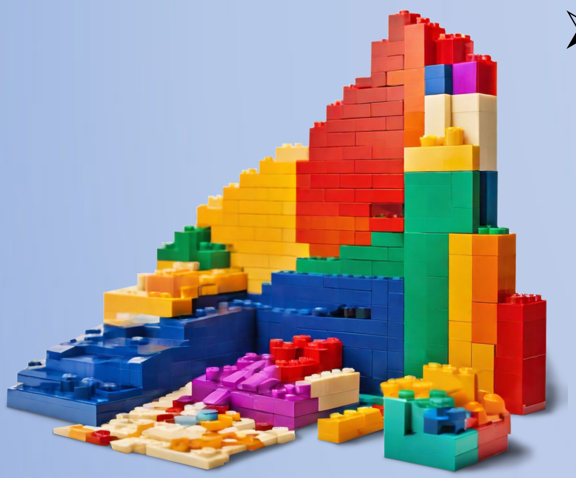
Description of regulatory challenges and discussions on paths forward

Common position statements on regulatory (policy and technical) issues

Suggestions for revisions to, or drafting of, the IAEA publications, especially the IAEA Safety Standards regarding SMRs

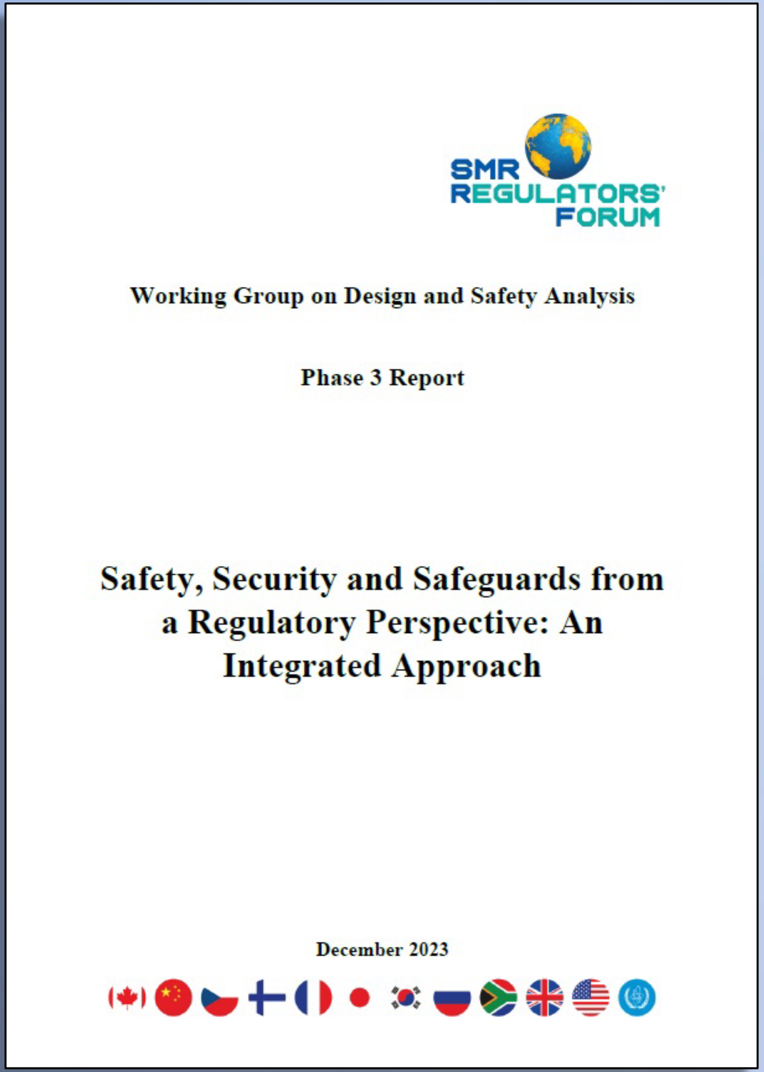
Suggestions for high level issues to be raised before international codes and standards organizations

SMR RF Design and Safety Analysis Working Group (DSA WG)



- DSA WG addresses issues related to **safety demonstration, the integration of safety, security and safeguards** and the **safety analysis approaches** for SMRs designs

- DSA Phase 3 Reports:
  - **Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach** – implications of the application of a process to enhance the integration of safety, security and safeguards into the design of SMRs.
  - **Containment Systems** – implications of the inherent and passive safety features of new advanced non-LWR on SMR containments systems.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Working Group on Design and Safety Analysis

Phase 3 Report

Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach

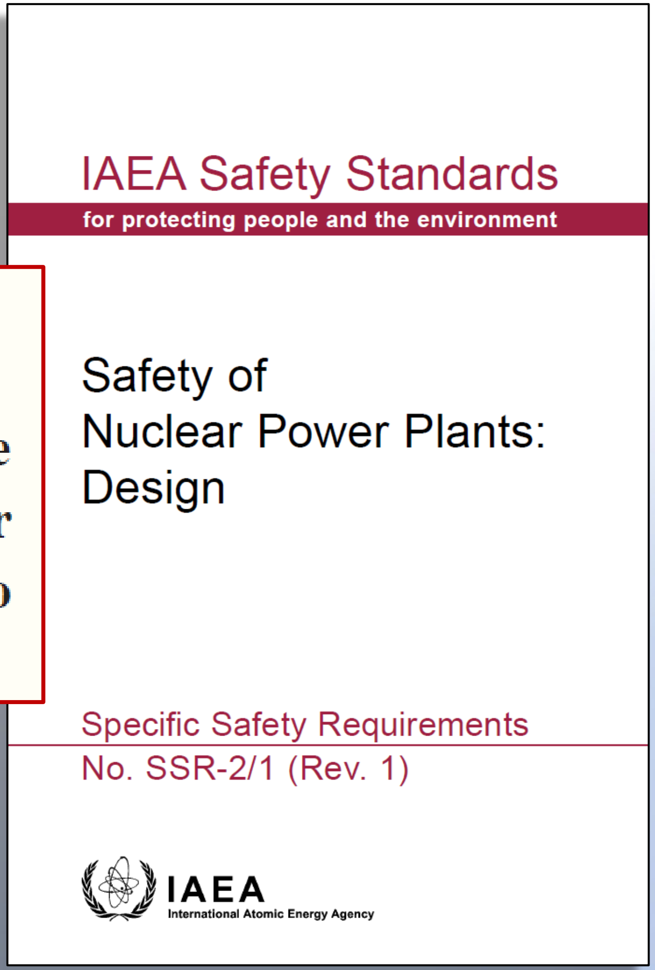
December 2023

Part 1.
Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach

Background

Requirement 8: Interfaces of safety with security and safeguards

Safety measures, nuclear security measures and arrangements for the State system of accounting for, and control of, nuclear material for a nuclear power plant shall be designed and implemented in an integrated manner so that they do not compromise one another.


IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

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3S: Brief Problem Description

- Various SMR designs encompassing advanced and innovative technology solutions are currently being developed
- Time to consider Safety, Security, and Safeguards (3S) interfaces
    - Unique time window
    - Hard to address afterwards
    - Current practice is different (security and safeguards are added later)
    - Some degree of integration exists, but needs to be improved
- Opportunity to **design out certain risks** not only for safety but also for security (security-by-design) and safeguards (safeguards-by-design)

SMR Novelties vs Challenges for 3S

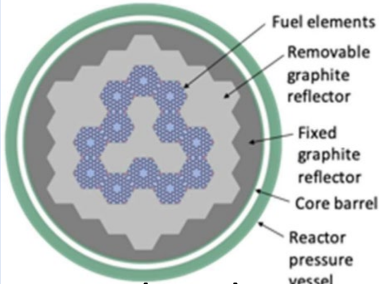
- Transportability
- Locations (remote, urban)
- New fuel concepts
- Long refueling periods
- Higher enrichment
- Factory sealed cores
- Highly integrated software-based systems

2-3.5MW eVinci (WEC)

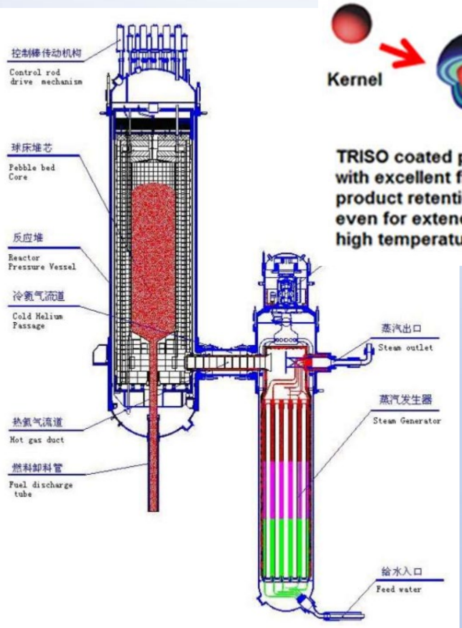
1.5-MW Aurora

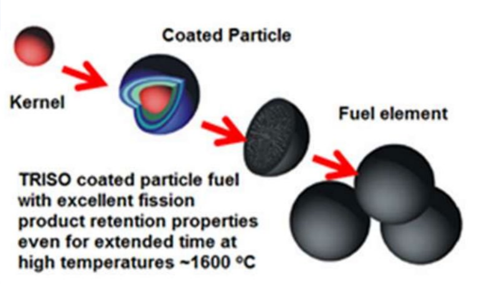
RITM-200M
(up to 120months)

35MW KLT-40S



MMR (USNC)





HTR-PM (Triso)

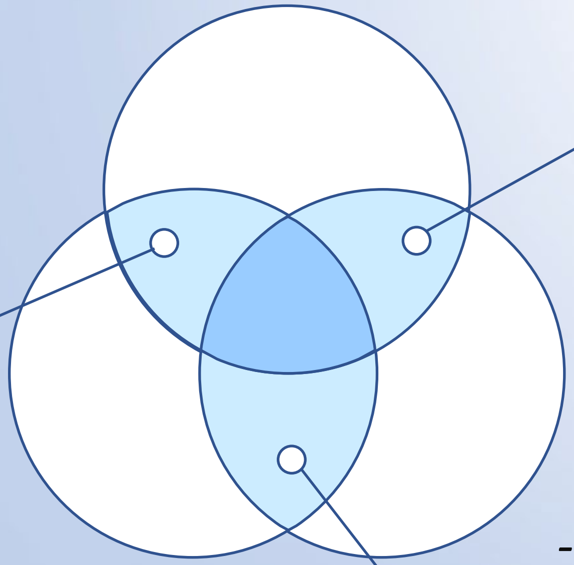
Source: IAEA SMR Booklet 2022 Edition

3S interfaces

Radioactive releases

Safety

- *Affect safety during inspections (CSA §87)*
- *Access of SG inspectors*
- *Use of common equipment*
- *Fuel design*



- *Access of external resources, pathways*
- *Software systems vs. security risks*
- *Information sharing*
- *Barriers (both pros and cons)*

Security

Sabotage or intentional misuse of rad. materials

Safeguards

Acquisition of nuclear weapons

- *Material control accountancy*
- *Delay access for security reasons*
- *Constant transmission of surveillance data*

Concept By Design

Expectation that SMR technologies must be safe, secure and proliferation-resistant given their potential standalone nature and application for remote locations

Adoption of the 3S concept early in the design phase (3S-by-Design) of an SMR:

- Safety-by-design: passive systems and inherent safety characteristics
- Security-by-design (SeBD): security is fully integrated into the design process of a nuclear facility from the very beginning
- Safeguards-by-design: international safeguards requirements are fully integrated into the design process of a nuclear facility from an early stage

Risk-informed approach that requires **multi-disciplinary teamwork**

Security-by-Design (SeBD)

What has changed for SMR compared to larger NPPs?

- Potentially different security risks because of the nature of new fuels (accessibility and size of the nuclear inventory), frequency of re-fuelling and innovative safety features (could prevent a significant offsite dose)
- Potentially different insider risks and cyber risks due to autonomous operation and remote monitoring
- Potentially different security risks because of the SMRs' compact designs. If all targets and safety features are gathered in a small area and can be destroyed at the same time, the added value of nuclear security for safety features will be significantly reduced
- Underground construction will reduce certain risks (e.g., from aircraft crash) but may create others (e.g., flooding)
- Multiple unit sites increase the nuclear inventory and thereby the security risk, but shared services may have positive implications for both safety and security
- Supply chain risks may be increased (insider threat vectors)

SeBD – Why?

Bureau of International Security and Non-proliferation in Security by Design in the United States, Dep. of State (2012): Successful "security by design" results in a more robust physical security infrastructure that:

- Minimizes insider access to nuclear material and the opportunities for and risk associated with malicious acts
- Provides flexibility to respond to a changing threat environment
- Decreases operational security costs by reducing the reliance on the Protective Force (e.g., on-site security guards)
- Increases the efficacy of Protective Force in the event of an attack

Safeguards-by-Design (SBD)

- SMRs can be expected to have the following characteristics that could affect the implementation of safeguards:

Low thermal signature - challenging to use satellite or other forms of remote sensing to verify operation

Coolant - use of coolants other than water such as lead-bismuth or sodium does not allow for traditional optical viewing of the fuel in the core or in the spent fuel storage

Number of units per site - the larger the number of units, the greater the need for refuelling and number of discharges per calendar year

Long life reactor core (sealed vessel) - misuse of the facility and diversion of spent fuel becomes more difficult

Fuel element size - small size tends to facilitate item concealment

Enrichment - if a design requires uranium fuel enriched to close to 20% (HALEU), this will involve modified safeguards measures from those customarily applied to LEU-fuelled reactors; above 20%, increased safeguards activities

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SBD – Why?

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- Reduces the burden on operators and the IAEA by optimizing inspections
- Enhances possibility to use advanced technologies like unattended monitoring systems and remote data transmission
- Reduces risk of costly retrofitting
- Facilitates joint use of equipment
- Increases flexibility for future installation of safeguards equipment
- Reduces risk to cost, scope and schedule
- Improves understanding by all stakeholders of safeguards obligations

Integration of the 3S

- **Benefit:** Inclusion of security and safeguards in conjunction with safety is important for overcoming growing security threats and increasing proliferation risks
- **Challenges:**
  - Communication and coordination among 3S organizations, given that each 'S' is often developed independently and regulated by different organizational units or even institutions
  - 3S interface management: Often a measure implemented on behalf of one 'S' (e.g., safety) may complement one or both of the other disciplines so that, for example a thick-walled containment building may benefit both safety and security. Sometimes, however, there may be conflicts.
- Interface management is a systematic way to recognise the decision points, to take advantage of the synergies and to resolve the conflicts

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Integration of the 3S

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SAFETY

Classification of assets based on random failure (only)

Health and dose monitoring

Environmental monitoring

Publicity of information on materials, locations, activities

Publicity of incident and emergency management

Information exchange /Early warning systems

SECURITY

Information exchange /Early warning systems

Classification of assets based on intentional, unlawful activity (only)

Personnel security: backgound checks, health and behavioural monitoring

Need-to-know basis

Delay (of access & exit)

Crime scene management
Forensics, investigations

Risk-informed, graded approach
Design and classification of systems, structures, and components (3SBD)
Leadership and management
Organisational culture
Information and computer/cyber security (CIA)
Access control & surveillance
Materials accounting and control
Detection, coordinated response

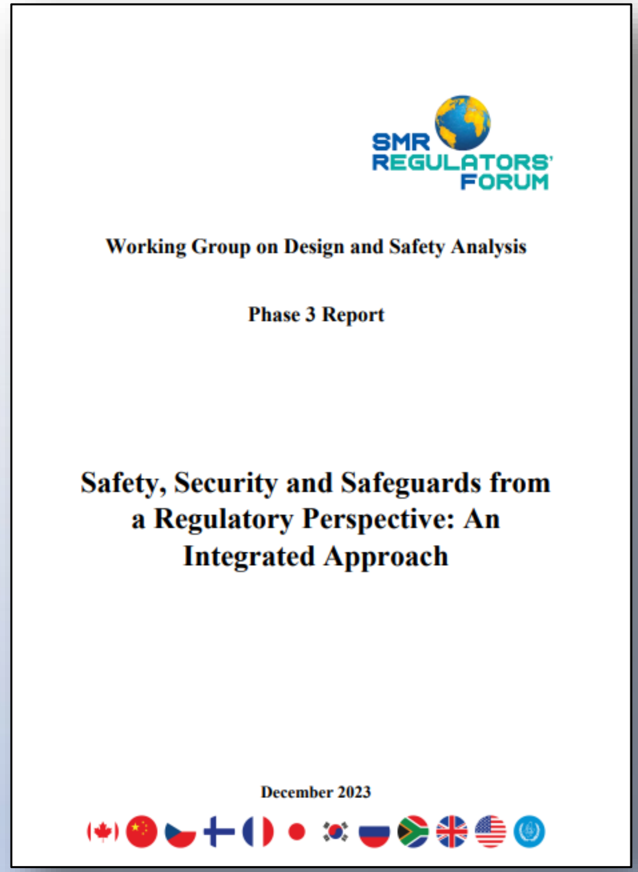
SAFEGUARDS

Reporting and declarations
Verification of declarations: open source information, environmental sampling...
Remote data transmission

Source: Karhu et al. (STUK)

Common Positions

- DSA WG came to agreements on various issues relevant to 3S integration and the introduction of SMRs. Where these differ from well-known existing approaches, they are highlighted here as “common positions”.
- Our report “Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach” examined and developed common positions on:
  - Safety and Security Interfaces
  - Safety and Safeguards Interfaces
  - Security and Safeguards Interfaces
  - Safety, Security and Safeguards Interfaces
- Also addressed:
  - Possible methodologies for integration of safety, security and safeguards
  - Regulatory role in 3S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Working Group on Design and Safety Analysis

Phase 3 Report

Safety, Security and Safeguards from a Regulatory Perspective: An Integrated Approach

December 2023

Common Position Example 1: Safety-Security

Passive/inherent safety

- Some developers claim that passive safety will prevent significant offsite releases resulting from nuclear security events.
- Common position: Claims made by developers that passive safety measures would reduce security risks need to be justified through the security risk assessment.

Use of safety analysis information to inform security

- There are significant interfaces between safety and security related to safety analysis. The identification of potential sabotage targets that need protection are informed by the safety analysis. However, Postulated Initiating Events (PIEs) are not the only source for potential initiating event of malicious origin (IEMOs). Security uses Sabotage Event Scenario (SES) which is derived from the IEMOs and the associated protective and mitigating SSCs.
- Common position: Licensees are recommended to: (a) use deterministic safety analysis information to inform security, and (b) develop or adapt PSA models used for security, recognizing that PSA models used for safety will not be directly applicable for security.

Common Position Example 2: Safety-Safeguards

Physical facility layout

- Common position: Licensees/developers should approach the IAEA in the early stages of the SMR development (SBD) to ensure that IAEA safeguards can properly be implemented. Existing IAEA safeguards measures may be applicable to SMRs. If not, new IAEA safeguards approach, measures and techniques need to be developed by the IAEA. Licensees/developers should be aware of the importance of physical facility layout and its potential constraints. Retrofitting to accommodate safeguards should be avoided as it may negatively affect safety and/or security.

Plating in Molten Salt Reactors (MSRs)

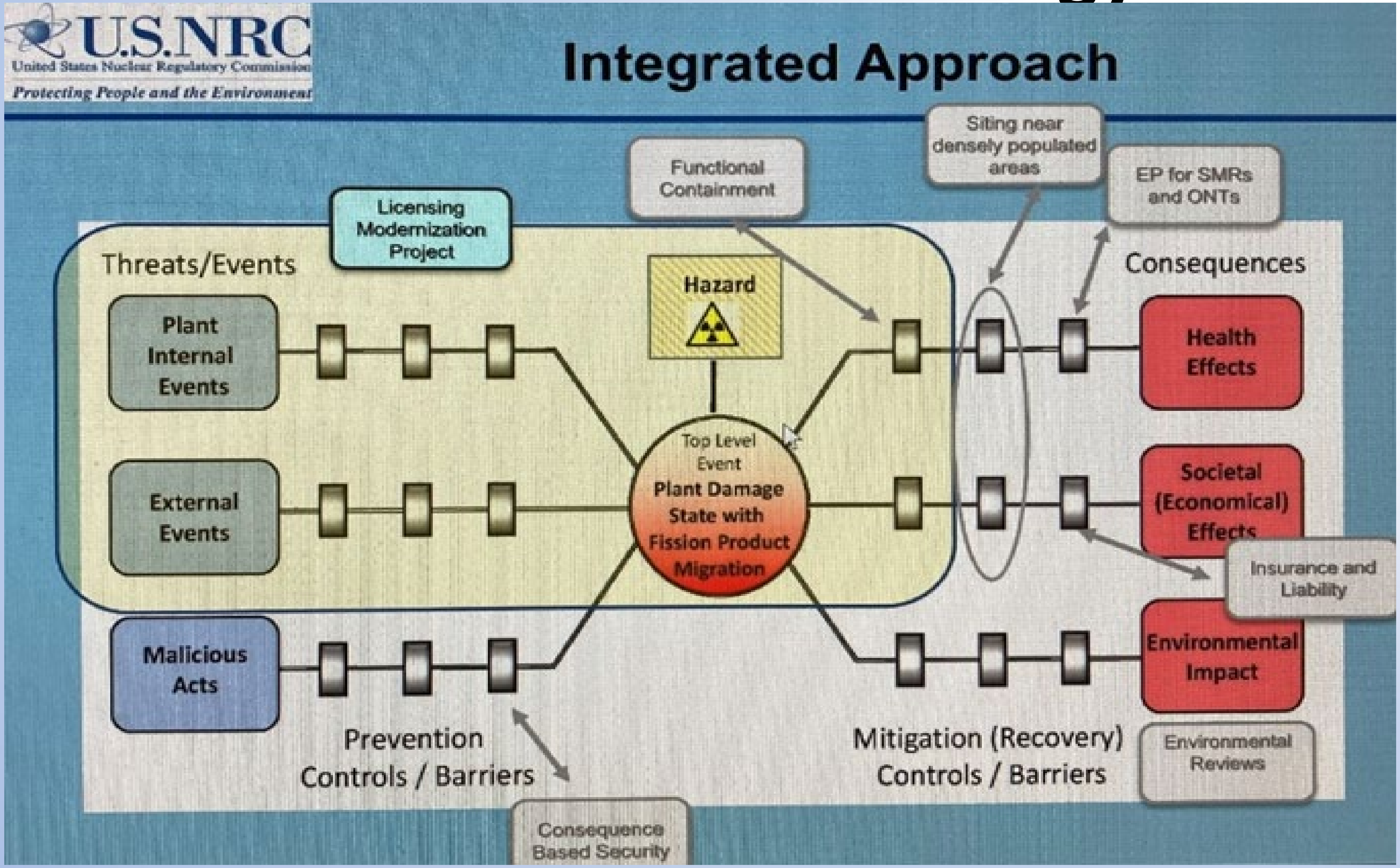
- In Molten Salt Reactors, the interaction of fuel salt with the plant SSCs can result into plating the reactor coolant boundary with radioactive material.
- Common position: For MSRs with an issue with plating with radioactive material, the IAEA needs to verify operator's information tracking the material under all operating conditions. This includes maintenance activities. The instrumentation for tracking fuel motion to get safety information should not have a negative impact on the same type of instrumentation used for safeguards purposes, and vice versa.

Common Position Example 3: the 3S Interface

Regulatory organizational culture and structure

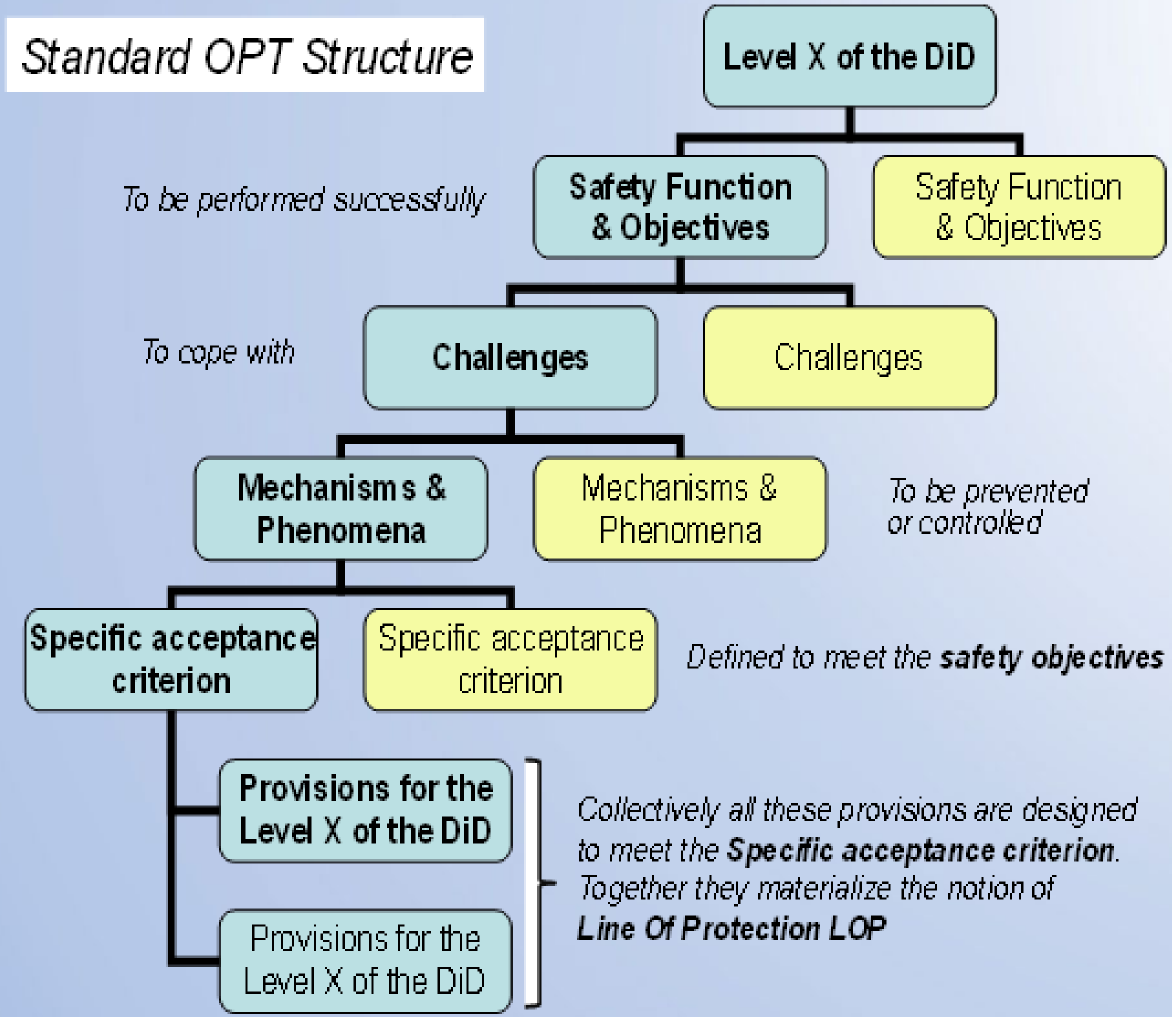
- To best deliver this cross-purpose working (a pragmatic mix of cooperation, collaboration, and some integration across 3 Ss and specialisms) requires a related organizational mindset, culture and structures that facilitate and inform joint working.
- Common Position: Regulators should be prepared to interface with all 3 S stakeholders by having sufficient capacity and facilitating information sharing among the 3 S disciplines.
- While it would not be realistic or necessary to change safety, security and safeguards assessment principles, the regulator should review higher-level guidance to regulation so to enable the 3 S approach. This internal regulator policy could in turn inform related training and other activities to build capability and capacity to regulate the SMR designs. International collaboration and lesson learning would also add value.

Integration of 3 S':
Bowtie methodology



Source: U.S. NRC

Integration of 3 S':
Objective Provision Tree methodology



Level of the DiD
E.g. Prevention

SF to be performed succesfully
Safety : e.g. Heat removal
Security : e.g. Vital Target protection

Challenge: to cope with
Safety : e.g. Heat removal path disruption
Security : e.g. Tentative of sabotage

Mechanism to be prevented or controlled
Safety : e.g. Loss of coolant
Security : e.g. Sabotage during Normal Operation

Objective to be met
Safety : e.g. Allowable flow reduction
Security : e.g. Avoid the access to Vital Equipment – Intercept the adversary

Provisions to be implemented to prevent and or control the mechanism
Safety : e.g. Conservative design, seismic design, etc.
Security : e.g. Control procedures, barriers, Response Force, etc.

Source: Ammirabile and Fiorini, IAEA Conference on Topical Issues in Nuclear Installation Safety: Strengthening Safety of Evolutionary and Innovative Reactor Designs, 2022

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Conclusions

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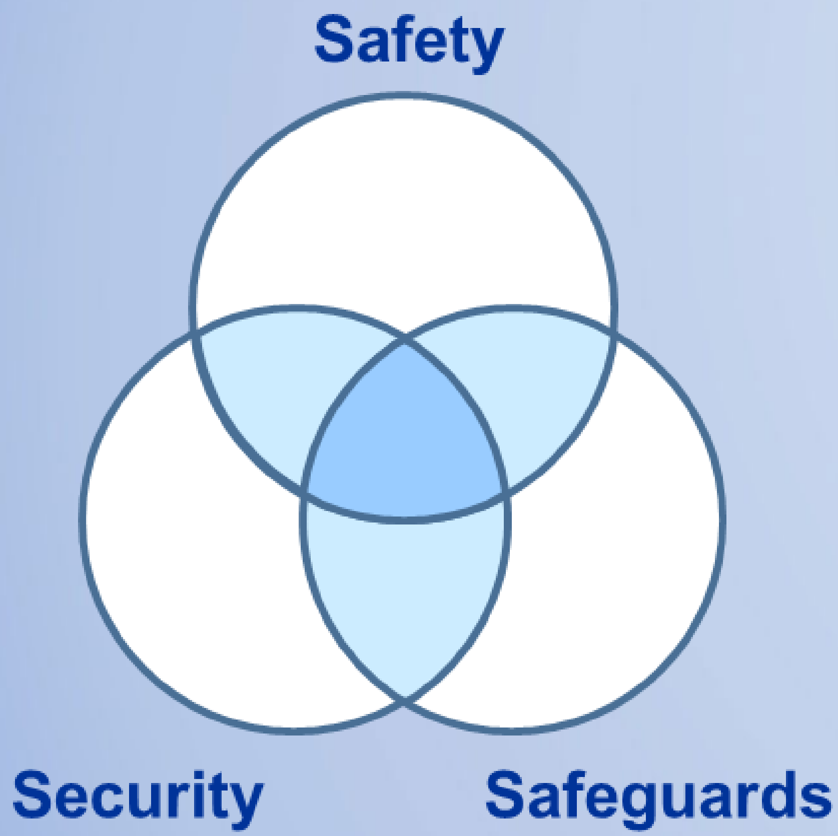
- Next steps to enhance the integration of 3S (DSA WG report for further details)

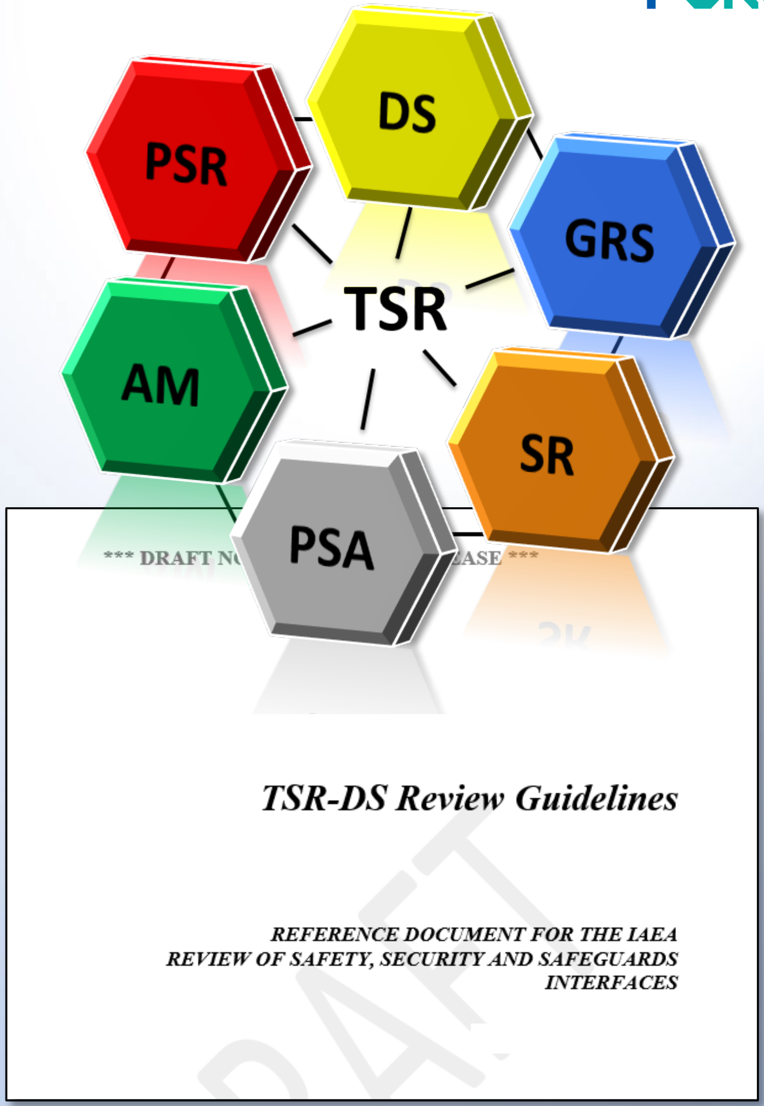
Interdisciplinary collaboration throughout the design, construction, and operation phases	Early inclusion of 3S principles in the design and planning phase of SMRs to avoid conflicts and inefficiencies	Regulatory alignment on standards for SMRs addressing 3S requirements	Incorporation of advanced security and safeguard technologies into the SMR design to reduce vulnerabilities and the need for later retrofitting	International cooperation and sharing of best 3S practices and expertise



IAEA Activities on 3S Interfaces and Challenges for SMRs

Review of 3S interfaces

- **Technical Safety Review (TSR) service** provides assistance to all stakeholders (e.g. regulators, operators, designers)
- **TSR-DS:** independent evaluation of the design documentation submitted to the IAEA against IAEA Safety Standards.
- Systematic **review of the interfaces** within IAEA TSR-DS review missions:
  - Guidelines for the review of 3S interfaces are being developed now



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Current activities on 3S interfaces

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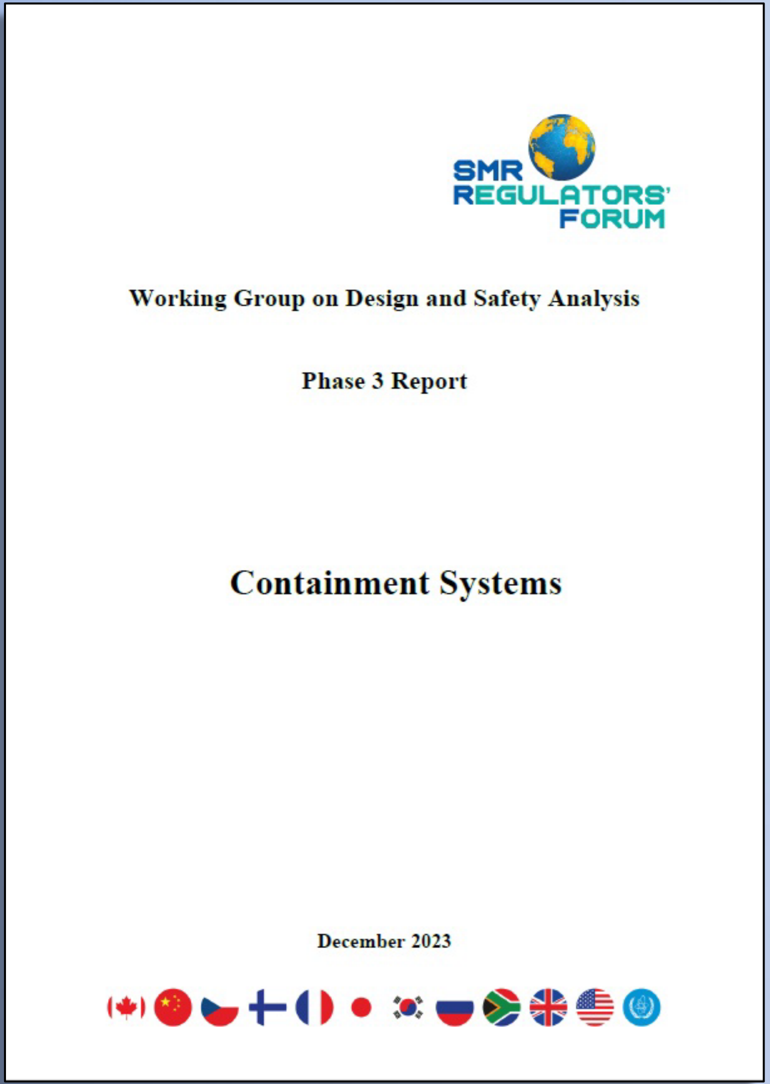
- **DS533/NST067 safety guide:** Managing safety-security interfaces
- **DS537 safety guide:** safety demonstration for FOAK (3S chapter)
- **TRS-1000 publication:** 3S by design for SMRs
- **TRS-1000 publication:** Use of Safety Analysis for Security purposes
- **TSR review guidelines** for 3S (review missions)
- **IAEA SMR Conference**, [Track 10] 3S for SMRs
- **INT2023 3S workshop for SMRs**, 4-8 November 2024, ORNL **(deadline for nominations - 24 May 2024)**

International Conference on Small Modular Reactors and their Applications, 21-25 Oct 2024, Vienna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Working Group on Design and Safety Analysis

Phase 3 Report

Containment Systems

December 2023

Part 2. Confinement / containment systems for non-water cooled SMRs

Requirement for the design of the containment

According to Requirement 54 of SSR-2/1:

“A containment system shall be provided to ensure, or to contribute to, the fulfilment of the following safety functions at the nuclear power plant:

(i) **confinement of radioactive substances in operational states and in accident conditions**;

(ii) protection of the reactor against natural external events and human induced events; and

(iii) radiation shielding in operational states and in accident conditions”


IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

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Terminology

Confinement

Prevention or control of releases of radioactive material to the environment in operation or in accidents. Confinement is closely related in meaning to containment, but confinement is typically used to refer to the safety function of preventing the ‘escape’ of radioactive material, whereas containment refers to the means for achieving that function

Containment system

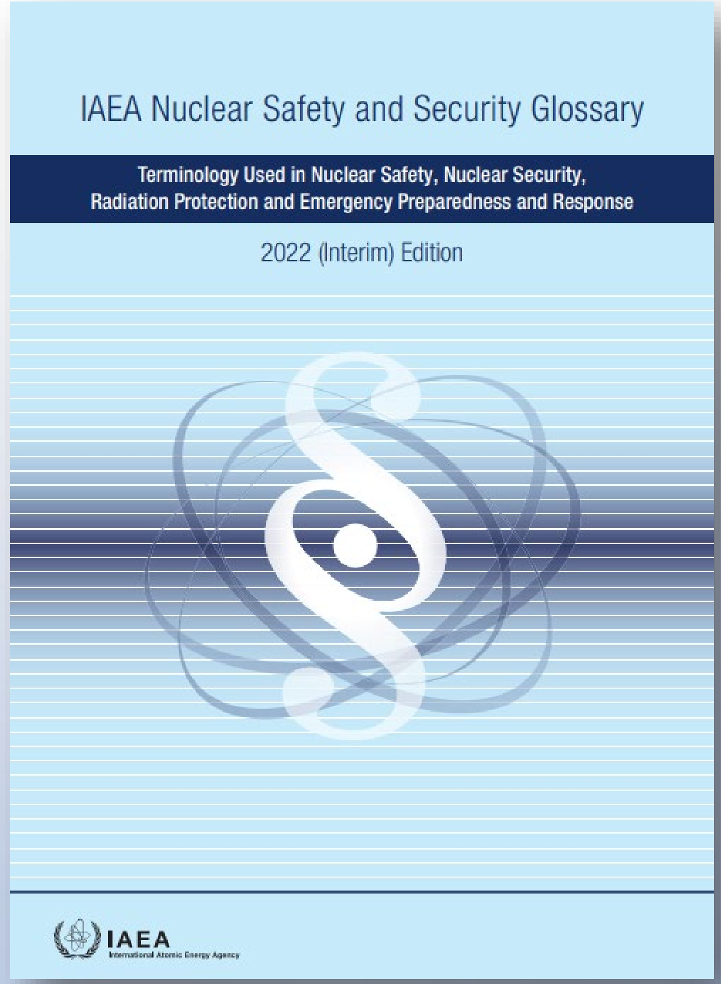
A structurally closed physical barrier (especially in a nuclear installation) designed to prevent or control the release and the dispersion of radioactive substances, and its associated systems

Containment

Methods or physical structures designed to prevent or control the release and the dispersion of radioactive substances

Barrier

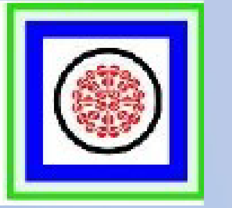
A physical obstruction that prevents or inhibits the movement of people, radionuclides, or some other phenomenon (e.g., fire), or provides shielding against radiation.



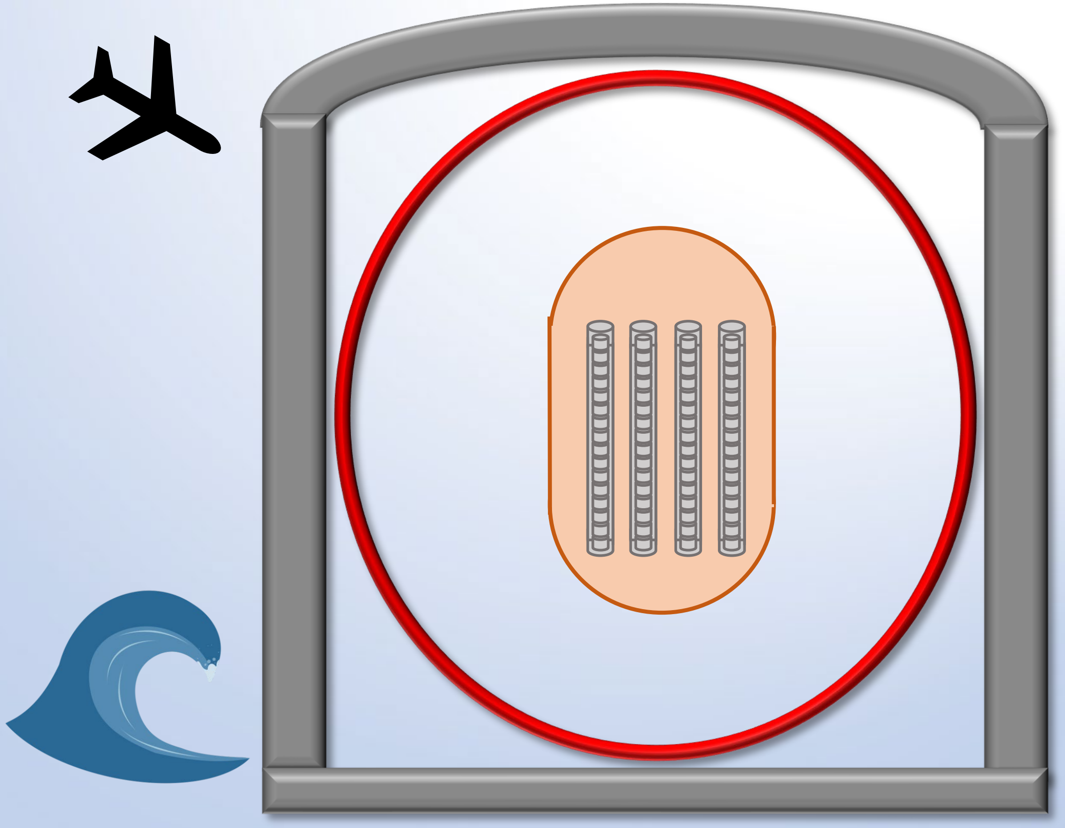
Traditional LWR designs

Typical LWR containment structure : a thick, steel-reinforced concrete walls and an interior steel liner

- Concrete/steel containment structure/building



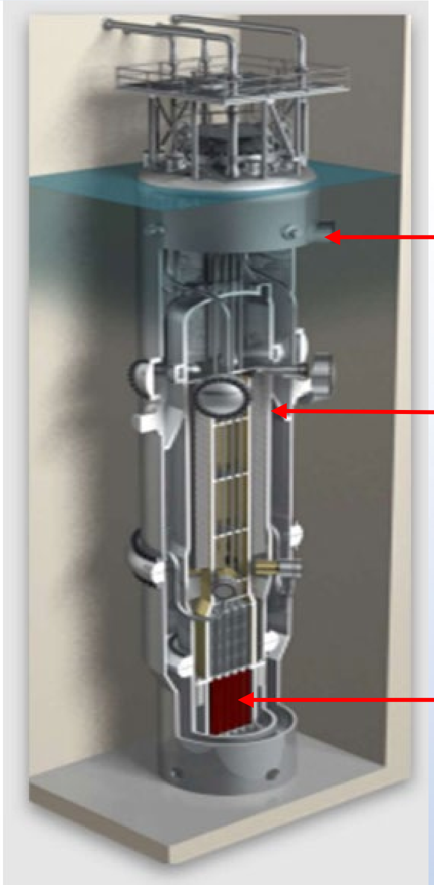
Reactor Building



LW SMR designs

- Steel Containment Structure

Steel Vessel



Containment Vessel

Reactor Vessel

Nuclear Core

Source: IAEA SMR Booklet 2022 Edition (NuScale)

Novel Technologies: Claims

A leak-tight and pressure retaining containment structure is not relied upon to restrict the consequences of accidents

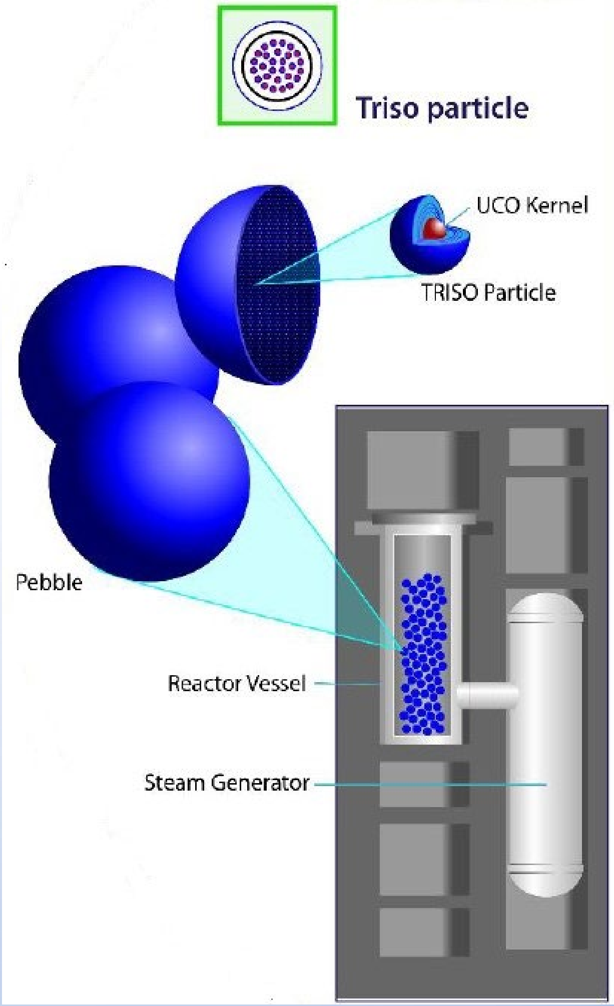
Inherent and passive safety features reduce the reliance on structure to provide the containment function

Different provisions can limit radionuclide releases to the environment (ex: retention in the fuel rather than reactor coolant system pressure boundary and containment structure)

Novel technologies

IAEA's TECDOC-1936 suggested the interpretation of Requirement 54 in SSR-2/1 as follows: "The term 'containment system' is to be interpreted here as a 'reactor **functional containment**' consisting of multiple barriers, internal and external to the reactor, including the reactor building".

The justification for the Suggested Interpretation is that "the expected contribution of the different barriers of the containment system of HTG-SMRs to the fulfilment of the safety functions of the NPP is different than in the case of the traditional LWRs. In HTG-SMRs, the fuel acts as the dominant contributor to the confinement function, and less importance is placed on the containment structure (reactor building). Multiple barriers are provided to control the release of radioactivity to the environment and to ensure that the 'reactor functional containment' design conditions important to safety are not exceeded in any of the plant states."



Source: CNSC

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Common positions

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The position of the Working Group is that, irrespective of technology, the adequacy of the design of containment systems **should be judged considering its features** (e.g., the design shall have barriers, robustness, prevention of consequential failures) **and overall effectiveness**, consistent with a risk-informed and performance-based regulatory approach.

Common positions

Barriers for DiD

- The design should include **multiple independent and diverse means** (DiD) to **ensure that the function of containment is met** for all operating states in accordance with SSR-2/1
- Due to an SMR's compact size, the independence of the barriers could be more challenging to achieve for SMRs than for large reactors. In accordance with the DiD approach, **the design should ensure that measures are included at each level.** The measures included at any particular level should remain independent as far as practicable of those at all other levels

Common positions

Graded approach

- Designs may be based on a graded approach in assessments of the novel containment systems to achieve safety, security and safeguards objectives. Nonetheless, a safety case must be presented to the regulatory authority to demonstrate that the proposed containment system design can and will comply with the overarching licensing requirements.

Common positions

Protection against hazards

External events have the potential to penetrate multiple layers of DiD and cause multi-unit or multi-module accidents (where applicable) if they are not adequately addressed in the design.

- Regardless of how the containment systems are designed, provisions are required to prevent accidents associated with internal and external (natural and manmade, accidental or intentional) hazards.
- Where containment systems are shared among the units/modules, the design should take account of the potential hazards such arrangement may introduce.
- Depending on the siting considerations (for example, for the underground/submerged containments or for floating SMR installations), the design of the containment systems needs to consider such potential specific hazards this arrangement may introduce.

Common positions

Accidents conditions

- The physical configuration and layout of SMRs, especially the ones based on novel and advanced technologies, may be very different from typical large LWRs. **It is necessary to identify all areas within the SMR containing radioactive material to determine where the actual release barriers providing confinement should be located**.
- The **identification of severe accident scenarios should consider a full range of initiating events** for which accident progression should be assessed based on justified assumptions concerning the credible degree of barrier degradation. For this purpose, **probabilistic assessment can be used in a complementary manner, but it should not be used solely to screen out low frequency events, since measures at Level 4 are intended to address such events**. This is in accordance with SSR-2/1 which reinforces that practical elimination should not be claimed solely based on compliance with a probabilistic cut-off value, but should primarily be justified by design provisions, and in some cases also strengthened by operational provisions. **Moreover, a justification for practical elimination should be based on a deterministic analysis taking account of uncertainties due to the limited knowledge of certain physical phenomena.**

Common positions

Personnel access

- Due to an SMR's compact size and design, access by personnel for various activities (for example, MTIR, security inspections and safeguards inspections) can offer different challenges.
- The access arrangements should take into consideration design-specific hazards without compromising the containment system design intent.
- For MTIR on or off site, the design should provide for suitable access arrangements for the 3S (safety, security and safeguards) structures, systems and components (SSCs).
- Design should accommodate the IAEA safeguards activities and provide physical access when required.

Common positions

Leakage

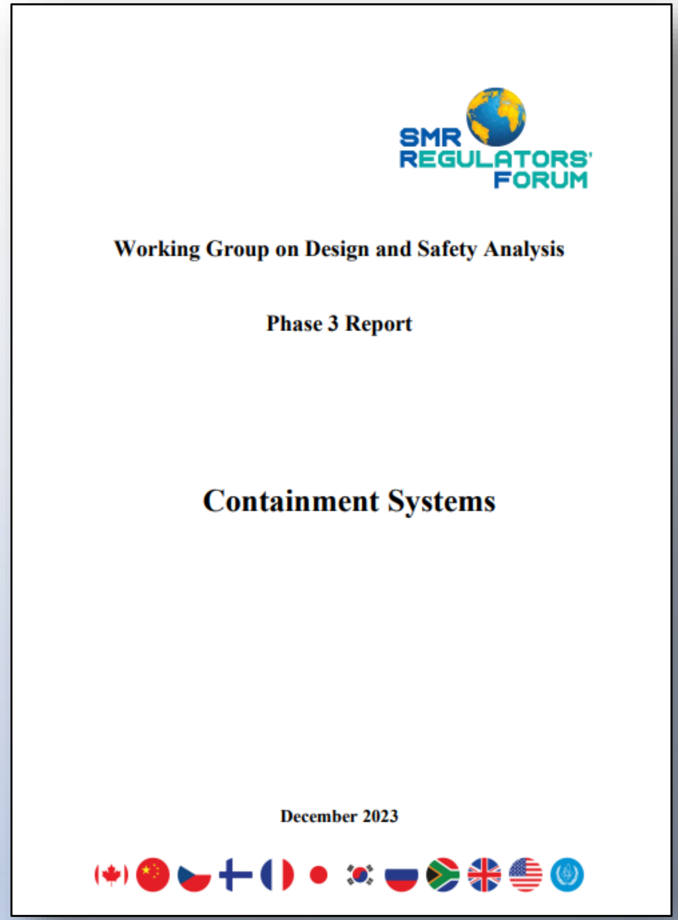
- Leakage rates for the containment system design are an important assumption in the safety analysis to demonstrate that the regulatory dose limits are met. In certain designs, some leakage rate assumptions are more significant (i.e., designs requiring strict limits on leak tightness). These should be justified. The design should provide for the verification that the designed leakage rates are not exceeded for the required lifetime.
- If for a design there is no claim on the need for a leakage rate on the containment structure, detailed justification and demonstration of the adequacy of such claim must be provided to the regulator.

Aging and degradation

- Novel SMR technologies and aspects related to their siting (for example, submerged containments and underground construction) may introduce unique degradation mechanisms of the containment systems. The degradation rate may also differ from that traditionally experienced in the nuclear industry

Conclusions

- During the Working Group discussions, it was clear that Member States recognized the importance of performance of containment systems.
- The focus of past regulatory effort was predominantly on large LWRs. This brought to light a potential gap for Member States to review their guidance available for SMRs.
- Regulators should strive and continue to develop or review regulatory requirements and guidance pertaining to SMR technologies, where appropriate. This is especially true in case of non-LW-SMRs, where containment system designs are substantially different from typical large LWRs and may change the emphasis with respect to which particular SSCs are important.
- The IAEA should continue to assess the extent to which the current safety standards address the safety of SMRs and develop guidance to address the identified gaps.
- The SMR Regulators' Forum will consider the work done by IAEA in the future.


SMR REGULATORS' FORUM

Working Group on Design and Safety Analysis

Phase 3 Report

Containment Systems

December 2023

Next Steps

The SMR RF DSA WG is currently considering:

Continuation of 3S topics

Mechanistic source term

Questions and Answers

SMR Regulators’ Forum Webinar Series

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