SMALL MODULAR REACTORS- A REGULATORY PERSPECTIVE

RAHMAN KHALIL UR[a], YOUNUS IRFAN[a], MUHAMMAD NOUMAN MAYO[a], MUHAMMAD ZAHID HUSSAIN[a], S.A.N BHATTI[a], FAIZA BATOOL[a], MUDASSIR SHAH[a]

[a]Pakistan Nuclear Regulatory Authority (PNRA),
G-8/1, Islamabad, Pakistan
Email: khalil.rahman@pnra.org

Abstract

In recent years, small modular reactors (SMRs) based novel technologies had emerged and became a center of attention in terms of a cost effective and flexible energy solution, owing to their enhanced passive safety features, modularity in design, factory fabrication and modern reactor concepts etc. Currently, traditional PWR based nuclear power plants (NPPs) are being operated and regulated in Pakistan through a robust nuclear regulatory framework that covers all stages throughout thelife cycle of NPP (i.e. siting, design evaluation, construction commissioning, operation and decommissioning). With the advent of Small Modular Reactors (SMRs) technologies in recent years, it is realized that there is a need to verify the appropriateness of existing framework for licensing of these technologies capable to supply power to smaller electrical grids or to remote, off-grid areas. These SMRs are typically smaller than traditional nuclear power plants and can also be located on sites that differ from those of traditional nuclear power plants and have ability to generate flexible power as per electricity demand and may be deployed on small grids or at off-grid locations. Deployment of SMR can also be a future option considering energy mix of Pakistan. The novel approaches in the design and deployment of SMRs can pose challenges to the existing regulatory framework. Considering these novel design features with respect to conventional NPPs, there may be gaps in current regulatory framework / licensing approaches of IAEA member states. The paper provides the description of areas that need to be considered in safety requirements of relevant standards and regulatory processes of regulatory bodies.

1. INTRODUCTION

Much of IAEA existing nuclear safety framework and experience is related to large, land based water cooled reactors since its inception. Over time, major nuclear power accidents have shaped the utilization of nuclear energy, approach to its regulation, safety focus [1], IAEA activities and international legal framework & obligations [2]. With the advent of new technology in beginning of this century, nuclear community shifted its focus and discussion on Small Modular Reactors (SMRs) which are considered as an appropriate option to fulfil flexible power needs with enhanced inherent safety, passive features and modularization. Currently, a limited international experience in regulating and licensing small modular reactors exists due to several challenges [3]. As per literature review [4], these challenges can be identified as: (i) limitations of current legal and regulatory framework, (ii) existence of prescriptive regulatory framework in some countries, (iii) less familiarization with novel technology, (iv) high cost/fees charged by regulators (v) regulatory capability gaps and (vi) lengthy licensing duration because of novel technology.

PNRA has an ample experience related to licensing and regulatory oversight of PHWR and PWR Nuclear Power Plants (NPPs) based on the existing regulatory framework. However, the government of Pakistan may plan to install SMRs according to power needs, locations and industrial applications. Considering licensing of emerging SMRs as a future challenge, it was realized that forthcoming regulatory challenges of SMRs deployment be studied. A Working Group (WG) was formulated for this purpose. The Working Group performed literature review of ongoing studies related to regulatory challenges in licensing of SMRs including IAEA and academia. The study is conducted with the objective to highlight need to address these challenges in revision of IAEA standards so that subsequently national regulations may be made consistent with IAEA Safety Standards and international practices. The paper describes the activities, insights of the WG related to literature review of existing safety requirements and way forward for regulating SMRs.

2. STUDY OF SAFETY ASPECTS OF SMRS

The Working Group performed a study to verify the applicability of existing IAEA Safety Standards, regulatory requirements and mechanisms of different countries to regulate the emerging nuclear technologies and novel reactor design like Small Modular Reactors (SMRs).The review and findings on the applicability of Safety Standards to emerging designs with actions to modify or add additional requirements are described in the subsections.

2.1. Design Safety of SMRs

The regulatory requirements for the design of structures, systems and components important to safety are set to ensure the prevention or mitigation of the consequences of events that could jeopardize safety. The requirements also include a comprehensive safety assessment of phenomenon due to potential hazards from the operation of the plant i.e. accident conditions [5].

It is found that most of design requirements in IAEA Specific Requirements SSR 2/1 are generic in nature e.g. requirements are related to safety of design, Defence in Depth (DiD), radiation protection in design, safety assessment, ageing management, human factors in design and likewise. These requirements are applicable to any design of land based nuclear power plant. However, there are some specific areas which need to be addressed in relevant standards for regulating SMRs. Some of these areas are described in Table 1.

TABLE 1. SOME AREAS FOR CONSIDERATION IN SSR-2/1 [6]

Specific Areas	Existing Safety Requirements	Proposed Actions
Control Rooms	Control Room (Requirement 65 (6.39 – 6.40A): availability for protracted duration, layout of instrumentation, availability of information, adequate margins.	The Requirement 65 (6.39 – 6.40A) is valid for general MCR design for SMRs. However, there is need to consider specific design requirements of MCR for SMRs with focus on controlling multi modules and separate panels for each module in an integrated control room. Moreover, requirements for remote operation of SMR may be considered in MCR design.
Multi-Module Interactions, Dependencies and common systems	No existing requirement	The followings may be considered in design requirements: o Design safety requirements related to multi-module units, o Interconnections among the reactor modules, o Function of control and protection systems of each module or integrated for all (one command or action to shutdown all modules.)
Extension of power through installation of new module at same site	No existing requirement	There should be requirements related to capacity enhancement by addition of future modules, plant lay-out, construction and provision for additional panels. Additional requirements should be developed to ensure safety to install modules in different phases (e.g. one module is in operation and other is in commissioning).

Human factors engineering	Requirements 32 (5.53-5.62): for design of optimal operator performance are applicable to single unit.	There are potential chances of human error, as one operator has to manage multiple modules supplying to the same turbine. Therefore, the existing requirements should be modified to cover the design of optimal operator performance for single module, operator performance to manage multi module simultaneously, human- machine interfaces, module layout, unit layout, necessary information about all modules and likewise. .
Design Extension Conditions for multi-module context	Requirement 33 (5.63) are related to provision of safety systems, and safety features for design extension conditions for multi modules /units at a site.	Some innovative designs claim that severe accidents are precluded owing to the reinforcement of design measures to prevent core damage after implementation of novel approaches for third and fourth levels of DiD compared with conventional water cooled reactors [7].There is a need to perform specific audit & safety analysis to evaluate the claims and modify requirements for provision for safety systems and safety features to manage accidents due to internal and external hazards from multiple modules.
Containment structure and containment systems	Requirements 57 (6.25-6.26) are related to access to containment.	The degradation mechanisms of submerged containments and underground construction in case of novel SMR technologies may be considered. Containments in some SMR designs does not allow for any human access during operational states and accident conditions and many SMR designs are not equipped with large doors or equipment access hatches. The requirements may be modified or added to cover all these aspects.

2.2. Safety of Commissioning and Operation of SMRs

The management and organizational structure, management of operational safety, event notification & reporting, operational safety programmes, commissioning & operation of plant and criteria and process for licensing of operating personnel are included in SSR-2/2 [8]. Most of these requirements and recommendations are generally valid for SMRs however; there are some specific areas which need to be addressed in relevant standards and regulations.

The Working Group reviewed and identified areas related to modification of operator personnel for multi-module facilities and for common control room for multi-modules or separate control rooms for each module. It is highlighted that sharing of one control room for several modules may pose concerns on control of the units. For instance, an accident in one module may impact the control and supervision of the others and co-activities in emergency situation [9].Some of the following areas, based on IAEA SRS-123 [7],are identified for further consideration for amendments in order to make it applicable to SMRs licensing considering design features [10].

i. **Operator qualification and training of personnel:** The specific training programme for multi-units and multi-design site operations, novel refuelling strategies, maintenance & testing, remote operations (if applicable), monitoring and control strategies for remote operations of training and qualification of personnel maybe considered.

ii. **Performance of safety related activities:** Safety related activities for multiple unit SMRs with alternative operating models including autonomous systems and remote monitoring and intervention capabilities may be considered in Standards and relevant regulations.

iii. **Control of plant configuration:** There is a need to consider configuration management for multi-reactor modules integrated in a plant and located in shared (common) structures.

iv. **Fire and explosion hazard safety:** There are chances of fire and explosion hazards due to the use of novel materials, additional flammable, explosive or combustible materials in water cooled as well a non-water cooled advance SMRs. A detailed industrial hazards assessments and fire safety of combustible materials may be included Standards and relevant regulations.

v. **Commissioning of SMRs:** There is a need to consider the provisions of (i) in-situ (off site) commissioning & assembling and (ii) on site commissioning requirements in Standards. As per literature review, the role of operator or licensee would be different in both commissioning phases. There is need for requirement to demonstrate that the results obtained during the off-site tests or commissioning are still valid at the plant.

vi. **Control rooms and equipment control operations:**It is anticipated that there would be a main control room connected / integrated with a series of localized control rooms to get data in case of multiple units or sites of SMRs. It seems that current requirement does not establish a control hierarchy of coordinated operations.

vii. **Core management and fuel handling:** The aspects related to fuel with no cladding, responsibilities of organizations for fuel loading & unloading at offsite or on site are recommended to be addressed in requirements.

viii. **SMR specific programs:** The requirements for SMR specific programs covering monitoring for testing, inspection, maintenance, and control need to be modified or added.

ix. **Refueling outage management:**The WG, based on study of IAEA-SRS 123, identified the need to address the specific aspects related to outage management including remote activities of maintenance, surveillance, inspection and testing techniques, on site outage work, offsite outage work and outage frequency in requirements.

2.3. Safety of Manufacturing, Transport, Emergency management and Decommissioning of SMRs

The WG evaluated requirements and identified key areas for considerations based on IAEA study [7]. The salient findings and recommendations of the WG are described as follows:

A. Safety of Manufacturing Equipment, Components and Modules

There is a need to establish requirements for the manufacturing of SMR engineered modules, assembling, fuel loading in factory, offsite commissioning (factory) before delivering to site. The WG identified that the requirements for regulatory review and inspection of organizational capability for in-factory manufacturing and off-site commissioning of modules (i.e. establishing of Management System, organizational manpower, qualification and experience) needs to be considered in the requirements and licensing process [11].

B. Transport Safety

The regulatory documents based on SSR-6 provide requirements for transportation of various types of packages of radioactive materials with specified limits of activity [12]. However, this standard does not cover the transportation of SMRs designed to be relocated geographically for manufacturing, assembling and final transportation to destiny for installation. There could be cases when a commissioned or operating pseudo mobile SMR is needed to be relocated based on the energy requirements and other demands. Such a case needs to be addressed in requirements. Moreover, there is a need to consider various modes of transportation by road, rail, air or ship with specified limits and criteria, vehicle design criteria, specific activity, test qualification criteria of manufactured package of SMR for transport, emergency preparedness in case of accident during transportation and physical security in preparation of requirements for SMRs.

C. Emergency Management

The regulatory documents based on GSR-part-7 establishes prescriptive requirements to define the size of emergency planning zones (EPZs) which is applicable to large reactors [13]. However, according to claims of innovative designs, the size of EPZs of SMRs are reduced owning to the reinforcement of design measures to prevent core damage, preclude severe accidents and provisions designed to potentially reduce off-site radiological consequences compared to large reactors [7].The prescriptive stringent requirements do not support the licensing of SMRs and this is one of the challenges being faced by nuclear regulatory bodies in the world. The WG recommended conducting a coordinated regulatory research to verify the claims of designer(s) and consider international feedback to revise requirements of emergency management for SMRs. The licensing process may need to consider the provisions of alternative risk-informed, performance-based, technology-inclusive, and consequence-oriented emergency preparedness requirements to define the size of EPZs and emergency management of SMRs.

D. Decommissioning

The regulatory requirements for onsite decommissioning are derived from GSR-part-6 [14]. However, it may not applicable as a whole to decommissioning of SMRs or SMR Modules due to remote / offsite and onsite decommissioning. WG identified following areas for consideration in requirements in relevant standards:

a) **Mechanism or Strategy of decommissioning of SMRs:** The strategy of offsite or onsite decommissioning, mechanism for the funding of offsite or remote decommissioning and cost estimation on the basis of the periodic update of the initial decommissioning plan or on the basis of the final decommissioning plan due to transportation for decommissioning needs to be incorporated.
b) **Decommissioning of modules in phases**: The modules completing its life early are the candidates of decommissioning whiles modules deployed later should be operating.
c) **Prevention of hazards among interconnected or interdependent modules/units:** The hazard assessment of modules phased out for decommissioning should be performed; as these modules are have interdependency with nearby non-nuclear industrial facility to supply the process heat.
d) **In-situ decommissioning and offsite decommissioning**: The provisions of offsite / remote decommissioning, partial decommissioning and complete onsite decommissioning need tobe addressed.
e) **Decommissioning of remotely operating SMRs:** Some of SMRs may be deployed remotelyto provide energy to remote regions and for such facilities, decommissioning, dismantling and predisposal waste management may not be performed at the site of deployment. Therefore, a centralized dismantling facility will be required. In such cases, decommissioning costs would include payment to the operator of the centralized dismantling facility.

3. POTENTIAL REGULATORY CHALLENGES FOR SMR LICENSING

3.1. FOAK SMR Licensing

Mignaca et al. revealed some regulatory challenges related to licensing and deployment of SMRs. These challenges are: (a) higher cost per kW for First-of-a-Kind (FOAK) SMRs, (b) longer licensing time & processes and additional regulatory assessments such as manufacturing inspections, installation verifications, integrated tests, are required at factories, potentially in third countries, implying changes in established procedures of regulatory bodies [15].It is also highlighted that advocates of SMRs ask regulatory bodies to relax regulatory requirements for SMRs such as alternative siting requirements, reduction of the Emergency Planning Zone (EPZ), as these designs are inherently safer compared to NPPs.

WG also identified in a study that licensing of FOAK non LWR SMRs such as HTR-PM may pose significant challenge due to less familiarization with design, lack of availability of appropriate regulatory framework, insufficient experience in regulatory oversight, review and assessment (because of use of different codes & standards, safety analysis based on different computer codes,) etc. The licensing process will involve more cost and a longer licensing process due to capacity building needed for confirmatory safety analysis.

3.2. SMR Specific Licensing Procedure

A. Licensing Process and Regulatory Stages

The WG identified and proposed additional stages (manufacturing, assembling, transportation, installation, commissioning, operation and other key milestones, etc.) for inclusion in licensing process and as well as additional submission requirements and activities for regulatory oversight of SMRs. The modified licensing process for SMRs is proposed in the Figure 1. It provides the comparison of existing licensing processes of IAEA SSG-12 [16], national licensing process and proposed licensing process for SMRs. The following licensing stages and safety requirement of regulatory submissions at these stages may be considered in licensing process of SMRs:

a) Manufacturing stage and regulatory documents,
b) Assembling and off site commissioning and associated regulatory submission,
c) Transportation stage and regulatory documents (programme),
d) Onsite commissioning and programme,
e) Remote operations, monitoring and reporting,
f) Refuelling Outage Frequency,
g) Revalidation of Operating License,
h) Licensing Beyond Design Life / Long Term Operation (LTO).

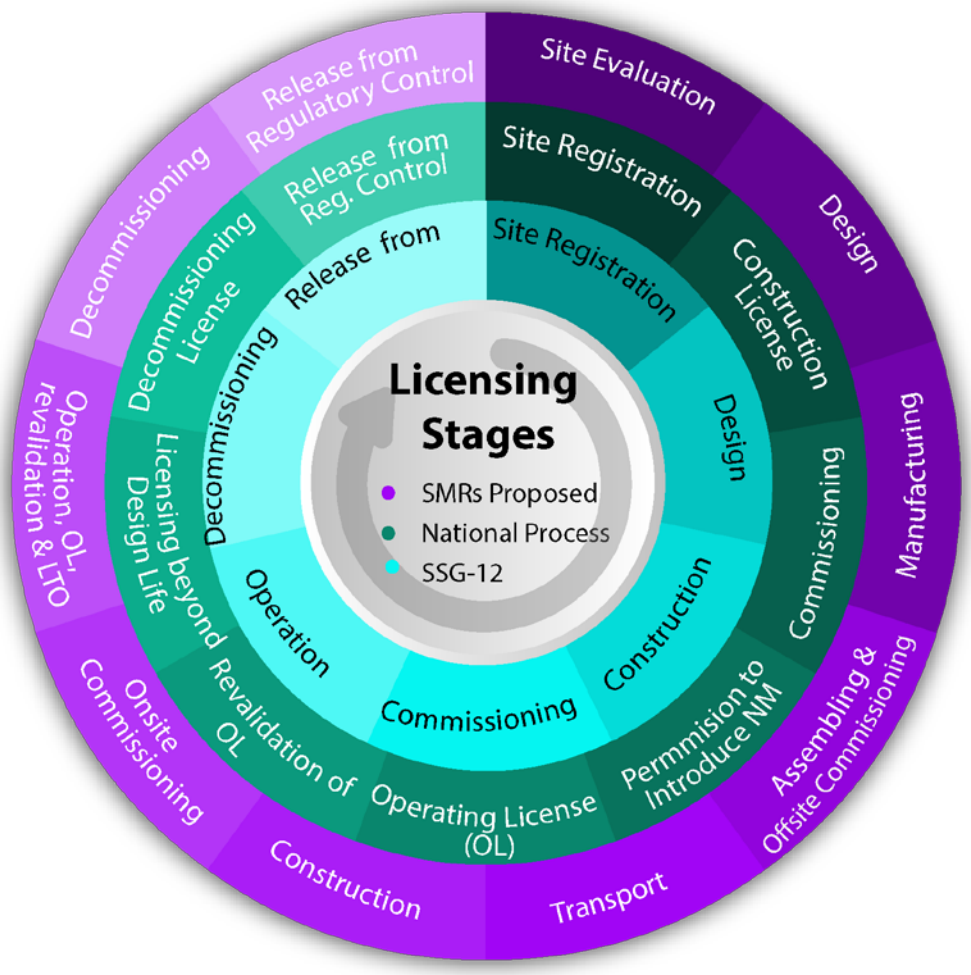

FIGURE 1. Comparison of existing Processes and Proposed Licensing Process for SMRs [16].

B. Licensing Fee

Licensing cost is realized as one of significant issues in the deployment of SMRs. According to international literature review, the licensing cost per kW is higher for SMRs with respect to large reactors as licensing of FOAK is almost independent of the size. For some of regulatory bodies, licensing of SMRs may also incur additional cost due to capacity building and involvement in pre-licensing design evaluation activities to verify

safety analysis. In order to manage the expenditure of regulatory activities, joint and coordinated regulatory activities of verification & validation may be performed.

4. WAY FORWARD FOR REGULATING SMRS

Some of the takeaways from the study are highlighted below:

a) In order to manage the delay in licensing process of SMRs, the WG suggested that regulatory bodies need to engage in early interaction with different stakeholders (utility, designers, and vendor) to familiarize with design, perform safety analysis, identify the issues for timely resolution and ensure smooth licensing. International practices have demonstrated the significance of pre-application involvement during licensing processes.

b) The working group prepared recommendations and it is expected that some national regulations may change in order to make their applicability for SMRs. For instance, some aspects related to design such as multi-module interaction, control rooms, human factors engineering and likewise highlighted in Table 1 may be considered in the regulations related to design of nuclear power plants in order to make these regulations applicable for SMRs. It is also highlighted that the specific areas (section 2.2 bullet i to ix of this article) may need to be addressed in regulations dealing with operation of Nuclear Power plants. The licensing stages, submission requirements, periodic reviews and validity of license in case of SMRs may need to be considered in national licensing process defined in regulations for licensing of nuclear installations.

c) The WG realized the need of joint regulatory research activities for capacity building of regulatory staff for licensing and regulatory oversight of SMRs. The joint regulatory research activities may be initiated among regulatory bodies as well as designer and licensee in the field of safety analysis such as accident analysis, multi-module probabilistic safety assessment (PSA), EPZ, review of advanced fuel, etc. Such cooperation of regulatory bodies may be extended through IAEA Coordinated Research Projects (CRPs) for developing understanding to facilitate in the licensing of SMRs.

d) The study highlighted some other issues for special focus such as (i) cyber security requirements for SMRs as most part of SMRs is expected to be digitized (man- independent), (ii) waste management consideration and emergency preparedness & response for SMRs and (iii) civil liability for transportable type of SMRs.

5. CONCLUSIONS

The working group highlighted that the licensing of novel SMR and innovative design reactors may pose challenge(s) to regulatory bodies and recommended actions to overcome the anticipated implications with detailed evaluation of existing safety requirements, identification of areas of concern and appropriate modifications of requirements. Some of the areas related to design, commissioning, operation, transport, emergency management, decommissioning and licensing process of SMRs are identified for consideration in relevant standards. The salient aspects are related to requirements for multi-module units, common control room or multi module control rooms, containment structure &systems, remote operations and emergency planning zone.

REFERENCES

[1] PIERRE TANGUY, “Three Decades of Nuclear Safety: Special Report” IAEA Bulletin 2 (1988).

[2] STEPHEN G. BURNS, “The impact of the major nuclear power plant accidents on the international legal framework for nuclear power” Nuclear Law Bulletin no. 101/VOL. 2018/2, ISSN 1609-7378, 2018.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), “Lessons Learned in Regulating Small Modular Reactors: Challenges, Resolutions and Insights” IAEA-TECDOC-2003, Vienna (2023).

[4] R. SAM et al., “Licensing small modular reactors: A state-of-the-art review of the challenges and barriers” Progress in Nuclear Energy 164 (2023) 104859.

[5] PAKISTAN NUCLEAR REGULAOTRY AUHTORITY (IAEA), “Regulation on the Safety of Nuclear Power Plant Design” (PAK/911) (Rev.2), PNRA, Islamabad (2019).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), ‘Safety of Nuclear Power Plants: Design’ Specific Safety Requirments SSR-2/1(Rev.1), Vienna (2016).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), “Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Samll Modular Reactors” IAEA-SRS-123, Vienna (2023).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), ‘Safety of Nuclear Power Plants: Commissioning and Operation’ Specific Safety Requirments SSR-2/2 (Rev.1), Vienna (2016).

[9] T. MURAKAMI, V. ANBUMOZHI, “Global Situation of Small Modular Reactor Development and Deployment,” [Online]. Available: https://www.eria.org/uploads/media/Research-Project-Report/2021-07-Small-Modular-Reactor-/Global-Situation-Small-Modular-Reactor-Development-Deployment.pdf (2021).

[10] A. KORNYTSKYI, N. PLAYEZ, AND S. ISRAEL, “Improved safety features of LW-SMR,” 2020.

[11] PAKISTAN NUCLEAR REGULAOTRY AUHTORITY, “Regulations for Licensing of Nuclear Safety Class Equipment and Components Manufacturers”PAK/907 (Rev.1), PNRA, Islamabad (2018).

[12] PAKISTAN NUCLEAR REGULAOTRY AUHTORITY, “Regulations for the Safe Transport of Radioactive Material” PAK/916 (Rev.1), PNRA, Islamabad (2022).

[13] PAKISTAN NUCLEAR REGULAOTRY AUHTORITY, “Regulations on Management of a Nuclear or Radiological Emergency” PAK/914 (Rev. 1), PNRA, (2022).

[14] PAKISTAN NUCLEAR REGULAOTRY AUHTORITY, “Regulations on Decommissioning of Facilities using Radioactive Material” PAK/930, PNRA, Islamabad (2016).

[15] B. MIGNACCA, G. LOCATELLI, T. SAINATI., “Deeds not words: Barriers and remedies for Small Modular nuclearReactors” Energy 206(2020) 118-137.

[16] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), ‘Licensing Process for Nuclear Installations’ Specific Safety Guide SSG-12, Vienna (2010).