SMR REGULATORS' FORUM

Phase 3 Summary Report

December 2023

FOREWORD

There continues to be sustained global interest in small modular reactors (SMRs), which have the potential to play an important role in globally sustainable energy development as part of an optimal energy mix. In particular, SMRs may enhance energy availability and security of supply in countries expanding their nuclear energy programs and those embarking on a nuclear energy program for the first time.

As the interest in SMRs continues to grow, so does the importance of international collaboration. Given that its main purpose is to bring together experienced regulators to identify and address key SMR-related challenges, the SMR Regulators’ Forum has an increasingly important role to play in making such collaboration possible.

This Report is a summary document that presents an overview of common positions and associated recommendations developed in Phase 3 (2021-2023) by the working groups (WG) of the SMR Regulators' Forum, namely:

- The Design and Safety Analysis (DSA) Working Group; and
- The Manufacturing, Construction, Commissioning, Operation (MCCO) Working Group.

In August 2022, the Forum’s Licensing Issues Working Group joined the IAEA Nuclear Harmonization and Standardization Initiative (NHSI) to lead the NHSI Regulatory Track WG 3: *Process for leveraging other regulatory bodies’ reviews*. The goal of the NHSI Regulatory Track is to increase regulatory collaboration among Member States, avoid duplication of efforts, increase efficiency, and facilitate the development of common regulatory positions without compromising nuclear safety and national sovereignty. The NHSI WG3 outcomes will be shared by the IAEA in 2024.

Forum’s outputs continue to enable regulators to collaborate more effectively, inform potential changes to their requirements and regulatory practices and provide common positions and recommendations for consideration by the IAEA. Increasingly, these cooperative activities are also being leveraged outside of the Forum’s work between participating regulators who are assessing the same or similar SMR concepts for potential deployment.

The work of the Forum focuses on cross-cutting and technology-neutral issues and does not involve technology-specific cooperation or assessments. Recognizing that regulatory requirements will differ between Member States, the IAEA publications applicable to nuclear reactor installations serve as benchmarks for the discussions within the Forum and to compare practices when developing common positions.

As of July 2022, the following countries are Members of the Forum: Canada, China, Czech Republic, Finland, France, Republic of Korea, Russian Federation, South Africa, United Kingdom, and United States. The Joint Research Centre (JRC) of the European Commission (EC), the OECD Nuclear Energy Agency (NEA), the CORDEL working group of the World Nuclear Association (WNA) serve as Permanent Observers.

During Phase 3 of the Forum, Mr. Brian W. Smith (USA) served as the Chairperson and Mr. Matthew Bamber (UK) as the Vice-Chairperson. The IAEA Scientific Secretaries of the Forum were Mr. Miguel Santini, and, since March 2022, Ms. Paula Calle Vives.

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1. BACKGROUND AND INTRODUCTORY COMMENTS

1.1 FORMATION OF THE THREE ISSUE-BASED WORKING GROUPS (WGs) FOR PHASE 3

Since its creation in 2014, the Forum completed three phases of work.

Phase 1 was a Pilot Phase that took place between 2015 and 2017 and addressed the following topics:

- Use of a Graded Approach;
- The implications of SMR characteristics on Defense-in-Depth (DiD); and
- Documenting considerations in implementing flexible Emergency Planning Zones.

Certain Phase 1 common positions [1] were carried through into the IAEA safety standards framework, e.g. updates to SSR 2/1 [2] and NS-R-3 [3], which was later included into SSR-1 [4]. Recommendations stemming from Phase 1 [1] were also carried forward into Phase 2, which took place between 2018 and 2020. Phase 2 WGs were:

- Licensing Issues (LI) [5];
- Design and Safety Analysis (DSA) [6]; and
- Manufacturing, Construction, Commissioning and Operation (MCCO) [7].

The Forum entered its Phase 3 in 2021, and its Phase 3 WGs remained the same, but they covered different topics.

Phase 3 finished in 2023, and this Summary report was developed based on the main common positions developed by the DSA and MCCO WGs. It is intended to provide useful information to regulators and industry in the development, deployment, and oversight of SMRs.

The WGs used IAEA publications on SMR designs as reference for discussions. It is important to note that although some conceptual designs may start off small, it is possible that developers may scale these up based on operating experience and leverage some of the safety features and principles demonstrated at the smaller facilities. In this respect, some of the observations and common positions expressed in the Phase 3 reports would likely also apply to scaled-up technologies.

1.2 WORKING GROUPS' CONSTRAINTS AND LIMITATIONS

The Forum's Working Groups experienced constraints and limitations. They established their scope of work accordingly and implemented other appropriate mitigation measures to address these. The major constraints and limitations are discussed below.

Ongoing large variety of SMR designs

The number of different SMR concepts being considered for deployment by countries around the world remains large. The Forum Members agreed that the Forum would remain technology-neutral, to the extent practicable, but would draw from a variety of experiences. This allowed Forum's experts to develop common positions and recommendations that could be applied both broadly by the IAEA and its Member States and, as appropriate, in each individual Forum Member's activities.

Limited operational experience, if any, for most SMR technologies

SMR deployment remains in its infancy and, as a result, substantiation of safety claims by technology developers is still in progress. There is limited operational experience from technology assessment, construction, and operation. However, for most designs, safety claims are in the early stages of regulatory assessment under pre-licensing engagement processes.

2. PHASE 3 WORKING GROUP TOPICS

2.1 SAFETY, SECURITY, AND SAFEGUARDS FROM A REGULATORY PERSPECTIVE

2.1.1 Purpose

Considerations of safety, security, and safeguards are essential in the design, construction, commissioning, operation, and decommissioning stages of nuclear reactors, including SMRs. The considerations should be approached in a coordinated, risk-informed, balanced manner, to take advantage of synergies and to resolve potential conflicts. This is called the 3S interface management.

Unlike safety, security and safeguards have long been considered an after-thought in nuclear facility design, addressed after operations or the activity are underway. For security, this is a result of the relative ease with which security measures have been added at the last stages of the nuclear-facility design. Even for facilities and activities where security requirements were known, development of security design and installation of security components were addressed only after the facilities were sited, designed, and constructed. For safeguards, this situation is the result of safeguards measures being well-known for conventional NPPs, and their implementation being the responsibility of the IAEA.

This approach is no longer valid. For security and safeguards, threats around the world have changed significantly and need to be taken into consideration from the beginning of the design process. For example, worldwide concern over involvement of terrorist and criminal elements (i.e., non-State actors) has informed the necessity to enhance security measures in nuclear facilities against malicious acts. Reactor designers are expected to consider safety, security and safeguards requirements together in the design process such that security issues can be addressed through facility design and engineered security features, formulation of mitigation measures, and reduced reliance on human actions.

2.1.2 Key Aspects

2.1.2.1 Safety by Design

SMRs have the potential to achieve improvements in safety over existing NPPs through simplicity of design and use of inherent and passive safety characteristics in addition to active safety components. SMR designs bring forward opportunities to enhance, at the design stage, the robustness and independence of the Defence-in-Depth (DiD) levels as well as resilience to different types of hazards. The objectives of safety by design of SMRs is to inherently eliminate or minimize potential accident initiators, and to mitigate/counteract the remaining initiators within the design limits, by simplified and reliable passive systems.

2.1.2.2 Security by Design

Security by Design (SeBD) is an approach in which nuclear security principles and provisions are integrated into the design process as early as possible. The principles and requirements for security by design should be set out in the nuclear regulatory framework and regulations. The threat assessment or design basis threat (DBT) and relevant nuclear security requirements based on national legislation, should be provided to the SMR developer for the development of a comprehensive set of nuclear security requirements for use during the design of the facility. The DBT is defined in the IAEA Safety and Security Glossary [8] as “the attributes and characteristics of potential insider and/or external adversaries, who might attempt unauthorized removal or sabotage”. Because of the sensitive nature and confidentiality of the DBT, competent authorities must take adequate provisions to protect the information. The SMR developer should then account for DBT and all applicable regulatory requirements for nuclear security during the design stage.

2.1.2.3 Safeguards by Design

Safeguards by Design (SBD) is the integration of safeguards considerations into the design process for new or existing facilities from initial planning through the design, construction, operation, waste management and decommissioning phases. Rather than waiting to consider safeguards measures for a finalized design and then retrofitting safeguards equipment (potentially increasing costs and schedules), stakeholders can discuss an optimal combination of safeguards measures early in the design process to reduce the need for inspections and to facilitate the installation of the IAEA equipment or joint use operator equipment.

Engagement between stakeholders on SBD is typically an iterative process, whereby the facility’s structures, systems and components, and the proposed safeguards measures are considered and adapted as the design matures. While the developer is responsible for the design, the IAEA is responsible for the development of an appropriate safeguards approach. The goal is to meet the State’s legal safeguards obligations and to align those measures with the operational constraints of the design.

While the SBD concept is not new, some SMR developers are not familiar with detailed safeguards requirements. Often the application of safeguards is seen as a requirement on the operator and IAEA, not the developer. However, consideration of safeguards aspects during the design phase can lead to easier application of safeguards during operations. This lack of general awareness can also create further design conflicts when developers export technology to a State with a different set of safeguards requirements (for example from a State with a Voluntary Offer Agreement in force versus one with a Comprehensive Safeguards Agreement).

2.1.3 Common Positions and Regulators’ Role

Common practice with existing NPPs has been to separate safety, security and safeguards design and operations. The move toward smaller and more operationally agile SMRs highlights a need to re-evaluate traditional and often isolated safety, security, and safeguards approaches. Historically, many designs of nuclear facilities have been retrofitted to accomplish the performance objectives of security and safeguards. The addition of security and safeguards features after a facility has been designed and without attention to optimization has led to cost increases and increased burden on operations due to inefficient implementation. Incorporation of security and safeguards features into the design phase of the facility is intended to significantly decrease implementation and operational resources throughout the facility’s life cycle.

Current SMR developments support renewed resources for exploring opportunities for better understanding 3S interfaces. Many safety, security and safeguards measures contribute to one or two other disciplines and complement one another, but there is also potential for conflict. The reason for conflicts is often a different "opponent". Safety measures are designed against unintentional events, while security and safeguards measures are designed to deal with active adversaries, who may adapt their actions based on their knowledge of the defenses (particularly acute when one considers insider security threats, or the fact that for safeguards the adversary is the operator and State themselves). Interface management is a systematic way to recognize the decision points, to take advantage of the synergies and to resolve the conflicts, to achieve the joint fundamental objective to protect people and the environment from harmful effects of ionizing radiation. For more information, see Ref. [9].

2.2 CONTAINMENT SYSTEMS

2.2.1 Purpose

In traditional light water-cooled reactor (LWR) designs, the function of containment is achieved by the structures, systems, and components (SSCs) that protect the reactor and other systems from the external and internal hazards, accidental or intentional. The principal barrier to radionuclide release credited during accidents is the containment building/structure. The limiting licensing basis event for the LWR is the large loss-of-coolant accident resulting from a breach of the reactor coolant system. This postulated accident sequence is a rapid transient characterized by high energy release of high temperature, pressurized-water reactor coolant into the containment structure. Since the initiating event is a breach in the reactor coolant circuit, it is assumed that the fuel cladding and reactor coolant pressure boundary are compromised. Thus, the containment building/structure is required to absorb the stored energy of the coolant system and to contain radionuclides released from the fuel, all reliant on the integrity of its design basis functions of pressure-retention and low leak rates.

Some advanced non-LWRs claim that a leak-tight and pressure retaining containment structure is not relied upon to restrict the consequences of accidents - operational, external, or human induced events. This claim is based on inherent and passive safety features, which are intended to reduce the reliance on the structure and its associated systems to provide the containment function. Such designs may propose different provisions that limit radionuclide releases to the environment, for example, retention of radionuclides at their source in the fuel rather than allowing significant fuel particle failures and subsequent reliance upon other barriers (the reactor coolant system pressure boundary and containment structure) to ensure that dose at the site boundary meets regulatory limits because of postulated accidents. For these types of design, without a pressure retaining containment structure, the DSA WG indorsed the term "functional containment" from the USNRC Reg. Guide 1.232 [10].

2.2.2 Key Aspects

The position of the DSA WG in Ref. [11] is that, irrespective of technology, the design of containment systems adequacy 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. To achieve 3S objectives, novel containment systems of SMRs may be designed using a graded approach.

Nonetheless, a rigorous safety case must be presented to the regulatory authority to demonstrate that the proposed containment system can mitigate accidents associated with internal and external events and comply with all other applicable regulatory requirements.

2.2.3 Common Positions and Regulators' Role

Containment systems mitigate the consequences of various accidents including Design Extension Conditions (DECs). The choice of the DECs as well as the identification of severe accident scenarios for advanced non-LWRs should be explained and justified. For this purpose, probabilistic assessment should be used in a complementary manner and not the sole justification to screen out low frequency events as supported by SSR-2/1 [2]. Functional containment of SMR designs should minimize the ingress of substances that may have a negative impact on SSCs important to safety. For example, for HTG-SMRs, functional containment should be designed to minimize air and water ingress, which can lead to oxidation of the core and possibly other SSCs in case of a depressurization accident.

Due to the smaller size of SMR's, the DSA WG concluded that independence of the DiD barriers could be more challenging than for large reactors. In accordance with the DiD approach, the design should ensure that independent measures are included at each level as far as practicable.

Some SMR designs propose novel approaches that may impact containment systems. For example, where modules share containment systems, the design should consider the potential hazards this introduces. There are also cases where SMR designs introduce siting considerations that require additional consideration of the design of the containment system (e.g. underground/submerged containments, floating installations, etc.). These siting considerations may also require novel inspection techniques.

2.3 MANUFACTURING, CONSTRUCTION, COMMISSIONING AND OPERATION

2.3.1 Purpose

During Phase 3, the MCCO WG considered in Ref. [12] how the introduction of SMRs might impact the conduct of authorized activities by Licensees[1]. In particular, their capability to ensure that work performed by the Licensee and their supply chain demonstrably meets the requisite standards, recognizing that some of this work (e.g. SMR design or module manufacture and construction) may have been completed long before making an application to the nuclear regulator. Consideration was also given to issues surrounding small or new Licensees.

The MCCO WG also produced an additional related report [13]. Here the specific issue of the manufacture of safety significant long lead items (LLI), such as the reactor pressure vessel, occurring prior to the establishment of a Licensee was considered. Organizations are seeking regulatory assurance to proceed with the manufacture of LLI to speed up delivery of multiple-

[1] Licensee is understood in this report as the entity licensed to construct and operate the facility.

unit projects. This may occur before a licensee organization has been established or with a smaller Licensee organization than typical.

2.3.2 Common Positions

Although the regulatory approaches may differ, regulators should understand the necessity for some safety significant components to be procured in advance to align with new build programs.

Some of the authorized activities (such as the design) for SMRs could be carried out in the absence of a licensee. All materials justifying the fulfillment of regulatory requirements at the stages that were implemented before the appearance of a prospective licensee, and the materials necessary for the license applicant to provide to the regulator when applying for a license, must be provided to the applicant by the vendor or manufacturer.

The regulator may allow the licensee to delegate authorized activities to the vendor or the manufacturer for safety-related equipment/products provided that the regulator has developed clear regulations and guidance. Licensees should ensure they have appropriate oversight over their vendor's or manufacturer's processes and the ability to contractually require their supply chain to meet the relevant standards/regulations (including an acceptable quality assurance process in place). This should extend to retrospective reconciliation of manufacturing standards which occurred prior to the establishment of a licensee. In all cases, the responsibility for authorized activities remains with the Licensee.

It was agreed that there is no minimum size of a Licensee, as long as they are capable to carry out activities that they are authorized and required to do. In all cases, the Licensee is responsible for meeting the applicable regulations or to seek appropriate exemptions. However, regulators should consider how their regulatory requirements with regards to 'intelligent customer' capabilities may be met for small licensee organizations and offer guidance.

It is likely that manufacturing, construction, commissioning, and operational experience will continue to be very limited, therefore SMR licensees and vendors will need to explore mitigation strategies, such as exploring the potential for using shared resources, other innovative approaches and use of technology and service-based models. There is a need to develop and establish training programs to ensure new nuclear expertise is being created and maintained.

3. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, Phase 3 reports produced by the DSA and MCCO WGs of the SMR Regulators' Forum Ref. [9,11,12,13] provide important information and common positions in relation to licensing and design, containment and safety elements, and construction efficiencies of SMRs.

According to the DSA WG, the integration of safety, security, and safeguards in the design, construction, operation, and decommissioning of nuclear facilities, with the particular focus on SMRs, is paramount for the safe and secure expansion of nuclear energy. This comprehensive approach, often referred to as 3S interface management, addresses the intricate balance between protecting people and the environment from radiation risks and unauthorized acts, and regulatory compliance.

The DSA WG observed that the next steps to enhance the integration of 3S, especially with the focus on SMRs, should include:

- Interdisciplinary collaboration: Encouraging collaboration and communication among experts in safety, security and safeguards throughout the design, construction, and operation phases.
- Early inclusion of 3S principles: Promote the early inclusion of safety, security, and safeguards principles in the design and planning phase of nuclear facilities to avoid conflicts and inefficiencies.
- Regulatory alignment: Collaboration among Member States regulatory bodies to establish consistent and harmonized standards for SMRs addressing safety, security, and safeguard requirements which can facilitate global deployment.
- Security technology integration: Encourage the incorporation of advanced security technologies into the design of nuclear facilities to reduce vulnerabilities and the need for later retrofitting.
- International cooperation: Foster international collaboration and sharing best practices and expertise related to safety, security and safeguards in nuclear facilities.

The DSA WG also found that 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-light water SMRs, where containment system designs are substantially different from typical large LWRs and may shift the focus in terms of which SSCs are most important to safety. The DSA WG recommends that the IAEA continue to assess the extent to which the current safety standards address the safety of SMRs and develop guidance to address the identified gaps.

According to the MCCO WG, current regulatory assessment practices of a Licensee's capability related to supply chain oversight is effective and can be applied to SMRs with some targeted improvements. However, changes in the ways of working will be needed for fast and efficient delivery of SMR projects globally. Regulators may need to engage earlier with the supply chain and associated accreditation initiatives to allow SMR vendors to press ahead with the design and manufacture safety significant components prior to the establishment of a licensee. When necessary, regulators and/or the IAEA should develop guidelines that Member State regulators can use to establish their principles and regimes for the regulatory oversight of SMR design and manufacture of safety significant components prior to the establishment of a licensee. The IAEA should establish a mechanism to facilitate the sharing of regulatory experience (in terms of both good practices and challenges encountered).

Overall, the Forum's Phase 3 reports, along with its previous outputs, will serve to inform regulators worldwide on important challenges associated with SMRs and help them to adequately prepare for addressing those. The IAEA will also continue using the recommendations regarding the need for revising the existing, or developing new, publications on safety and security of SMRs contained in the Forum's Reports to inform its related programme of work.

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LIST OF ACRONYMS AND ABBREVIATIONS

3S	Safety, Security and Safeguards
CORDEL	Cooperation in Reactor Design Evaluation and Licensing Working Group
DBT	Design Basis Threat
DEC	Design Extension Conditions
DiD	Defense-in-Depth
DSA	Design and Safety Analysis
EC	European Commission
HTG	High Temperature Gas-cooled
JRC	Joint Research Centre
LLI	Long lead item
LWR	Light Water-cooled Reactor
MCCO	Manufacturing, Construction, Commissioning and Operation
NEA	Nuclear Energy Agency
NHSI	Nuclear Harmonisation and Standardisation Initiative
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
SBD	Safeguards by Design
SeBD	Security by Design
SMR	Small Modular Reactor
SSC	Structures, systems, and components
WG	Working Group
WNA	World Nuclear Association

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