Facilitating Global Deployment of Floating Nuclear Power Plants

Cooperation in Reactor Design Evaluation and Licensing Working Group

WORLD NUCLEAR ASSOCIATION

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World Nuclear Association is the international organization that represents the global nuclear industry. Its mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate.

The Cooperation in Reactor Design Evaluation and Licensing (CORDEL) Working Group of World Nuclear Association was created in January 2007 with the mission of establishing international standardization of individual reactor designs and harmonization of approaches to licensing. CORDEL activities cover a wide range of technical areas, while maintaining close cooperation with the OECD Nuclear Energy Agency, the International Atomic Energy Agency, and standards developing organizations (SDOs), in pursuit of the CORDEL goals.

Contributors to the report

Technical author
Alexander Izmaylov, Independent Consultant

Project coordinator
Ronan Tanguy, World Nuclear Association

Contributors
Alexander Tsibulya, Rosatom
Andrey Shkarbanov, Rosatom
Efreim Yakubov, Rosatom
Ilya Sesyutchenkov, Rosatom
Nadja Joergensen, Saltfoss Energy
Nadezhda Salnikova, Rosatom

Reviewers
Denise Cheong, National University of Singapore
King Lee, World Nuclear Association
Mark Tipping, Lloyd's Register
Meg Dowling, ABS
Ross Peel, King's College London
Simon Chaplin, WNTI

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Abbreviations and acronyms

ABS	American Bureau of Shipping
CNS	Convention on Nuclear Safety
CPPNM	Convention on the Physical Protection of Nuclear Material
IACS	International Association of Classification Societies
IAEA	International Atomic Energy Agency
IMO	International Maritime Organization
NEMO	Nuclear Energy Maritime Organisation
NHSI	Nuclear Harmonization and Standardization Initiative
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
SOLAS	International Convention for the Safety of Life at Sea
UNCLOS	United Nations Convention on the Law of the Sea
WNTI	World Nuclear Transport Institute

Technical nomenclature

FNPP	Floating nuclear power plant
PPS	Physical protection system
SBD	Safeguards by design
SMR	Small modular reactor

Executive summary

Floating nuclear power plants (FNPPs) represent a transformative innovation in clean and reliable energy production, offering a versatile and sustainable solution to addressing climate change and increasing global power demand. Based on existing experience and current developments, this report explores the strategic, technological, and regulatory considerations surrounding FNPP deployment.

FNPPs are designed to be mobile, scalable and flexible in terms of site selection and resilient against natural disasters, making them an attractive alternative to traditional land-based nuclear facilities – especially in remote areas where the construction of large nuclear facilities is not feasible. Since FNPP units can be assembled in shipyards using modules manufactured in the supplier's country, they can be deployed quickly and require fewer resources and supporting infrastructure from their host country.

At the same time, there is a clear need for dedicated actions to be taken by stakeholders of future international FNPP projects in order to address the challenges associated with such innovative projects. The licensing and supervision of internationally-deployed FNPPs combines civil nuclear and maritime safety regulations as it involves the routing of nuclear facilities with loaded reactor cores between different countries. Thus, strong cooperation between nuclear regulators, maritime administrations and classification societies is a key prerequisite for the success of future FNPP projects.

This report discusses the importance of complying with international conventions and treaties in nuclear and maritime safety, security and safeguards, as well as nuclear liability. A tailored allocation of responsibilities between stakeholders should be clearly set out in intergovernmental agreements and contracts to enable the unambiguous transfer of these responsibilities for FNPP projects deployed overseas.

To further boost the deployment of FNPP technologies globally, the respective legal frameworks should be updated. The International Convention for the Safety of Life at Sea (SOLAS convention) along with other maritime codes and standards have to be revised to cover floating nuclear power plants. The clarification of classification rules for FNPPs is needed for a widely-acknowledged international reference for the planning and deployment of FNPPs. Moreover, as experience in FNPP deployment expands, the International Atomic Energy Agency (IAEA) standards and guidelines should be adjusted to reflect best available knowledge and practices derived from implemented and ongoing projects. In this regard, World Nuclear Association recommends that the IAEA and International Maritime Organization (IMO) member states interested in FNPPs should advocate for the IAEA and IMO to collaborate on the development of international regulatory frameworks and standards for FNPPs.

1 Introduction

Floating nuclear power plants (FNPPs) are essentially movable entities. In contrast to land-based nuclear power plants, they can be manufactured, moored, operated, relocated, refuelled, maintained and decommissioned in different locations. Their mobility and relative compactness allow them to be located almost anywhere in a body of water.

Besides heat and electricity supply, there are plenty of other technological applications of FNPPs, *e.g.* seawater desalination or production of fuels such as ammonia and hydrogen for further industrial decarbonization. Clean energy can be seamlessly supplied from FNPPs to a wide variety of users, whether near heavily populated areas or in remote locations. For example, over the five-year period since it started producing electricity up to the end of 2024, the *Akademik Lomonosov* FNPP provided more than 978 million kWh of electricity to Pevek – the northernmost city of Russia – and other industrial consumers in the Chukotka region.[1] This plant is also supplying domestic heat in harsh Arctic conditions.

There are of course several regulatory and technical challenges that are specific to FNPPs. However, with strong political support, along with the development of suitable technical solutions and regulatory frameworks, these issues should not prevent the widespread deployment of FNPPs.

Definition

There are different reactor technologies under development which could be suited to new FNPP projects. In this report, an FNPP is defined as:

> *A non-self-propelled vessel that hosts a nuclear reactor, which is capable of producing energy products such as electricity and heat, supported by onshore equipment and buildings.*

An illustration of such a facility is provided in Figure 1.

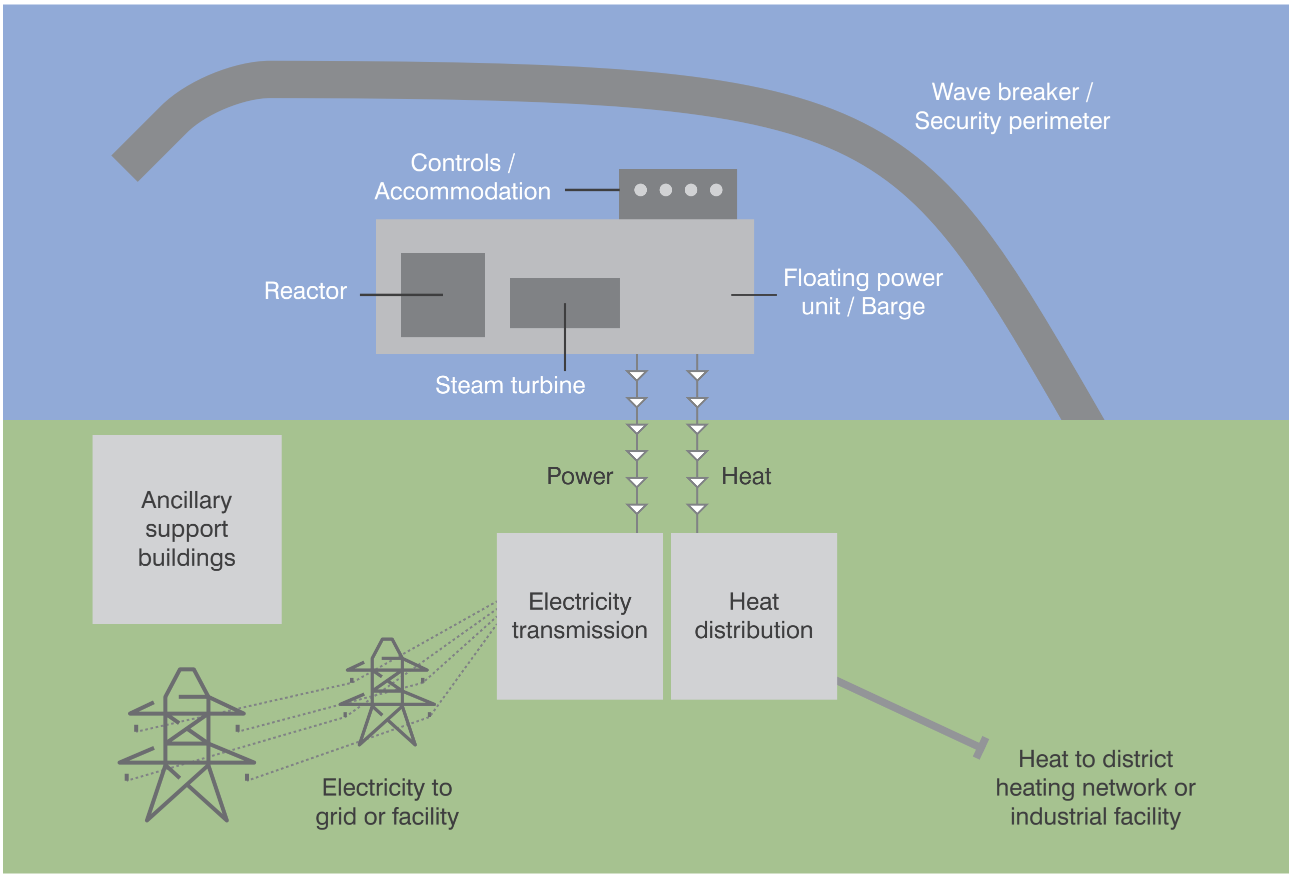

Figure 1. Diagram of a generic floating nuclear power plant

[1] The world's only floating nuclear power plant is capable of increasing electricity generation by 70% in the face of growing consumption in Chukotka, Rosatom (19 December 2024)

The International Atomic Energy Agency (IAEA) Nuclear Safety and Security Glossary[2] quotes the following definition for a "nuclear facility", noting that it is specific to a 2005 convention[3], but otherwise does not refer to the concept of an FNPP:

> *Any nuclear reactor, including reactors installed on vessels, vehicles, aircraft or space objects for use as an energy source in order to propel such vessels, vehicles, aircraft or space objects or for any other purpose.*

While applicability of IAEA safety standards to transportable nuclear power plants and marine-based nuclear power plants has been preliminarily examined in the IAEA Safety Report No. 123, *Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors*,[4] an internationally recognized definition of an FNPP would help to determine more precisely which safety standards and security guidance previously developed for land-based nuclear facilities would be applicable to FNPPs as a whole.

Although the absence of a precise definition is not considered a significant bottleneck for planning and execution of FNPP projects, World Nuclear Association calls for a general FNPP definition to provide more clarity in future FNPP-related developments.

[2] IAEA Nuclear Safety and Security Glossary, 2022 (Interim) Edition, International Atomic Energy Agency (October 2022)

[3] International Convention for the Suppression of Acts of Nuclear Terrorism, United Nations (April 2005)

[4] Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors, Safety Reports Series No. 123, International Atomic Energy Agency (November 2023)

2 History of floating nuclear power plants

The use of nuclear power at sea started with the commissioning of the USS Nautilus submarine in 1954, it has since seen numerous naval applications for both surface fleets and submarine services across the world. The first civilian projects, in which nuclear facilities were operated by the operating organization of one state, then moved by sea and entered the territory of other states, were implemented the following decade, in the 1960s. The cargo-passenger nuclear ship *Savannah* (USA, 1962-1972), *Otto Hahn* nuclear merchant ship (Germany, 1968-1979) and Mutsu nuclear merchant ship (Japan, 1974-1992) were self-propelled vessels driven by low power nuclear power plants.

Civil nuclear applications at sea continued with the long-term development and operation of nuclear icebreakers in the USSR, now Russia. The USSR built several nuclear icebreakers, the first of which was *Lenin* (1957-1989), the world's first nuclear-powered surface ship as well as the first civil nuclear powered vessel. Another significant example is the cargo carrier *Sevmorput* (1988-2007; 2016-present) with one KLT-40 (PWR) reactor unit.

Today, the fleet of civil self-propelled nuclear vessels is operated exclusively in the Russian Arctic. Nuclear icebreakers help to enable navigation and commercial shipping via the Northern Sea Route by connecting the European and Far Eastern ports of Russia over a distance of over 5600 km.[5] The most recent are four icebreakers with RITM-200 light water reactors commissioned in 2020-2024 under Project 22220. Three more vessels of the same series are under construction or ordered, as well as construction of the first of the Project 10510 large icebreakers, with two RITM-400 reactors. As self-propelled vessels, these would not be considered to be floating nuclear power plants according to the definition in the previous section.

The world's first FNPP was the MH-1A (Mobile High Power Reactor 1A) reactor that was installed on a surplus World War II Liberty cargo ship, *Charles H. Cugle*, renamed *Sturgis*.[6] Construction of the MH-1A reactor began in 1963 and it reached first criticality in 1967 and was supplying 10 MW of electricity in the Panama Canal Zone in 1968-1976. The reactor was retired from service in 1976 and defueled the following year.

Figure 2. The Sturgis operating in the Panama Canal Zone[7]

[5] Nuclear icebreakers help Northern Sea Route to record year, World Nuclear News (5 January 2024)

[6] Floating Nuclear Power: The MH-1A *Sturgis*, U.S. Army Corps of Engineers headquarters website

[7] Photograph from U.S. Army Corps of Engineers, MH-1A, STURGIS Nuclear Barge

The next floating nuclear power plant wasn't built until the 21st century. The *Akademik Lomonosov* commenced operation at Pevek, in the Chukotka region in Russia's Far East in 2019. The only operating FNPP in the world, the *Akademik Lomonosov* carries two KLT-40S reactors of 35 MWe each, similar to ones used in nuclear-powered icebreakers. Three further Russian FNPPs with two RITM-200S reactors each are under construction and one more has been ordered to secure energy supply to a mining and processing plant, a perspective source of copper and other metals located in the same region.[8]

Today there is a great deal of interest in the deployment of FNPPs around the world. Companies such as Core Power, KEPCO E&C, Prodigy Clean Energy, Rosatom, Saltfoss Energy and others are developing their own FNPP designs. And though conceptually, technically, and from a regulatory perspective, these designs may differ, they share many of the same benefits and challenges described in this report.

[8] Floating nuclear power plant plan for Russia's Far Eastern coast, World Nuclear News (27 March 2024)

3 Advantages of FNPPs

In addition to the environmental, security of supply and other benefits associated with conventional land-based nuclear plants, floating nuclear power plants offer several additional advantages:

- Siting: since FNPPs are located offshore, site selection and preparation may take much less time than for onshore nuclear plants.
- Manufacture: shipyard based assembly of FNPPs, bringing together modules fabricated off-site offers an opportunity to improve quality control, shorten timespans and reduce capital costs.
- Construction: the construction of FNPPs could be significantly shorter than for land-based plants as there is no need to perform so many site investigations and preparatory works, or complex civil and installation works.
- Maintenance and refuelling: outage activities of FNPPs can be centralized through the relocation of vessels from the operation site to the shipyard.
- Waste management and decommissioning: back-end activities for FNPPs can also be simplified through centralization at a supplier's facility.

The main challenges facing a large expansion of the nuclear power sector are the scaling up of construction and reducing the costs of construction. In particular, the licensing and construction of large nuclear power plants can take many years. They require large amounts of capital, complex construction arrangements, and in general more effort to build.

Centralized manufacturing is expected to both lower capital costs and speed up construction times. Bringing key FNPP manufacturing and construction activities under the highly productive environments of shipyards could play a significant role in optimizing costs and speeding up the deployment of new nuclear plants. Moreover, some FNPP designs feature modular construction, which may offer extra flexibility for vendors when targeting international markets and uncover pathways to series production and unified supply chains.

Full construction offsite could be an additional benefit for nuclear newcomer countries whose national infrastructure is less prepared for new nuclear projects. Longer fuel campaigns typical for FNPP designs may also provide host states with more confidence in energy security and forward-looking national and regional energy planning.

Further advantages of FNPPs include the potential for reduced manpower and financial resources needed for site preparation and licensing processes. Due to a smaller number of buildings and absence of a traditional base slab, FNPP construction requires less material – and consequently a smaller footprint. The amount of concrete required for a 100 MWe land-based nuclear plant could be around 30,000 tonnes.[9]

A key prerequisite for construction and operation of any nuclear facility is ensuring its safety and security and protection against initiating events and hazards. According to preliminary analysis, the IAEA standards can be applied to FNPPs. In addition, depending on its geographical location and distance from the sea bed and shore, an FNPP could be comparatively safe against earthquakes and tsunamis because it may not experience ground movements and impacts from waves could be much less than for land-based nuclear power plants.[10] Nevertheless, detailed studies on resistance against external hazards for FNPPs will be required that will be different from those for land-based nuclear plants due to the nuclear reactor being incorporated in a non-self-propelled vessel.

Experience in operation of FNPPs shows that the technology can be deployed under existing regulatory frameworks. To unlock the large-scale deployment benefits presented by the international deployment of civilian FNPPs, there are certain legal, institutional and technical issues covered in the following sections that should be addressed.

Licensing

According to provisions of the Convention on Nuclear Safety (CNS)[11] and principles laid down in the International Atomic Energy Agency's (IAEA's) SF-1 Fundamental Safety Principles,[12] with regard to nuclear installations IAEA member states shall establish a system of licensing as well as prohibit the operation of a nuclear installation without a licence. As FNPPs are subject to both nuclear and maritime regulatory frameworks, these have to be licensed and supervised by both nuclear and maritime regulators.

FNPP technology introduces unique challenges in selecting the optimal regulatory approach for FNPP projects, since in some scenarios the construction of a facility can be carried out in the territory of an experienced supplier country relying on its national regulations, and the fuel-loaded FNPP can then be relocated to a newcomer country for operation. Due to the cross-border nature of international

9 Based on 297 tonnes of concrete per MWe. Source: Figure 62, Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, United Nations Economic Commission for Europe (September 2022)

10 Floating nuclear plants could ride out tsunamis, MIT News (16 April 2014)

11 Convention on Nuclear Safety (adopted 17 June 1994; entered into force 24 October 1996)

12 Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, International Atomic Energy Agency (November 2006)

FNPP projects – with a need to take into account the provisions of international conventions, standards of the IAEA, International Maritime Organization (IMO), and potentially regulations of transit states – the approach to FNPPs licensing and oversight should be adapted from the one used for land-based nuclear power plants. In this regard the regulatory experience with nuclear ships could be considered to be mostly applicable to FNPPs.

Allocation of roles and responsibilities in licensing and oversight by the supplier's and host's regulators should be specified in intergovernmental or other agreements on a case-by-case basis. This would make the process transparent for all the stakeholders and open opportunities for strengthening international regulatory cooperation.

To accelerate deployment of new nuclear plants, the World Nuclear Association report titled *A Framework for International Regulatory Efficiency to Accelerate Nuclear Deployment*[13] proposes further steps to increase efficiency of nuclear design reviews. As indicated in the report, one of the possibilities for minimizing the time and cost for approving reactor designs is to rely on work carried out by other competent nuclear regulatory authorities. Regarding international FNPP projects, the Association considers that enabling one regulator to leverage all, or part, of the outcomes from reviews undertaken by other regulators to support its own regulatory process would help to lower FNPP project costs as well as optimize schedules. Regulatory cooperation and joint reviews of design and safety documentation are needed to deploy FNPPs where the vendor and operator originate from different states.

The report also draws on experience from other industries, in particular aviation, on how to manage objects under operation that move from country to country.

Interaction between national regulators regarding nuclear plant deployment is already under way, for example in the work of the IAEA Nuclear Harmonization and Standardization Initiative (NHSI) Regulatory Track.[14] Regulators are also cooperating with each other on small modular reactor (SMR) designs, *e.g.* a joint review of the Nuward SMR was carried out by the French, Finnish and Czech nuclear regulators.[15]

Regular dialogue and extensive cooperation between maritime and nuclear regulatory authorities, as well as other relevant organizations, are essential for the success of FNPP projects. When defining the licensing strategy for FNPPs, the industry should use experience and lessons learnt from nuclear power plant and nuclear ship projects. National governments, nuclear and maritime regulators, and international organizations should share information on practical solutions in licensing and best practices from past projects, and incorporate these into their respective regulatory frameworks in order to streamline the permitting of FNPPs.

Classification

Several organizations besides nuclear regulatory authorities should be involved in the licensing and construction of FNPP projects. Classification societies have a long history and function as independent organizations whose mission includes verification on behalf of flag states that ships have been constructed and are maintained in compliance with international and national statutory regulations.

Classification societies should affirm that a vessel intended to carry a nuclear power plant and associated facilities is designed and constructed according to safety and environmental protection standards. One key element verified by classification societies is the structural strength of the ship's hull, its appendages, and other systems important for ship operation. Several classification societies, such as Lloyd's Register, Bureau Veritas, Russian Maritime Register of Shipping and American Bureau of Shipping, possess experience in vessels with onboard nuclear installations.

As the principal technical adviser to the International Maritime Organization (IMO), the International Association of Classification Societies (IACS) participates in establishing, reviewing, promoting and developing minimum technical requirements for the design, construction, maintenance and survey of ships and other offshore facilities. The IACS assists international regulatory bodies and standards organizations to develop, implement and interpret international regulations and industry standards in ship design, construction and maintenance, with a view to improving safety at sea and the prevention of marine pollution. One of the key IACS activities is the development of minimum requirements referred to as Unified Requirements (URs) that are subject to incorporation into member states' own rules and requirements.

Essential steps of classification of vessels include appraisal of the design and various ship surveys. The arrangement of supervision by flag state administrations or their recognized organizations during construction and operation is necessary to confirm that vessels are designed, constructed, maintained and managed in

[13] A Framework for International Regulatory Efficiency to Accelerate Nuclear Deployment, World Nuclear Association (September 2023)

[14] NHSI Regulatory Track webpage, International Atomic Energy Agency

[15] Nuward SMR Joint Early Review, Pilot Phase Closure Report, French Nuclear Safety Agency (ASN), Finnish Radiation and Nuclear Safety Authority (STUK) and the Czech State Nuclear Safety Authority (SÚJB) (September 2023)

compliance with the requirements of IMO conventions, codes and other instruments. Notably, classification carried out by any classification society should be recognized by other classification societies, IACS member or not.

A potential FNPP era would benefit from the IACS experience of the development of rules and interactions with classification societies and the IMO. World Nuclear Association therefore recommends that the nuclear industry and international key stakeholders from the maritime industry such as the IMO, IACS and classification societies cooperate on outlining future frameworks for FNPPs.

Nuclear and maritime safety

The 1994 Convention on Nuclear Safety (CNS) established the most important high-level obligations for contracting parties: legislative and regulatory framework; regulatory body; resources; quality assurance; and safety assessment. Despite its scope limitation to land-based nuclear installations, most of the CNS provisions could be substantially applicable to FNPPs.

Another important nuclear safety convention is the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.[16] The IAEA's 2013 preliminary study on FNPPs concluded that generally the Joint Convention could be applicable for transportable nuclear power plants.[17] It points out that where a supplier state is in charge of used fuel management obtained from operation of a transportable nuclear plant, the provisions of the Joint Convention would be applicable to the supplier state although the plant's operation is in the host state. This feature could be beneficial for customers from nuclear newcomer countries since they would otherwise have to invest significant resources to develop the workforce and practices needed to meet the requirements of the Joint Convention.

A preliminary conclusion of the IAEA Safety Report Series No. 123 is that a number of the IAEA's General Safety Requirements and Specific Safety Requirements are applicable to innovative nuclear technologies including transportable nuclear plants insofar as they relate to them. Also, some Specific Safety Requirements may be considered in future for revision in order to fully reflect the specificities of the FNPP lifecycle. Another useful conclusion is that IAEA General Safety Guidelines and Specific Safety Guidelines do not provide more detailed standards for FNPPs because these documents are formed on the basis of experience derived from practice. As experience in implementing FNPP projects accumulates these recommendations could also be developed to include FNPPs.

The IAEA safety standards take natural and anthropogenic external events into account. A specific list of external events is not provided, though recommendations on its formation are available in several standards.[18] Since FNPPs are to be operated in the marine environment, the list of external hazards considered in the safety analysis report should be supplemented with specific events including collision with ships and other objects, stranding, and flooding. The list and characteristics of such specific hazards are dependent on navigation practices, intended route of movement and operation site, as well as statistics of navigation accidents.

Existing fundamental nuclear and maritime safety principles are considered applicable to FNPPs. In addition, the safety of the FNPP should be assessed comprehensively taking into account technical solutions of the ship and the reactor being an integral part of it. Therefore, safety assessments of FNPPs should be taken into account maritime regulatory framework along with nuclear safety requirements.

The United Nations Convention on the Law of the Sea (UNCLOS) establishes a legal framework for all maritime activities. The way UNCLOS is applied to FNPPs may be influenced by several variables (*e.g.* type, location, purpose and other FNPP features). Therefore, applicable rules would change each time an FNPP moves between maritime zones – this aspect along with applicable UNCLOS provisions should be considered for any international FNPP project.

The International Convention for the Safety of Life at Sea (SOLAS) – regarded as the most important international treaty concerning the safety of merchant ships – gives standards for the construction, equipment and operation of ships, while flag states are responsible for ensuring that ships under their flag comply with its requirements. The SOLAS Convention, as it now stands, has a limited and somewhat confused coverage of floating nuclear technologies since its provisions do not cover vessels

[16] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (adopted 5 September 1997; entered into force 18 June 2001)

[17] Legal and Institutional Issues of Transportable Nuclear Power Plants: A Preliminary Study, IAEA Nuclear Energy Series No. NG-T-3.5, International Atomic Energy Agency (October 2013)

[18] *e.g.* Format and Content of the Safety Analysis Report for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-61 (September 2021), Design of Nuclear Installations Against External Events Excluding Earthquakes, IAEA Safety Standards Series No. SSG-68 (December 2021), Protection against Internal Hazards in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-64 (August 2021).

that are non-self-propelled. At the same time, civil nuclear vessels are not exempt under any circumstances from fulfilling the requirements of the SOLAS Convention. Therefore updates and tailoring of SOLAS and possibly other marine conventions and codes are expected in a near future with the aim to explicitly cover floating nuclear power plants.

The development of new – or adaptation of existing – nuclear and maritime legal frameworks can draw on existing nuclear safety standards, several thousand operating reactor years and decades of nuclear material carriage at sea. As national and international FNPPs are deployed, and operational experience is accumulated, special recommendations for FNPP safety may be developed under the auspices of international organizations such as the IAEA and the IMO.

Safeguards

According to Article 3 of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT),[19] each non-nuclear-weapon state undertakes to accept safeguards, as set forth in a comprehensive safeguards agreement to be negotiated and concluded with the IAEA, with a view to preventing diversion of nuclear energy from peaceful uses.[20] Therefore, for FNPPs, the safeguarding measures could be applied at the central factory, during delivery of the fuelled reactor, as well as during its operation at the deployment site. A nuclear-weapon state could also apply safeguards according to its voluntary agreement or other agreements with the IAEA.

Cooperation between the IAEA and member states on adapting existing safeguards to FNPPs is ongoing. The existing framework of safeguards agreements and associated practices form a solid foundation for encompassing a wide range of future FNPP projects.

From a technical point of view, FNPP projects may provide opportunities for optimization of IAEA safeguards as the majority of FNPPs are based on innovative reactors with a long-term fuel campaign of more than a year and a compact integral layout. Moreover, FNPP projects may provide possibilities for facilitating the IAEA inspections with wider use of containment and surveillance equipment.

Safeguarding measures in FNPPs should be implemented within a relatively compact layout without compromising the safety of operating personnel and IAEA inspectors as well as the security of the plant. By following the Safeguards by Design (SBD) approach,[21] safeguards measures can be incorporated early enough at plant design stage in order to avoid unsystematic case-by-case retrofit afterwards. It should provide an opportunity for future owners to reduce unexpected costs from plant re-design and for regulators and the IAEA to facilitate their verification activities.

Nuclear security

Key provisions on physical protection[22] of nuclear material and nuclear facilities are set out in the Convention on the Physical Protection of Nuclear Material (CPPNM) and the Amendment to it.[23] Being party to these international legal instruments is essential for a state seeking to supply or host a FNPP.

A state on whose territory (or in whose territorial waters) an FNPP is located becomes fully responsible for the plant's physical protection. Thus, the transfer of one state's responsibility for adequate physical protection of nuclear materials to another state in course of project should be clearly defined and agreed in accordance with the provisions of the CPPNM and its Amendment. Furthermore, issues of physical protection that may arise with regards to FNPP projects should be addressed through intergovernmental agreements between the states concerned

The design of physical protection systems for FNPPs will require due consideration of FNPP innovations, relocation, maritime operating conditions, and multiple siting locations. Physical protection analyses should take into account new potential threat scenarios such as surface and submersible threats to FNPPs. Special consideration should also be given to protection of FNPP connections with the shore and protection of the whole infrastructure that is created for the operation of the FNPP at the mooring place.

In practice, a physical protection system (PPS) within the boundaries of the vessel would be established. This can be developed either by the vendor state or by the customer state. The requirements for the PPS are set by the customer

[19] Treaty on the Non-Proliferation of Nuclear Weapons (NPT; adopted 12 June 1968; entered into force 5 March 1970)

[20] The rights and obligations of the IAEA and the States are presented in model agreements INFCIRC/153 and in INFCIRC/540.

[21] See IAEA webpage on Safeguards by design.

[22] The term 'physical protection' has been historically used since adoption of the Convention on the Physical Protection of Nuclear Material to describe what is now referred to as nuclear security of nuclear material and nuclear facilities (see definition of 'physical protection' in the IAEA Nuclear Safety and Security Glossary, 2022 Interim Edition).

[23] Convention on the Physical Protection of Nuclear Material (CPPNM, adopted 26 October 1979; entered into force 8 February 1987); Amendment to the Convention on the Physical Protection of Nuclear Material (adopted 8 July 2005; entered into force 8 May 2016)

and may vary from state to state. The exact configuration including its segmentation into various technical components as well as operating procedures and responsibilities is to be agreed between the customer and vendor.

The IAEA Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (NSS-13)[24] states that potential conflicts between safety and security measures should be identified and minimized during the design stage. Nuclear security measures should not diminish the implementation of safety measures at the FNPP, its operation and survivability, and vice versa. For this reason, safety and security designers and experts should work in one team to ensure that the design of physical protection systems does not reduce the level of safety of FNPP and its personnel.

Nuclear liability and maritime insurance

The principal nuclear liability conventions are the 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy[25] and the 1963 Vienna Convention on Civil Liability for Nuclear Damage[26] which have been amended several times since their adoption. Later, in response to the Chernobyl accident in 1986 and the need to broaden the geographical scope of the international nuclear liability Joint Protocol[27] was adopted in 1988 which ensures that only one of the two conventions will apply in case of a nuclear incident. In addition, the Convention on Supplementary Compensation (CSC) further increases the amount of compensation should the national amount be insufficient to compensate the damage caused by a nuclear incident.[28]

Beyond international conventions setting minimum limits for compensation in case of nuclear damage most countries with commercial nuclear programmes also have their own legal basis for nuclear liability.

According to the report by the IAEA Director General to the 2019 General Conference,[29] the International Expert Group on Nuclear Liability (INLEX)[30] conclusion is that despite the wording in the Vienna Convention,[31] a transportable nuclear power plant in a fixed position (*i.e.* a floating reactor, anchored to seabed or shore, and attached to the shore by power lines) would fall under the definition of a 'nuclear installation' and therefore be covered by the nuclear liability regime; and in the case of relocation of a factory-fuelled reactor, the plant would also be covered by the nuclear liability conventions in the same way as any other transport of nuclear material.

As the nuclear liability regime mostly covers reimbursements to injured parties in case of nuclear accident, the principles of maritime insurance – which for centuries has played an essential role in mitigating risks of damage caused to ships and their cargo – should be explored for FNPPs, including any implications which may arise from the combined application of maritime insurance and the nuclear liability regime.

Global nuclear liability regime harmonization is a process which is constantly being developed. Ultimately, the establishment of a nuclear liability regime for a specific FNPP will be determined by the project model, FNPP route, and thus, states whose territories involve FNPP delivery and operation. In this connection, issues of liability for nuclear damage that may arise in connection with FNPP projects should be addressed through intergovernmental agreements between the states concerned.

[24] See paragraph 3.28 of Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, International Atomic Energy Agency (January 2011)

[25] Paris Convention on Third Party Liability in the Field of Nuclear Energy (adopted 29 July 1960; entered into force 1 April 1968); Brussels Convention Supplementary to the Paris Convention (adopted 31 January 1963; entered into force 4 December 1974). The combined Paris/Brussels regime provides for a minimum compensation amount of €1.5 billion.

[26] Vienna Convention on Civil Liability for Nuclear Damage (adopted 21 May 1963; entered into force 12 November 1977); Protocol to Amend the Vienna Convention (adopted 12 September 1997; entered into force 4 October 2003)

[27] Joint Protocol relating to the Application of the Vienna Convention and Paris Convention (adopted 21 September 1988; entered into force 27 April 1992)

[28] Convention on Supplementary Compensation for Nuclear Damage (adopted 12 September 1997; entered into force 15 April 2015)

[29] Nuclear and Radiation Safety, Report by the Director General, Doc. GOV/2019/27-GC(63)/4, page 28: L. Civil Liability for Nuclear Damage, International Atomic Energy Agency (17 July 2019)

[30] The International Expert Group on Nuclear Liability (INLEX) consists of experts from around the world with recognized competence in the field of civil liability for nuclear damage and related issues, including from countries with and without nuclear power reactors.

[31] According to the Vienna Convention, a "nuclear installation" refers to "any nuclear reactor other than one with which a means of sea or air transport is equipped for use as a source of power, whether for propulsion thereof or for any other purpose."

Conclusions

Floating nuclear power plants offer diversification of nuclear energy applications, especially when land-based options are not feasible, or the infrastructure required for a large nuclear power plant is not available. FNPPs have many advantages, such as: shorter deployment schedules; siting flexibility; electricity supply in remote areas; opportunities for series production; and centralized refuelling/outage activities.

Despite FNPPs being an innovative energy solution, relevant experience in regulation and operation of nuclear power plants and nuclear ships is available. Previous studies along with the existing experience of FNPP operation have shown that pilot international FNPP projects could be successfully deployed under the current regulatory framework. At the same time, the realization of widespread series deployment of international FNPPs would require the challenges discussed in this publication – particularly regarding safety, security, safeguards and liability – to be addressed.

Many challenges that FNPPs face are shared by nuclear-propelled merchant ships. Both the nuclear and maritime industries could cooperate with each other to resolve these challenges.

World Nuclear Association recommends that the following actions should be taken to facilitate the global deployment of FNPPs:

- Countries planning to develop and deploy FNPPs should examine their respective national rules for licensing and oversight of marine nuclear facilities. The key national nuclear and maritime safety regulators should provide clarity on readiness of the national legal frameworks for FNPP deployment, *e.g.* by identifying legislative gaps or overlaps that hinder FNPP projects and the next steps for harmonization of nuclear and maritime regulatory frameworks.
- Since FNPPs may change their location throughout their lifecycle, project stakeholders should address the applicability of international conventions and distribution of responsibilities regarding safety, security, safeguards and liability. This requires cooperation on FNPP-related matters between governments, nuclear safety authorities, maritime administrations, classification societies and other stakeholders.
- IMO member states could explore revising and extending the SOLAS Convention, in particular Chapter VIII (Nuclear Ships) to cover FNPPs.
- The technical standards and rules for the design, construction and survey of FNPPs' marine structures and systems need to be further developed. Classification societies should work together on the development of international class rules for FNPPs with the support of IACS.
- The IAEA and the IMO, together with national nuclear and marine regulators should refine existing guidance and collaborate to further develop relevant nuclear safety, security and safeguards requirements and standards.
- Project developers should cooperate with the IAEA and the IMO to identify best practices and frameworks that are applicable to FNPP projects.

World Nuclear Association
York House
23 Kingsway
London WC2B 6UJ
United Kingdom

+44 (0)20 7451 1520
www.world-nuclear.org
info@world-nuclear.org