# Issues and Challenges of Regulatory Framework for Deployment of SMRs ─ Pakistan Perspective

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**Abstract**

The increasing interest in Small Modular Nuclear Reactors (SMRs) is primarily governed by the climate change. SMRs are unique in design in contrast to existing fleet of nuclear power plants thus regulatory framework should be tailored in areas of licensing, design, siting, manufacturing including emergency preparedness and response. Nuclear regulatory agencies around the world including Pakistan Nuclear Regulatory Authority (PNRA) is facing new challenges e.g. licensing of smaller-scale reactor, different FOAK designs, factory production of units, innovative safety measures, multiple-modules with one control center, deployment near populous areas with application of co-generation (e.g. hydrogen production, district heating, desalination) smaller site footprint etc. SMR designs concepts may challenge our existing national laws and regulations and may need to be tailored to support graded approach to facilitate the licensing process e.g. unique design, multi-modules, national/international design certification, third party nuclear civil liability etc. There might be many legal issues that need to be resolved among different countries such as Intellectual Property Rights (IPRs), safeguard issues. The harmonization and standardization at global scale is another challenge. The smooth licensing process for SMRs is the key to their successful deployment. The safety requirements for design also facing new challenges such as devising a mechanism for application of defense-in-depth (DiD) in parallel with innovation, integration and modularity. Also, application of design extension conditions and practical elimination of high consequences and low probability event with high confidence level will be a principal challenge. Site specific conditions also pose challenges in the deployment of SMRs. It includes, but not limited to, proximity of SMRs to hazardous facility such as hydrogen, chemical industries, refineries etc., fulfillment of exclusion area boundary and low population zone requirements near population centers, feasibility of emergency planning zones and protective actions in close proximity of cities etc.

## INTRODUCTION

After Fukushima accident, there has been a wide interest in the deployment of SMRs for safe, secure, economically viable and environmentally clean source of nuclear energy. It is highlighted that climate change is an important driving force for the development and deployment of SMRs since SMRs are one of the lowest contributors of greenhouse gases in comparison to other low-carbon energy sources while being highly reliable at the same time. Due to inherent safety features, lesser financial resources are required after some time in terms of reactor and associated nuclear infrastructure, making SMRs an even more attractive proposition. One of the advantages of SMRs’ construction, in contrast to conventional large nuclear reactors, is that it could be deployed in larger numbers, even in isolated places, in a relatively quick deployment scheme. Therefore, it is naturally an attractive choice for countries expanding their existing nuclear energy shares in national grid particularly embarking countries. While there are several potential advantages with SMRs, there are some challenges that may impede the smooth deployment of SMRs, with an important one being licensing. The licensing of SMRs is not likely to be straightforward in perspective of existing legislative framework which is strongly based on current fleet of large nuclear power plants.

License is a legal document issued by the regulatory body granting authorization to establish nuclear installation(s) and to perform specified activities generally covering a particular stage of the lifetime of a nuclear installation namely, site registration, construction, commissioning, operation, decommissioning and subsequent release of the site from regulatory control. The whole process aims to provide reasonable assurance at each step that public, radiation workers and environment will be protected from undue effects of ionizing radiation.

Site registration is one of foremost and important licensing stage in which site characterization and design bases are determined with reference to specific site features. It is initiated after fulfilment of some requisite formalities with regulatory body e.g. formal request of the project, establishment of interface for efficient execution, finalization of scope and objective of the project. In the second stage of the licensing, licensee proceeds to the next stage i.e. construction license. It is based on the basic design of the proposed nuclear power plant. It is highlighted that it generally covers civil construction work, manufacturing of equipment/components and then subsequent installation. Commissioning activities are performed after completion of construction activities which include, but are not limited to, testing of individual equipment/component as well as at system-level, comparison of test results with established acceptance criteria as agreed with the regulatory body etc. The successful completion of cold and hot commissioning tests will result in issuance of operation license generally for some specific time-period e.g. ten (10) years and regulatory body re-validates operation license after performing periodic safety review. The licensee may operate a nuclear installations after completion of its design life by obtaining a license for beyond design life operation. Finally, successful completion of decommissioning stage will conclude in removal of regulatory control and the site may be used for any other purpose as per applicable national laws and regulations. Generally, SMRs also follow these logical steps with some exceptions like overlapping of two or more licensing stages e.g. commissioning at manufactuing setups. Such deviations from established process for existing fleet of nuclear power plants require special consideration in legal framework.

Generally, large nuclear power plants are constructed away from population centres to avoid deterministic health effects and to reduce stochastic health effects. However, SMRs may be constructed in close proximity to large population centres e.g. nearby cities in order to optimize certain application requirements. Also, conventional large nuclear power plants are potentially located away from hazardous industrial facilities, military installations, airports, airways etc. On the other hand, SMRs are strong candidate and advocate of co-generation e.g. hydrogen production, high temperature requirements at process industry.

There are many innovative SMR design concepts being proposed thus design organizations with little or even no experience may be embarking in the nuclear industry. Generally, design certification of nuclear installations is carried out, however, licensing design organization is not carriedout which would otherwise ascertain the competence of the designer. Also, application of graded approach, interpreting DiD concept in the realm of modular design and consideration of design extension conditions is another challenge and may require special attention in legal framework. Further, IPRs situation may be more complex because of participation of designers may be scattered globally thus legal system should address diverse legal requirements.

In light of the practices prevalent in shipbuilding and aerospace industries, it is proposed that SMR modules may be manufactured offsite and then transported to the proposed site for installation and operation. Though the same idea is employed by conventional large nuclear reactors, SMRs may take it even further by performing fuel loading and commissioning activities prior to delivering them to the site i.e. prior to the licensee decision to construct SMRs and thus without the beginning of any licensing process.

Moreover, transportation of offsite fuelled SMRs will pose another licensing challenge in contrast with onsite refuelling of conventional large nuclear power plants. The consideration of safety, security and safeguards during transportation of the fuelled SMRs would be of paramount importance in licensing perspective. The additional challenge will be compliance of national and international transport regulations e.g. transportation through different countries or international sea routes.

Likewise, SMRs also introduce a new operation concept and thus pose additional licensing challenges in view of existing licensing process e.g. remotely operated facilities (no operators onsite), multi modules/units licensing, multiple modules operated from common control room by same operators, accident response of multi-modules and/or multiple operators at a site etc.

It is envisaged that globally many regions would be contributing in the design, manufacturing, transportation of SMRs. Thus, codes and standards of different regions could impede the deployment process in any country and/or region. Such complex legal situation requires special attention to overcome the legal challenges to provide ease in the deployment of SMRs.

The successful deployment of SMR requires substantial capital investments thus some member states requires financial arrangements through some international financial institutions. It also requires legal framework to address some speciality of nuclear industry particularly third party civil nuclear liability which may otherwise cause delay in the deployment or even cause unfeasibility of SMRs.

## pakistan’s legislative framework – SMR Licensing and site

The legislative framework of Pakistan covers all aspects of nuclear installations including licensing, siting, design, manufacturing, design organizations, nuclear emergency, radiation protection, physical protection and other relevant areas. In this study, a thorough review of existing legislative framework of Pakistan vis-à-vis licensing and siting of SMRs is performed. The opportunities and challenges for the successful deployment of SMRs in Pakistan are presented in subsequent sections.

### Site Evaluation

The existing national regulation for site evaluation i.e. PNRA PAK/910 [1] is in line with IAEA requirements. The key aspect of SMRs regarding siting is multiple modules at a site, proximity to population centres and industrial facilities that may pose threat to the safety of SMR e.g. hydrogen production. The current regulations on site evaluation principally address multiple modules aspect. Large conventional nuclear power plants are principally located away from population centre and industrial facilities particularly those that may pose a safety threat to the nuclear facility. However, these two important aspects could be indirectly addressed through risk metrics e.g. CDF, LERF i.e. risk metrics of the proposed SMR should be in compliance with the established regulatory risk metrics of PNRA PAK/911 i.e. CDF is 10-5/reactor-year and LERF is 10-6/reactor-year. The population proximity also challenges implementation of protective actions in case of nuclear emergency. Though, most of the vendors claim that there would not be any protective action needed that would take place offsite. However, studies were conducted to assess the requirements of emergency planning zones for SMRs and it was concluded that nuclear emergency arrangements should be in place for taking protective actions offsite e.g. evacuation, sheltering, distribution of ITB etc. The PNRA PAK/910 [1] also requires site feasibility for implementation of emergency preparedness plan in case of nuclear emergency as well as requires licensee to demonstrate emergency preparedness plan before granting permission to introduce nuclear fuel into the installations. It is highlighted that Pakistan’s national legislative framework addresses the various aspects in an integrated manner and thus it should be implemented coherently for fulfilling the safety requirements particularly SMRs.

### Design

The design aspect in view of licensing would not be substantially changed from existing large nuclear power plants. However, it is expected that many new design organization may be participating in the design activities of SMRs. Thus, it might be required to thoroughly assess the capabilities of such design organizations for reasonable assurance that design will meet the safety requirements. The national legislative framework of Pakistan also addresses such challenges through licensing of design organization as stipulated in PNRA PAK/905 [2] (draft issued for public comment). It is regulatory requirement that the design organizations involved in the designing of safety related structures, system and equipment/components must obtain design license from the national regulatory body i.e. PNRA. In this regard, a rigorous licensing process has been developed and effectively implemented. It is a three (03) step process including submission of documents (Step-01), QA inspection (Step-02) and demonstration of design development capability (Step-03). In Step-01, licensee submission (e.g. scope of authorization, management system manual, experience, software etc.) ascertains that design team is experienced, possess requisite design and analytical tools and management system is in place in compliance with PNRA PAK/921 [3] which is in line with IAEA requirements. In Step-02, regulator performs inspection activities at design organization to verify that all design activities are performed in accordance with the management system. Finally, licensee submits design reports to PNRA for mutually agreed SSCs in line with scope of authorization. After, entire satisfaction of the Authority, a design license is issued to the organization. The licensing process thus provides reasonable assurance that design organization possesses requisite capabilities to design safety related SSCs without jeopardizing safety. It is highlighted that the licensing process is applicable to national design organizations. In case, designer(s) is of other country(ies) then national legal framework requires the approval of either design organisation or design of safety related SSCs granted by the other country(ies) regulator. However, there is a need to develop a mechanism to fulfil these licensing requirements for design organizations of other countries where such requirements could not meet.

Another area of concern may be consideration of extensive sharing of safety system, personnel and control room in SMR design though the same is also applicable to existing fleet of nuclear power plants but practically up to very little extent. Such sharing would pose additional safety concern and thus should be carefully and critically evaluated at appropriate licensing stage. The existing national regulatory framework addresses the safety requirements for shared facilities at a site, however, it would not consider some unique concepts of SMR e.g. shared control room for multiple SMR of various design philosophy.

Also, DiD concept is fully integrated in national regulations for existing fleet, however, the novel ideas for SMRs are not explicitly addressed. Likewise, graded approach is generally applied in nuclear industry and thus already covered in national regulations. However, it's application for SMRs needs further attention in national legislation. Moreover, IPRs may also pose hinderence for swift deployment of SMRs. It is highlighted that existing national legislative framework provides an opportunity to address such challenges through international protocols. However, strengthening of the international cooperation is envisaged as designers of different origins are expected.

### Manufacturing

Many SMR designs foresee offsite manufacturing of SMR modules which will be transported to the utility site. The proposed scheme would result in high-quality construction, as well as manufacturing, construction and commissioning time would be significantly reduced thus directly impacting economics of the SMR. It is highlighted that existing reactor fleet also utilizes the proposed scheme to some extent. However, it is one of the challenges in view of licensing e.g. testing and regulatory involvement, offsite fuel loading even overseas, experience of manufacturers, SMR modules as inventory etc. The national legislative framework of Pakistan addresses such manufacturing schemes through PNRA PAK/907 [4] and PAK/909 [5]. These national regulations provide mechanism to address such unique and overlapping authorizations that would be required at a manufacturing setup. PNRA PAK/907 [4] applies to all organizations in Pakistan involved in the manufacturing of nuclear safety class equipment and components. The licensing process assesses manufacturer’s capabilities, experience, management system, codes & standards, testing facilities etc. to ascertain that manufacturing of safety class equipment/component would meet all the design and safety requirements. The manufacturers submit Q-plans, process flow diagrams, manufacturing schedules etc. to regulatory body to select control points for regulatory inspection. Also, PNRA PAK/909 [5] applies to nuclear installations including facility(ies) that use nuclear fuel for production of nuclear material or facility(ies) where nuclear material is stored other than storage incidental to the carriage of such material. If commission and nuclear fuel loading activities is performed at manufacturing setups then PNRA PAK/909 [5] would also be applicable. Thus, Pakistan’s national legislative framework addresses such unique licensing requirement in an integrated manner. It is underscored that the licensing process is applicable to national manufacturers. In case, manufacturer(s) of other country(ies) then national legal framework requires the manufacturing licence should be granted by the other country(ies) regulator. However, there is a need to develop a mechanism to fulfil these licensing requirements for manufactureer(s) of other countries where such requirements could not meet.

### Construction

The duration of construction for SMR would be significantly reduced in comparison with existing fleet of nuclear power plants as discussed in Section 2.3. It is highlighted that SMR modules would be constructed at a site as per requirements thus simultaneous SMR construction in parallel with operating SMRs could be envisaged. It will pose additional hazard to existing operating units in terms of safety (e.g. external hazard to already operating units) and security and thus should be considered in advance. The safety and security of operating units is assured in PNRA PAK/913 [6] through regulators’ inspectors at nuclear power plant(s) site(s) and regional offices. Also, PNRA PAK/911 [7] requires consideration of multi-unit impact during design of nuclear power plant(s). Thus, PAK/913 [6] and PAK/911 [7] addresses SMR construction challenges and would meet relevant safety and security requirements.

### Transportation

The transportation of SMR which will be fuelled at site will be same as of existing fleet of nuclear power plants. However, transportation of SMRs that would deploy fuel loading at manufacturing setups as discussed in previous section would be challenging in view of safety, security and safeguards particularly when international boarders and/or water are involved. It is highlighted that existing fleet of nuclear power plants require fresh fuel to the site while spent fuel is normally stored onsite. Many SMR designs envisage compact nuclear core vessel that could be entirely replaced to reduce long refuelling time as well as removal of the module(s) in short time. Thus, transportation of modules that contain fresh fuel to site and contain spent fuel from site will be challenging due to unavailability of certified packaging that is large enough. The existing national regulatory framework for transportation of nuclear material addresses such requirements; however, the availability of such certified packaging is a challenge.

### Operation

The operation of SMRs also poses some uniqueness in comparison to the existing nuclear power plants e.g. remotely operated units i.e. no operators onsite, common control for multiple SMRs, multiple operators at a site etc. which would pose licensing challenges e.g. safety and security arrangements of remotely operated sites, safe and reliable operation of different SMRs from shared control room, responsibility of safety for multiple operators at site. It is highlighted that such divers and unique requirements are not explicitly addressed in current national legislative framework.

### Emergency Planning

Keeping in mind the diverse SMRs designs having different power levels, coolants, moderators, fuels types, layouts (below-grade or in-ground construction), there will be a significant variation in source term composition and characteristics, and will impact the EPZ sizes. Therefore, the requirements and guidance related to emergency preparedness and response for conventional large Nuclear Power Plants (NPPs) need to be revised as per SMR scope. The smaller size, lower power density, low probability of severe accident, slower accident progression and smaller off-site consequences per module suggest that SMRs are capable of supporting a reduced EPZ but the reduction remained to be confirmed in the design, safety margins, and site factors. Small Modular Reactors (SMRs) are gaining significant interest for their reduced footprint, lower power output, modularity and innovative features. The licensing of SMRs is key to their successful deployment. For SMR emergency planning, reduced source term and slower accident progression will play a key role in reducing the EPZs sizes and effective & timely implementation of urgent protective actions such as evacuation and iodine prophylaxis. While the inherent safety features of SMRs surely justify the consideration of a reduced EPZ, the closer proximity to a large population must also be considered. In this regard, PAK/914 [8] applicable to large NPPs emergency planning needs to be tailored to accommodate the SMRs emergency preparedness and response requirements.

### Codes and Standards Harmonization – Regulatory and Industrial Perspective

There is a wide interest in the deployment of SMRs worldwide as mentioned in Section 1 thus it would be envisaged that legislative framework vis-à-vis safety, manufacturing and transportation for SMRs at different countries would be involved, therefore, there is a need to harmonize legal framework worldwide to resolve such complex inter-country(ies) situation. The existing national regulatory framework PNRA PAK/909 [5] already includes the provision for application of inter-country(ies) codes and standards. It requires licensees to fulfil PNRA requirements as stipulated in national regulations, however, if PNRA regulations are not available in some areas then licensee may use USNRC or alternatively IAEA legal framework. Also, licensee could use codes and standards of other countries provided those codes and standards offer same or better safety standards then USNRC and/or IAEA. It is highlighted that regulator requires that licensee to perform comparison among codes and standards of other countries with IAEA and/or USNRC. The comparison should provide assessment and evaluation of all the requirements set-forth in the codes and standards in terms of criteria, methodology, bases & assumptions, process etc. After entire satisfaction of the regulator, licensee is allowed to use/consider the codes and standards of other countries. Also, manufacturing industry at national level uses codes and standards which are widely accepted worldwide with some exception. Further, trans-boundary transportation for SMRs particularly through seawaters needs special attention. A well-established legal framework is in place at national level to address seawater routes, however, it needs further strengthening considering various part of the globe. It is highlighted that IAEA initiated an effort to harmonize regulation and standardized industrial codes and standards through its NHSI program. It will provide an opportunity to all IAEA member states to come forward and develop a mechanism to harmonize their legislative regime and thus provide ease and promote deployment of SMRs globally.

### Financial Arrangement

Since, SMRs are under design and development stage and will be deployed in near future widely thus involves substantial capital investments. The feasibility of SMR deployment would be a challenge for many countries due to high capital cost. Some financial arrangement may be sought through international financial institution(s) or agency(ies) to support the SMR deployment. The existing national legislative framework supports to finance projects through international financial institutions, however, detailed regulatory requirements regarding third party civil nuclear liability needs to be developed. It is highlighted that IAEA initiated an effort to facilitate member countries for financial arrangements of nuclear projects including SMRs.

## Recommendations

SMRs are similar to existing traditional nuclear power plants but at the same time possess some unique features and attributes. Thus, existing national legislative framework would address various aspect of licensing of SMR and need special consideration to address such novel ideas. Some of the recommendations in the light Section 2 discussion i.e. key areas of SMR and provisions of Pakistan’s national legislative framework are as follows:

* The existing legislative framework principally addresses site evaluation requirements for SMRs, however, it may be further strengthened to explicitly address some unique attributes of the SMR e.g. development of risk metrics at site level, compliance of safety goals, development of specific site screening criteria that would exclude some hazards through exclusionary criteria otherwise could be included for further consideration for traditional nuclear power plants;
* The existing regulatory framework in the area of design provides reasonable assurance that safety and security requirements will be met for SMR, however, the regulatory regime would be further strengthened through incorporation of safety requirements for some novel design(s);
* The existing regulatory framework provides licensing requirements for national design organizations and manufactures, however, the same could be extended beyond geographical boarders through establishing collaboration with regulators of other countries;
* Application of DiD approach should be rigorously implemented according to current regulatory regime and could relaxed after compliance of established risk metrics or more preferably safety goals with high confidence level;
* Graded approach may be linked established risk metrics or more preferably safety goals;
* The regulatory requirements may be stipulated in systematic fashion for ease of understanding and clarity for manufacturing setup where commissioning and fuel loading activities would be performed;
* The existing legal protocols for IPRs are covering substantive design areas, however, further strengthening is required to address wider community globally;
* Construction activities would be closely inspected through resident inspectors;
* The revision of existing regulatory regime for transportation is envisaged to address some unique safety, security and safeguard requirements for SMR;
* The validity of operation license and frequency of periodic safety review should be formulated in the light of SMR;
* Emergency planning requirements need to be tailored to accommodate the SMRs specific features and to optimize emergency preparedness and response requirements;
* Active participation at IAEA NHSI and financial arrangement initiatives would pave the road of successful deployment of SMR;

## Way Forward

The national legislative framework addresses key areas of SMRs. However, there are some areas that requires special attention in order to address some specific requirements of the SMRs as highlighted in Section 3. It is suggested that a forum may be established at national level comprising of all stakeholders to work out in accordance with the recommendations set-forth in Section 3 and provides guidance to accommodate them in the national legislative framework. It will include amendments to the existing national legislations as well as establishment of effective liaison with other potential regulatory bodies worldwide including active participation at IAEA particularly NHSI and financial arrangements initiatives.

## conclusion

SMRs are source of safe, secure, economically viable and environmentally clean nuclear energy materialized through application of novel ideas thus require special consideration in Pakistan’s national legislative framework. The existing national regulatory framework provides opportunities for licensing and siting requirements for SMRs particularly in the areas of site evaluation, design, manufacturing, construction, transportation, operation, emergency planning, harmonization of codes and standards and financial arrangements through international financial institutions. There are also some challenges in these areas thus focus should be paid to further strengthen the national regulatory regime to address unique features of SMRs.

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