Considerations on the Accelerated Deployment of SMRs

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**Abstract**

The global efforts towards sustainable and resilient energy solutions have fueled interest in Small Modular Reactors (SMRs) as transformative elements in the nuclear energy landscape. The paper discusses the need for accelerating SMR deployment, emphasizing collaborative approaches involving stakeholders such as vendors, Owner/Operators, Regulators, and governments. Key considerations include economic benefits, regulatory framework development, and collaborative initiatives to advance SMR technology. The International Atomic Energy Agency (IAEA) plays a crucial role in facilitating global collaboration on SMRs through two interconnected mechanisms: the Nuclear Harmonization and Standardization Initiative (NHSI) and the SMR Platform. All those elements are essential for realizing the full potential of SMRs in building a sustainable energy future.

Recognizing the potential economic advantages, the paper highlights the need for a shortened timeline for the deployment of SMRs, especially in Phase 2 of the IAEA Milestone Approach, including early engagement of vendors in this process. The paper also describes incentives for vendors, Owner/Operators, Regulators, and governments, including job creation, investments, expanding market presence, ensuring energy security, and carbon emission reduction goals. At the same time, the IAEA serves as a cornerstone in ensuring a harmonized, monitored, and well-educated landscape for SMR deployment. Hence, through strategic collaborations, early engagement, and regulatory streamlining, the trajectory toward global SMR deployment is illuminated and reinforced against potential impediments.

As the world stands on the brink of a possible new nuclear renaissance, the joint effort from various stakeholders promises not only economic prosperity but also a resilient, low-carbon energy landscape. This shared vision of prosperity through the accelerated deployment of SMRs necessitates concerted and continuous efforts to pave the way for a promising and sustainable future in nuclear energy.

## INTRODUCTION

The global pursuit of sustainable and resilient energy solutions has prompted a closer examination of SMRs as a transformative force in the nuclear energy landscape [1]. Recognizing their potential to provide a safe, flexible, and economically viable alternative to large nuclear power plants (NPPs) in some cases, the need to accelerate the deployment of SMRs has become increasingly clear [2]. In navigating this trajectory, a collaborative and strategic approach is crucial, involving key stakeholders — governments, vendors, owner/operators, and regulatory bodies.

SMRs offer a highly adaptable and scalable approach to nuclear power generation, making them particularly appealing to nations trying to diversify their energy portfolios while simultaneously curtailing carbon emissions. Notably, SMR technology shows significant promise in meeting the electricity needs of remote or isolated regions lacking conventional power infrastructure. In addressing challenges such as limited grid connectivity and dependence on costly and environmentally detrimental fossil fuel-based generators, SMRs present a compact and modular solution that can be deployed effectively in such locales, delivering dependable and eco-friendly energy without the necessity of extensive grid networks.

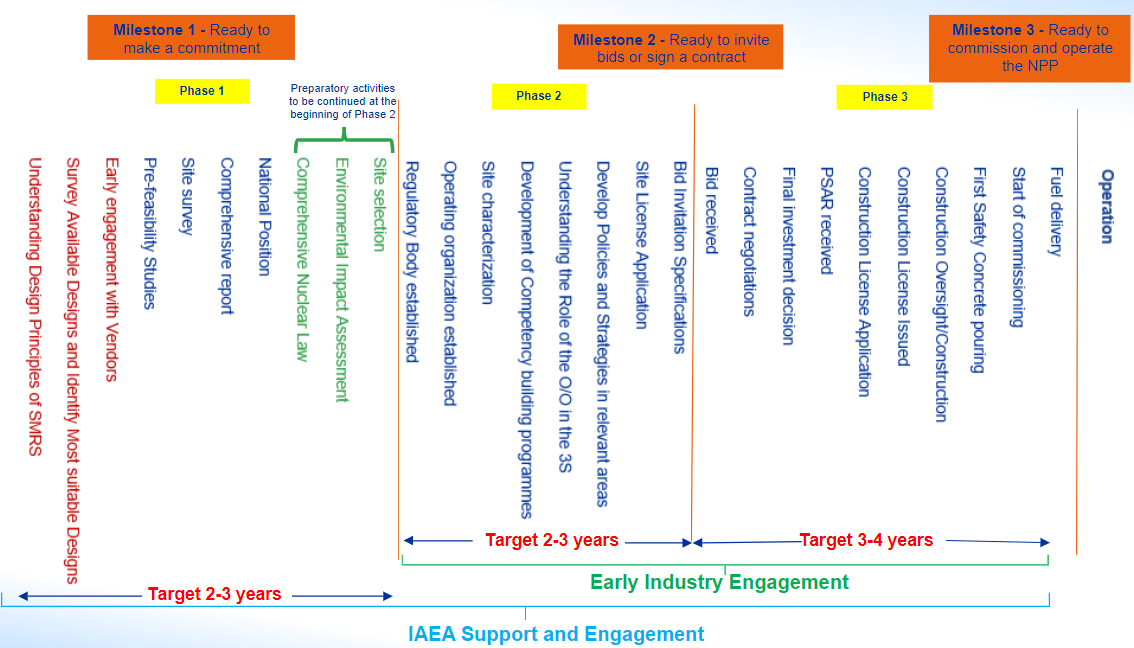
In 2007 the IAEA published the guidance publication titled “Milestones in the Development of a National Infrastructure for Nuclear Power”, then it was revised in 2015 and 2023. In preparing the necessary nuclear infrastructure, there are several activities that need to be completed. These activities can be split into three progressive phases of development. This publication provides a description of the conditions expected to be achieved by the end of each of three phases to assist with the best use of resources. The IAEA Member States (MS), including those interested in SMRs, recognize the IAEA Milestones Approach as the framework to be followed for a successful deployment of nuclear power programmes. Consequently, as countries’ interest in SMRs is continuously increasing, the second revision of this publication includes an annex on infrastructure considerations for SMRs and it is currently available in preprint version. Assuming that the timeline for SMRs deployment will be shorter than for large NPPs, there is a need to review it and activities to be done in each phase of the IAEA Milestones Approach to accelerate the deployment of SMRs.

This paper explores the considerations associated with accelerating SMR deployment, emphasizing the economic benefits, the need for regulatory streamlining, and the collaborative initiatives that can pave the way for a more efficient, sustainable, and globally competitive nuclear energy future. As countries embark on this journey, the integration of an updated deployment timeline adds a dynamic layer, offering insights into the current progress and anticipated milestones on the path to the deployment of SMRs.

## Updated Deployment Timeline

Traditional large NPPs sometimes face challenges in flexibility and economic viability, particularly in regions lacking conventional power infrastructure. As the demand for sustainable energy solutions grows, SMRs become increasingly attractive due to their enhanced flexibility, lower grid requirements, possibility of deployment in remote areas. Additionally, SMRs offer significant CO2 reduction, being an alternative for replacing coal-fired power plants in the pursuit of a sustainable energy future. . SMRs offer a flexible and economically viable alternative, making them particularly suitable for regions with limited infrastructure [3]. By accelerating SMR deployment, countries can address energy needs while curbing carbon emissions and promoting economic growth [2].

A nuclear power programme with large NPP involves 10-15 years of preparatory work and a commitment of at least 100 years [4]. Due to its characteristics that are different from large NPPs, SMRs may require certain considerations under the Milestones Approach framework, as it is expected that preparatory work will take 7-10 years. It is believed that the Milestones Approach is applicable to SMRs, but to facilitate the deployment, some actions in Phases 1 and 2 could be accelerated.

  
*FIG. 1. Updated deployment timeline for SMRs*

The primary focus in the updated deployment timeline for SMRs (see Fig. 1) is on shortening Phase 2 of the deployment process, aiming to achieve economic benefits through reduced time and costs. Phase 2 is crucial as it encompasses the project feasibility, planning, and preparation activities. By optimizing and shortening this phase, we can significantly reduce the overall project timeline, which is essential for achieving faster deployment of SMRs. Shortening Phase 2 can also lead to a reduction in pre-construction costs, including regulatory, legal, and engineering expenses. Moreover, by shortening Phase 2, potential risks and uncertainties associated with market conditions, regulatory environments, and technological advancements can be mitigated. This shortening is contingent upon a country possessing a mature regulatory framework and having initiated preparatory activities in Phase 1 [2].

However, establishing early prototypes of regulatory body and operating organization in Phase 1 will be of significant help in shortening the time of Phase 2. While it means that the government will need to provide funding in Phase 1, more comprehensive analysis to accelerate the process can also avoid the risk of subsequent failure, recognizing that the importance of safety and security cannot be understated. On the one hand, co-groups with regulatory and owner/operator functions within NEPIO could be responsible for site selection, environmental impact analysis and communication with vendors in Phase 1, hence not only accelerating the deployment, but also strengthening the NEPIO. On the other hand, this approach enhances the overall continuity of the nuclear power programme implementation, facilitating a seamless transition between Phase 1 and Phase 2 without prolonged delays in establishing essential organizations from scratch and allows to anticipate some activities.

Early engagement with vendors, accompanied by a comprehensive request for information on available designs and meticulous identification of the most suitable options, plays a pivotal role in enabling member states to grasp the intricate design principles of SMRs and to assess their compatibility with national energy requirements.

Moreover, preparatory activities for site selection, environmental impact assessment, and comprehensive nuclear law are proposed to be initiated in Phase 1. This proactive approach aims to streamline the regulatory and licensing processes in Phase 2, thereby leading to an overall reduction in deployment timelines. It is important to understand that achieving this regulatory streamlining and efficient processing depends significantly on having a competent and well-trained staff. Without skilled personnel who understand the complexities of nuclear regulation, the effectiveness of these streamlined processes could be compromised. Therefore, investing in the training and development of regulatory staff is essential to ensure the success of these initiatives and the safe implementation of NPP projects.

## Importance of Early Engagement WITH KEY STAKEHOLDERS

Early dialogues with key stakeholders will allow Member States (MSs) to convey their specific energy needs, facilitating a customized approach to technology development and deployment. This ensures that the chosen SMR design aligns seamlessly with the country's energy goals and requirements. This can also enable MSs to identify potential challenges and risks associated with SMR deployment. Addressing these challenges early in Phase 1 allows for the development of effective risk mitigation strategies, enhancing the deployment's overall success and safety.

Moreover, engaging governments, vendors, owner/operators, and regulatory bodies in the accelerated deployment of SMRs holds several compelling benefits for each stakeholder group.

### Governments

Accelerated SMR deployment can serve as an economic stimulus, creating more jobs and driving investments in the nuclear energy sector. Governments can use this opportunity to foster innovation, support local industries, and contribute to overall economic growth. This is particularly applicable for countries with smaller grids or in remote areas, where construction of large NPP is not feasible or not possible. Furthermore, accelerated deployment of SMRs fosters the development of the local industry. By investing in SMR technology, countries can stimulate innovation and expertise within their own borders, driving economic growth. This local industry development not only supports the nuclear sector but also has spillover effects on other related industries, further boosting the economy.

The timely deployment of SMRs supports governments in meeting carbon emission reduction targets. As a low-carbon energy source, SMRs can play a crucial role in transitioning to a more sustainable and environmentally friendly energy landscape.

Governments engaging in the accelerated deployment of SMRs position themselves as leaders in nuclear technology innovation. This can enhance the country's global standing and attract international collaborations.

The ability to meet the country's energy demand more rapidly through SMRs not only addresses immediate energy needs but also reduces financial risk associated with prolonged energy shortages. With SMRs, deployment timeline can be shortened, ensuring a quicker response to energy demands and reducing the potential economic impacts of energy scarcity.

Also, the adoption of SMR technologies enhances energy security and ensures affordable energy is available in a shorter period. With traditional large-scale nuclear projects often facing lengthy approval processes and construction timelines, SMRs may offer a more agile solution to meeting energy needs. Moreover, by accelerating the availability of nuclear energy, countries can stabilize energy prices and mitigate the risk of volatile energy markets, providing affordable and reliable energy to consumers more rapidly.

For the government, quick and risk-free completion of the national nuclear power programme is imperative. Consequently, the government should allocate additional resources and funds early on to acquire comprehensive information regarding SMR nuclear power initiatives. Sharpening your axe will not delay your job of chopping wood，proactive investment in the initial stages expedites the progression of the nuclear power plant and ensures smoother next operations.

### Vendors

Early engagement in the deployment process provides an opportunity to expand their market presence. By actively participating in Phase 1, vendors can show themselves as key players in emerging markets, potentially securing long-term contracts for multiple deployments.

Early involvement allows vendors to collaborate closely with nuclear energy programme implementing organizations (NEPIO), gaining insights into specific legal and regulatory requirements and potential challenges. This collaboration facilitates risk mitigation strategies, ensuring that the design and technology align seamlessly with possible future regulatory expectations.

For vendors, the challenge of recovering upfront investment costs through a single project is significant. Therefore, propagating a particular model of SMR across multiple nations presents an optimal strategy for spreading the costs associated with research and development activities, supply chain, and manufacturing. To facilitate this, suppliers can focus on establishing dedicated training centers and delivering comprehensive training programs. These initiatives not only serve as effective avenues for promoting SMR technology at a lower cost but also serve to provide member countries with essential technical expertise. This, in turn, enables emerging nations to access a broader spectrum of SMR technology information. As vendors establish a strong market presence and gain widespread recognition, they naturally attract more orders, leading to a self-sustaining cycle of growth and cost-sharing.

### Owner/Operators

Early participation facilitates Owner/Operators enables a comprehensive understanding of key technical features associated with diverse SMR designs, enhancing decision-making and project planning efficacy. Moreover, in conducting thorough technical evaluations and selecting suitable technologies, this cooperation will support the definition of project requirements and will allow to gain knowledge on regulatory requirements applied by the designers. Additionally, early involvement fosters strategic partnerships with vendors and engagement with regulatory bodies, promoting collaborative efforts towards achieving project goals.

Early participation can enable Owner/Operators to familiarize themselves with the regulatory framework more quickly, ensuring they are fully prepared for site license applications, and thereby accelerating the licensing process. At the same time, sufficient information collection will help Owner/Operators obtain more insights during the bidding negotiation.

Early engagement allows Owner/Operators to establish comprehensive communication channels with vendors. This includes discussions on employee training, supply chain deployment, and the transportation, storages, and installation of modular equipment. By addressing these issues upfront, Owner/Operators can ensure smoother project execution and minimize potential delays or misunderstandings during later stages of deployment.

Accelerated deployment can reduce the overall time and costs associated with implementing SMR projects. Owner/Operators stand to benefit from streamlined regulatory processes, shorter project timelines, and lower upfront costs, enhancing the economic viability of nuclear energy projects.

### Regulatory Bodies

The updated deployment timelines for SMRs require member states to spend less time in Phases 1 and 2, and regulatory streamlining plays a significant role in shortening the timelines.

For embarking countries, establishing a robust regulatory framework is paramount in Phase 1 and 2 of nuclear power programme. This framework not only dictates the next project steps but also profoundly influences the construction and operation of nuclear plants in the long term. Therefore, Member States must prioritize the development of a streamlined regulatory framework, particularly crucial for SMRs. It is essential to maintain that national regulatory bodies should be the primary architects of the regulatory framework. Frameworks from vendor countries should serve as references, with adjustments made to tailor the regulatory framework to the specific needs and circumstances of the embarking country.

Before SMRs technology is supplied by vendors, a reference plant is usually built in the vendors' countries, and they will have a complete regulatory process as well. In communicating with vendors in Phase 1, embarking countries should conduct international regulatory activities and information exchange to identify the best regulatory framework.

## ROLE OF THE IAEA

The IAEA serves as a pivotal hub for fostering global collaboration in nuclear energy, and its SMR Platform can play a crucial role in advancing the accelerated deployment of SMRs, as it coordinates the IAEA’s activities in the field of SMRs and serves as the mechanism by which the IAEA responds to requests from Member States related to SMRs. To maximize the impact of the IAEA SMR Platform [5], it is imperative to broaden its activities. In line with this, the IAEA established the Nuclear Harmonization and Standardization Initiative (NHSI) with the goal of effectively deploying safe and secure advanced nuclear reactors worldwide.

The IAEA set up two separate but complementary tracks for the technology holders/operators and the regulators: the NHSI Regulatory Track and the NHSI Industry Track. The NHSI Industry track aims to develop common industrial approaches by aligning technology holders with users' requirements and criteria by operators. This alignment ensures consistency with principles of fair global competition, protection of intellectual property rights, and support for innovation and continuous improvement. The NHSI Regulatory track seeks to establish harmonized regulatory approaches among national regulatory bodies. This includes the development of a common set of internationally recognized reference frameworks and processes for licensing and pre-licensing reviews, while maintaining individual national responsibilities for safety and security [6]. The NHSI bringing together top-level decision makers from governments, regulators, designers, technology holders, operators, non-traditional end-users, and other international organizations and associations to collaborate under one framework.. The Regulatory Track comprises three working groups:

* International Framework for pre-licensing/licensing information sharing to facilitate collaborative reviews and multinational reviews;
* Developing a process and reference framework for multinational pre-licensing regulatory reviews;
* Developing a process to leverage the reviews of other regulators and for regulators to work together during ongoing regulatory reviews.

Moreover, the IAEA SMR Platform can spearhead collaborative initiatives among countries facing similar SMR deployment needs. By fostering resource-sharing and enabling a collective approach to regulatory challenges, the platform becomes a nexus for countries to leverage shared experiences and expertise. This collaborative synergy can contribute to streamlined regulatory processes and accelerate the global adoption of SMRs.

In terms of tailored trainings, recognizing the unique challenges and requirements associated with SMRs, the IAEA can design specific training programs. These programs would educate regulatory professionals, ensuring they are well-versed in the intricacies of overseeing this innovative technology. By empowering regulatory bodies with specialized knowledge, the IAEA contributes to the development of effective and responsive regulatory frameworks.

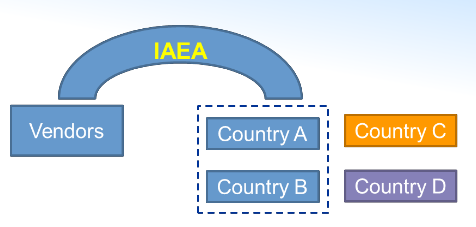
To facilitate knowledge sharing and global access to the information, the IAEA can also establish a robust monitoring and evaluation mechanism to assess the progress of SMR deployment worldwide. Regular assessments will not only help identify challenges but also track improvements, allowing for adaptive strategies to be implemented swiftly. This proactive monitoring ensures that the global community remains agile in addressing emerging issues, fostering continuous improvement in the SMR deployment landscape.

Finally, to ensure access to knowledge, the IAEA can establish an online learning platform offering courses related to SMRs. This innovative approach facilitates global access to educational resources, enabling professionals from various regions to enhance their expertise without geographical constraints. Such a platform aligns with the IAEA's commitment to knowledge-sharing and capacity-building on a global scale.

## new collaboration model FOR EMBARKING COUNTRIES

To facilitate knowledge exchange and resource sharing between countries with similar infrastructure, economic situation and aiming at introducing the same reactor technology, it is suggested to introduce a new collaboration model. Such collaborative efforts involving both regulatory agencies and industry stakeholders can speed up regulatory and licensing approvals and enhance the efficiency of SMR deployment. This cooperative approach not only accelerates deployment but also helps to recognize lessons learned that promote regional energy security and collaboration in nuclear technology advancement. The proposed model (see Fig. 2) offers several advantages for both countries:

* Collaborating on SMR deployment enhances regional energy security by diversifying the energy mix and reducing dependence on external energy sources. With shared SMR infrastructure, countries can better withstand disruptions in energy supply and mitigate the impacts of geopolitical tensions or natural disasters.
* Countries can pool their resources and expertise, leveraging each other's strengths in design, engineering, and operation. This knowledge-sharing accelerates the development process and fosters innovation as both countries contribute unique insights and experiences.
* Jointly investing in SMR projects allows countries to share the financial burden associated with nuclear technology development and deployment. This can significantly lower the costs for each participating country, making nuclear energy more financially feasible and reducing the risk of overburdening national budgets.



*FIG. 2. New cooperation model for embarking countries*

This model suggests several steps to be done by interested Member States, namely:

* Sign the joint Memorandum of Understanding between country A and country B outlining the intentions and terms of cooperation.
* Establish a joint task force or working group with representatives from both countries. This group can work on specific aspects of the collaboration, such as technology assessment, regulatory harmonization, and project planning.
* Work towards aligning regulatory frameworks between the two countries.
* Collaborate on a joint technology assessment to evaluate the suitability of the chosen SMR technology for both countries.
* Facilitate joint discussions with potential vendors.
* Collaborate on capacity-building initiatives, including training programs, knowledge transfer, and skill development.
* Explore opportunities for resource sharing, such as joint funding mechanisms, to support collaborative projects.
* Establish a dispute resolution mechanism within the collaboration framework to address any disagreements or challenges that may arise during the partnership.

## cONCLUSION

In conclusion, the pursuit of accelerated SMR deployment necessitates a concerted effort from regulatory bodies, governments, and industry stakeholders. The proposals put forward in this paper emphasize the importance of early engagement and collaboration among all parties involved. By adopting a proactive approach and leveraging collective expertise, countries can expedite regulatory processes, streamline project timelines, and mitigate risks associated with SMR deployment.

The economic advantages stemming from initiation of several activities in Phase 1 and condensed Phase 2 timelines serve as a compelling incentive for vendors and owner/operators, while the broader spectrum of job creation, investments, and carbon emission reduction aligns governments with their sustainability goals. The envisaged roles of entities such as the IAEA and other international organizations serve as cornerstones in ensuring a harmonized, monitored, and well-educated landscape for SMR deployment.

The introduction of an updated deployment timeline for SMRs, coupled with a new collaboration model for embarking countries, underscores the significance of synchronized efforts in realizing the potential of SMRs as a transformative force in the global energy landscape.

Furthermore, the role of the IAEA is paramount in facilitating knowledge exchange, providing training programs, and establishing monitoring mechanisms to ensure the efficient deployment of SMRs worldwide. By fostering collaboration and innovation, the IAEA can serve as a catalyst for accelerating SMR deployment.

As we stand at the precipice of a transformative era, a paradigm shift towards proactive engagement and collaborative decision-making is needed. By embracing this approach, regulators, governments, vendors and Owner/Operators can collectively harness the potential of SMRs to meet energy demands, mitigate climate change, and foster global energy security.

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