

Enabling Nuclear-Powered Feeder Ships

| A Joint Development Project on Port Call Feasibility and Regulatory Pathways



Lloyd's Register

Lloyd's Register (LR) is a global professional services group specialising in marine and offshore engineering, technology and digital solutions. We were created more than 260 years ago as the world's first marine classification society to improve and set standards for the safety of ships.

Today we are a leading provider of classification and compliance services to the marine and offshore industries, helping our clients design, construct and operate their assets to accepted levels of safety and environmental compliance.

In the race to zero emissions, our research, advisory and technical expertise and industry-firsts are supporting a safe, sustainable maritime energy transition. Lloyd's Register Group is wholly owned by the Lloyd's Register Foundation, a politically and financially independent global charity that promotes safety and education. www.lr.org

Port of Rotterdam

The port of Rotterdam is a cornerstone of the Dutch and European transport and economic systems. In addition to the significant economic and social value the port holds in the Rotterdam-Rijnmond region, it also benefits the logistics sector and businesses that import and export in the rest of the Netherlands and Europe through employment, added value, revenue and business locations.

The Port of Rotterdam Authority's core tasks are the sustainable development, management and operation of the port and maintaining the smooth and safe handling of shipping. The aim of the Port of Rotterdam Authority is to strengthen the port's position as a logistics hub and future-proof industrial complex. In doing so, it's not size, but rather quality that takes precedence. The Port of Rotterdam Authority takes responsibility for the impact of the activities in the port on the climate and immediate surroundings. The health and safety of current and future generations are an integral consideration in our decision-making, including in our cooperations with businesses.

CORE POWER

CORE POWER is building the industrial platform to enable fleet-scale maritime nuclear infrastructure. As the leading OECD-based systems integrator, the company is partnering with selected reactor technology developers to turn advanced nuclear systems into deployable assets: floating nuclear power plants and nuclear-propelled vessels. These will be delivered through modularised production, nuclear-grade shipyard integration, and an end-to-end approach that aligns policy, regulation, insurance, and industrial capability.

Headquartered in London with offices in Washington, D.C., and Tokyo, CORE POWER brings together nuclear and marine engineering depth with regulatory, policy and industrial expertise. We are supported by strategic maritime shareholders and a fast-expanding network of shipyards, shipowners and operators, trading houses, banks, and energy companies.

A.P. Moller Maersk

A.P. Moller - Maersk (Maersk) is an integrated logistics company connecting and simplifying its customers' supply chains. As a global leader in logistics services, the company has 100,000+ customers, operates in about 130 countries, and employs 100,000+ people. Maersk delivers innovative, reliable ocean network solutions, offers truly integrated logistics products and operates advanced container terminals, both gateways and hubs, with 60+ locations globally.

Executive summary

This White Paper presents the results of a joint development project (JDP) examining the safety and regulatory considerations associated with a nuclear-powered feeder ship calling at an EU port. Although the study uses a defined port scenario to structure the assessment, the findings, conclusions and recommendations are framed to apply to any EU port that may expect to admit a civil nuclear ship. The work is intended to support ports, regulators, shipowners, technology developers and other stakeholders in understanding the steps required to move nuclear ships from conceptual acceptance to operational readiness.

The study demonstrates that the principal barriers to nuclear ship port calls are not technical, but relate instead to regulatory alignment, governance, risk management integration and public acceptance. These barriers can be addressed using risk-based port safety frameworks already familiar to EU ports, provided that nuclear-specific considerations are systematically incorporated and supported by appropriate national and international guidance.

Objectives

- Identify the safety and regulatory regimes that a nuclear ship would encounter during arrival, berthing, cargo operations and departure;
- Assess whether existing port safety frameworks, regulations and operational practices are sufficient to manage the presence of a nuclear ship;
- Identify gaps and barriers that may prevent entry by nuclear ships;
- Develop a Roadmap of Activities setting out recommended actions to address those barriers, including an indication of roles and responsibilities for the parties to whom this publication is directed; and
- Highlight areas requiring further study to support future regulatory development and port preparedness.

The overarching aim is to inform decision-making by EU ports and authorities, enabling early preparation rather than a reactive response once nuclear ships approach commercial deployment.

Approach and scope

The study adopts a risk-based port safety framework, aligned with internationally recognised port readiness methodologies, as the primary assessment tool. This approach reflects how ports make admission and permitting decisions on new fuels and technologies by identifying hazards, assessing risks, and implementing appropriate controls.

Rather than proposing a bespoke or nuclear-specific port regime, the study examines how nuclear propulsion can be integrated into existing safety themes, including governance, external safety, control zones, terminal readiness, nautical safety, mooring, bunkering, simultaneous operations, port safety operations, and emergency response. This yields results transferable across EU ports, regardless of local governance structures or terminal configurations.

To maintain focus, the assessment is based on a single nuclear-powered feeder ship scenario operating under normal conditions during a port call, with no nuclear incident occurring. This initial feasibility and regulatory-readiness study was not intended to be a full operational safety or security assessment, but rather to establish whether a nuclear ship could, in principle, be assessed within an EU port context and to identify the principal regulatory and governance gaps. The scope explicitly excludes nuclear refuelling, nuclear material handling, and security threats involving malicious actors, noting that these topics are identified as next-phase work requiring a more detailed design basis, operating concept and emergency-response framework.

Key findings

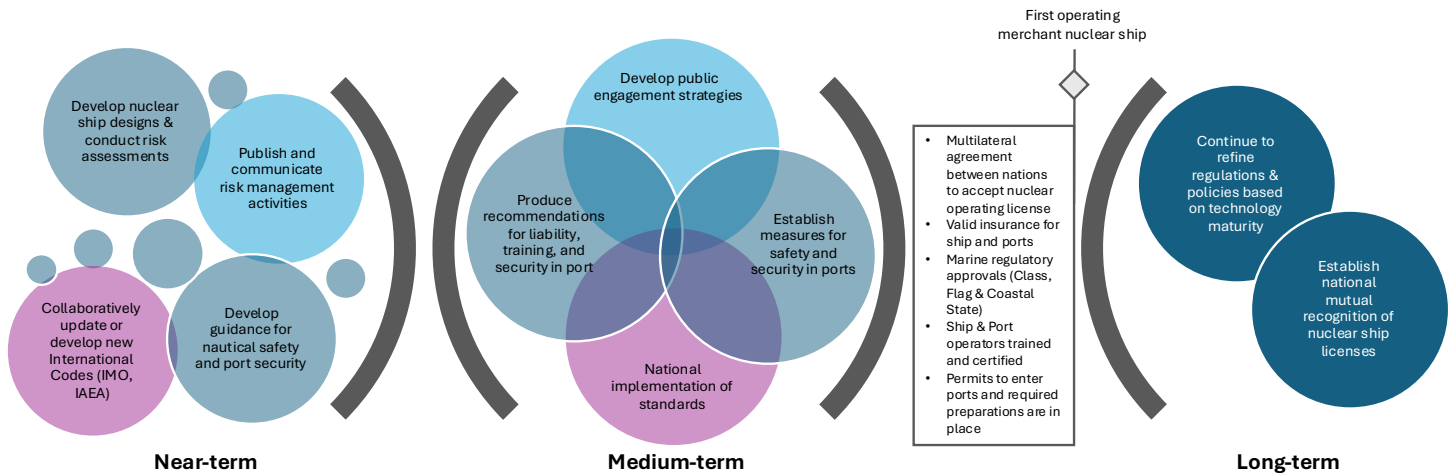
A central conclusion of the study is that the challenges identified are not port-specific. While individual ports differ in size, governance and operating environment, the same categories of barriers apply across the EU:

- Existing regulations rarely make explicit provision for nuclear ships other than military nuclear ships;
- Nuclear safety and maritime safety regimes exist in parallel, with limited integration; and
- Ports lack clear guidance on how to interpret nuclear licensing, insurance and liability for visiting ships.

Accordingly, the Roadmap and recommendations are framed as generic actions for EU ports and authorities, scalable to local circumstances. The assessment demonstrates that nuclear ships can be evaluated using the same safety themes and processes already applied to other high-risk maritime activities. Where gaps exist, they are typically due to a lack of guidance rather than technical incompatibilities.

Roadmap of Activities to address barriers

The principal output of this White Paper is the Roadmap of Activities to Overcome Barriers to Nuclear Ship Adoption. The Roadmap describes actions in the near-, medium-, and long-term, recognising that regulatory development, public acceptance, and technology maturation proceed on different timescales.



Near-term actions should begin immediately or within the next five years, focusing on building foundational resources.

- **Communication and public engagement.** Ports, supported by national authorities and industry, should initiate transparent communication on nuclear maritime technologies, risks and governance. Early engagement reduces uncertainty and enables informed discussion before commercial pressure arises.
- **Technology understanding and risk definition.** Shipowners and technology developers should advance ship designs and operational concepts to support port-level assessments. Ports cannot prepare without credible technical information.
- **Parallel regulatory development.** National authorities should begin developing regulatory approaches for nuclear ships in parallel with international efforts. EU ports cannot wait for future international instruments before preparing locally.
- **Use of existing safety methodologies.** Ports should explicitly apply their established safety frameworks to nuclear ship scenarios, identify any gaps in nuclear-specific guidance, and document them for regulatory follow-up.

Medium-term actions are required to enable first-of-a-kind nuclear ships to operate commercially. These activities depend on progress in technology definition and early regulatory alignment.

- **Guidance for nuclear ship operations in port.** Develop national and regional guidance for emergency response, berthing, terminal readiness and personnel training specific to nuclear ships;
- **Insurance frameworks.** Establish insurance and liability frameworks acceptable to Port States, shipowners and insurers, avoiding unlimited liability regimes incompatible with commercial shipping;
- **Training.** Update maritime training and certification regimes to include nuclear ship operations; and
- **Implement.** Formalise port governance arrangements to address nuclear ship admission, oversight and enforcement.

Long-term activities support standardisation and scale up, including:

- Harmonisation or mutual recognition of nuclear ship licences between states;
- Integration of nuclear provisions into international maritime design codes and classification rules; and
- Refinement of port safety practices based on operational experience.

Roles and responsibilities

The Roadmap makes clear that no single party can address the identified barriers alone. Key responsibilities include:

- **Ports and port authorities.** Apply existing safety frameworks to nuclear ships, define local admission criteria, coordinate emergency preparedness, and lead public engagement at the local level.
- **National nuclear and maritime regulators.** Develop coherent licensing, safety and liability frameworks for nuclear ships, aligned with port operations and Classification Rules and implemented through national legislation.
- **International organisations (IMO, IAEA, IAPH).** Update international codes, standards and guidance to reflect modern reactor technologies and commercial shipping realities, supporting consistent national implementation.
- **Shipowners and technology developers.** Provide transparent design, safety and operational information; support risk assessments; and engage constructively with ports, regulators and insurers.
- **Insurers.** Develop insurable risk models and liability structures suitable for nuclear ships and ports.

Contents

1.	Introduction.....	1
1.1	Objectives	1
1.2	Project scope	1
1.3	Content of this deliverable.....	1
1.4	Definitions and assumptions.....	2
1.4.1	Definitions.....	2
1.4.2	Acronyms	2
1.4.3	List of project assumptions.....	3
1.5	Scenario description	3
2.	Safety Framework Assessment	4
2.1	Safety themes	4
2.2	Assessment of Safety Themes	7
3.	Conclusion and Recommendations.....	7
3.1	General	7
3.2	Roadmap of activities to address barriers	7
3.2.1	Near-term	7
3.2.2	Medium-term	10
3.2.3	Long-term	11
3.3	Commentary on project assumptions.....	11
3.3.1	Nuclear license and other approvals to operate.....	12
3.3.2	Insurance and liability frameworks.....	12
3.3.3	Nuclear ship impacts on port safety strategies	12
3.4	Further areas of study	13
3.4.1	Nuclear incident in port.....	14
3.4.2	Managing nuclear technology in port.....	14
3.4.3	Security measures.....	14
3.5	Conclusion.....	15
3.6	References	15
Appendix A	Roadmap to overcome barriers	20

List of Figures

Figure 1: Passage from international waters to Eemhaven Short Sea terminal in Port of Rotterdam.....	4
Figure 2: Roadmap of actions to overcome barriers	7

List of Tables

Table 1 General definitions	2
Table 2 Acronyms.....	2
Table A-1 Roadmap of actions to overcome barriers to nuclear ship adoption	16

1. Introduction

1.1 Objectives

Lloyd's Register (LR), CORE POWER, A.P. Moller-Maersk and the Port of Rotterdam (Havenbedrijf Rotterdam N.V.) have undertaken a joint development project (JDP) on the safety and regulatory considerations of a nuclear-powered feeder ship calling at the Port of Rotterdam. The overall objectives were:

- Define a scenario of a high-level nuclear ship design performing a port stay at an EU port such as the Port of Rotterdam;
- To determine the conceptual safety considerations and regulatory regimes that the nuclear ship will encounter when performing a port stay;
- Identify potential gaps and barriers that prevent a nuclear ship from staying at an EU port;
- To propose a Roadmap of recommended actions to address these barriers; and
- To identify areas for further study, including:
 - a list of potential future updates to existing regulations/frameworks to allow a successful port stay in an EU port such as the Port of Rotterdam, and
 - a list of topics to be examined in more detail after the initial project term.

Outcomes of the collaborative study are intended to provide insights into nuclear ship operations in an EU port and advise the marine value chain on future fleet shipping strategies.

1.2 Project scope

The scenario followed a feeder containership and investigated the safety and regulatory aspects of the ship's arrival and normal cargo operations at the Port of Rotterdam, assuming nuclear power is used for primary propulsion.

To investigate the safety and regulatory regimes that a nuclear ship might encounter when performing a port stay, safety themes of the Rotterdam Harbour Master's safety framework were considered. The assessment reviewed aspects of the safety framework for evaluating ship safety in ports and identified current barriers that may prevent a nuclear ship from visiting. A roadmap to address the barriers was developed, with near-term, medium-term and long-term activities.

The context of the assessment is based on a series of assumptions about the ship's safety. The project assumed that the nuclear ship would have a nuclear operating licence from an established nuclear regulator and a classification certification from LR, collectively assuring that the ship could operate safely without undue risk to the crew or the public. This also assumes the ship has appropriate insurance coverage. These assumptions, while foundational to the safety assessment, are revisited later to review their validity and inform further areas of study.

No planned nuclear material handling, nuclear refuelling, or service to the nuclear island was considered. Hazardous situations involving radiation exposure or security attacks were not considered. Conventional bunkering of diesel fuel for backup systems and the connection of the nuclear ship to shore power (or the delivery of electricity from the nuclear ship to shore) were also outside this scope of work.

The development of a detailed ship design is excluded from this scope, including the assessment of radiation control areas (which may be required for monitoring, safeguarding, or maintenance), nuclear maintenance and refuelling activities. Security incidents or events involving bad actors operating against the nuclear ship were excluded from the scope of work. This includes the complete evaluation of current or existing regulations or guidance for the security of nuclear facilities.

The safety and regulatory assessment of the nuclear ship visiting any other terminal within the Port of Rotterdam, or visiting any port other than the Port of Rotterdam, was not considered.

1.3 Content of this deliverable

This report summarises the results of the assessment according to the scope. The project assumptions are first described to establish the context. Then, the scenario is described in more detail.

Section 2 includes information on the safety assessment using the Rotterdam Harbour Master's safety framework. Even though national regulatory regimes in the EU may differ between countries, the safety framework is used in this project as a representative of the typical approach of EU ports for evaluating the safety of new technologies. The safety regimes currently

used to evaluate the safety of ships in port are described, including typical regulations, industry guidance, and regional or national legislation.

From experience with the Port of Rotterdam Harbour Master’s safety framework, and seeing the process applied to a nuclear ship, the project team described current practices and the desired outcomes that would be suitable for evaluating the safety of a nuclear ship in port. This clearly revealed gaps in safety, regulations, industry guidance, legislation or operational procedures that should be addressed to achieve those desired outcomes.

Based on the team’s expertise and understanding of safety, regulations, and the developmental process for international and national regulations, a list of recommendations was produced as a roadmap, including suggestions on the responsible parties or roles.

Section 3 provides conclusive remarks for this work, including expanding upon recommended further areas of study. First, the roadmap of recommendations to address barriers is presented, as the key results of the safety framework assessment. Second, additional recommendations were derived based on the review and commentary on the validity of the assumptions used in the original context of this study.

Finally, the extent of the scope of work is reviewed, and the remaining recommendations consider topics not addressed in this scope of work, including technical, insurance/liability, and security issues.

1.4 Definitions and assumptions

1.4.1 Definitions

Table 1 General definitions

Term	Definition
Feeder ship	A feeder ship is a small or medium-sized container ship that transports shipping containers between smaller ports and larger ports, container terminals or transshipment hubs.
Nuclear island	Encompasses all nuclear systems, the primary containment, the reactor control room or rooms and nuclear emergency power systems. The nuclear island is the ultimate radiation boundary, encompassing all radiation-controlled areas. Note that the reactor control room is assumed to be physically and functionally separate from other control rooms on the ship.
Nuclear ship	A merchant ship operating primarily by nuclear power. The physical boundary of the nuclear ship encompasses all systems necessary to meet operational objectives, including emergency power sources required for safety functions.
Port call	A scheduled, intermediate stop on a ship’s itinerary to load or unload cargo. A ship may have multiple terminal calls during a single port call.
Primary containment	Encompasses the reactor systems and all very high radiation areas, including any onboard spent fuel and waste storage areas.

1.4.2 Acronyms

Table 2 Acronyms

Acronym	Term	Acronym	Term
ANVS	Autoriteit Nucleaire Veiligheid en Stralingsbescherming (Netherlands)	ISPS	International Ship and Port Facility Security Code
ATLAS	Atomic Technologies Licensed for Application at Sea	ISM	International Safety Management Code (IMO)
EPZ	Emergency planning zone	LR	Lloyd’s Register
EU	European Union	MWe	Megawatt electric
EURATOM	European Atomic Energy Community	NGO	Non-governmental organization
IAEA	International Atomic Energy Agency	NRC	Nuclear Regulatory Commission (United States)
IAPH	International Association of Ports and Harbours	SIMOPS	Simultaneous operations
IMDG	International Maritime Dangerous Goods Code	SMS	Safety Management System

Acronym	Term	Acronym	Term
IMO	International Maritime Organization	SOLAS	International Convention for the Safety of Life at Sea
INF	International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Waste	US	United States

1.4.3 List of project assumptions

Assumptions related to the scenario, including the nuclear ship port visit and manoeuvring in port, are as follows:

1. The nuclear ship carries a valid license to operate from the US Nuclear Regulatory Commission (NRC).
2. The local national nuclear regulator with jurisdiction in the port (e.g., in the Netherlands, the Autoriteit Nucleaire Veiligheid en Stralingsbescherming (ANVS)) accepts the US NRC license to operate as the basis for allowing the ship to enter the port, subject to any additional approval activities required by ANVS.
3. The nuclear ship is flagged by the US.
4. The nuclear ship operates in compliance with a regulatory regime comprising the Flag State, port states, and coastal state¹ jurisdictions.
5. The nuclear ship carries a valid Classification Certificate from LR.
6. A permit for the nuclear ship to operate in the port is available from the Port of Rotterdam.
7. The nuclear ship enters Rotterdam's Eemhaven Short Sea terminal for cargo operations (a few kilometres from the city centre).
8. Manoeuvring in port is conducted entirely on nuclear power (normal power operation).
9. The nuclear ship is designed and operates such that it achieves operational safety and independent manoeuvrability at least equivalent to a conventionally powered ship of the same size. It operates in such a way that the *following activities are not required* during the port visit:
 - a. refuelling of nuclear fuel
 - b. maintenance work that can affect nuclear safety
 - c. disposal of nuclear waste
 - d. emergency response related to a nuclear incident on the ship itself (i.e., no anticipated operational occurrences of the reactor)
 - e. bunkering of conventional fuel for other systems (e.g., diesel)
 - f. power to shore or shore power supply to the ship.

It is understood that the nuclear licensing process requires multiple phases of evidence-based safety analysis. The assumption of a nuclear operating license in this scenario provides assurance that, in normal operating conditions, the dose rate to crew on board and the dose rate beyond the ship boundary remains well below established radiation limits for the public, where EU nations implement the International Commission on Radiological Protection (ICRP) limits through EURATOM legislation. This can be independently verified by radiation measurements at the port.

Additionally, it is worth noting that the assumption of a nuclear ship license to operate implies sufficient assurance that, in the event of incidents related to connected systems, radionuclide containment, reactor cooling and reactivity control are maintained. Thus, it is assumed that no incident occurs at the port that would result in unacceptable radiation exposure.

1.5 Scenario description

A 3,600-TEU² container feeder ship of the Maersk Winter Palace Class (Maersk V-Class) was selected as the baseline concept. The ship is fitted with approximately 16 MWe of total power, with about 12 MWe allocated to propulsion and the remaining power to hotel loads.

The preliminary design of the nuclear ship features a single nuclear reactor installed in the same area as the original prime mover, supported by two main diesel generators to meet the full onboard power demand. The ship can be assumed to have power systems that are resistant to common-cause failures, or at least remain partially functional in the event of a major failure in the power generation or distribution systems, including failures caused by human error.

¹ The UN Convention on the Law of the Sea (UNCLOS) addresses innocent passage of nuclear ships.

² Twenty-foot equivalent unit (TEU) is a common measure containership capacity.

This scenario investigates a port call at the short-sea terminal at Eemhaven Harbour, shown in Figure 1.

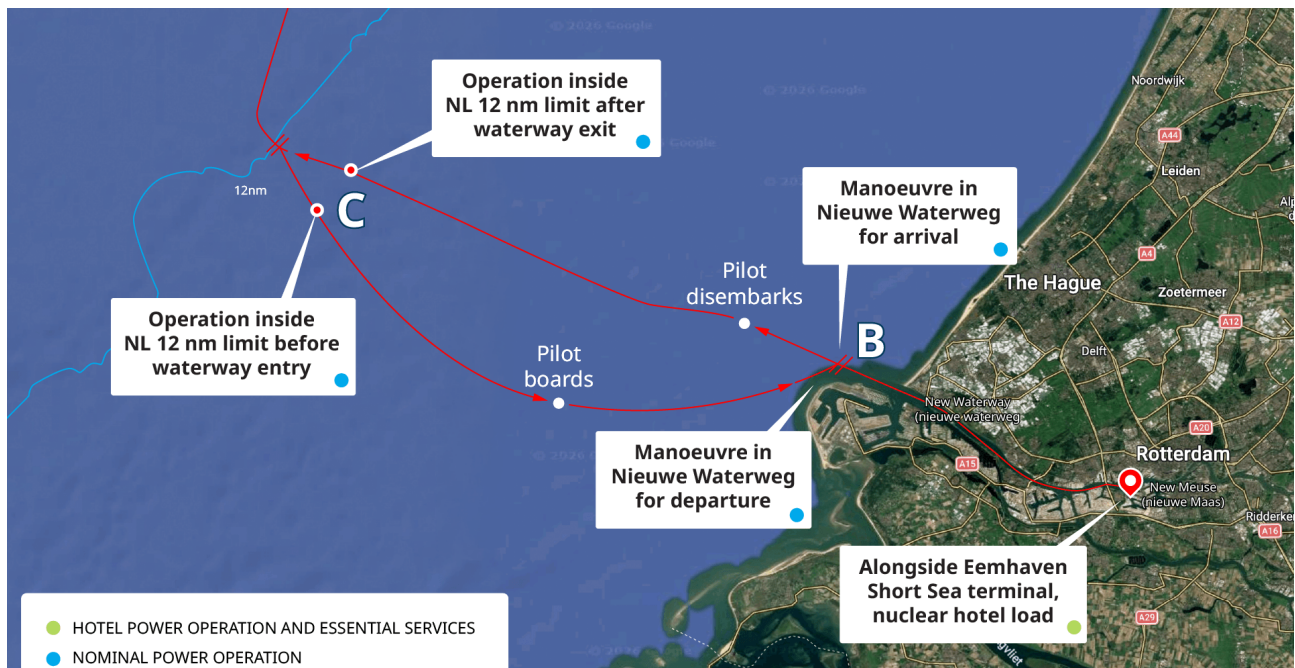


Figure 1: Passage from international waters to Eemhaven Short Sea terminal in Port of Rotterdam

In addition to the above description, the reactor system meets the following operational assumptions, for this study and in accordance with the scenario assumptions described in Subsection 1.4.3.

1. The reactor and its power conversion system have sufficient load following capabilities to meet the operational demands of the ship.
2. The reactor design minimises the need for operators and moving components that require inspection, maintenance and replacement, to meet the availability demands of the ship and the expectation that no maintenance on the nuclear systems is done during the port visit.
3. The reactor design minimises the frequency of refuelling to meet the availability demands of the ship and the expectation that no nuclear fuel handling or refuelling is done during the port visit.
4. Radiation areas are provided onboard to limit the risk of exposure to the crew and public³.
5. The nuclear reactor is assumed to have an emergency planning zone (EPZ) within the boundaries of the ship.

2. Safety Framework Assessment

2.1 Safety themes

The framework of this assessment is based on the existing safety framework of the Rotterdam Harbour Master, developed specifically by the Port of Rotterdam according to the International Association of Ports and Harbors (IAPH) Port Readiness Level for Marine Fuels (PRL-MF) assessment tool for Bunker Ports (IAPH, 2024). This safety framework provides nine levels indicating how far a port has progressed in preparing for new (high-risk) marine fuels and technologies.

The framework progresses through a series of safety considerations for visiting ships. For each activity listed, both safety⁴ and regulatory considerations are provided.

- **Governance.** This refers to the entire set of structures, processes and agreements that govern how a port is managed and administered. It encompasses how public and private entities, such as port authorities, governments, companies, regulators, and municipal organisations, collaborate, make decisions, and allocate responsibilities to ensure the port operates efficiently, safely, and sustainably. Governance is typically achieved through regional safety area

³ Radiation safety areas are precautionary zones onboard, but could indicate that radiation may be present during an incident and for which safety measures may be required.

⁴ Note on interpretation of safety, although external safety is excluded, where the focus is primarily on hazardous substances.

- Safety refers to both physical and cyber (digital) safety, unless explicitly stated otherwise.
- When safety falls under the authority of the Harbour Master, this includes cybersecurity aspects.

designations, local legislation (e.g. by-laws, policies, and decrees), and the implementation of international Codes for ship safety. National legislation related to nuclear energy and the management of nuclear material is implemented locally, including the establishment and practice of emergency response procedures.

- *External safety.* This refers to the management of risks to people, the environment and infrastructure arising from activities involving dangerous goods. This includes the production, transportation, storage and transshipment of dangerous goods. With the rise of alternative fuels (including nuclear energy), external safety is becoming increasingly important in the maritime sector. In complex, dynamic environments such as ports, it is essential to thoroughly assess and manage risks to protect everyone in and around the port area (first-, second-, and third-party individuals). Policy frameworks and risk management tools, such as individual and group risk assessments, are central to this process. Advice on safety distances and other requirements of activity in proximity to nuclear reactors should be available from national nuclear regulators.
- *Control zones.* Within the Port of Rotterdam, 'control zones' (safety zones) are designated areas where additional measures are in place to ensure the safety of the surrounding area. These are also the areas where the Harbour Master has safety, environmental and security supervision. Distances are determined through risk analyses and nautical traffic conditions, in accordance with national regulations. This can also refer to control zones within ships, such as the Hazardous Zone (defined in the ship's Safety Management System (SMS)), the Safety Zone, and the Marine Exclusion Zone. These zones help manage risks and are incorporated into inspections and permitting procedures to ensure alignment between shore and ship safety protocols. Local laws or permits typically establish safety zones, following the guidance from international maritime cargo regulations such as the International Maritime Dangerous Goods (IMDG) Code.
- *Terminal readiness.* The energy transition requires terminals to be physically and operationally prepared for ships using alternative fuels. Each fuel type presents specific risks related to safety, environment and operations. Terminal readiness means that a terminal is technically, organisationally, and operationally capable of safely receiving and handling these ships. The International Ship and Port Facility Security (ISPS) Code requires that risks associated with ships visiting port be categorised and addressed, and that other local requirements or guidelines for environmental protection or the use of alternative fuels be used to establish the criteria for safe operations. National nuclear regulators are commonly involved in local activities related to nuclear energy or the handling of nuclear materials.
- *Nautical safety.* This refers to the full range of measures, supervision, and coordination required to ensure the safe passage, arrival, berthing, and departure of ships. This includes the physical safety of ships, infrastructure and the continuity of port operations. Safety is ensured through traffic guidance, enforcement, incident management, risk assessments and collaboration between services and regulators. Locations with elevated risks of collisions or incidents are identified and monitored as critical port areas, characterised by busy traffic junctions or intersections, limited manoeuvring space, complex current or wind patterns and the presence of specific ship types, cargo or hazardous material. Nautical safety is generally achieved through a combination of measures and regulations. This includes the use of vessel traffic services (VTS) and automatic identification systems (AIS) for ships, as well as the application of traffic rules on the water. National or regional legislation implements IMO codes of ship operations such as the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS), the International Convention for the Safety of Life at Sea (SOLAS), the International Safety Management (ISM) Code, and the International Code of Signals. Police regulations and local zoning laws are used for enforcement. Nautical safety is not only an operational responsibility but also a strategic foundation for the entire port. Demonstrating competence in nautical safety builds trust among shipping companies, terminals and governments and is a prerequisite for innovation and sustainability in the maritime sector.
- *Safety of other (involved) ships.* Risks to nearby ships and individuals are considered when developing the safety system for ships that may pose additional hazards to nearby activities. During the handling of these ships, active measures are taken to ensure the safety of all involved parties, including nearby bunker ships, waste collectors, supply ships, pilots, terminals, and emergency services. In some cases, it may be necessary for other individuals to board the ship, for example, for supervision, service delivery, or emergency assistance to manage hazards external to the ship itself. For specific hazardous cargoes on board vessels and in ports, national procedures should be in place. In addition, international security requirements apply pursuant to the ISPS Code. Nuclear material should be managed according to the IAEA Convention on the Physical Protection of Nuclear Material and Nuclear Facilities (CPPNM) through statutory legislation.
- *Safe mooring.* Although mooring of all types of ships may appear routine, it requires a high level of coordination, expertise and safety awareness. A wide range of factors is considered in mooring safety, including the ship type (manoeuvrability), cargo, weather conditions, currents, the condition of the berthing facilities and the presence of

other ships nearby. Incidents during berthing, such as mooring line failures or quayside damage, can have serious consequences. Mooring is one of the largest contributors to personal injury in the marine industry and a major contributor to asset damage. Therefore, strict procedures, guidelines and supervision mechanisms are established. Mooring is included in the ISM Code requirements for a Safety Management System (SMS), and other international guidelines on mooring safety are available from various forums. Port by-laws and specific policies for mooring ships are established and enforced by ports, including the potential use of tugboats, pilots, or patrol vessels.

- *Bunker safety.* The supply of fuel or alternative energy carriers to ships involves specific safety risks for both the ship and its port surroundings. Depending on the type of fuel or energy carrier to be bunkered, specific requirements are imposed to ensure that the bunkering process is safe for the surrounding environment. Bunkering safety is therefore an integral part of a broader nautical safety policy and requires close cooperation among ships, terminals, bunker suppliers and regulatory authorities. Bunkering is also addressed in the ISM Code as a shipboard operation that involves inherent risks and therefore must be assessed and managed within the vessel's SMS. International guidance on safe bunkering is available from various forums. National laws and port policies implement national requirements and guidance, providing more specific requirements according to the port or the specific hazards present. Permits and associated audits are typically required for certain activities in port, including bunkering.

In this scenario, nuclear refuelling and bunkering conventional fuels were not considered; however, regulations and safety related to bunkering conventional or alternative marine fuels for the supporting engines of nuclear ships should still be included in the safety framework, as if bunkering were required, as this is more likely to occur in the Port of Rotterdam than nuclear refuelling.

- *SIMOPS safety.* Simultaneous operations (SIMOPS) may include bunkering fuel while cargo is being loaded or unloaded, waste collection during maintenance or pilots boarding during other ongoing tasks. While these activities can be efficient, overlapping operations pose increased safety risks that are managed by imposing strict conditions for conducting SIMOPS. Through notification procedures, risk assessments and the establishment of temporary safety zones, safe and controlled execution can be ensured. SIMOPS require close coordination between all involved parties and are a key focus within the port's broader safety policy. The ISM Code and SMS require the assessment of risks during SIMOPS, and guidance is available for considering specific risks associated with dangerous goods. Port by-laws and national legislation implement international requirements.
- *Port safety operations.* This concerns the safe execution of all activities conducted around a ship while it is in port, including mooring, cargo handling, bunkering, waste collection, maintenance and crew changes. Through supervision, regulation and collaboration with terminals and service providers, a controlled and safe execution of all operations can be ensured. Port safety operations are therefore an essential component of a port's broader nautical safety policy. Port safety is indirectly addressed through shipboard SMS under the ISM Code, insofar as it relates to ship-shore interactions, but otherwise not specifically provided for in international mechanisms. A single international convention does not govern port safety; instead, it relies on a combination of national legislation, local port bylaws, and operational standards applied by terminals and service providers. Regional regulations (e.g., EU Fit-for-55 and FuelEU Maritime Regulations) set specific requirements, and states implement legislation to address safety in ports, including the handling of dangerous goods, pollution prevention, and labour laws for ships and ports.
- *Risk resilience and emergency response.* Incident response for ships is carefully organised through collaboration between national, regional and local authorities. Responders are equipped for both physical and cyber incidents. Cybersecurity is increasingly critical to protecting maritime port operations and the broader logistics network. The responsible parties for incident response depend on the incident location and the nature of the issue. Incident management in and around the port is based on existing international, national and local frameworks. The practice focuses on identifying risks, establishing emergency procedures and organising stakeholder cooperation. The emphasis is on minimising harm to people, the environment and infrastructure.

At the national level within the EU, guidelines and procedures exist for responding to nuclear incidents based on the IAEA Emergency Preparedness and Response (EPR) Framework. However, these frameworks are primarily focused on land-based incidents, such as those involving nuclear power plants or the transport of radioactive materials. When it comes to nuclear ships, these tools offer only limited coverage. Where such ships are mentioned, the content primarily concerns military ships.

Response to emergencies, whether in port or specific to nuclear incidents, is provided for in national policy and implemented locally within identified safety regions and by responsible parties. Different levels of response should be provided for specific types or categories of events.

2.2 Assessment of Safety Themes

The assessment of a nuclear ship within the safety framework shows that, while some regulatory and safety provisions may exist for either nuclear or marine aspects, a common gap is that existing IMO provisions for nuclear ships are largely based on outdated technologies and operational concepts, and therefore do not fully address contemporary nuclear vessel designs and use cases. In this case, the safety framework for the nuclear ship corresponds to the stage in which the required framework has been designed ('framework designed').

The assessment is summarised in the following section. Considerations for nuclear ships must be integrated into the port safety framework if the port is to welcome a nuclear ship in the future.

3. Conclusion and Recommendations

3.1 General

This section summarises the results of the safety framework assessment considering the nuclear ship scenario. First, a roadmap is presented outlining recommended activities to address barriers to the adoption and acceptance of nuclear ships in port. Second, the project assumptions are revisited, with discussions of their credibility and recommendations for future refinement. Finally, additional areas of study are presented, considering the scope of this work and the recommended expanded scope for future work.

3.2 Roadmap of activities to address barriers

Based on the assessments of the safety themes, barriers to the adoption and acceptance of nuclear ships entering ports have emerged. These barriers are identified and described in Appendix A, along with commentary on which barriers should be addressed in the near term or in the medium- to long-term. Figure 2 summarises the roadmap of activities, indicating that near-term activities should begin immediately, medium-term activities must be completed before the first operating merchant nuclear ship is commissioned, and long-term activities focus on continued refinement and development of international regulations based on greater experience with the technology.

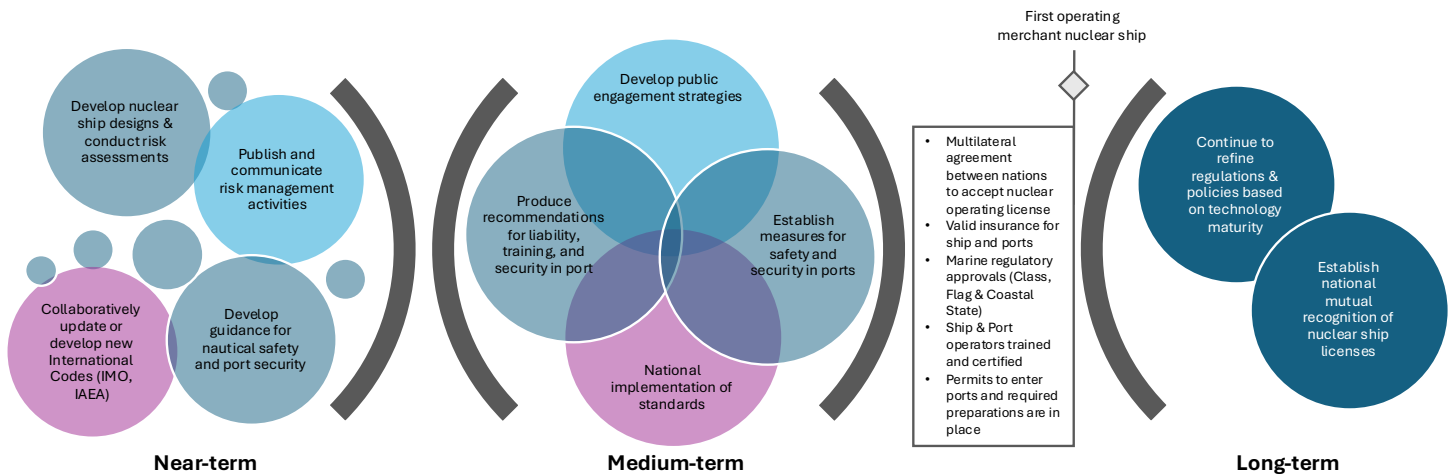


Figure 2: Roadmap of actions to overcome barriers

3.2.1 Near-term

Immediate and near-term actions to address key barriers for nuclear ships visiting an EU port are summarised below. 'Near-term' implies that, if the work hasn't already started, it should begin within the next five years. Some near-term activity is preliminary or foundational to subsequent work, and therefore must occur first, while other activity should begin early due to the expected length of completion. For example, international code development or updates could take 10 years or more to be adopted or implemented after the original mandate, and therefore must be initiated in the near term.

3.2.1.1 Communication and public engagement

Although this project did not fully address issues and approaches related to public perception of nuclear power, addressing barriers related to public perception should be prioritised, since progress can start locally and independently from technology and regulatory developments. For instance, press, publications and research can initiate conversations and disseminate basic facts about nuclear technologies. Early communication makes it easier to address other barriers, especially regulatory, liability and legal gaps.

Communication experts should be involved when engaging the public with proposed technology solutions, as the messaging may need to be tailored depending on the audience to reach a consensus.

3.2.1.2 Near-term technology development

Technology development should be considered foundational to subsequent work and should continue to be pursued in the near-term because developing national and local regulations requires a strong understanding of the technology, its operation and risk management strategies.

Project teams should look to continue research on technology development and refine the risk profile of operating nuclear technology. In general, mature and complete ship designs and operational profiles enable more comprehensive risk assessments that can examine more nodes, situations, and incidents, and explore the design in greater detail.

Risk assessments and an integrated safety case are prerequisites for nuclear ship construction, licensing and ship certification processes. Site characteristics are comprehensively considered in terrestrial nuclear plant safety assessments. For nuclear ships, it is envisaged that these assessments would also include considerations of ship operations, such as interfacing with port operations, including normal cargo operations or supplying power to shore from the operating reactor onboard. Port-specific hazards and environmental standards may be present that need to be considered in nuclear ship design and risk management activities, for example, temperature restrictions on cooling water discharge⁵.

When published and shared, mature designs and associated risk assessments inform updates to existing regulations and the development of new regulations, legislation, insurance frameworks, and other policies.

3.2.1.3 Near-term regulatory development

This initial feasibility and regulatory-readiness study established whether a nuclear-powered vessel could, in principle, be assessed within an EU port context and identified the principal regulatory and governance gaps. If that baseline finding had been negative, more detailed work on security, emergency response, or hostile-actor scenarios would not have been meaningful. This project emphasised that security and malicious-threat scenarios were not dismissed; rather, they were identified as next-phase work requiring a more detailed design basis, operating concept and emergency-response framework.

Regulatory developments should prioritise those areas that have not yet made significant progress. Although these topics were not considered within the scope of this JDP, the project team foresees the major regulatory barriers that should be addressed in the near term include:

- Port-specific security measures,
- IAEA guidance on the safety, security and safeguards of nuclear ships, and
- Design and regulatory guidance on nuclear materials handling.

3.2.1.4 International regulatory development

Ongoing development of the Code of Safety for Nuclear Merchant Ships (Resolution A.491(XII)) (the Nuclear Code) will require continued work and collaboration, as the process may take over 10 years before an updated code is adopted. Since this Code is under IMO review, activities to develop complementary guidance on security and safeguards should be initiated in parallel to support the update of the Nuclear Code.

⁵ In the Netherlands, legal temperature limits apply to discharged cooling water. Industrial installations typically operate between 25°C and 35°C, and ecological guidelines state that surface water may not be heated more than 3°C above ambient temperature, measured over a specific period and within a defined mixing zone. This is applied at the Borssele nuclear power plant on the Dutch southern coast.

International support should be provided to the IAEA's Atomic Technologies Licensed for Application at Sea (ATLAS) program⁶ and to any other international collaborative efforts between maritime and nuclear states to align guidelines, standards, legislation and regulations for nuclear ships.

It should be noted that national and international regulatory development should occur in parallel. While both are mutually informed, neither can wait for the other to complete.

International regulations are implemented in the EU through various national mechanisms of adoption and legislation. Therefore, if Regulations specific to nuclear ship safety and security in ports are updated or developed within existing international Codes or Conventions, only minor changes to national statutes may be needed to incorporate them, subject to delays due to normal processes for updating and implementing statutory changes.

3.2.1.5 Regional and national regulatory development

Conversely, national regulations can be developed without guidance from international Codes or Regulations, and this is likely what will be needed by those regions expecting to first adopt nuclear merchant shipping. Given the current industry demand and rate of technological progress, these nations cannot afford to wait for international regulatory development or harmonisation. Once national regulations and policies are developed, they should directly inform the international development of standards and guidance.

Countries in which nuclear in maritime could play a role should develop integrated safety management systems that function for each ship and port area. Ideally, this system should coherently align governance, safety, and infrastructure with both national and international laws and regulations, where available. This means that nautical safety and port-specific operations must also be integrated so that established procedures, responsibilities and operational frameworks are clear to all parties involved, including port companies, regulators and emergency services.

Risk assessments and risk management activities are central to local policy and permitting, including the admission of a ship, the allocation of berths, port operations and emergency procedures. When updating emergency protocols in port, a range of activities on or near the ship should be considered. Additional hazards associated with the presence of an operating reactor should be addressed in port safety operations. These assessments should pay special attention to port-specific conditions, and it is essential to recognise that not all individuals can be easily reached or evacuated, for example, crane operators, crew members of ships moored alongside, or personnel at large terminals. These factors can influence the effectiveness of emergency procedures and may require tailored safety measures.

By bringing these safety considerations into national integrated frameworks in the near term, countries can prepare for the safe and responsible introduction of nuclear ships into their ports, with attention to safety, transparency, and international cooperation.

Existing incident response systems tailored to conventional maritime risks are not specifically designed for incidents involving (commercial) nuclear ships. To maintain the efficiency of the port response system, it will be essential to evaluate existing capabilities and to address gaps needed to prepare for the safe entry and operation of these future ships.

EU Ports are currently gaining valuable experience with alternative energy carriers such as ammonia and hydrogen, and governance structures are being developed around safety, licensing, permitting and collaboration. The safety frameworks used to evaluate the safety of alternative fuels in port can also guide the application of nuclear power. If gaps are identified, additional collaboration may be justified to align alternative energy provisions with nuclear technologies. These experiences provide valuable insights into how to develop a robust, widely supported integrated management system (governance, safety, and infrastructure) that also complies with future laws and regulations for nuclear ships.

Near-term research should investigate whether updates to existing traffic rules are required. Mature ship designs and operational profiles, current traffic patterns, collision studies and safety analyses should inform this research. An internationally accepted methodology for a collision study can serve as a basis for national studies. The outcomes of these studies can guide whether specific routing, speed restrictions or escort measures are needed at the national and local levels. Such research can inform the designation of safety distances (permanent and temporary) around the nuclear ship in port, as well as necessary measures to protect others in the vicinity.

⁶ March 2025 LR Horizons Article [Framing the future of maritime nuclear technology](#). "The ATLAS project is a significant step towards creating an international regulatory framework for maritime nuclear applications."

To assess the impact of nuclear ships on traffic patterns, simulations and scenario studies are needed. Near-term research should map worst-case scenarios and interactions with other ships, including incidents, evacuation needs and disruptions to regular traffic flows. These types of studies are, in principle, possible when the ship design is clearly defined and can inform whether adjustments to regional (EU), national, and local nautical safety regulations are necessary. Additional measures to enhance nautical safety may include mandatory deployment of pilots and tugboats in busy or complex navigation areas, as well as technological support such as real-time traffic monitoring, automatic warning systems, enhanced safety protocols and supervision.

3.2.2 Medium-term

Near and medium-term actions are those needed to overcome barriers to successfully commission and operate a nuclear ship and enter ports along its intended route.

Medium-term actions are considered tasks that sequentially follow near-term activities. They may depend on the initiation or completion of near-term activities, or may also be considered tasks that can be completed in less time and therefore could start later.

The development of research and guidelines should occur early in the medium-term, and establishing or adopting measures into legal frameworks or regional procedures should occur later in the medium-term phase.

National regulations will likely be needed first, if international guidance or Regulations are not available. For example, bilateral agreements can be established to approve a nuclear (or 'pink') corridor between two nations' ports, thereby aligning expectations among national nuclear regulators, flag administrations, and insurers.

3.2.2.1 Communication

Activities related to addressing public perception should continue in the medium-term. To gain public consensus on where the proposed technology will operate, public engagement is essential, using specific strategies and targeted campaigns. Communication and public engagement activities should ensure transparency regarding the various Roadmap activities. Whenever engaging with the public, it is recommended to include communication and public relations experts to manage messaging.

3.2.2.2 Medium-term technology development and integration

As nuclear ship designs mature over time, they should continue to inform port safety assessments and relevant regulations. Even after technology is first demonstrated, more experience with it or similar technologies will inform safety response measures and emergency planning for nuclear ship operations near shore and within ports.

Standardisation of technology can help meet medium and long-term objectives of establishing an achievable regulatory regime in the international and domestic communities. When design and construction codes and standards begin prescribing technical solutions based on operating experience, it becomes easier for port safety regimes to predict ship specifications and prepare to manage risks in port.

3.2.2.3 Medium-term regulatory development

Other medium-priority activities are related to developing national and international guidance and regulations for nuclear ships, but depend on the maturation of the technology and ship design. These include developing and establishing international and national guidance for, among other things, emergency response, berthing, port-related safety aspects, operational procedures in port, and training of ship and port personnel to handle normal and emergency operations. Therefore, they must occur after near-term activities provide specific inputs for integrated nuclear ship design and operating profiles.

Regulatory development also includes research and development of appropriate liability frameworks and established insurance frameworks for nuclear ships and activity in ports. However, because specific aspects of insurance depend on a clear understanding of the technical and operational risks associated with nuclear ships, this activity should proceed once a sufficiently high technology readiness level is achieved. In the medium term, proposed liability and insurance frameworks can be established and adopted once an agreement is reached among relevant stakeholders.

3.2.3 Long-term

Following first-of-a-kind nuclear ship demonstrations, long-term activities should continue to develop international guidance and regulations that could assist with scaled-up implementation according to mutual recognition schemes and standard nuclear ship design approaches. Long-term actions build on operational experience and the refinement of prescriptive requirements informed by industry recommendations.

3.2.3.1 Long-term technology development and operating experience

Continued development and adoption of nuclear technology beyond first-of-a-kind maritime deployment is recommended to expand the understanding of various types or arrangements, and include lessons learned from various designs in regulatory development and refinement. Scaling up technology deployment also directly impacts the demand and capacity of training programs to provide for appropriate pipelines of certified crew, operators, or emergency responders, for example.

As lessons are gathered related to the use of nuclear technology for ships, designers tend to avoid novel solutions after safe and economic deployment can be demonstrated. This results in the standardisation of technology within certain applications, which helps to stabilise supply chains and establish standard procedures for safety, security and emergency response.

Successful first movers are useful to demonstrate appropriate practices, which are then adopted by fast followers, including provisions for insurance and establishing limited liability for appropriate stakeholders.

3.2.3.2 Long-term regulatory development

Long-term focus areas of regulatory development are related to activities necessary to achieve standardisation in design and regulatory efficiencies through harmonisation or mutual recognition schemes.

Ideally, future nuclear ships will be able to acquire a license to operate from one national nuclear regulator, and another nation's national nuclear regulator will recognise that license as sufficient evidence of safe operations within their jurisdiction.

These approaches can also allow for nuclear ships to acquire operating licenses or port permits in less time, or receive approval to enter a new port without major impacts to business. Mutual recognition schemes would, in theory, allow nuclear ships to visit more destinations. It is unlikely that mutual recognition among more than two or three countries can be achieved in the near term. Still, it could serve as a targeted vision for international regulatory development applicable to nuclear ships in the distant future.

Long-term activities should specifically look to integrate additional nuclear provisions and oversight into modern maritime frameworks suitable for international shipping assurance and Classification. When developing requirements for nuclear ship design, considering the need for uniformity in areas such as the reactor compartment and ship structure could be helpful to designers, shipyards, and port destinations. Uniformity enhances predictability, improving safety in ports by making emergency services, inspectors and operators familiar with expectations, thereby simplifying risk management. It also supports the deployment of pilots and tugboats. Predictability is essential for safe and reliable operations.

While uniformity of design will support risk management in port, design guidance and standards should still allow for different types of reactors and power arrangements onboard by starting with IMO goal-based standards. Classification Societies should support studies and work related to the Classification Rules for nuclear ships as experience grows in designing and operating nuclear technology for ships, including the IMO update to the 1981 Nuclear Ships Code, by including specific, prescriptive guidance on the design and surveys of nuclear ships to support uniformity in design in the long term.

3.3 Commentary on project assumptions

The context of this project was founded on a set of assumptions that ensured ship safety while in port. While this approach simplified the assessment of the safety framework, it may also inadvertently overlook the practical challenges that nuclear ships face when entering ports. This section provides a review and commentary on the assumptions presented in 1.4.3, including whether the assumption was appropriate or valid, and if further studies are needed to qualify the claim.

3.3.1 Nuclear license and other approvals to operate

For the nuclear ship in this scenario, the assumed nuclear safety case — including radiation protection, EPZ extents, and reactor-related risks — is established through the nuclear license issued by the US NRC. However, the framework to apply for a license to operate nuclear power plants on ships does not yet exist. The project team based its expectations on existing practices of hazard assessment and risk management documentation from terrestrial nuclear licensing processes.

It is unclear at this time how a national nuclear regulator of a destination port would permit the entry of a nuclear ship that holds a license from another nation's regulator. The expected primary safety risks of nuclear ships compared to conventional ships concern radiation protection in port. Current evidence expected from visiting ships by port states does not include provisions for nuclear safety, insurance for nuclear incidents, or evidence that the crew is certified for nuclear operations and emergency response. There may be many gaps in documentation and evidence that the port state is entitled to request from ship owners and operators to approve entry.

Based on the results of this study, it is recommended that licensing regimes for nuclear ships should include considerations for operations in port and the various jurisdictions that may interface with the ship, especially for the first-of-a-kind nuclear ships. Ideally, in the future, a license to operate nuclear ships should not require specific information about the routes or destination ports, but should only be concerned with the safe and secure operation of the nuclear systems within a clearly defined 'ship operating profile.' This defined envelope should be developed collaboratively by maritime and nuclear industries to a level of detail sufficient to satisfy regulators and insurers that the technology can meet the expected functions within that operating envelope.

When preparing to receive nuclear ships, port authorities should be able to leverage evidence from the nuclear licensing process, including safety assessments for nuclear safety, and try to limit any additional requirements to local nautical safety, traffic management, terminal operations, and emergency coordination. Ultimately, ports have the right to impose additional requirements on ship calls beyond international regulations if deemed necessary.

Finally, careful consideration should be given to the perception of deregulation during the development and implementation of new licensing regimes for nuclear ships. Developers and end-users of small modular reactors are emphasizing the need for faster, more predictable licensing schemes to enable quicker deployment. National nuclear regulators should seek to balance the extent of regulatory oversight and the level of risk acceptance, including the level of documentation demonstrating that risks are managed in accordance with appropriate acceptance criteria.

3.3.2 Insurance and liability frameworks

Assuming that the nuclear ship carries a valid license to operate and other appropriate regulatory approvals from the Flag Administration, Classification Society, and Port State, this project also assumed that appropriate insurance policies sufficiently cover the expected conditions. However, it is unclear how port states will address this, or what may be required from the shipowner or implemented locally to address the insurance and liability of a nuclear ship.

Considering the potentially severe consequences of nuclear incidents and depending on the hazards of the proposed technology, insurance and liability allocations are essential to ensure the safety of operations, manage appropriate response and reduce consequences to all affected parties.

When established, a liability framework may impose additional requirements for the ship design or increase the responsibilities of ship operators or ports. Therefore, designers and regulators should work in parallel with insurers to establish expectations of safe operations and risk management activities.

3.3.3 Nuclear ship impacts on port safety strategies

This work assumed that the nuclear ship operating license assured safety in port and that no nuclear incidents occurred. However, it is not clear what additional safety measures may be necessary to establish in ports that receive nuclear ships, for normal or emergency conditions, even if they hold operating licenses.

3.3.3.1 Berth and mooring safety assessments

Ideally, nuclear ships should be able to berth in a port in the same way as conventionally powered ships, without additional restrictions, special facilities or different procedures, unless clearly justified by demonstrated safety or operational differences. While safe operations are assumed in this project, a mature design and a complete risk assessment may reveal

potential hazards in the port due to the presence of the nuclear ship. These additional assessments can both inform the original nuclear ship licensing process and recommend additional safety provisions for individual port operations.

When detailed nuclear ship specifics are available, including failure modes analyses, thorough risk analyses should be carried out by the port where a nuclear ship intends to berth and conduct various operations alongside. Port safety assessments for nuclear ships should, at a minimum, include the location; water movements (e.g., from passing ships); other activities in and around the water and land areas; SIMOPS; and security and digital (cyber) risks. The assessments should also determine whether the terminal's equipment and mooring procedures are suitable or require enhanced safety standards.

Safety of other ships and nearby facilities or terminals should also be addressed when considering nuclear ship safety and security in port. Such measures have been essential for ships carrying hazardous cargoes and fuels, and should also be explicitly implemented for nuclear ships. This can include nearby or land-based measures, such as radiation detectors at strategic locations, clear incident protocols and emergency evacuation and containment procedures.

It should be investigated whether nuclear ships require designated berths, depending on the level of nuclear safety, the safety zones onboard the ships and the surrounding port environment.

Mooring assessments should assess whether additional provisions are needed to effectively manage risks during mooring, including manoeuvrability and propulsion response time of nuclear ships. The requirements for safe manoeuvrability and response time should be at least as stringent as those of conventional ships. If the nuclear ship does not fully meet those requirements, additional technical provisions or specific operational measures may be recommended.

Various port analyses may result in recommendations for specific safety considerations that should be included in the national nuclear regulator's licensing process for the nuclear ship. The results of these assessments can also inform future updates to the ISM Code, providing specific guidance on identifying and evaluating risks associated with nuclear ships operating in ports.

3.3.3.2 Shore connections for emissions reductions

As of January 1, 2030, (sea-going) container and passenger ships in EU ports are required to use shore power. This measure, part of the EU's Fit-for-55 package and the Fuel EU Maritime Regulation, aims to drastically reduce emissions and noise pollution in port areas. Ships may also use onboard zero-emission technologies, such as batteries, instead of shore power. Nuclear power is a zero-emission technology and may not require shore power to comply with the EU Fit-for-55.

This project assumed that, since the ship can operate under its own power while in port—emissions-free, in this case—there was no need to connect to shore power. For simplicity, connecting the nuclear ship's power-generating systems to the land-based grid was also not considered.

For nuclear ships, if the reactor is shut down during a port stay in the EU, it would not be permitted to use fossil fuel generators for onboard energy supply, even during loading and unloading operations. In such cases, the ship must switch to shore power or another zero-emission technology.

It is therefore important to investigate the implications of connecting a nuclear ship to shore power, including technical compatibility, safety, radiation control and the impact on existing onboard systems. Such research is essential to determine whether additional measures or adjustments are needed for the ship and within the port infrastructure.

Alternatively, if the reactor operates while the ship is at berth, studies should assess the implications of supplying power to shore, including potential benefits for the ship owner (power provision or sale to port) and the port (reducing emissions).

3.4 Further areas of study

Commentary on the assumptions of this project also resulted in feedback for consideration in future scopes of work. Specifically, research areas that investigate the requirements for nuclear ship licenses and permits for port entry (including insurance requirements), or scopes of work that may investigate specific ship design features for nuclear safety and security.

This section highlights recommended topics for further study, based on the results of the safety assessment and commentary on the assumptions for this project. Other recommendations for further research include expanding the scope of work pursued in this project.

3.4.1 Nuclear incident in port

A nuclear incident in port was not specifically considered in the scope of this joint project. Further studies should investigate nuclear incident scenarios (e.g., radiation exposure or the release of radioactive material) in ports to evaluate the need for detection, alarm, and response measures. Based on technology maturity, incident likelihood/frequency, initiating events/causes, and consequences (including immediate, second-, and third-party damages, as well as other unusual downstream consequences), should be clearly mapped.

Depending on the incident and location, research should focus on developing recommendations to the responsible parties for response and party liability. Evacuation routes and safe havens should be assessed for suitability during nuclear incidents in ports. Research on operating scenarios should inform safe distances based on potential dose limits, to support supervision and communication among non-specialists. Recommendations should include measures to enhance port safety and the safety of surrounding communities, such as installing radiation detectors at strategic locations and establishing clear protocols for incidents, including evacuation and containment.

Incident response research should also include the recommended crew and terminal (or other facility) personnel training. Nuclear incident response may involve national and international agencies from both maritime and nuclear authorities.

3.4.2 Managing nuclear technology in port

3.4.2.1 Handling nuclear material

The handling, transfer, or refuelling of nuclear fuel or radioactive waste, which is outside the scope of normal port operations, was not considered in this study. This project team assumed that such activities would occur only at specialised nuclear facilities with appropriate security and safeguards measures in place and assumed that they should not be interpreted as a prerequisite for routine port calls by nuclear ships, including any technical, regulatory, liability, licensing or permitting requirements for ships and port facilities to handle nuclear material in port.

Research should investigate the following activities related to the handling of nuclear material and the disposal of nuclear waste in ports or within specific countries:

- Transshipment or temporary storage of nuclear materials or radioactive waste.
- Activities involving access to the onboard nuclear installation and nuclear materials.
- Maintenance activities on board that involve radiation risks.
- Security and emergency procedures related to nuclear safety.

Research should identify the appropriate national regulations or provisions responsible for mandating the safe handling of nuclear material and make recommendations to address any gaps.

3.4.2.2 Maintenance of nuclear systems

This joint project did not consider situations involving work on the nuclear systems during port visits. Further studies should assess the risks to and requirements for port facilities and personnel when maintaining or servicing nuclear systems while in port, which may pose nuclear risks.

Handling nuclear material and nuclear equipment, as well as access to protected radiation zones, may involve the local nuclear regulator and the national nuclear regulator of the licensed nuclear ship. Security arrangements and security clearances should also be considered when preparing to maintain nuclear systems in port.

3.4.3 Security measures

Security measures for the nuclear ship were not considered in this scope of work. However, strict security measures are required to protect the ship, the reactor, and the fissile materials. These measures form part of the nuclear ship's licensing and permitting processes and should be explicitly incorporated into the relevant provisions of the ISPS Code, ensuring that unauthorised individuals—regardless of intent—are prevented from accessing the ship or its vicinity

Additional areas of study should consider the mature design of nuclear ships and inform security measures during port operations, including gaps between current ISPS-based port security regimes and any additional security measures that nuclear ships may require while in port.

Ships also depend on digital information exchange with shore-based entities such as terminals and authorities. This ship-shore interface represents a potential cybersecurity vulnerability. It is therefore essential to include these digital interfaces explicitly in risk assessments and incident response planning, particularly given the security sensitivity of nuclear systems. Additional studies should assess cybersecurity threats, potential gaps in marine cybersecurity systems, and the possible need for enhanced nuclear-specific cybersecurity requirements within the ISPS framework.

3.5 Conclusion

Though nuclear ships for commercial or civilian uses are in early stages of development, ports should proactively prepare for their arrival. Globally, efforts focus on technology, safety, and regulations. Locally, this involves legal, safety and operational measures, as well as cooperation with nuclear authorities.

A key aspect of this preparation is gaining insights into the potential risks associated with nuclear power and understanding the technology so that risk perception is managed by engineering logic rather than public or promoter misconceptions. Further research and communication are needed on radiation safety, reactor incidents, security threats, and their effects on ships, terminals, and personnel. Only with a thorough understanding of these risks can appropriate measures be taken, allowing the port to anticipate future developments responsibly.

Each port expecting future nuclear ships must assess safety, security, safeguards and emergency procedures. Since ports vary, these local assessments help shape national, regional and international guidance or regulations.

A future-proof port would consider not only technological and logistical aspects, but also the unique safety and societal challenges posed by nuclear ships. Public perception is key. Nuclear ships may raise concerns among residents, port workers and stakeholders. Transparent communication, safety protocols, and community involvement are essential for building support and acceptance.

3.6 References

- IAEA. (2007). *Nuclear Power Plant Design Characteristics: Structure of Nuclear Power Plant Design Characteristics in the IAEA Power Reactor Information System (PRIS)*. Vienna: IAEA. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/te_1544_web.pdf
- IAPH. (2024). *Port Readiness Level For Marine Fuels (PRL-MF) Assessment tool for bunker ports*. International Association of Ports and Harbors. Retrieved from <https://sustainableworldports.org/wp-content/uploads/Port-Readiness-Level-for-Marine-Fuels-assessment-tool-July-2024.pdf>
- LR. (2024, August 15). LR and COREPOWER to conduct next-generation nuclear container ship regulatory study. London. Retrieved from <https://www.lr.org/en/knowledge/press-room/press-listing/press-release/2024/lr-and-core-power-to-conduct-next-generation-nuclear-container-ship-regulatory-study/>
- Ministerie van Infrastructuur en Waterstaat. (n.d.). *Landelijk Crisisplan Straling*. Retrieved from <https://open.overheid.nl/documenten/ronl-99c4f56e-4331-4ec8-b30c-cc94ebd9078a/pdf>
- Port of Rotterdam. (2025). *Rotterdam port adaptation strategy for climate resilient transport and business activities*. European Environment Agency. Retrieved from <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/rotterdam-port-adaptation-strategy-for-climate-resilient-transport-and-business-activities>
- US NRC. (n.d.). 10 CFR Part 20 - Standards for Protection Against Radiation. Retrieved 2025, from <https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/index>

Appendix A Roadmap to overcome barriers

Issues presented in the Roadmap are categorised as communication, technology development, guidance/regulatory development or implementation.

Although the suggested responsible parties are identified for each recommendation, many stakeholders should collaborate to address barriers. Role and responsibility assignments require careful consideration. Even organised stakeholder groups may not successfully address all barriers if they exclude certain parties.

Table A-1 Roadmap of actions to overcome barriers to nuclear ship adoption

	Barrier	Description	Actions	Suggested Responsible Party	
Communication	Understanding Risks	<p>In a complex and dynamic environment such as Rotterdam Port, it is essential to thoroughly assess and manage risks to safeguard everyone in and around the port area</p> <p>Currently, the design and operation of nuclear ships are not well developed; therefore, policies and regulations for their management cannot be established until the technology has advanced to the point where the safety and security risks can be clearly defined and managed.</p>	<ul style="list-style-type: none"> Publish and promote the results of integrated nuclear ship concepts. Provide transparency regarding technical and operational risks. 	Shipowners/naval architects with nuclear technology developers.	Near-term
			<ul style="list-style-type: none"> Conduct HAZIDs, HAZOPs, and other Risk Assessments, including Security Threat Assessments specific to the ship concept of operations and region. Publish and promote the results, if possible. External events should inform the design of the nuclear ship, for example, protection from a cargo handling incident. 	Shipowners/naval architects with nuclear technology developers, led by 3 rd party independent organisation.	Near-term
	Public Perception	<p>A well-coordinated communication strategy contributes to trust, acceptance, and administrative legitimacy. Communication focused on public perception of nuclear energy and nuclear ships is a prerequisite for the successful implementation of nuclear maritime technology. Still, it has not yet been initiated at the Port or nationally. The conversation must involve local governments, port authorities, and civil society organisations.</p>	<ul style="list-style-type: none"> Develop public engagement strategies for nuclear ship entry Leverage existing public perception research and increase social engagement for nuclear energy to build constructive dialogues. 	Port Authorities expecting nuclear ships, with national nuclear regulatory input.	Near-term
<p>Develop public engagement strategies for nuclear ships.</p>			Shipowner and nuclear vendor (once an operational concept is proposed).	Medium-term	
Technology development	Mature designs	<p>Experience with standard approaches for assessing the suitability of design characteristics and developing prescriptive requirements for safety and security is needed to convey information about the nuclear ship. Current designs for nuclear ships are conceptual, and identifying safety and security measures for the ship in port depends on the complete design. Conversely, nuclear ship design should be informed by port operations.</p>	<ul style="list-style-type: none"> Develop integrated (and uniform, where possible) nuclear ship design and operational concepts with technology developers and operational stakeholders. Use results to engage insurers, inform public engagement campaigns and regulatory developers. 	Shipowners/naval architects with nuclear technology developers.	Near-term

	Barrier	Description	Actions	Suggested Responsible Party	
	Standard method for determining safety distances	Safety distances to nuclear installations are determined through risk assessments and are included in the nuclear ship license. Risks to people and the environment arising from the presence and operations of nuclear ships should be effectively managed, and individual and group risks associated with nuclear ships in port should be assessed.	<ul style="list-style-type: none"> Propose suitable methodologies to determine safety distances for nuclear ships. Identify the basis or minimum EPZ for nuclear ships. Specific safety provisions for nuclear ships should be available from the national nuclear regulator of the port of destination. 	National nuclear regulators expecting or planning to regulate nuclear technologies for ships. Collaborate with environmental agencies.	Near-term
Guidance and regulatory development	International nuclear ship design code	The 1981 Nuclear Ship Code is obsolete and specific to pressurised water reactors (PWRs) that provide direct-drive power for ship propulsion.	<ul style="list-style-type: none"> Update the 1981 Nuclear Code using any type of reactor technology. Emphasise the need for guidance to provide a sufficient legal and technical basis for the admission of commercial nuclear ships. 	IMO and Member States.	Near-term (ongoing)
		ABS Classification Rules were used to class the NS Savannah in the 1960s, but have since been retired. No Classification rules are available from any IACS member suitable for addressing nuclear technology for ships.	Classification Societies develop Rules for Nuclear Ships for uniform design decisions.	Classification Societies involved in international regulatory development.	Near-term (ongoing)
		International Codes are transposed into national statutory measures through EU legislation. SOLAS Chapter VIII must be adopted or implemented at the national level so that ports and local authorities can apply these rules.	National implementation/adoption of SOLAS CH VIII.	EU Member States.	Medium-term
	Legal framework for licensee and ship owner or operator	Given the unlimited liability assumed today for nuclear power plants and the nations in which they are located, clarification of the legislative regime governing liability for the ship and its related operations will be required for further development. Current legislation requires the central government to be responsible for crisis management in the event of a nuclear incident. However, ships have primary responsibility for any incidents that occur on board during a port visit.	<ul style="list-style-type: none"> Produce guidance or recommendations on a potential liability regime for nuclear ships, considering operating profiles and proposed areas of operation. Based on proposed ship concept designs and depending on nuclear technology, propose emergency response measures suitable to the liability regime. 	Nuclear and maritime insurers with shipowners and nuclear operators.	Medium-term
	Guidance for emergency response for nuclear ships	There is no valid international guidance on the safety and security provisions for ports that accommodate nuclear ships, including emergency response and procedures for which additional security measures may be required.	Develop guidance for ports on the safety and security of visiting nuclear merchant ships, based on proposed ship concept designs and nuclear technology, and informed by the expected development of the liability regime.	Industry organisations or recognised standards organisations with experience dealing with nuclear safety, security and safeguards and maritime operations. For example, the IAPH could publish new guidance.	Medium-term

Barrier	Description	Actions	Suggested Responsible Party	
International security code for ports	The ISPS Code requires that companies that manage or operate port facilities where international seagoing ships dock must have an approved security plan that includes measures for access control, supervision and incident response. While the ISPS Code requires ports to have a port-specific security plan, it doesn't specifically cover nuclear ship port calls.	Based on an understanding of the concept of nuclear ship designs and risk assessments, investigate whether the ISPS Code is sufficient to enable ports to add plans for security measures for nuclear ships, or if further guidance and regulations are required.	Industry or recognised standards organisations with experience in nuclear safety, security, safeguards, maritime operations, and nuclear-related incident and emergency response.	Medium-term
Nautical regulations	Existing requirements for nautical safety, including communication/signalling, ship manoeuvring and supervision, do not specifically include provisions for merchant nuclear ships during transit into port and safe mooring.	Based on an understanding of the concept of nuclear ship designs and risk assessments, develop guidance and proposed standards for nuclear ship nautical safety.	Industry organisations or recognised standards organisations with experience dealing with nuclear safety and port operations.	Near-term
International Standards for Training	The International Standards for Training and Watchkeeping (STCW Code) does not specifically address the operation of nuclear merchant ships.	Update the STCW Code with specific requirements for crew training and certification on nuclear ships.	IMO Sub-committees and member states.	Medium-term
		National implementation of the STCW Code and the Maritime Labour Convention, specific to the operation of nuclear ships, by national statute	National maritime authorities.	Medium-term
	Current training and crew certification requirements do not address the operation of nuclear ships or emergency response training for nuclear ships in port.	<ul style="list-style-type: none"> Based on understanding of concept nuclear ship designs and risk assessments, develop guidance and proposed standards for training ship crew and port/terminal personnel specific to nuclear ships. Develop information and training on the properties and risks of nuclear technology, and make available to crew, port employees, and the public. 	Industry organisations or recognised standards organisations with experience dealing with nuclear and maritime (ship and port) operational training and certifications.	Medium-term
Nuclear ship license international recognition	Alignment between national nuclear regulators on mutually recognised approvals for reactors is uncommon and has not been achieved for ship use cases.	<ul style="list-style-type: none"> Compare the licensing requirements between two or more national nuclear regulators of a nuclear reactor technology intended for ship use. Identify consensus and provide recommendations on the process and documentation required to operate a nuclear ship that will be mutually recognised by the national nuclear regulators of the ship's operating regions. 	National nuclear regulators.	Medium-term
IAEA Guidance on Safety, Security and Safeguards for Nuclear Ships	International collaboration is needed to interpret modern nuclear safety standards and guidance for use in shipping applications.	<ul style="list-style-type: none"> Develop frameworks for the safe and responsible use of nuclear power for ships, including stakeholder identification and alignment with proposed liability regimes. Update the IAEA Integrated Management System (IMS) to specifically include nuclear ships in the approach to assess nuclear safety. 	<ul style="list-style-type: none"> International Governmental Organisations, including the IMO and IAEA, through the ATLAS Program. Support from Member states and NGOs such as the Nuclear Energy Maritime Organisation (NEMO). 	Near-term

	Barrier	Description	Actions	Suggested Responsible Party	
Implementation		EU implementation of IAEA Guidance through the EURATOM Treaty	Develop or update EURATOM provisions specific to nuclear ships	EURATOM / EU Nations.	Medium-term
		National implementation of IAEA Guidance	Update national legislation to align with EURATOM / EC provisions	EU Nations.	Medium-term
	Safety measures in port for nuclear safety	If any measures are necessary, ports are not currently equipped with the specific infrastructure or safety devices required to maintain safety in ports related to nuclear ships.	<ul style="list-style-type: none"> Nuclear ship specifications are available to study and manage risks in port. Using the information available, identify specific equipment and installation instructions of radiation monitoring and other safety devices provided for port facilities. Terminal and port incident response plan established and communicated to all parties. 	Port authorities and national nuclear regulators with national governments.	Medium-term
	Port/Regional Governance addresses nuclear ships	Current port governance is not expected to sufficiently encompass all the plans and procedures necessary to receive a merchant nuclear ship.	<ul style="list-style-type: none"> Publish and implement a formal governance framework to coordinate public and private parties on the admission of nuclear ships. Establish joint crisis management exercises for nuclear ships in port. National and regional berthing policy implemented for nuclear ships in port, including berth zoning and established safety zones. If recommended by safety studies, update local law to reflect nautical safety provisions for nuclear ships in port, including any requirements for pilotage or oversight. Establish suitable enforcement regimes to ensure appropriate oversight and monitoring of nuclear ship operations in port. 	Port authorities and national nuclear regulators.	Medium-term
	Security measures in port for nuclear ships	If any measures are necessary, ports do not currently have standard security practices in place for nuclear merchant ships.	<ul style="list-style-type: none"> Security provisions in port are established, including personnel certifications, monitoring and marked security areas suitable for the security of a nuclear ship in port. 	Port authorities and national nuclear regulators	Medium-term
Legal framework	The current legal framework does not address the operation and entry of nuclear ships, including the insurance pathway for the licensee, ship owner/operator, and destination port facilities, depending on the activity.	<ul style="list-style-type: none"> Differences or gaps in the existing legal frameworks should be reconciled, and legal requirements should be established for receiving nuclear ships at terminals. 	Port authorities and national nuclear regulators.	Medium-term	