Security Considerations for Floating

Nuclear Power Plants when Stationary

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**Abstract**

The nuclear industry is currently anticipating the start of a transition within this decade from a technologically narrow set of gigawatt-scale reactors to a much more diverse array of technologies, including many evolutionary and innovative reactor designs. Both the security lessons of the past and today’s latest international guidance are being applied to this suite of novel technologies with some success. One particularly unique group of innovative nuclear technologies are floating nuclear power plants – floating platforms which may be moved on water and operated as nuclear power plants to supply energy to consumers. The unique context within which these technologies will exist, operate, and be maintained and refueled creates the potential for a range of emerging security challenges, in part created by the likely requirement to comply with established maritime law. These include new threat actor groups, intentions, and attack vectors, designed to exploit the unique vulnerabilities of these technologies. The paper details the range of unique physical protection, cyber and insider threat challenges faced by floating nuclear power plants and operators, focusing on those encountered when the plant is stationary during its various lifecycle stages, as opposed to in transport, when a somewhat different set of considerations would apply. In doing so, it takes a non-technology-specific approach, looking across the range of floating nuclear power plant subtypes. It is recommended that developers consider security as a key design driver from the earliest stages of the design process to address these issues effectively.

## INTRODUCTION

Amongst the wide range of small modular reactor (SMR) and advanced reactor technologies currently under consideration, one particularly novel group are transportable nuclear power plants (TNPP), defined as nuclear power plants which are factory manufactured, transportable and/or relocatable, and which can produce electricity and/or heat when stationary for various users. They are further defined as not being propelled by their own nuclear power plant [1]. A subset of TNPPs are floating nuclear power plants (FNPP), a term used in this paper to indicate any TNPP sited in or on water, either close to or far from shore, including those mounted onto floating platforms as well as those attached to fixed structures or resting on the bed of the water body. The definition of FNPP does not exclude siting in inland waters, including rivers and lakes, but no information has been found indicating such sites are being considered. As with other types of TNPP, FNPPs are not self-propelled – such a device would instead by termed a nuclear-powered ship. There is currently growing interest in FNPP in a range of quarters, as was demonstrated at a November 2023 International Symposium on the Deployment of Floating Nuclear Power Plants hosted by the International Atomic Energy Agency (IAEA) [2]. A range of states are exploring the use of FNPP to meet their energy needs, particularly littoral and archipelagic states seeking to acquire their first nuclear power plants. The Russian Federation already operates an FNPP, the Akademik Lomonosov, based on its experiences operating nuclear-powered icebreakers [3], but so far this plant has only been built, operated, fuelled and relocated within the territory and territorial sea of the Russian Federation [4].

FNPP exist at an intersection of two bodies of international law, regulation, engineering best practice and standards, and cultures. On the one hand, as nuclear power plants they are of the civil nuclear world, and at first glance would appear to be subject to the IAEA, the Convention on Nuclear Safety (CNS), 1994, the Convention on the Physical Protection of Nuclear Material (CPPNM), 1987, licensing by national nuclear regulatory bodies, and so on. On the other hand, as large floating objects that travel by sea, they would also appear to be potentially subject to the International Maritime Organisation, the International Convention for the Safety of Life at Sea (SOLAS), 1974, surveys by maritime classification societies, and so on. However, in fact, many of the existing legal instruments in both spheres are not well equipped to account for floating nuclear power plants, and several specifically exclude them from their texts [5]. FNPPs thus currently exist in a state of legal ambiguity, which various organizations, including the IAEA, are currently seeking to resolve.

Within the nuclear domain, many FNPP developers are designing their concepts to fulfil two functions which have until now been separated in the civil nuclear domain by using them to carry nuclear fuel materials, irradiate those materials, and then carry the spent fuel. They are thus combining the role of a nuclear power plant for electricity and/or heat production with the role of a conveyance in nuclear materials transport. This is not necessarily a requirement – FNPPs can be moved without nuclear material aboard, although a variety of developers are considering this combined option.

The above-described legal ambiguities, combined with the need for FNPPs to be relocatable during their operating lives, create a range of unanswered questions and evolving design requirements, which in turn have the potential to create novel considerations for safety, security, non-proliferation, liability and more. This paper focuses on the security considerations that are specific to FNPPs when they are stationary, as opposed to during relocation operations. It does so by considering the FNPP at the various locations where it will undergo activity, starting from the design organization, to shipyards where it will be constructed and likely decommissioned, to the site where it will be installed and operated. Relocation can occur during and between any of these lifecycle stages, and refueling and maintenance may occur at either a shipyard or the licensed site.

## SECURITY DURING FNPP DESIGN

A number of FNPP concepts are currently being designed globally, the most advanced of which are discussed in a recent IAEA publication [6]. Several developer organizations are working to bring competitive FNPP designs to market in a timely fashion, and are undertaking design, licensing and other activities whilst engaging with international organizations and other bodies to facilitate the development of international instruments related to FNPP, such that legal and other uncertainties can be minimized. In the currently ambiguous legal environment, developers take risks in advancing their concepts too far too quickly, and so need to temper their desire to have a market-ready design as soon as possible with readiness to respond to changing requirements.

As with any nuclear power plant concept, designers are encouraged to embrace the security-by-design philosophy from the earliest stages of the design process [7]. Nuclear security represents a significant proportion of nuclear power plant operating budgets today, largely as a result of the large numbers of guard and response force personnel used to deliver security performance [8]. This has resulted from considering security only late in the design process and seeking to build security onto a completed design, rather than designing a plant to be secure from the outset. Security-by-design encourages the consideration of security alongside nuclear safety and other design requirements, and has the potential to greatly reduce operating costs of nuclear facilities, including FNPP.

The application of the security-by-design principle is not specific to any given nuclear power plant technology or deployment scenario, and so is unlikely to be different for FNPP as compared to other nuclear power plants. However, the application of the principle will differ, as a result of the novel features of FNPP, and developers are encouraged to consider the novel security considerations outlined below and elsewhere as the overall understanding of these technologies continues to evolve.

The likely need to be compliant with maritime legal instruments may create conflicts with usual approaches in nuclear facility design for security. For example, SOLAS places strict requirements on vessel layout, such as the need for internal spaces to have unrestricted escape routes in case of emergency evacuation [9]. This stands in conflict with nuclear security design practices, which would dictate that vital areas, such as nuclear materials storage areas, the reactor compartment, the plant control room, and so on, have as few access points as possible, ideally only one, and that such areas are not readily accessible by unauthorized individuals, which will very likely include at least some of the FNPP personnel [10]. This is but one example of such a conflict, and various organizations are currently engaged in the review of all relevant international instruments to identify such conflicts and other ambiguities, and make recommendations for their management.

## CONSTRUCTION AND DECOMMISSIONING IN SHIPYARDS

It is almost a defining feature of SMRs that they will be serially produced in factory environments to a much more complete state than today’s existing nuclear power plants were, transported as complete plants or modules to a site, and then installed. FNPPs take this to an even greater extreme. It is generally expected that each FNPP will be fully assembled in one or more shipyards, e.g., a non-nuclear shipyard would construct the hull and major structure, and a nuclear shipyard would then install the nuclear equipment. Commercial shipyards are used to constructing large vessels to a range of specifications, and it is thus anticipated that there would be a desire to use existing shipyards for this purpose, at least for non-nuclear activities. Nuclear fuel might be loaded onto the FNPP at a nuclear shipyard, or this might be performed only at the licensed site of operation. If fuel is loaded, the FNPP might also be commissioned prior to being relocated to the licensed site, resulting in nuclear equipment being irradiated and undergoing neutron activation.

Any shipyard involved in FNPP construction would need to comply with a range of nuclear security requirements to prevent sabotage to the FNPP and the unauthorized removal of nuclear material, if present. Threat groups might attempt to attack the shipyard using physical force and/or cyber methods, and so additional security measures may be required to be retrofitted at shipyards where FNPP construction takes place, based on an assessment of the threat and application of a graded approach to nuclear security. Whilst nuclear ship construction does already occur, this is largely in military-controlled facilities where security may be applied differently than in the civil nuclear sector, and so this experience may be of only limited applicability. Furthermore, the shipyards used may be in states without existing nuclear activities and which may thus lack a regulator or the necessary national law to ensure nuclear security during construction, to say nothing of safety, non-proliferation and other considerations. Such shipyards may also be ill-prepared to play their role in securing the supply chain against the introduction of counterfeit, fraudulent and suspect items (CFSI).

Of particular concern during shipyard operations should be the insider threat risk posed by workers. Shipyards employ large numbers of skilled and unskilled laborers who generally do not require extensive background checks before being employed, and who are normally not subject to ongoing human reliability and fitness-for-work monitoring programs. Nuclear security cultures will also very likely not exist in such organizations. An insider could perform a wide range of actions to compromise nuclear security, and so measures will be required to mitigate this risk. Whilst nuclear shipyards will likely have higher consequences from security incidents than non-nuclear shipyards, all shipyards involved in FNPP construction will need to be assessed from a nuclear security perspective and appropriate measures put in place based on the risks to be managed.

Shipyard operations may not solely relate to FNPP construction – FNPPs may also be decommissioned, refueled, and/or maintained in shipyards. These operations will be largely similar from a security perspective to those to be managed during construction, however, as was noted above in relation to the potential for commissioning of FNPPs prior to departure from the shipyard, the nature of the nuclear material present will be different. The presence of spent fuel, contamination and activated components, instead of fresh fuel, alters the potential consequences of a nuclear security incident, and the use of a graded approach may allow for different levels of required security measures depending on the type of activity being carried out in the shipyard.

## DEPLOYMENT SCENARIO AND SITE SELECTION

FNPPs, as defined broadly in the introduction to this paper, are being considered for a range of deployment scenarios, based on whether they are buoyant during operation, their distance from shore, and whether they are fully or only partially submerged. This leads to six potential scenarios, each with their own security considerations:

* Floating plants at the sea’s surface
  + Located far from shore, usually anchored by cables to the seabed
  + Located close to shore, usually moored to a jetty or other structure
* Gravity-based structures resting on the seabed or attached firmly to fixed platforms
  + Located far from shore and with their upper portions above the surface of the water
  + Located close to shore and with their upper portions above the surface of the water
  + Located far from shore and completely submerged beneath the water’s surface at all times
  + Located close to shore and completely submerged beneath the water’s surface at all times

The security risks to the FNPP will change depending on the deployment scenario. For example, floating plants may be more prone to capsize and sinking, certainly as compared to those already on the seabed. Anchor cables for such plants will be critical components of the security and safety system, and will require appropriate protection. As a second example, distance from shore and level of submersion will affect both the capabilities required by threat actors to carry out physical attacks, as well as the ability of response forces to effectively neutralise threats. For instance, an offshore, submerged facility in deep water may require response forces to be able to operate effectively in such environments, should an attack against such a facility be considered credible enough to form part of the design basis threat. As a third example, consideration will need to be given to how cooling of the FNPP might be achieved during shutdown. Passive cooling may only be assured subject to the stability of the platform, which may not be guaranteed for floating power plants in rough seas. However, active cooling may be dependent on the availability of offsite power, making power cables a critical component for security protection, as they are with land-based nuclear power plants. As a final example, emergency planning requirements will likely differ depending on the deployment scenario, with the level of acceptable radiological release potentially being greater far from shore due to potentially lower human health consequences, despite the environmental consequences potentially being worsened due to direct release into oceanic waters.

The above represent a small number of possible security considerations which are impacted by the deployment scenario for an FNPP. Despite this, it can be seen that the deployment scenario will strongly impact on the vulnerabilities of a given FNPP that could lead to a radiological release, the capabilities of the threat required to deliver an attack, and the potential consequences should an attack be successful. Thus, FNPP designers must consider the full range of deployment scenarios under which their technology might be employed and ensure security requirements can be met for all of these.

Deployment scenarios are concerned with how a given FNPP technology might be used. However, it is also necessary to consider site specific factors for each deployment type. Two novel risks to FNPPs are collision with ships or the seabed or shore, as well as the use of fast boats by attackers to rapidly approach the FNPP. Siting far from shipping lanes and other marine traffic will reduce the number of vessels in the vicinity of the FNPP, making it easier to identify potential attackers and respond in a timely manner, but to achieve may require siting far from shore. However, one of the major considerations when siting far from shore will be the ability of the host state to project its influence over the FNPP. Should the site be outside of the state’s territorial waters, the FNPP will be subject to international law, making effective response, and possibly detection and delay, much more difficult. These novel security considerations for FNPP siting are additional to the usual considerations for SMRs.

## INSTALLATION AND OPERATIONS

FNPPs may be designed to be entirely self-contained facilities or may be designed to operate in conjunction with other infrastructure constructed on shore or on an offshore platform. Whilst the former may appeal, in that it eliminates the requirement for construction of permanent structures and installation of equipment at the site, this will likely enlarge the FNPP whilst also concentrating all safety and security system elements onto it, creating common modes of failure for critical systems. Designers must thus consider where to place their FNPP on the spectrum, ranging from a completely self-contained FNPP at one end, to a standard land-based SMR at the other. What equipment, systems, capabilities, processes, services and so on should be provided on the FNPP, and what, if any, should be provided through fixed infrastructure at the site? The case for the placement of some systems off the FNPP is perhaps best made when seeking resilience through redundancy. This is required in the case of control rooms under Requirements 65 and 66 of the IAEA safety requirements for nuclear power plants [11].

For anything but an entirely self-contained FNPP, prior to its arrival at the licensed site a range of preparation activities must be carried out. From a security perspective, this may include the construction and installation of any elements of the physical protection system deemed necessary by the operator and regulator to protect the site and its nuclear equipment and material. These might include physical barriers around the FNPP and any anchor or power cables or pipelines, e.g., concrete caissons or breakwaters, floating booms, and sub-surface netting. These would likely be fitted with sensors to detect contact or damage, supported by surface and subsurface sensors as part of a complete detection system to prevent the unidentified approach of vessels or divers. There would also be physical protection system elements for shore-based facilities. This is in addition to the necessary digital and communications infrastructure to be installed prior to and during the arrival and set up of the FNPP, which will require suitable computer security, and the necessary training and other programs required to prepare staff and mitigate insider threat risks. Many of these elements must be put in place and fully operational prior to the arrival of the FNPP and the nuclear fuel, although as with any nuclear facility, the security posture may evolve with changes in the risk environment, e.g., if fuel is present or absent, in what form, and if a fueling operation is ongoing.

The size of the FNPP site will also greatly impact on how security is delivered. As discussed in the first section on security during design, FNPP sites may have a very small footprint, with the site boundary effectively being the outer edge of the FNPP itself. In such cases, physical separation of vital areas from the edge of the site may be very small, necessitating that any attacker be slowed from achieving their objective through other measures than simple distance. Delivering effective physical protection within such a small area is expected to present new challenges compared to those previously encountered by many security professionals in the nuclear sector, where large sites are common. Alternatively, some area of water and/or land may also be considered part of the nuclear site, subject to the control of the site owner or operator for physical protection purposes. Nevertheless, if an attacker does successfully board the FNPP, response forces will need to be able to neutralize the threat in novel settings, possibly even below the surface of the water.

A significant unresolved question for FNPPs relates to how security responsibility will be held. The mobile and international nature of FNPPs potentially opens up the possibility of FNPP being operated by a supplier outside of the state in which the FNPP will operate, and this may extend the delivery of security functions by the supplier state. It is not yet clear whether such security responsibility models might be considered for FNPPs, but this would be subject to significant legal ambiguity [5]. It is a fundamental principle of nuclear security that states are responsible for ensuring the physical protection of nuclear material and facilities within their territory, and for nuclear materials they are transporting until the responsibility is properly transferred [10]. It is questionable whether a state can transfer this responsibility, or if it would be desirable to do so given the challenge to the host state’s energy security and ability to exercise sovereign control over critical national infrastructure. Should security be under the responsibility of a foreign state provider, this would create significant complexity in delivering effective physical protection. Even if physical protection responsibility is solely held by the host state and delivered by its own national competent authorities, the FNPP may still be operated or maintained at the site by the host state. For instance, the supplier state might have a team of personnel who travel between deployed FNPP sites carrying out routine maintenance activities. The involvement of personnel from the supplier state would represent a potential insider threat to the FNPP. Conducting background checks upon these foreign teams is likely to be more challenging for competent authorities than conducting such checks on personnel within their own state.

## CONCLUSIONS

As with all SMR technologies, the potential advantages of floating nuclear power plants are attractive, and particularly so for states seeking to achieve the benefits of peaceful nuclear energy without going to the cost and risk of constructing a land-based nuclear power plant. However, the promised advantages must be weighed against the potential challenges to be overcome, and for floating nuclear power plants these are significant. Like many novel SMR designs, they have various novel features which create new considerations in the security domain, as well as in safety, non-proliferation, and more.

FNPPs straddle two distinct domains of nuclear activity, nuclear facility activities and the transport of nuclear materials. The conjunction of these creates challenges both within the nuclear domain and extending out into the maritime world, with experts across the divide seeking to comprehend the implications and suggest approaches by which the numerous legal ambiguities might be clarified.

This paper has explored some of the security considerations for FNPPs during design, when stationary at shipyards, and when stationary at licensed sites. Several FNPP deployment scenarios are considered, and each will have its own security particularities for developers to explore, preferably from the earliest stages of their design activities as a key set of drivers alongside nuclear safety.

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