# Floating Nuclear Power Plants: Legal and Regulatory Gap Analysis

Hamid Saeed Raza

Pakistan Nuclear Regulatory Authority

Islamabad, Pakistan

Email: hamid.saeed@pnra.org

Noreen Iftakhar

Pakistan Nuclear Regulatory Authority

Islamabad, Pakistan

Muhammad Abid Aslam Meo

Pakistan Nuclear Regulatory Authority

Islamabad, Pakistan

Jan Muhammad

Pakistan Nuclear Regulatory Authority

Islamabad, Pakistan

**Abstract**

Floating Nuclear Power Plants (FNPPs) present a novel approach to install small modular reactors (SMRs) on floating barges or platforms to provide clean electricity and heat for remote coastal locations, to decarbonize offshore oil and gas or mining activities, or even to provide grid scale electricity production. Their mobility offers advantages over traditional land-based plants, but also pose unique transport-related legal and regulatory challenges. The international legal and regulatory framework for the peaceful use of nuclear energy has evolved over time to govern the diverse applications of nuclear technology and achieve nuclear safety worldwide. However, specific requirements for floating reactors are still missing in the legal instruments governing nuclear safety. For example, the Convention on Nuclear Safety (CNS) primarily addresses only land-based facilities. On the other hand, deficiencies also exist in the legal regime of maritime safety regarding the definition of FNPPs as nuclear ships. In addition, there is a need to evaluate the existing IAEA safety standards for nuclear installations such as SSR 2/1 ‘Safety of Nuclear Power Plants: Design’, GSR Part 4‘Safety assessment for facilities and activities’, and SSR-6 Rev. 01 ‘Regulations for the Safe Transport of Radioactive Material in the light of peculiar safety aspects of FNPPs. The paper will highlight the gaps in the existing international nuclear safety regime with regard to FNPPs. Based on the gap analysis, the paper aims to contribute to the safe and responsible deployment of FNPPs, facilitating their potential as a clean energy source.

## INTRODUCTION

The international community is currently at a critical juncture in pondering upon legal and regulatory framework for innovative reactor technologies, specifically Transportable Nuclear Power Plants (TNPPs), with a focus on Floating Nuclear Power Plants (FNPPs). Nevertheless, like any other technology, FNPPs also require a legal and regulatory basis to perform under safety perimeters. This necessitates either the development of a legal and regulatory framework or amend the scope of existing laws and standards related to nuclear and maritime safety. The international legal and regulatory framework for the peaceful use of nuclear energy has evolved to govern the diverse applications of nuclear technology and achieve nuclear safety worldwide. Hence, there is a need to conduct a comprehensive legal and regulatory gap analysis to build a position for either formulating new laws or amending the existing ones to fill the gap related to FNPPs. Keeping this into consideration, this paper aims to analyze the existing legal framework related to nuclear safety and maritime safety. This paper will present a gap analysis of IAEA safety standards SSR 2/1, GSR Part 4, and SSR-6.

With this background, the paper is divided into five sections: Besides introduction, Section-2 discusses deployment scenarios regarding the transport of radioactive material (fuel, waste, etc.) and FNPPs to and from the on-shore and off-shore facility, to understand the applicability of current legal and regulatory framework. Section-3 thoroughly analyses the legal aspects of the deployment of FNPPs with a primary focus on the applicability of the existing nuclear law devised by the IAEA in the domain of nuclear safety, nuclear security, and nuclear liability. This section also briefly discusses some of the International Maritime Organization (IMO) legal instruments related to maritime safety. The applicability of CENNA, MARPOL, SUA convention etc. are discussed in detail. Moreover, possible solutions and ways forward for settling legal lacunas associated with the deployment of FNPPs are elaborated in this section. Section-4 entails a comparison of the design and safety assessment requirements of land-based NPPs with the transport related requirements given in SSR-6. The objective is to provide a gap analysis in the applicability of current SSR-6 requirements for safe deployment of FNPPs.

## FNPP and radioactive material Deployment scenarios

The following deployment scenarios (from legal aspects) and associated challenges are discussed in the proceeding sub-sections:

### Transport of radioactive material to/from on-shore and off-shore facility

### *Transport of radioactive material (fresh nuclear fuel) to on-shore/off-shore facility*

After manufacturing the nuclear fuel of FNPPs at the supplier industry, it has to be transported to the location in the host state (where FNPPs are being operated) or to the particular on-shore service center for refueling (as per the agreement of the Host State and the Supplier State). The fresh fuel is transported in packages that have multilateral approval (if required). The quality assurance of the fabricated fuel is verified at the supplier state.

During the transport of fresh nuclear fuel to the Host State, IAEA Regulations for the Safe Transport of Radioactive Material (SSR-6) is fully applicable during the transportation of fresh fuel by sea. SSR-6 covers the accident conditions and measures are outlined for safe transport.

The transport of fresh fuel may pass through state(s) territorial waters having disputes or may or may not be the signature of international treaties. So, this study outlines some legal requirements from international treaties/agreements that govern transportation through specific waters considering the location of on-shore/off-shore facility, apart from the region-specific laws. Currently, fresh fuel is being transported by sea in approved packages which should be under regulatory control through bilateral agreements/international laws between certain countries/regions. Once the fresh fuel has been transported to the facility and loaded to FNPP, then the requirements outlined for FNPPs are applicable.

### *Transport of radioactive material (spent nuclear fuel or radioactive waste) from an on-shore/off-shore facility*

During the operation of FNPPs, the spent nuclear fuel and radioactive waste generated needs to be transported for processing, treatment, or storage. Considering the spent nuclear fuel as high-level waste and the activity of the radioactive waste generated, special packages are used for their transportation. If the FNPP doesn’t have a fuel handling system or equipment the FNNPs is transferred to Servicing Centre, where spent fuel is removed from the reactor and sent for interim storage, awaiting reprocessing or direct disposal. During this transportation, the requirement of FNPPs is applied.

For safe transport of these radioactive materials, SSR-6 is applicable. SSR-6 imposes limitations on the quantity of radioactive material to be transported using approved (multilateral, if needed) packages. Besides such technical requirements, considerations are given to legal aspects and relevant international treaties regarding the transportation of radioactive materials through international waters, and their region-wise legal bindings.

In case vessels are equipped with fuel handling systems and storage pools/areas for spent fuel storage or radioactive waste and these radioactive materials (spent nuclear fuel and radioactive waste) are being transported along with FNPPs, in such a scenario the relevant legal and technical requirements of FNPPs are applied.

### Transport of FNPP with radioactive material (fuel, waste, etc) to/from on-shore& off-shore facility

### *Transport of FNPP as a facility from on-shore to off-shore and from offshore to on-shore*

Considering FNPPs being transported from onshore to off-shore with a loaded core, it means it contains a huge quantity of enriched uranium and other radioactive material in the form of waste. For this case, the implementation of safety/Safeguard requirements during transport is a great challenge, depending upon the design of the SMR module.

Further, FNPP as a facility with a loaded core is in ready-to-operate condition, and during transportation through the sea, the facility may encounter special consequences (such as extreme weather, collisions, external threats, human errors, fire/explosion, etc.), that need special features in the design to avoid accidental criticality, containment as well as confinement of radioactive material to control radioactive release into the marine environment.

In addition, FNPP transported as a facility may raise several proliferation concerns. These concerns focus on the risk of material diversion when the plant is being transported in another state's territorial waters; the security of the plant, both when in transit to another state and on lease to that state is a big challenge.

### *FNPP being transported as a Facility from on-shore to off-shore with Irradiated fuel*

If FNPPs are being transported after operation at some specific location, having irradiated fuel in it then decay heat removal from the facility will be vital. In such a situation, certain systems will be required to remove this decay heat. This will be a challenge as the ultimate heat sink of decay heat will be into the sea. If the whole SMR package is considered as a transport package, current IAEA regulation does not allow in/out from the package.

Furthermore, currently, SSR-6 does not impose any routing-related restrictions for the transport of packages having irradiated material. FNPP transported as a facility may follow a specific route as it contains a large quantity of enriched fuel.

## FNPP and [legal] Gap Analysis

There are four sets of legal documents applicable to FNPPs: nuclear safety, nuclear security, liability, and maritime safety. The detailed analysis of legal aspects related to FNPPs is given below:

### Applicability of the Existing Nuclear Law (IAEA)

Nuclear Law is fundamentally based on the requirements specified in legally binding instruments (e.g., international conventions) and other non-legally binding instruments such as IAEA Safety/Security Standards. Following is a brief analysis of the conventions in each nuclear domain and their applicability related to FNPPs.

#### Nuclear Safety:

* Convention on Nuclear Safety (CNS), 1996: The CNS (Article 3 of the CNS) “shall apply to the safety of nuclear installations (nuclear power plants), including storage, handling and treatment facilities for radioactive materials located on the same site and directly related to the operation of the installation” under the jurisdiction of a contracting party. The majority of convention’s provisions apply to any nuclear installation. However, regarding the definition of “nuclear installations”, FNPPs do not appear to be explicitly mentioned as nuclear installations considering they are not land-based civil nuclear power plants. Considering the significance of CNS as the cornerstone of the nuclear safety regime, its scope may be broadened or otherwise, a new dedicated convention for FNPPs may be formulated.
* Convention on Early Notification of a Nuclear Accident (CENNA) 1986: CENNA establishes the obligation for the States Parties to provide notification, directly or through the IAEA, of “nuclear accidents”, as defined in Article 1 of the convention, from which a release of radioactive material occurs or is likely to occur and that may have a transboundary radiological consequence. “To minimize the radiological consequences, State Parties may notify in the event of nuclear accidents other than those specified in Article 1” of this convention. Thus, this convention does not bar the location or source of nuclear accidents, hence only concern is to minimize the transboundary impact of these accidents. Thus, CENNA may apply to FNPPs.
* Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (CACNARE) 1986: CACNARE provides a system of cooperation among its State Parties and with the IAEA as it provides for the right of a State Party to request assistance from the IAEA and/or from another State Party in the case of a nuclear accident or a radiological emergency in compliance with certain conditions and procedures. Both emergency conventions also referred to as sister conventions, address nuclear accidents by establishing a general framework, and state parties are encouraged to conclude bilateral and multilateral arrangements to implement in detail the obligations of the conventions. Thus, the provision of these conventions may be addressed in the relevant Inter-Governmental Agreements (IGA) or any other regional-level cooperation mechanism.
* Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (Joint Convention), 2001: The Joint Convention applies to the management of spent (irradiated) fuel and radioactive waste from all civilian applications, including radioactive sources and discharges. For deployed FNPPs, the provisions of the Joint Convention can be applied to the spent fuel removed from an FNPP on the territory of the Supplier State, as well as radioactive waste generated in the Supplier and Host States. The prime responsibility for the safety of spent fuel and radioactive waste management rests with the holder of the relevant license. The ultimate responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the Contracting Party which has jurisdiction over the spent fuel and radioactive waste. The miscellaneous provisions (Article 27) of the Joint Convention cover the transboundary movement of spent fuel and radioactive waste. They apply to the transport of spent fuel and radioactive waste directly between Supplier State and Host State and to movements that cross third-party state boundaries.

#### Nuclear Security:

Though responsibility for nuclear security within a State rests entirely with that State, international cooperation is encouraged to strengthen nuclear security globally. In case of FNPPs, more than one entity is involved, hence require a shared burden of responsibility. The Convention on the Physical Protection of Nuclear Material (CPPNM) and its 2005 Amendment (A/CPPNM) are the only international legally binding instruments in the area of physical protection of nuclear material and nuclear facilities used for peaceful purposes. The application of the existing A/CPPNM appears to sufficiently cover the deployment of FNPPs. Basic physical protection principles, systems, and measures applied for conventional land-based NPPs would remain valid for FNPPs. However, additional technical guidance on nuclear security for FNPPs may be devised in coordination between the IAEA and IMO.

Considering the contemporary security environment, the threat of sabotage of FNPPs/ missile attacks during international voyages or transit requires special attention. Furthermore, practices related to the transport/transit of radioactive nuclear material between States are well established, however, commercial transport/transit of nuclear facilities between States has no precedents. One possible way is to establish an agreement among the Supplier State, any Shipping State or transit States, and the Host State laying out in detail the arrangements for physical protection in transit and the transfer of that responsibility among the States, all in conformance with their respective national and international laws and applicable standards.

#### Nuclear Liability:

Several international nuclear liability conventions and maritime liability conventions have established liability and compensation frameworks for transboundary radioactive damage. Based on the literature survey [1, 2], following points need additional attention in the case of FNPPs:

* Under existing nuclear liability conventions, the application of basic principles of the nuclear liability regime, like channelling exclusive liability to the operator; imposing supplementary liability to the installation state; establishing exclusive jurisdiction of the courts in the state where a nuclear accident occurs; setting limitations for the liability, etc., could face problems in the case of FNPPs. The existing nuclear liability regime imposes exclusive liability on the operator, which may make the supplier and other service providers free from liability and compensation. Thus, it may irk intense debate.
* The different positioning of FNPPs and resulting inconsistent principles and approaches for liability channelling may lead to confusion in determining the civil liabilities and compensation. If defined as land-based facilities or structures, FNPPs-related liability and compensation can be solved by nuclear liability conventions. However, if defined as ships, the application of these liability conventions would face controversies. Although the 1962 Convention on the Liability of Operators of Nuclear Ships (Brussels Nuclear Ship Convention) addresses nuclear ship-related liability issues, the ratification of the convention has become deadlocked and failed to enter into force. These legal issues need settlement beforehand.
* If FNPPs are deployed in disputed waters or waters beyond the deployment state’s jurisdiction and an accident happens, only allowing victims to bring lawsuits to the courts of the deployment state may impede victims’ access to prompt and effective relief.

#### Safeguards:

The deployment of FNPPs involves significant legal and institutional considerations. Deploying FNPPs at various locations, including international waters, complicates the application of the International safeguards protocols. This complexity necessitates clear guidelines for the roles and responsibilities of supplier and host states. Generally, the IAEA’s Safeguards by Design (SBD) guidance series supports to incorporate International safeguards into the design and pre-licensing processes. However, the transportation of FNPPs among different states during their life cycle could pose additional challenges in safeguards implementation, especially when supplying and recipient states differ in their safeguards. It is worth mentioning that the safeguards requirements may be different for Non-nuclear Weapon States i.e. Comprehensive Safeguards Agreements (CSA) and the Nuclear Weapon States i.e. Voluntary Offer Safeguards Agreements (VOAs). Moreover, under the Safeguards Member State Support Programme (MSSP), the IAEA and the suppliers may cooperate to develop approaches in implementing the Safeguards by SBD concept [3].

Safeguards obligations are derived from several International legal instruments. These include the Comprehensive Safeguards Agreements (CSA) (INFCIRC/153 (Corr.), IAEA, (1972)) and the Item-specific Safeguards Agreements (INFCIRC/66, 1965; /Rev. 1, 1967; and /Rev. 2, 1968, IAEA). Other commitments have also been undertaken by states pursuant to their membership and participation in export control arrangements, e.g., the Zangger Committee and Nuclear Suppliers Group (NSG); Nuclear liability law; Conventions, standards and guides under the auspices of other United Nations bodies such as the International Maritime Organisation and the UN Office of Legal Affairs Division for Ocean Affairs and the Law of the Sea; Sea transportation of nuclear modules (fuelled or otherwise) destined for land-based facility; Nuclear maintenance ships (i.e. ships having fuel storages on board without a reactor) Operational safety; Decommissioning; Radioactive waste management; Environmental discharges. Till now, specific for FNPPs, IAEA has not developed safeguards approach. Such safeguards approach needs to be generic that can be adapted for different types of FNPPs that have comparable characteristics.

FNPPs with onboard fuel handling allows direct fuel management on the vessel, reducing transportation risks but requiring continuous, direct monitoring to prevent fuel manipulation. Additionally, access for regular inspections is crucial, for the unique environment of a floating vessel. FNPPs without onboard fuel handling will also require monitoring during transit, particularly when the FNPP operates across international waters. Traditional safeguards measures designed for land-based nuclear facilities must adapt to the mobile nature and specific operational contexts of FNPPs. Moreover, the FNPP may be constructed and fuelled in the Supplier State, then sent to the Operating Site in a Host State, or FNPP is an existing facility that has undergone at least one operating cycle, such that it has been in service in a Hosts State, then relocated to a Service Centre prior to redeployment in a Host State (that may be the same Host State or another Host State). In such cases, the Supplier State should provide the Host State with sufficient information on the design and operation of the FNPP (Provision, Examination, and Verification of Facility Design Information and Nuclear Material Accountancy) in a timely manner in order that the Host State may satisfy its design information reporting requirements. The Host State should undertake such steps, as soon as it takes a decision to acquire (or lease) a FNPP from the Supplier State.

### Applicability of the Existing Maritime Law

Existing maritime law consists of the United Nations Convention on the Law of Sea and other maritime safety conventions developed by the IMO. Below is a brief analysis of each:

* United Nations Convention on the Law of the Sea, 1982 (UNCLOS) [4]: UNCLOS does not provide an explicit definition of ships or vessels. This omission may be interpreted as inclusivity. The applicability of UNCLOS on FNPPs can be proven when reading Articles 22 (Sea lanes and traffic separation schemes in the territorial sea) and Article 23 (Foreign nuclear-powered ships and ships carrying nuclear or other inherently dangerous or noxious substances). There is a clear separation of rights and obligations related to the division of sea in terms of territorial waters, exclusive economic zone, continental shelf, high seas, etc. Deployment of FNPPs in each category will evoke different obligations. Deploying and regulating FNPPs may inflict concerns with the freedom of navigation. Nonetheless, the deployment of FNPPs within a country’s territorial waters does not generally conflict with the principle of freedom of navigation if:
* The deployment of FNPPs do not obstruct the innocent passage of other countries;
* The deploying state may declare a right to suspend other ships’ innocent passage when FNPPs are deployed within its territorial sea;
* The deploying state may designate specific sea lanes for other countries to ensure their navigational rights;
* Coastal states are allowed to establish, in the exclusive economic zones or waters above the continental shelf, reasonable safety zones when necessary around the artificial islands, installations, and structures. These safety zones are meant to ensure the safety both of navigation and the artificial islands, installations, and structures. (UNCLOS, 1982, Articles 60, 80).

Nevertheless, in case of FNPPs are ‘declared’ as “artificial islands, installations, or structures”, coastal states (deploying FNPPs) can establish safety zones. Coastal states are required to consider “applicable international standards” (UNCLOS, 1982, Article 60) while determining safety zones. Since relevant “applicable international standards” in terms of FNPPs deployment-related safe zones are not clear, hence IMO and IAEA can work on it by defining safety zones with minimum negative effects on freedom of navigation.

* International Convention for the Safety of Life at Sea, 1974 (the SOLAS Convention) [5]: SOLAS has introduced a special chapter to ensure the safety of nuclear ships by requiring the flag states to “take measures to ensure that there are no unreasonable radiation or other nuclear hazards at sea or in port, to the crew, passengers or public, or to the waterways or food or water resources” (SOLAS, 1974, Chapter VIII, Regulation (6). Applicability of Chapter VIII just as for Chapter VII, relies on the interpretation of Regulation 3 of Chapter I i.e. definition of nuclear ship. [A nuclear ship is a ship provided with a nuclear power plant. EXCEPTIONS Ships not propelled by mechanical means;] Word selection is very important and subject to interpretation. Definitional aspects may be amended and added to the SOLAS convention. The relevant safety standards may be updated with technical aspects keeping design, construction, operation, commissioning, and decommissioning into consideration (where applicable).
* International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL) [6]; the 1978 Protocol and Annexes I-VI to the Convention: MARPOL provides a broader and more comprehensive definition of the ship in Article 2 (4), “Ship” means a vessel of any type whatsoever operating in the maritime environment and includes hydrofoil boats, air-cushion vehicles, submarines, floating craft, and fixed platforms. Article 3 MARPOL applies to ships entitled to fly the flag of a Party to the convention. The applicability of MARPOL on FNPPs is clear. It means MARPOL applies if the FNPPs deploying state is a party to MARPOL. MARPOL also applies to FNNPs not only during navigation but also once they arrive at the destination (transit or host state).
* Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation (SUA Convention) 2005 Protocol to the SUA Convention: [7] In March 1988 a conference in Rome adopted the SUA convention. The main purpose of the Convention is to ensure that appropriate action is taken against persons committing unlawful acts against ships. The convention defines ship in Article 1 as “ship” which means a vessel of any type whatsoever not permanently attached to the sea bed, including dynamically supported craft, submarines, or any other floating craft. The convention defines ship in Article 1 as “ship” which means a vessel of any type whatsoever not permanently attached to the sea bed, including dynamically supported craft, submarines, or any other floating craft.

### Possible Solution

As of now, there is no specific convention/legal regime dedicated to addressing legal aspects related to FNPPs. Existing legal framework have somewhere ambiguity and somewhere inconsistent applicability. Nevertheless, some conventions/treaties can be partially interpreted for FNPPs-related issues. The legal position and status of FNPPs are instrumental in determining their legal and regulatory framework (can be termed as a ship). If FNPPs have actual navigability; can be termed as an artificial island if moored. Furthermore, there are some political and strategic issues too. Deploying FNPPs in disputed waters may irk political and diplomatic tension in the region and it may also lead to overlapping jurisdiction and the application of different state laws for regulating FNPPs.

To sum up the legal debate, there can be the following solutions to settle the legal debate around FNPPs:

New Legal Framework: As the navigation of FNPPs from supplier states to deployment states may involve different marine zones, including the territorial seas, exclusive economic zones, or even the high seas, the safe transportation as well as deployment of FNPPs requires a comprehensive legislative and regulatory framework covering the obligations/responsibilities of Supplier State; Host State; Transit State; Coastal State; Third party (IAEA and IMO). To balance the regulatory powers and responsibilities of multiple states in different maritime zones, effective coordination among these states/entities would also be required. Therefore, a new binding/obligatory Convention on the Safety and Security of Nuclear and Other Radioactive Materials and Facilities during International Transport may be formulated. Until the provision of a convention is agreed upon, a Code of Conduct on Safety and Security of Nuclear and Other Radioactive Material and Facilities during International Transport may be devised, which may outline requirements of IAEA and IMO for nuclear safety, security liability, and maritime safety.

Bilateral and/or regional cooperation treaty mechanism: In case FNPPs are deployed in a particular region, bilateral or regional cooperation agreement may be concluded between all entities involved (Host state, supplier state, operator, transit state, territorial waters states, etc) for safety, security, liability, insurance, port access-related issues. Such bilateral and regional agreements are well established in the maritime domain, particularly for dealing with port access and territorial water passage issues for nuclear-powered merchant ships. For example, the 1964 USA-UK Agreement relating to the Use of United Kingdom Ports and Territorial Waters by the N.S. Savannah, the 1968 Agreement between the Federal Republic of Germany and the Kingdom of Netherlands on the Use of Dutch Waters and Harbors by the NS Otto Hahn, and the 1970 Treaty between the Federal Republic of Germany and Liberia on the Use of Liberian Waters and Ports by the NS Otto Hahn are such bilateral agreements [8].

Harmonizing legal documents and standards of IMO and IAEA: The existing legal and regulatory framework is composed of both nuclear-related conventions devised by the IAEA and maritime conventions formulated by IMO. IAEA and IMO have a detailed set of standards/codes in relevant domains. As a starting point, IMO in coordination with the IAEA may devise a model IGA defining responsibilities as well as the transfer of responsibilities related to nuclear safety, maritime safety, and liability of FNPPs. Furthermore, both organizations can harmonize their documentation by agreeing upon unified applicable international standards for FNPPs deployment.

There can be two sets of codes and standards:

1. Technical (definitional and technical design aspects related to construction, operation, commissioning, and decommissioning of FNPPs);
2. Administrative or Standard Operating Instructions (SOI) covering responsibilities as well as the transfer of responsibilities concerning safety, security, and liability among entities involved (Host State, Supplier State, Transit State, and or Coastal State) in the deployment of FNNPs.

Yet some questions are still left to answer: What would the point of transition for the safety responsibility from the supplier state to the host state if in between there is more than one transit state? And regarding liability issues, are the Supplier State and the Host State in treaty relations through one or more of the existing conventions on civil liability for nuclear damage? These legal issues require further ponderance.

## applicability of existing IAEA safety standards

A comprehensive comparative study and gap analysis of requirements of SSR-2/1 and GSR Part 4 perspective of SSR-6 requirements was conducted. It aims to elucidate the similarities and differences in transport safety requirement aspects. By examining the distinct methodologies and criteria set forth by such requirements, this comparative gap analysis highlights the unique aspects of nuclear safety for the safe deployment of FNPPs. This comparison of SSR-2/1 and GSR Part 4 with SSR-6 (Rev.1) requirements may serve to be useful for international harmonization, to foster a better understanding of global best practices in transport safety regulations. Key issues highlighted are mentioned in the following sections:

### Applicability of SSR-6 (Rev.1) to Requirements of SSR-2/1

The basic gap is that the SSR-6 establishes requirements of safety that provide an acceptable level of control of the radiation, criticality, and thermal hazards to people, property, and the environment during the transport of radioactive material while SSR-2/1 establishes requirements, particularly for the design of nuclear power plants. Certain requirements of SSR 2/1 are identified to be addressed in the design of the FNPPs perspective of SSR-6 for transport safety i.e., in SSR-2/1 planned release is allowed, however, SSR-6 does not support it. Moreover, NPPs are designed and operated to not preclude limited release of authorized amounts of radioactive substances to the environment in operational states; however, there is no concept of planned radioactive releases from FNPPs during transport. This gap can be addressed by ensuring that FNPPs may not be in operation during transport.

SSR- 2/1 requires Deterministic Safety Analysis (DSA) and Probabilistic Safety Assessment (PSA) based on Postulated Initiating Events (PIEs). These are not described in SSR-6, Rev. 1. However, SSR-6 defines testing and design requirements regarding transport safety related to accidents. For criticality safety analysis, the deterministic discrete ordinates technique and the Monte Carlo statistical technique are used. Scenarios regarding accident analysis based on initiating events or failure should be addressed in the design of FNPPs to ensure safety during transport from the perspective of SSR 2/1.

Regarding the safety classification of structures, systems, and components; SSR-6, Rev. 1 regards the country practice for item manufacturing, which is based on code and standards. Generally, three categories for quality are defined. Category A is defined as the items that are critical to safe operation (containment). Category B is defined for the items that may have major impacts on safety (lifting/tie down). Category C is defined for the items that may have minor impacts on safety (seal/lock pins). Compliance with these quality categories during manufacturing is ensured by relevant codes and standards. However, the safety classification of components is not covered in SSR-6, Rev. 1 as in the case of NPPs. Moreover, SSR-6 requires Tests to demonstrate the ability to withstand accident conditions of transport. However, design basis accidents in the case of FNPPs are used to define the design bases, including performance criteria, for safety systems and for other items important to safety that are necessary to control design basis accident conditions, to return the plant to a safe state and mitigate the consequences of any accidents. However, for NPPs SSR-2/1 specifies the safety classification of structures, systems, and components which are normally based on the pressure retention capability of the equipment. In the case of FNPPs, additional requirements will arise for FNPPs which include:

* Vibrations in the platform, especially if offshore;
* Deviation of the reactor from its normal vertical alignment.

The extent to which such requirements are possible would depend on the design of FNPPs. In many cases, a modular design could limit the extent to which maintenance, repair, and replacement would be possible. Items important to the safety of FNPPs during transport shall be designed to be calibrated, tested, maintained, repaired or replaced, inspected, and monitored as required to ensure their capability of performing their safety functions during the transport of FNPPs.

Moreover, another important aspect for the safe deployment of FNPPs would be the measures regarding accident condition, criticality safety, heat removal, and prevention of release of radioactive material to the environment, considered in SSR-6, Rev.1. Possible transport accidents and measures regarding mitigation of radiological consequences are also considered. However, radioactive release/discharges (plant radioactive effluent) are not in the scope of SSR-6, Rev.1. Measures shall be considered in the design of FNPPs from the requirement 34 perspectives of SSR-2/1.

In summary, during transport, apart from transport conditions, criticality safety has been ensured during the design and demonstration. There is no active equipment whose operation needs to be controlled remotely; accordingly, there is no concept of a control room to monitor the variable or parameters during a particular mode of operation as in the case of NPPs. Moreover, there is no concept of a supplementary control room (i.e. electronically and physically separated), offsite power source, auxiliary systems, treating solid & liquid radioactive wastes, effluent treatment system, and fuel handling systems, in SSR-6, Rev. 1. Such features should be considered in the design of FNPPs to ensure safety during transport from requirements perspective of SSR 2/1.

### Applicability of SSR-6 (Rev.1) to Requirements of GSR Part 4

In general, SSR-6, Rev.1 applies graded approach in the implementation of requirements considering possible radiation risks. The graded approach is also addressed in SSG-66, which is a subsidiary document of SSR-6 regarding the Format and Content of the Package Design Safety Report for the Transport of Radioactive Material. Features should be considered in the design of FNPPs to ensure transport safety if FNPPs are with loaded core, in perspective of GSR part 4. Moreover, SSR-6, Rev. 1, considers provisions for radiation protection, dose limits, and constraints. It considers activity concentration limits and applies administrative requirements. In the case of NPPs, radiation risks for normal operation, anticipated operational occurrences, and accident conditions in which occurrences of events challenge safety, are considered. This can affect local or geographically remote population from the NPPs. While there is no concept of radiological consequences for geographically remote populations in SSR-6, Rev. 1. Further, as NPPs are operating on the same site for a long time, radiation risks for waste management, effluent release that have long-term effects that should be considered, while waste management and effluent control is not in the scope of SSR-6, Rev. 1. For NPP PSA and DSA methods are used for analysing challenges to safety in NPP, however, SSR-6, Rev. 1 considers qualification test based on transport accident conditions that include fire and flooding. If FNPPs are in operation, with fuel loaded core during transport, safety should be ensured during transport by considering the relevant requirements of GSR part 4. Moreover, for the safe deployment of FNPPs, anticipated operational occurrences and accident conditions that challenge safety shall be identified in the safety analysis, considering both deterministic and probabilistic approaches. Besides, the Requirement of independent verification of the safety assessment before it is used by the operating organization or submitted to the regulatory body can be addressed by ensuring the concept of independent verification in the perspective of GSR Part 4. This also includes ensuring the concept of the use of the safety assessment and the concept of the use of the periodic review and updating of the safety assessment in perspective of GSR Part 4.

## Conclusion

The international legal framework for peaceful uses of nuclear technology has evolved to govern the applications of nuclear technology and achieve nuclear safety worldwide. Nevertheless, the existing nuclear legal framework is affected by rapid technological advancements. The time lag between the legal framework for nuclear safety and innovative technologies must be addressed to strengthen nuclear safety. Like other emerging technologies, FNPPs have the potential to make a paradigm shift. As the name implies, the jurisdiction of FNPPs is beyond land thus requiring the integration of legal aspects of nuclear safety with maritime safety. This paper attempted to analyze the existing legal and regulatory framework of safety-related nuclear and maritime. Along with the development of two deployment scenarios for understanding the current legal and regulatory framework, the paper includes a summary of the comparison of existing SSR-2/1 and GSR Part-4 with perspective of SSR-6 and related commentary. Such commentary includes a gap analysis for the requirements of SSR-2/1 and GSR Part 4. These gaps suggested the need for a harmonized approach towards the development of a regulatory framework for the safe transport of the FNPPs. As the FNPP technology is evolving, so are the related legal and regulatory frameworks also evolving. The paper has suggested possible options of either amending the existing IAEA conventions or bringing additional conventions and related standards to plug the legal and regulatory gap related to FNPPs, and to strengthen the spirit of nuclear safety viz-a-viz maritime safety. Perhaps it is the best time to re-think the scope of the international legal framework for nuclear and maritime safety as much has changed and changing rapidly.

references

1. Jakub Handrlica, Transportable Nuclear Power Plants: An enigma of international nuclear liability law, Journal of World Energy Law and Business. Published online 2019. doi: 10.1093/jwelb/jbz018
2. INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Institutional Issues of Transportable Nuclear Power Plants: A preliminary Study, IAEA Nuclear Energy Series No. NG-T-3.5, IAEA, Vienna (2013).
3. INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Law the Global Debate, IAEA (2022).
4. United Nations Convention on the Law of the Sea (UNCLOS) 1982, UNITED NATIONS. Available at: <https://www.un.org/depts/los/convention_agreements/texts/unclos/closindx.htm>
5. International Convention for the Safety of Life at Sea (SOLAS), 1974,INTERNATIONAL MARITIME ORGANIZATION. Available at: [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-%28SOLAS%29%2C-1974.aspx)
6. International Convention for the Prevention of Pollution from Ships (MARPOL), Adoption: 1973 (Convention), 1978 (1978 Protocol), 1997 (Protocol - Annex VI); Entry into force: 2 October 1983 (Annexes I and II), IMO. Available at: [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-%28MARPOL%29.aspx)
7. Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation, Protocol for the Suppression of Unlawful Acts Against the Safety of Fixed Platforms Located on the Continental Shelf, adopted 10 March 1988; Entry into force 1 March 1992; 2005 Protocols: Adopted 14 October 2005; Entry into force 28 July 2010, IMO. Available at: <https://www.imo.org/en/About/Conventions/Pages/SUA-Treaties.aspx>
8. Qiuwen Wang, Hu Zhang, Puxin Zhu, Paul B. Tchounwou, Using Nuclear Energy for Maritime Decarbonization and Related Environmental Challenges: Existing Regulatory Shortcomings and Improvements, International Journal of Environmental Research and Public Health. 2023 Feb; 20 (4): 2993. doi: 10.3390/ijerph20042993. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9966280/>