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Considerations to Facilitate the Accelerated Deployment of Small Modular Reactors

IAEA Nuclear Harmonization and Standardization Initiative

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CONSIDERATIONS TO FACILITATE THE ACCELERATED DEPLOYMENT OF SMALL MODULAR REACTORS

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CONSIDERATIONS TO FACILITATE THE ACCELERATED DEPLOYMENT OF SMALL MODULAR REACTORS

IAEA NUCLEAR HARMONIZATION AND STANDARDIZATION INITIATIVE

INTERNATIONAL ATOMIC ENERGY AGENCY
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For further information on this publication, please contact:

Nuclear Infrastructure Development Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

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FOREWORD

Interest among IAEA Member States in the deployment of small modular reactors (SMRs) has grown substantially in recent years. In response to this increasing interest, the IAEA launched the Nuclear Harmonization and Standardization Initiative (NHSI) in 2022. This initiative seeks to foster collaboration among high level decision makers, regulatory bodies, designers, technology holders, operators, non-traditional end users and relevant international organizations and associations under a unified framework, with the overarching goal of enabling the effective global deployment of safe and secure advanced nuclear reactors.

The NHSI is structured in two complementary tracks, the Regulatory Track and the Industrial Track, that work to develop technical publications, produce reports and establish networks of collaboration to support technology holders and operators in developing and achieving the objectives of the initiative. This publication was developed by one of the technical groups under the Industrial Track, Topical Group 4, which focuses on the acceleration of nuclear infrastructure development for SMRs, specifically in the context of the 19 infrastructure issues described in IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 2), Milestones in the Development of a National Infrastructure for Nuclear Power.

This publication presents an assessment of nuclear power programme infrastructure in the deployment of SMRs and is based on contributions from IAEA experts, industry organizations, technology holders, newcomer and expanding Member States, vendors, international organizations and other experts. It proposes some key strategies to support the acceleration of nuclear power infrastructure development in countries considering SMR projects, drawing on lessons learned from the implementation of existing large nuclear power plant programmes in Member States and taking into account the specific characteristics of SMR technologies.

The IAEA is grateful to the contributors listed at the end of this publication. The IAEA officers responsible for this publication were S. Debrah, M. Scott and B. Lepouzé of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

There is a strong and increasing interest in small modular reactors (SMRs) by many States because of their potential. Key factors are lower upfront cost, fitting for smaller grids, and shorter construction timelines. Thus, in response to Member States interest in SMRs, the IAEA launched the Nuclear Harmonization and Standardization Initiative (NHSI) in June 2022. NHSI aims to advance the harmonization and standardization of SMRs.

The NHSI initiative has two complementary tracks: the Regulatory Track and the Industry Track. The Regulatory Track has three Working Groups and aims to 'increase regulatory collaboration among Member States, avoid duplication of efforts, increase efficiency, and facilitate the development of common regulatory positions without compromising nuclear safety and national sovereignty'[1]. The Industry Track aims to develop more standardized industrial SMR development and deployment approaches. The Industry Track has several Topical Groups (TGs)[2].

One of the Topical Group (Topical Group 4) focuses on the acceleration of nuclear infrastructure development for SMRs in order to respond to the foreseen faster deployment models. This group aims to review the 19 infrastructure issues in Phases 1, 2 and 3 described in IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 2), Milestones in the Development of a National Infrastructure for Nuclear Power [1] and to identify if some infrastructure issues can be accelerated or applied using a graded approach in nuclear power programmes considering SMRs.

This publication is part of the outputs of Topical Group 4, and is intended to complement the Milestones approach [1] and not to replace it. It has been prepared in response to the requests received from more than 30 embarking and expanding countries on how SMR technologies and new deployment models can facilitate, and in some cases accelerate, the implementation of the required nuclear infrastructure and project development.

Some considerations presented in this publication are currently under discussion and have not been fully implemented in Member States.

1.2. OBJECTIVES

The objective of this TECDOC is to help Member States understand how nuclear infrastructure development for a nuclear power programme based on SMRs can be accelerated or graded and optimized when compared to a programme based on conventional large nuclear power plants (LNPPs).

It is proposed that the content of this TECDOC be revisited in the future, as the development and implementation of SMR projects advance, so that experiences in terms of nuclear infrastructure development for SMRs may be incorporated.

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[1] https://www.iaea.org/services/key-programmes/smr-platforms-nhsi
[2] https://nucleus-qa.iaea.org/sites/smr/SitePages/Nuclear-Harmonization-and-Standardization-Initiative.aspx

1.3. SCOPE

This publication addresses primarily the development of nuclear infrastructure required for nuclear power programmes based on mature SMR technologies and are likely to be commercially deployable in the near term. These technologies would be mainly used for electricity production.

Many innovative designs and new deployment models are in development and at different stages of technology readiness. How nuclear infrastructure would need to be adapted to take into account these technologies and how they are operated remains to be demonstrated. This could be the scope of future revisions of this TECDOC as experience grows with other SMR technologies.

1.4. STRUCTURE

This publication comprises 5 sections in addition to this introduction (Section 1). Section 2 provides an overview of SMRs and the deployment models used by vendors and designers to support embarking and expanding countries undertaking nuclear power programmes based on SMRs. Section 3 outlines potential strategies for the accelerated deployment of SMRs in relation to key identified nuclear infrastructure issues that than can support the infrastructure development acceleration. Section 4 describes roadmap for the implementation of a nuclear power programme employing an SMR technology. Section 5 outlines current international cooperation frameworks that support accelerated deployment of SMRs. Annexes I and II provides information on two initiatives being developed that might support SMR deployment acceleration. Annex III provides SMR deployment roadmap scenarios for an Nth-of-a-kind SMR project.

2. OVERVIEW OF SMALL MODULAR REACTORS

2.1. DEFINITIONS

SMRs are advanced reactors with an electrical output typically of up to 300 MW(e) per module or the equivalent in other applications such as steam production, desalination and hydrogen production. Reactors with a power capacity typically lower than 10 MW(e) or equivalent are identified as microreactors [2]. SMRs have advanced engineered safety features and are intended to be produced in series in factory production and shipped to utilities for installation as demand arises. They are deployable either as a single or multi module plant, and SMRs are under development in all the principal reactor technologies.

A particular category of SMRs is transportable reactors. A transportable nuclear power plant (TNPP) is a factory manufactured, movable nuclear power plant, which when fuelled can produce final energy products such as electricity and heat. TNPPs are not designed to operate during transportation [2]. Interest in nuclear propulsion is also growing as a means of decarbonizing civil merchant shipping. Some proposed deployment scenarios for TNPP and marine propulsion raise legal and practical questions that still need to be clarified [3].

2.2. TYPICAL SMR FEATURES

There are about 70 designs proposed by different designers. Each one has some specific design characteristics. The following features are generally found in SMRs although not necessarily in every design [4].

- Designed for load following, when connected to the grid;
- Standardized designs requiring limited adaptations for different sites;
- Serial production of structures, systems and components (SSCs);
- Reduced requirements for external cooling water in favour of heat sinks that dissipate heat to the atmosphere;
- Inherent safety features that ensure predictable behaviour of the facility and sufficient time to mitigate potential accidents;
- Modular SSCs to enable improved robustness against external events, better integration of safety, security and safeguards, faster construction on site, improved maintainability, and reduced decommissioning complexity;
- Robust nuclear fuels that better resist harsh operation conditions and allow for manoeuvrability and longer fuel campaigns.

Other features of many advanced current and evolutionary SMR designs include:

- Improved concepts of operation such as next generation control room designs by utilizing digital technologies, sophisticated instrumentation and control (I&C) systems, along with cybersecurity measures to enhance plant operations;
- Multiple unit arrangements deployed in groups or as a single facility containing multiple units;
- Provisions in the facility architecture for generation of non-electrical applications.

Many of these advanced features are not necessarily unique to SMRs. Some are already introduced in new LNPP designs. However, these features are expected to be applied to a greater degree and in increasing combination with one another in SMR designs.

2.3. SMR TECHNOLOGIES

References [4, 5] identify six main technology lines of SMRs that are briefly presented below.

2.3.1. Land based water cooled SMRs

With 15 different designs, land based water cooled SMRs make up the largest group of new designs, according to the Advanced Reactors Information System (ARIS) database[3]. They rely on technology developed for large reactors such as pressurized water reactors, boiling water reactors and in some cases heavy water reactors. Most designs focus on simplification and modular construction to control cost. Some designs include innovations such as integrated pressure vessels.

Some reactor designs under this category are expected to be commercially available between 2026 and the early 2030s.

2.3.2. Marine based water cooled SMRs

Six pressurized water reactor designs are listed in the ARIS Database for applications in barge mounted floating nuclear power plants (NPPs). One such design has been in operation since May 2020 on the Akademik Lomonosov in Pevek, Russian Federation. TNPPs such as this example offer an innovative deployment model with only a simplified nuclear infrastructure needed in the host country. However, this deployment model raises legal and practical questions that still need to be addressed to enable large scale deployment.

2.3.3. High temperature gas cooled reactors (HTGRs)

Fourteen HTGR designs are described in the ARIS Database, of which one design has already been in operation in China since 2022. In addition, there are three test reactor designs, two of which have been in operation for testing purposes. These designs use tristructural isotropic fuel which allows them to retain fission products, even at high temperatures.

2.3.4. Liquid metal cooled fast neutron spectrum reactors

The ARIS database identifies 10 designs of fast reactors that use sodium, lead or lead bismuth as coolants. As progress is achieved on fast reactor development, SMRs relying on this technology may become a credible option, although some models currently considered are more for demonstration purposes with the building large fast reactors coming later.

Fast reactors are traditionally associated with a closed nuclear fuel cycle, which simplifies the strategy for the nuclear fuel cycle. However, radioactive waste streams still need to be managed, and a disposal facility will still be needed, no matter what type of fuel is used, whether oxide fuel (UO_2, MOX), metal fuel (U-Zr, U-Pu-Zr alloy) or nitride fuel (UN, U-PuN).

[3] https://aris.iaea.org/

2.3.5. Molten salt reactors

Molten salt reactors represent 12 designs in the ARIS database, one of which is considered for deployment on a barge. Molten salt reactors are one of the six categories of Gen IV reactors and have to overcome some challenges.

2.3.6. Microreactors

Microreactors can be of many different designs, with coolant ranging from light water, helium, molten salts, and liquid metals. Their output power is typically less than 10 MW(e) and intended for niche applications, such as remote regions or mining industries currently supplied by diesel generators. Although these reactors may be smaller, how they are deployed and the technologies they use can present considerations that need to be addressed in the nuclear infrastructure.

As microreactors are transportable and likely adopt advanced fuel cycles, their potential numbers make safeguards potentially complex to implement. The small size of their footprint and the fact that they are transportable may however lead to innovative deployment models, which may in turn facilitate nuclear infrastructure implementation in the host country.

2.4. SMR TECHNOLOGY MATURITY

Technology maturity refers to how close a given design is to commercialization and deployment [6]. The most mature technology is one where one or more examples have been licensed, constructed, and commissioned, a supply chain has been established, and operating experience exists. A design with this level of maturity, also known as advanced current design, can provide a ‘reference plant’ for other projects. The information and expertise from a reference plant can significantly support the deployment of other NPPs of similar design in other countries including embarking countries. The IAEA International Safety Advisory Group stated that “it is expected that a new entrant country will use the ‘reference plant’ concept for its first NPP” [7].

The Milestones approach [1] assumes that embarking or expanding countries will choose mature designs for which a reference plant exists to reduce project risks and gain support for implementing the nuclear energy programme. The cooperation between the vendor organizations and the embarking country for exchanging information, knowledge and experience related to the reference plant is paramount for the decisions needed during Phase 3 of the project from the operating organization and regulatory body in the recipient country. The level of cooperation is not intended to compromise the sovereignty of the embarking country or the independence of the embarking country’s regulatory body.

The next level of maturity, also known as advanced evolutionary design, is one in which a design has not yet been in operation, but for which the project proponent, generally in the country of origin, has assembled a comprehensive safety case that a regulatory body has reviewed as the basis for authorization of construction or operation. In this case, there is confidence that the reactor design meets regulatory requirements if constructed and operated in accordance with the licensing basis documentation. However, the construction of the plant, and its actual performance after construction remains to be verified.

The lowest level of maturity is one in which the proponent has received some form of structured and documented feedback from an experienced nuclear regulatory body with a suitable regulatory framework. This can take the form of either a binding regulatory decision, such as design certification, or a non-binding pre-licensing opinion [8].

To date, only a few SMR designs have reached high levels of maturity. The Nuclear Energy Agency (NEA) SMR Dashboard [9] defines criteria for assessing progress across six dimensions of readiness: licensing, siting, financing, supply chain, engagement, and fuel. Ranked against these criteria, water cooled and high temperature gas cooled reactors are among the SMR designs that are closest to readiness for commercial deployment.

SMR designers and companies worldwide continue to progress in developing and deploying SMR designs. Therefore, this report will be updated periodically to reflect the experience gained in SMR design and deployments.

2.5. DEPLOYMENT MODELS

In a broad sense, the ‘deployment model’ for a nuclear power programme refers to the choice among various forms of ownership and operating models and different approaches to contracting for the supply of the NPP.

One of the challenges an embarking country faces is establishing and developing the operating organization for the SMR so that it can discharge its roles and responsibilities throughout the phases of the programme. A practical approach for the embarking country in addressing this challenge is to utilize foreign experience including support provided by the vendor country [10].

Embarking and expanding countries generally include request for a support package to ensure the programme's long term sustainability in addition to the specifications for the NPP. Such support packages may include:

- Project finance;
- Assurance of fuel supply either for a limited period or for the lifetime of the reactor;
- Support to establishing the design authority and other functions of the operating organization;
- Training of personnel;
- Support for commissioning, operation and maintenance of the NPP;
- Support for the regulatory body and enhancement of the regulatory framework;
- Support for licensing;
- Technical and scientific support;
- Support for decommissioning and radioactive waste management;
- Spent fuel management (long term storage and/or recycling).

Experience shows that technology providers for conventional LNPPs have the capacity to offer support to assist the newcomer country in implementing its programme.

SMRs, with claims of a lower upfront cost, a shorter construction period, and being small and scalable, can potentially reduce the need for support compared to LNPPs. However, the SMR technology has to address issues related to licensing and oversight of manufacturing and construction.

The costs of constructing manufacturing facilities also need to be considered as they might not yet exist. Furthermore, many companies currently developing and offering SMRs have only a relatively small staff and resources and are focused on developing their designs and gaining parallel regulatory approval in several countries. They usually lack experience with manufacture, construction, or operation of an NPP. Such companies thus may lack the capability to provide extensive customer support unless they enter into joint ventures with project developers, operating organizations and fuel suppliers to respond to the needs of embarking countries.

Some SMR designers, mainly for reactors in the lower power range, are proposing novel deployment models that go beyond current practice. This is the case, for example, where companies are proposing to supply the reactor and the fuel, to own, operate and maintain the plant, deal with the wastes generated during operation, and take responsibility for decommissioning and removal of the reactor at the end of its life. This model is attractive for embarking countries, as it reduces scope of some nuclear infrastructure elements. However, these practices in some cases might not align with the current international legal framework, safety and regulatory approaches specified in the IAEA Safety Standards. Additional efforts are required by the international community to assess the safety implication of these approaches and ensure compliance with the current international legal framework and safety and regulatory approaches.

3. STRATEGIES FOR THE ACCELERATED DEPLOYMENT OF SMRS

3.1. THE MILESTONES APPROACH

A nuclear power programme, whether based on LNPPs or SMRs, requires the development of an adequate nuclear infrastructure that provides the environment, processes and capabilities enabling the safe, secure and sustainable introduction of nuclear power. Specific activities are carried out to implement the first NPP project and the Milestones approach [1] provides a comprehensive and phased approach for the development of the required infrastructure covering 19 infrastructure issues throughout the 3 phases. It is complemented by a methodology for evaluating the status of national infrastructure development [11].

Based on Member States experiences in developing a nuclear power programme for large NPPs, the Milestones approach [1] envisages a time frame of 10–15 years (Shown in Fig. 1) to progress from Phase 1 (considerations before a decision to launch an NPP) through Phase 2 (preparatory work for contracting and construction of an NPP) up to the completion of Phase 3 (activities to implement the first NPP) and reaching Milestone 3 (ready to operate the first NPP). This suggested time frame relates to the experience of countries that have implemented nuclear power programmes consisting of conventional LNPPs.

There is significant agreement across nuclear energy experts that the Milestones approach [1] remains applicable to SMRs as the approach and its evaluation methodology are being used by newcomer countries to develop nuclear programmes. Some of the 19 infrastructure issues activities in each of the Phases of the Milestones approach can be accelerated or addressed using a graded approach to improve efficiency and enable countries to deploy nuclear power faster in a safe, secure and safeguarded manner.

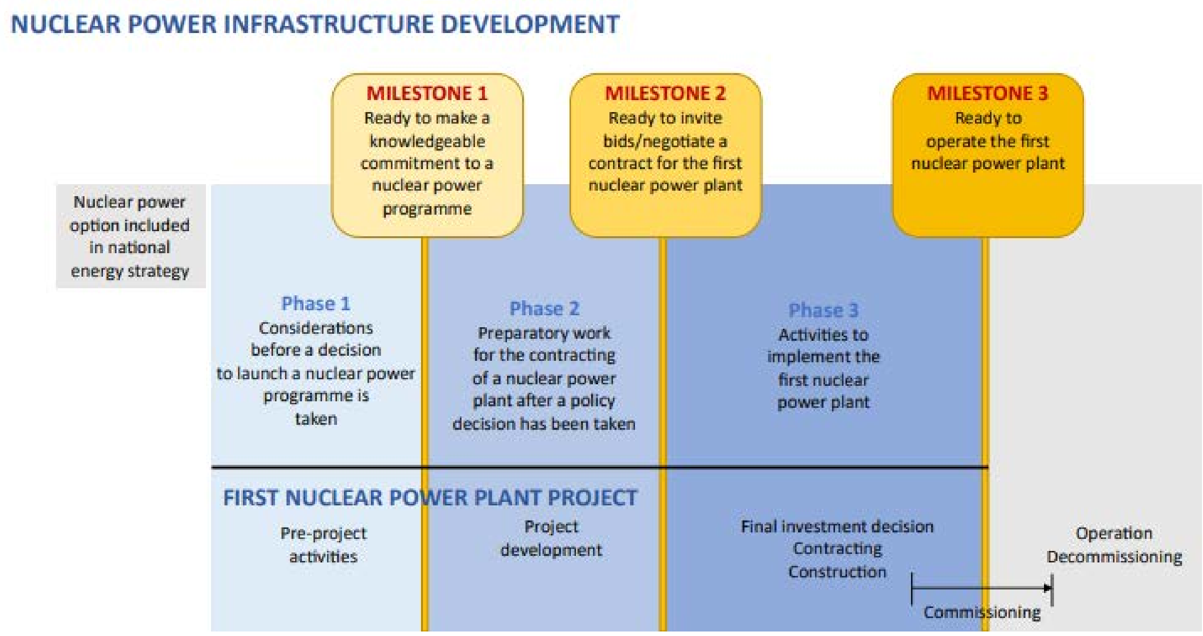

FIG. 1. Development of the infrastructure for a national nuclear power programme [1]

The Annex to NG-G-3.1 (Rev. 2) [1] provides some specific infrastructure considerations for SMRs for the 19 infrastructure issues. Focusing on some key infrastructure issues, the following sections explore the potential reductions in the timeline that may be achievable with nuclear power programmes based on SMRs that and are considered deployable in the near term.

3.2. INFRASTRUCTURE CONSIDERATIONS ENABLING SUCCESSFUL NUCLEAR POWER PROGRAMME IMPLEMENTATION

The experiences of Member States that have recently embarked on new nuclear power programmes, and the results of IAEA peer review missions, reveal different approaches to several key nuclear infrastructure issues that enabled, and conversely in some cases hindered programme implementation in each country. These issues are illustrated in Fig. 2 [12].

The following sections discuss the enabling approaches and challenges observed in embarking countries along with specific considerations for SMRs. As noted in the Milestones approach [1], while all 19 infrastructure issues are relevant to SMRs, the smaller footprints, different risk profiles, and claimed shorter manufacturing times of SMRs may enable alternative solutions for each issue.

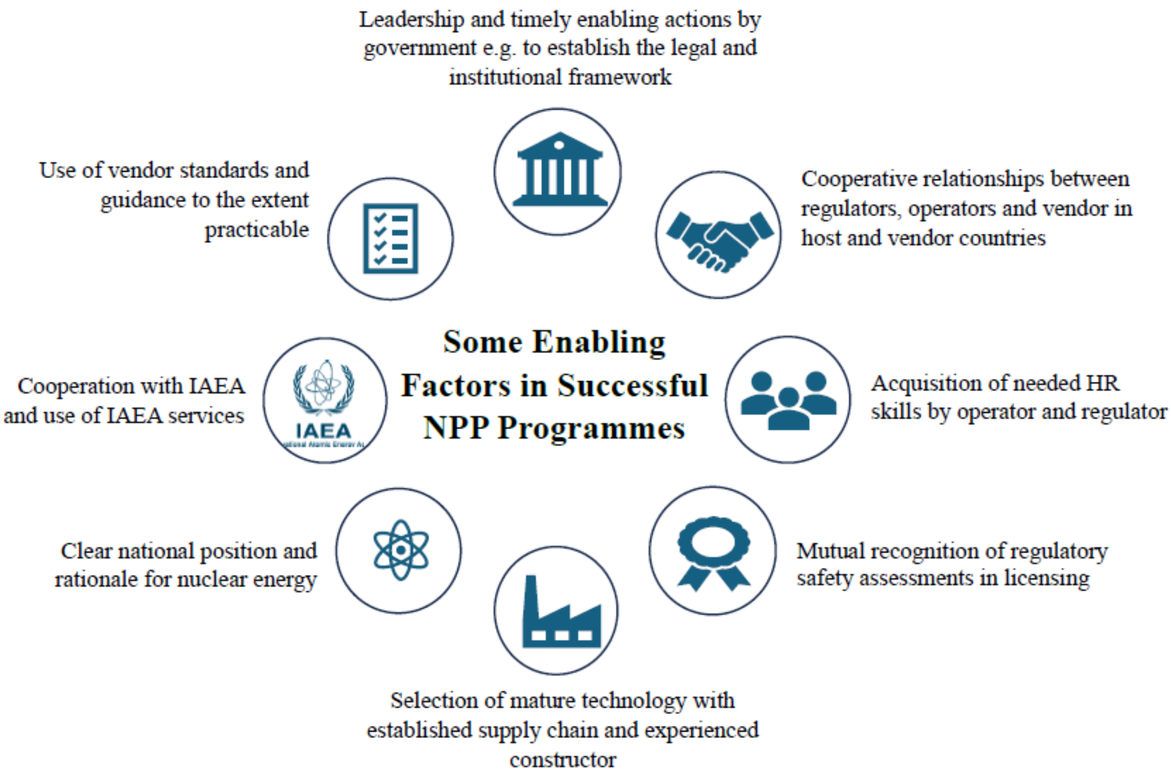

FIG. 2. Enabling factors supporting implementation of a nuclear power programme

3.2.1. National position

3.2.1.1. Issue outline

The national position provides the foundation for a safe, secure and sustainable nuclear power programme. Under the Milestones approach [1], various conditions need to be satisfied to demonstrate the establishment and update of the national position during each Phase of a nuclear power programme [11].

To reach Milestone 1, the conditions to be met comprise, first, a clear statement from the government recognizing the importance of a long term commitment, safety, security and non-proliferation in developing a nuclear power programme; second, the establishment of an effective Nuclear Energy Programme Implementing Organization (NEPIO); and third, the preparation of a comprehensive report [13], based on the prefeasibility studies, that sets out the national strategy for introducing nuclear power.

The conditions for reaching Milestone 2 reflect the evolution of the nuclear power programme in Phase 2, namely, the role of the NEPIO in ensuring that the approved programme policies and strategies are translated into concrete actions and that corresponding responsibilities are assigned to the organizations that will become permanent parts of the nuclear infrastructure. The NEPIO's coordination function and responsibilities also needs to be clear.

The conditions for reaching Milestone 3 reflect the further evolution of the nuclear power programme: the government support role is defined and effective; the national strategy is successfully implemented, and long term support through international cooperation is evident.

3.2.1.2. Enablers and challenges observed

Case studies of countries that have recently implemented nuclear power programmes, including Belarus and the United Arab Emirates, show that the government in each country conducted early studies and planning that resulted in the establishment of a sustainable national position on nuclear power that included a clear policy and the rationale for introducing nuclear power and had significant stakeholder support.

Other aspects of the successful national approaches in these countries included sourcing of mature NPP technology from an experienced vendor with a reference plant in the country of origin, and establishing cooperation agreements with the governments of the respective vendor country that facilitated the transfer of knowledge and expertise [14].

Conversely, Integrated Nuclear Infrastructure Review (INIR) missions [12] have identified factors that inhibited the formation of a sustainable national position in other countries, including the following:

- Political considerations, for example, a lack of high level political support, or change of the political party in power, or lack of support from one or more major stakeholders such as an important government ministry;
- Changing energy demand scenarios that affect the rationale for the NPP project;
- Financial considerations, where some NPP projects have been delayed by the lack of a realistic financial strategy that wins the confidence of potential lenders;
- Shortcomings in public opinion and acceptance necessary to build and sustain a national position;
- Technical considerations impacting the implementation of the nuclear power programme, for instance, limitations in the electrical grid capacity.

3.2.1.3. Considerations for programmes based on SMRs

The experience of INIR missions relates to programmes based on large NPPs with extensive government involvement. However, even SMR projects led by private companies as promoters and developers need the government to head up the development of a national position in line with international standards and legal instruments. Therefore, it is essential that the government of a country that is considering the introduction of a new nuclear power programme or the expansion of an existing programme using SMR technology takes steps to develop a national position in line with the Milestones conditions in a way that can be sustained for the duration of the programme. The characteristics of SMRs with smaller footprints, shorter construction period, smaller electrical outputs, enhanced safety features, and lesser financing requirements per unit, can help address the challenges identified above.

Key steps that governments can take to develop a sustainable national position for deployment of SMR technology include the following:

- Obtaining broad national support for the nuclear power programme by engaging with all relevant stakeholders who influence decisions, including political leaders, national and local authorities, non-government organizations, the public and particularly population close to the site(s);
- Establishing an effective NEPIO with a clear allocation of responsibilities, resources and timescales for the work required in developing the national position and coordinating the implementation of the nuclear power programme;
- Conducting and updating regularly realistic and sound energy planning to provide a rationale for nuclear power as a viable and long term option;
- Conducting comprehensive and realistic prefeasibility studies.

3.2.2. Management

3.2.2.1. Issue outline

Establishing and maintaining the Management systems of the key organizations for a new nuclear power programme is both challenging and demanding, thus, highly competent managers are vital to success at all stages.

The senior managers of the operating organization and the regulatory body develop their respective organizations, recruit and motivate staff, develop a training programme, establish management systems, build project management capabilities, and lead the activities required to develop the NPP project and associated nuclear infrastructure. The roles and responsibilities of the organizations evolve as a national nuclear power programme progresses from consideration to implementation and ultimately to operation.

To reach Milestone 1, the condition to be met is the recognition of the need for appropriate leadership and management systems.

To reach Milestone 2, the conditions to be met are the following [11]:

- Contract specifications and evaluation criteria are determined;

- Operating organization competence is evident for procuring and managing the NPP contract, and plans are in place to develop operator competence;
- Management systems are established in each of the three key organizations.

To reach Milestone 3 the conditions to be met are the following [11]:

- Ongoing arrangements for support are clear;
- Structure and staffing of the operating organization for commissioning and operation are in place;
- Management system for operation developed;
- Mechanisms are in place for verification of construction and handover of SSCs.

3.2.2.2. Enablers and challenges observed

Early in the programme, the NEPIO and/or the government play a significant role in establishing nuclear infrastructure, including putting in place the necessary legal and institutional frameworks. As the programme progresses, experience in embarking countries shows that a strong ownership team and an experienced and capable delivery team are vital to successful project delivery [10].

However, INIR missions have identified that the establishment of the operating organization sometimes lags when compared with other aspects of programme development. In some countries, another organization, such as the Atomic Energy Commission/Agency, works on behalf of the future operating organization.

In several embarking countries, organizations have initiated the development of management systems to structure their activities but have not effectively completed or implemented these management systems. Another factor identified is the need to further develop a safety and security culture.

3.2.2.3. Considerations for programmes based on SMRs

Management of the nuclear power programme remains challenging, requiring the key organizations to be established and effective early in the programme.

Considering the compressed time frame for SMR programme implementation, particularly for Phase 3, the key organizations need to be established and effective early in Phase 2 to respond to the project needs in this and the subsequent Phases of the programme. Strategies to meet this objective include developing in Phase 1 detailed plans and roadmaps for organization development, and in Phases 2 and 3 using, technical and scientific support organizations (TSOs) and external experts to augment the skills available inhouse to support implementation. Transferable skills around modularization will be essential to secure for the main contractor in order to aid in delivering projects on schedule.

For certain SMR designs, the increased use of factories is foreseen to serially produce large complex modules for use in many projects which could be deployed in different countries. Some SMR concepts may see most of the facility constructed and potentially commissioned to some degree on the factory floor. The future operating organization in the embarking country needs to develop internal capabilities and appropriate technical support mechanisms to oversee these activities. The understanding and adoption of standards by the future operating organization used in the serial production can be a good starting point.

While conducting construction oversight activities, the future operating organization also needs to develop the organization and ensure the qualification of personnel for operation and maintenance. The staff complement of the operating organization of an SMR may be lower than that of a large NPP, but the range of competencies required will be largely the same.

The shorter time needed for SMR project implementation allows less time for the capacity and capabilities of the operating organization to be established in time to effectively oversee the project and assume readiness to operate. This is especially a challenge for embarking countries given that certain functions need to begin development in the very early stage of Phase 2 to meet the facility in-service date. To overcome such constraint the vendor country can provide early support to enable capacity and capability building for the future operating organization. In addition, the vendor country may provide support in SMR operations.

3.2.3. Legal framework

3.2.3.1. Issue outline

The national legal framework for nuclear power is expected to comprehensively cover all aspects related to nuclear safety, nuclear security, safeguards and civil liability for nuclear damage and implement all related international legal instruments. The Milestones approach [1] identifies three main elements to be implemented by an embarking country:

- Adherence to the international legal instruments adopted by and under the auspices of the IAEA;
- The enactment of a comprehensive nuclear law;
- The enactment or revision of other legislation that may have an impact on the nuclear power programme.

To reach Milestone 1, plans need to be in place for adhering to the international instruments, enacting the nuclear law and revising or enacting other relevant laws. For reaching Milestone 2, these processes need to be completed. For Milestone 3, the focus is on implementation of the international instruments and the maintenance and update, as necessary, of the national legal framework.

3.2.3.2. Enablers and challenges observed

Several recent embarking countries acted early in their programmes to adhere to international safety, security, safeguards and nuclear liability instruments. In Phase 2, most countries enacted a comprehensive nuclear law that reflected the obligations of the international instruments and established an independent regulatory body with authority over safety, security, and safeguards. The new legal frameworks in each country built on pre-existing arrangements for control of radiation sources and other nuclear activities.

INIR missions identified that most embarking countries had ratified some international legal instruments in Phase 1; however, some lacked a clear plan to adhere to the remaining instruments. Drafting and enacting the nuclear law by the relevant government departments and the legislature in some countries took longer than initially expected, with corresponding impacts on the programme schedule.

Most embarking countries had made a limited assessment of other legislation that might impact the nuclear power programme and/or failed to make the necessary amendments when issues were identified.

3.2.3.3. Considerations for programmes based on SMRs

The main elements of the legal framework remain the same for SMRs, as the legal framework defines the responsibilities of all organizations necessary for any nuclear power programme.

Some SMR deployment models, such as those where a reactor is transported to or from the country of origin for refuelling or maintenance, may require additional legislation and/or adherence to other international legal instruments, such as the International Maritime Organization conventions.

As part of acceleration, the ability for regulatory body and operating organizations to easily contract TSOs is paramount. This may require some reviews or changes to the procurement laws in the host country. As part of the legal infrastructure, countries are expected to review the laws regarding procurement to allow the regulatory body and operating organization to go for competitive dialogue or one to one discussion with the vendor or TSO and not be obliged to go for a bidding process.

3.2.4. Regulatory framework

3.2.4.1. Issue outline

A competent, independent, well resourced nuclear regulatory body that has the strong support of the government is crucial to the safe and secure operation of an NPP. The confidence of the public and international community and, ultimately, to the long term success of a national nuclear power programme. Core elements of the regulatory framework comprise the following [15]:

- Assignment of core functions for safety, security and safeguards;
- Development of regulations and guides;
- Notification and authorization of facilities and activities;
- Review and assessment of facilities and activities;
- Inspection of facilities and activities;
- Enforcement;
- Emergency preparedness and response;
- Communication and consultation with interested parties.

To reach Milestone 1, one condition to be met is related to planning the development of an adequate regulatory framework.

To reach Milestone 2, the conditions to be met are the following [11]:

- A competent, effectively independent nuclear regulatory body is established;
- The regulatory framework is developed.

To reach Milestone 3, the conditions to be met are the following [11]:

- Competent and independent regulatory body operating effectively;
- Management system extended to cover commissioning and operation;

— Regulations and guides in place and reviewed regularly;
— Arrangements in place for cooperation with regulatory bodies in other countries.

3.2.4.2. Enablers and challenges observed

Case studies show that several countries that have successfully implemented a new nuclear power programme took early action to establish an independent regulatory body responsible for nuclear and radiation safety, security, and safeguards, thereby taking advantage of the synergies among these three areas. The organization of the regulatory body varies from country to country depending on the specific legal framework and the regulated activities.

In addition to the core functions referred to above, regulatory bodies in these countries are also charged with a variety of additional functions and responsibilities, including: establishing a national inventory of radiation sources, establishing a radiation dose register, setting up the state system of accounting for and control of nuclear materials, control of import and export of nuclear material and dual use items, commissioning or conducting research, fulfilling the State's international obligations, reviewing the radiological aspects of the environmental impact assessment, advising on nuclear liability, and cooperating with and advising other government departments and agencies.

However, experience shows that in other cases, the development of the regulatory body lagged behind the nuclear power project. While many countries began planning the regulatory framework in Phase 1, INIR missions identified the need for most countries to further enhance these plans [12]. Phase 1 INIR missions also identified the need for several regulatory bodies to make arrangements for external technical support for future activities, such as review and assessment, and inspections during construction.

Phase 2 INIR missions also identified the need in many countries to ensure that the regulatory body is fully established and has the necessary resources and competence to perform its future functions in Phase 3. Phase 2 INIR missions also identified the need for regulatory bodies to complete the development or adoption of the regulations and guides required for Phase 3.

3.2.4.3. Considerations for programmes based on SMRs

The accelerated schedule offered by new technologies such as SMRs and the technological differences as well as new deployment models [16] presents a further challenge to regulatory bodies. Therefore, the development of the regulatory body needs to be given high priority by the NEPIO in Phase 1, either as a new regulatory body or as an expansion of an existing regulatory body. Furthermore, the regulatory body would benefit from learning early about the new aspects that an SMR may bring to ensure they can progressively build their capacity and independence.

The practice used by some embarking countries of leveraging the regulatory evaluations and the regulatory submissions between the recipient country and the vendor country or another country that has licensed a similar facility is a valuable facilitator for SMR deployment and a basis for deep understanding by the regulatory body of the safety case for the technology. This is further discussed in Ref. [7] which states that "Once the nuclear power plant technology has been selected, there is a need for formal arrangements between the regulatory body of the new entrant country and one or more experienced regulatory bodies that have licensed a similar facility." Furthermore, safety reviews performed working with multiple regulatory bodies are encouraged in order to identify issues as early as possible. Also, regulatory authorities may focus on collaborative initiatives underway between regulatory bodies in different States.

The technical capabilities of the regulatory body need to be sufficient for assessing nuclear and radiation safety, security and safeguards issues and verifying compliance with all relevant aspects of the nuclear power programme. In general, most of the countries embarking on a nuclear programme receive technical and scientific support from several TSOs, via bilateral agreements, projects, and contracts [17]. Support from the SMR supplier country in that respect may be essential. In addition, government need to encourage the harmonization and alignment of regulations among regulatory bodies. However, for some novel aspects of SMRs, there may be challenges for newcomer country regulatory bodies to apply current safety practices such as in the IAEA safety standards [16]. Regulatory bodies from embarking countries could benefit from targeted technical support from the IAEA to gain further understanding on SMR specific safety and regulatory considerations.

3.2.5. Site and supporting facilities

3.2.5.1. Issue outline

Siting studies involve several stages, including identifying suitable areas, ranking specific sites, and justifying the suitability of chosen sites.

The selection and evaluation of a suitable site for an NPP requires the adoption and application of a clear set of attributes and associated criteria. This generally involves exclusionary attributes, used to discard regions/areas/sites that are unacceptable where there are no practicable engineering solutions, and discretionary attributes, used to identify favourable areas and ultimately to rank potential sites where protective engineering solutions are available.

To reach Milestone 1, the condition to be met is as follows [11]:

— General survey of potential sites conducted and candidate sites identified.

To reach Milestone 2, the conditions to be met are the following [11]:

— Detailed site characterization completed;
— Plans in place to prepare site for construction.

To reach Milestone 3, the conditions to be met are the following [11]:

— Confirmation of the site related design bases and the completion of all licensing and approval processes established effective;
— ongoing monitoring of the site before operation to confirm its acceptability.

3.2.5.2. Enablers and challenges observed

Several countries conducted site characterization studies during Phase 2, but the regulatory body did not complete its evaluation. Most countries used consultancy services from foreign technical and scientific support organizations in addition to their domestic capabilities to conduct the site characterization studies.

Areas where INIR missions identified gaps include [12]:

- The need for the regulatory body to issue guides for site evaluation to ensure that a firm clear basis exists for site selection and evaluation;
- The need to initiate activities for the confirmation of the site selection and site evaluation early in Phase 2, as studies and approvals are likely to take time and will require the involvement of various Ministries and stakeholders;
- The need for competent staff and an appropriate system for effective management and oversight of the site evaluation activities;
- In several countries there is a need to allocate responsibilities for works related to the development of the site infrastructure among the different organizations – e.g. vendor, operating organization, local government, national government and companies, and ensure adequate funding for those works.

3.2.5.3. Considerations for programmes based on SMRs

It is expected that, owing to the smaller source term and the lower demand for cooling water (dry cooling may be applied), more sites may be acceptable. This enhances the opportunities for countries with a small area to deploy SMRs in their territories. Technology developers may also apply higher safety margins against external events, which could allow a standard design to be deployed in a broader range of sites.

There could be a reduced demand for supporting facilities that need to be planned and built to accommodate construction workers and allow access to services. However, there may be SMRs with large, prefabricated modules that may require special transportation considerations.

Several concepts propose underground reactor placement; in such cases, further underground investigations will be needed. In the case of marine based water cooled SMRs, the SMR supplier may also assist in the site selection and design of onshore hydraulic structures at the site.

3.2.6. Human resources development

3.2.6.1. Issue outline

A nuclear power programme requires an adequate number of staff across all relevant organizations with the necessary scientific, technical, managerial and administrative knowledge and skill. Although the infrastructure for existing applications of radiation sources and nuclear energy provide a foundation, in most case studies, additional skilled personnel are needed to perform the regulatory functions for the nuclear power programme. Acquiring the necessary human resources to support all aspects of a new nuclear power programme is a significant challenge for embarking countries.

To reach Milestone 1, the conditions to be met are the following [11]:

- Necessary knowledge and skills identified, and gaps in current capability are assessed;
- Development of human resources is planned.

To reach Milestone 2, the conditions to be met are the following [11]:

— Knowledge and skills needed in organizations for Phase 3 and operational phase identified;
— A plan is available (for each organization) to develop and maintain human resources;
— An integrated national strategy has been developed.

To reach Milestone 3, the conditions to be met are the following [11]:

— Ongoing human resource development programme in the operating organization effective;
— Ongoing human resource development programme in the regulatory body effective;
— National educational programmes and research and development to support the nuclear power programme in place.

3.2.6.2. Enablers and challenges observed

Case studies show that successful embarking countries early in their programme identified the knowledge, skills and staff numbers required by each key organization and developed national strategies to acquire these competencies to support the plans of each organization. Elements of these strategies included the following:

— Establishment of an operating organization, including through a joint venture with a partner from a vendor country;
— Setting up programmes in national universities and colleges to educate and train new professional and technical staff;
— Scholarships for specialized education in foreign universities;
— Recruiting experienced workers from abroad to support the early phases of the programme;
— Contracting with experienced technical and scientific support organizations or owners engineers to augment inhouse capabilities;
— Support and training from the NPP technology vendor and/or the regulatory body from the country of origin;
— Technical cooperation with the IAEA.

However, INIR missions have found that in most countries, each of the key organizations needed to do additional work to plan and implement their human resources strategies in Phases 2 and 3. Training and development of people is a long process and case studies give examples where shortfalls in staffing of both the operating organization and the regulatory body have impacted the project.

3.2.6.3. Considerations for programmes based on SMRs

The range of competences required for a programme based on SMRs is similar to those for a large NPP. The operating organization may need a smaller workforce to operate an SMR than a large plant, although this is less likely for the case of the NEPIO or the regulatory body. The reduced staffing numbers associated with SMR operations may ease the burden that embarking countries face with human resources development. Furthermore, the expectation of shorter project timelines reduces the period available to develop and acquire the necessary human resources.

Viable strategies for the regulatory body and the operating organization to gain the necessary competence to augment the resources available in the country, especially in the early stages, include:

— Cooperate and obtain support with counterpart organizations in the technology provider country;
— Recruit foreign experts to help establish the programme and follow up by backfilling with national talent;
— Contract with consultants and TSOs with experience providing similar services in other countries. Annex I describes a novel concept for an International Technical and Scientific Support Organization (ITSO);
— Engage in cooperation programmes with the IAEA.

Even though the number of operating personnel may be lower for an SMR, the size of the design authority is likely to be very similar. On the other hand, the vendor may also be a need for additional experimental staff to support any first-of-a-kind (FOAK) SMR. If the required expertise for SMRs is not widespread, as for example water cooled reactors, additional efforts will be necessary to develop qualified personnel and to establish diverse sources of scientific expertise especially for the regulatory body.

3.2.7. Financing

3.2.7.1. Issue outline

The funding and financing requirements for a nuclear power programme are substantial. Financing for the first NPP can be pursued in several ways. The host government may consider a typical financing structure for a project will include debt and equity finance from several sources. However, the viability and extent of such financing will depend on the country's overall economic situation. The prospects for such financing may be severely limited for some countries.

To reach Milestone 1, conditions to be met are the following [11]:

— Strategies for funding established;
— Potential strategies for financing identified.

To reach Milestone 2, conditions to be met are the following [11]:

— Funding plan available;
— Means of financing established and strategy for management of financial risks available.

To reach Milestone 3, the conditions to be met are the following [11]:

— Adequate income to sustain operation available;
— Funding mechanisms in place for radioactive waste management, long term spent fuel management and decommissioning;
— Funding for compensation for nuclear damage in place.

3.2.7.2. Enablers and challenges

Historically, funding and financing has been one of the biggest challenges for nuclear development: nuclear new builds are very large and highly capital intensive projects, with specific features that pose unique challenges for investors. These include a long and technically complex development and construction phase with uncertainties over construction time and overall cost, a lengthy and complex regulatory regime and, in liberalized markets, a significant revenue risk (price and volume risks).

Commonly in the past, the contractual and ownership models employed for NPP projects transferred much of the risk surrounding such projects either to taxpayers, the power consumers, or both. This was made possible because either the NPP was owned by a state owned company to which taxpayer subsidies could be transferred in the event of cost overruns, or the plant was built and operated within a regulated market. Governments are now looking for constructors and/or private investors to finance and bear more of the risk associated with new project investments under different financial models.

Most Phase 1 INIR missions identified the need to develop a financial model of the proposed programme to evaluate potential sources of financing and the impact of their costs on the proposed programme. Phase 2 INIR missions identified the need for further work and resources to evaluate financing and contracting models to demonstrate feasibility and understand the risks and how they will be addressed in future contracts.

3.2.7.3. Considerations for SMRs

In order to attract the large investments into SMR projects, it is paramount that the construction risks of SMRs are substantially reduced, and their deployment achieve an Nth-of-a-kind status. This will require a lot of due diligence to define, characterize and understand the risks. This requires that individual technologies reach technical maturity through learnings from the FOAK and become commercially proven through successful deployment on an industrial scale in several countries as reference plants.

In economic terms, both SMRs and large reactors share the same lifetime cost structure dominated by capital costs, have very long project lifetimes and are characterized by low, stable and predictable operating costs. Many other risk factors are also similar for nuclear projects, irrespective of their size. However, SMRs have the underlisted specific features that could potentially improve their attractiveness to investors and make financing easier, especially in embarking countries:

- Smaller unit size and hence lower capital requirements;
- Shorter construction time and earlier generation of revenues;
- Better predictability of delivery time and construction cost;
- Suitability for a wider range of applications, including remote locations, smaller grids, heat generation and other non-electric applications;
- Possibility to phase the financing of several modules of an SMR installation.

Other specific considerations that could potentially increase the adoption of SMRs by newcomer countries are described as follows:

Smaller size and scalability: The smaller unit size of an SMR could be a better fit for embarking countries that may face challenges in deploying a large reactor, due to grid constraints and limitations or insufficient electricity demand growth. Building a series of smaller reactors, as opposed to a single large unit, could be a better approach to match electricity demand growth and/or available financial resources. The smaller size of SMRs could also be better suited to the needs of specific industrial processes (mining operations, desalination, hydrogen production, industrial heat) or for a dedicated ‘inside the fence’ use in an industrial facility.

Lower initial capital cost: The lower aggregate cost of an SMR leads to lower financial requirements, making it easier to raise the required amount of debt and equity from different sources. Reduced equity needs could ease balance sheet funding from project owners, which could benefit from a more limited impact of the project on their credit rating. Also, it would potentially reduce the need to engage with multiple financial institutions, thus streamlining the overall financial process.

Shorter delivery time and lower construction risk: The modular design and reliance on factory fabrication is expected both to reduce the construction and to provide more certainty on delivery time and construction costs. If proven, this would contribute to reduce the overall construction risk of an SMR and potentially lead to easier financing and lower financing costs. Shorter pre-construction and construction periods would lower the interest during construction, permit an earlier revenue generation and, potentially[4], allow for a shorter payback period. This would make possible an earlier refinance of the project, thus reducing financing cost and freeing capital for new projects.

Staggered construction: In addition to better matching the projected growth of electricity demand, staggering the completion of multiple units/modules provides an 'option value' to the investor as well as interim revenues to the projects that have a positive financial impact to the project. For instance, earlier revenues could be used to pay ongoing construction costs of subsequent units, thus reducing borrowing needs and accrued interest during construction. Also, the fact that the project is already generating revenues, could reduce the perceived risk for the debt providers, and thus allow for a lower cost of capital for the subsequent units/modules. These financial advantages, however, need to be weighed against the potential cost increased due to the delayed construction of modules/units.

Generation and revenue diversification: The ability to diversify revenue streams across different products (sale of electricity, heat and other by-products) could enhance the economy of the project and reduce revenue risk for investors. For marine-based water cooled SMRs, the refuelling may be taken to the supplier country with simultaneous exchange for the SMR with fresh fuel.

An innovative concept for a multilateral bank for nuclear infrastructure as a mechanism to provide supportive finance for nuclear infrastructure projects and plug the gaps in existing financing mechanisms is presented in Annex II.

3.2.8. Other infrastructure considerations

3.2.8.1. Emergency preparedness and response

Based on the smaller footprint and lower source term of SMRs, as compared to LNPPs, both onsite and offsite arrangements for emergency preparedness and response are expected to be limited. The reduced activity regarding this issue has the potential of accelerating the infrastructure development for a nuclear power programme. Operating organizations and regulatory bodies are encouraged to engage with vendors earlier to develop emergency preparedness arrangements and ensure there are no misunderstandings around the size of the emergency planning zone and potential considerations for the design (e.g. severe accident management strategy and systems).

[4] If the overall generation cost of SMRs is comparable with that of a large reactor

3.2.8.2. *Electrical grid*

The generally applied rule that a single unit does not exceed 10% of the overall installed capacity of the grid is a limiting factor for countries with smaller grid sizes. For a large NPP to fit into a smaller grid, there needs to be significant investment in the electrical grid. SMRs with lower power present potential for countries with smaller grids to have nuclear power since the investment on upgrading the electrical grid is projected to be less as compared to large NPP, which can be an accelerating factor for SMR deployment. While the need for electrical grid upgrades may be reduced, ensuring the robustness of electrical power supply remains crucial, particularly under severe accident conditions, where continuous operation of essential instrumentation, control, and emergency lighting systems is vital for effective mitigation. Off-site power is the preferred and primary power source for NPPs, including SMRs, to maintain operational integrity and safety functions.

3.2.8.3. *Stakeholder engagement*

Public acceptance is key for a successful nuclear power programme, even for SMRs. SMR based nuclear power programmes would have to consistently communicate their rationale, implementation strategies, and progress updates to all stakeholders. Due to the size of SMRs, lower source term and potentially reduced financing, stakeholder engagement can be less complicated compared to a large NPP and can be a catalyst for acceleration. The potential of SMRs to change the negative perceptions of the public and governments about nuclear power can be a stimulus for accelerating SMR deployment.

3.2.8.4. *Fuel cycle*

The two components of the fuel cycle (front end and the back end) are valid for both large NPPs and SMRs. Regarding the front end, the availability of fuel suppliers needs to be ensured since the fuel types in SMR designs are varied. Regarding the back end, newcomer countries need to have discussions with vendors to gain a better understanding of the back end of the fuel cycle. In both front end and back end of the fuel cycle, newcomers need to have an early strategy in place. This can support acceleration of SMR deployment.

3.2.8.5. *Radioactive Waste Management*

Just like from large NPPs, radioactive waste from SMRs needs to be managed. It is expected that new forms of radioactive waste will be generated with SMR technology. Even though the waste categorization is expected to be the same as large NPP, the volumes are expected to be lower. The low volumes of waste generated from SMRs may be a point of interest to countries that want to adopt SMRs and may aid acceleration of deployment.

4. IMPLEMENTATION ROADMAP FOR SMRs

As presented in the Annex of NG-G-3.1 (Rev. 2) [1], the 19 infrastructure issues and the three phases still apply for SMRs. However, there is a potential to shorten the overall implementation of the programme due to:

- The shorter construction schedule for SMRs, up to 4 years or less significantly than that for existing commercial LNPPs [5].
- The more streamlined licensing process that some regulatory bodies are considering for SMRs subject to vendors and developers being able to make the case that the nuclear safety risks are lower. The streamlining is mainly related to pre-licensing engagement process.
- The downscaling of some infrastructure elements due to the smaller footprint of SMRs (e.g. grid, environmental impact assessment, siting, emergency preparedness and response).
- The deployment models of some technology providers that proposes a package of support that goes beyond of what is typically offered for LNPP projects.
- The potential support of vendors and technology providers in developing the processes, organizations and competencies required for the nuclear power programme in the embarking country, always ensuring national sovereignty.

To estimate the potential shortened time frame for implementing a nuclear power programme based on an SMR, a roadmap was developed by a group of experts familiar with the Milestones approach [1], the characteristics of SMRs, and their deployment models for land based SMR. The roadmap schedule is presented in Fig. 3. The relevant adaptation for the roadmap for marine-based water cooled SMRs are not considered due to the different scope of the licensing process.

The roadmap schedule considers the most significant activities in the three phases of a nuclear power programme. Its development was based on the following considerations:

- An SMR with a mature technology, complete design, safety case and available reference plant;
- First module of the SMR to be implemented in the embarking country;
- No nuclear infrastructure available in the embarking country at the beginning of Phase 1, except for the existing infrastructure for medical and industrial uses of ionizing radiation.

The activities were categorized based on the main organization responsible for the implementation:

- Government and NEPIO in blue;
- Regulatory body(ies) in green;
- Operating organization in red.

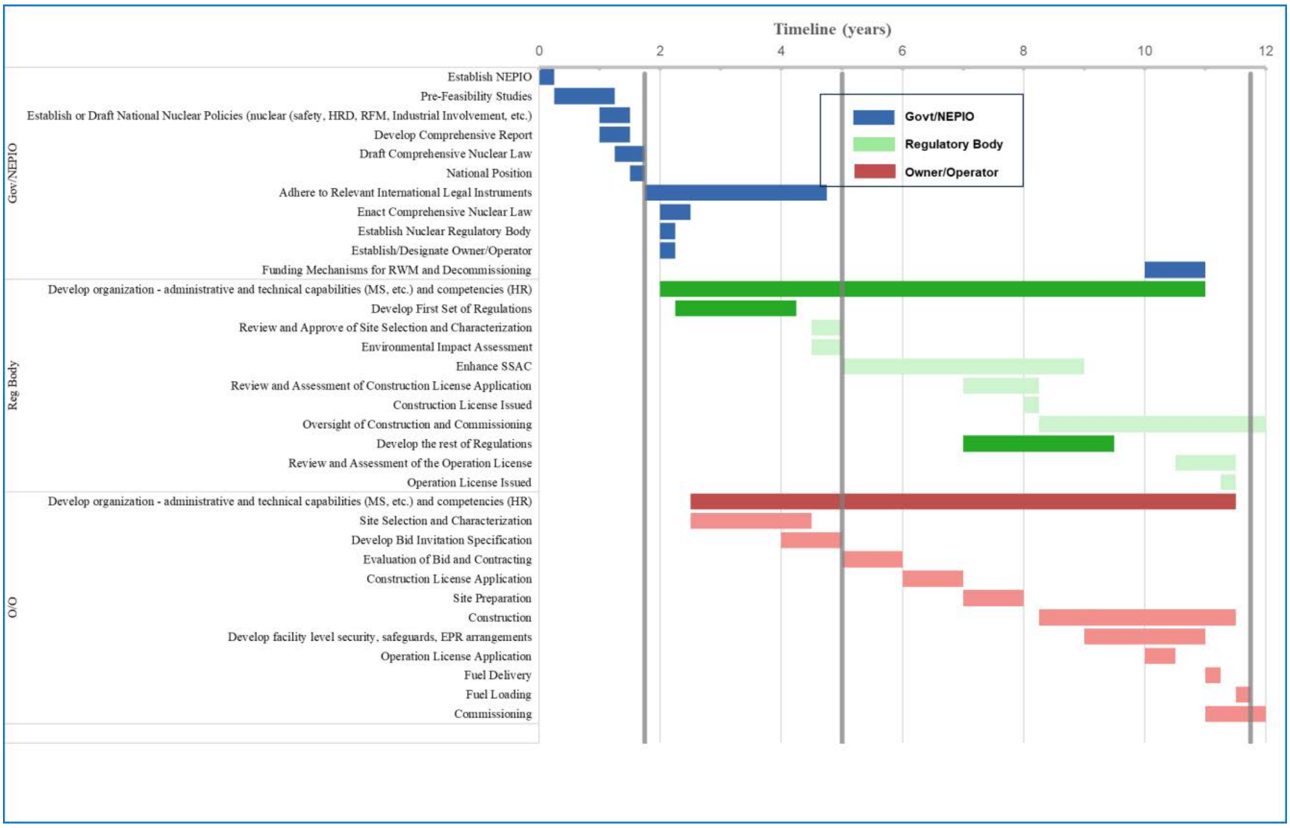

FIG. 3. Roadmap for implementation of the first SMR in a newcomer Country

4.1. CRITICAL PATH ACTIVITIES

The critical path in any project is defined as the sequence of tasks determining the shortest time to complete the project. Ways of speeding up the project schedule include:

- — Reducing the duration of each activity on the critical path by changing work methods or applying additional resources.
- — Resequencing activities on the critical path so they can be done in parallel instead of sequentially. However, the possibility of parallel working may be constrained by several factors, such as:
  - The dependence of an activity on the completion of its predecessor activities;
  - The availability of resources (space, workforce, equipment, etc.) to perform activities simultaneously.

A practical example of such constraints on some of the key activities in a typical NPP project is given below. Because the output of one activity forms the input for the next, the activities need to be performed in sequence and so potentially form part of the critical path that determines the overall project schedule:

- — Construction of the NPP can begin only after the regulatory body issues the construction licence;
- — Before issuing the construction licence, the regulatory body reviews and assesses the licence application;

— To start the regulatory review, the operating organization prepares and submits the licence application;
— To prepare the licence application, the operating organization enters into a contract with the technology vendor.

Similar dependencies may exist among other activities in the project. All such linkages need to be carefully identified in optimizing the schedule.

Some activities identified in the NPP roadmap schedule are more resource intensive than others and will require more time to implement. These activities need to be planned and executed on time to achieve the intended overall programme schedule.

The activities presented below were identified based on Ref. [18].

4.1.1. Phase 1

In the Milestones approach [1], Phase 1 is a phase where States make considerations before a decision to launch a nuclear power programme is taken. Milestone 1 is reached when the State makes a knowledgeable commitment to a nuclear power programme based on the considerations. The 2 meta-activities identified to be caried out in this phase are as follows:

4.1.1.1. Prefeasibility studies and policies development

The prefeasibility studies consist of a set of economic, financial and technical evaluations of the infrastructure required for a new nuclear power programme. It also covers the planning for the next phases of the programme in case a positive decision to move forward with the programme is taken.

Policies are intended to guide the entities involved in a certain area or infrastructure issue. Typically, policies are developed for the safe, secure use of nuclear power for peaceful purposes, spent fuel and waste management, industrial involvement and human resource development.

The NEPIO is generally responsible for performing or commissioning these studies, developing the referred policies and ensuring their coherence.

To perform its tasks in Phase 1 and the subsequent phases of the programme, the NEPIO needs an appropriate mandate and the necessary human and financial resources.

4.1.1.2. Comprehensive Report and decision making

The Comprehensive Report is the culmination of a process that includes the completion of the prefeasibility studies summarizing the outputs [13]. For coordination purposes, the compilation and review of data from different sources and stakeholders may require establishing a schedule that identifies the different steps and responsible organizations for drafting, reviewing and approving the Comprehensive Report by meeting the deadline for its submission to decision makers.

In most embarking countries, the Comprehensive Report needs to be submitted to the Parliament for analysis and approval or to the Prime Minister or Cabinet. This process can take time and quite often requires interactions with members of the NEPIO.

In many countries, significant expenditures like setting up organizations and hiring staff first require a government decision to proceed with a nuclear programme. This affects the earliest start date for such activities, making it often unfeasible to begin them in Phase 1.

4.1.2. Phase 2

In accordance with the Milestones approach [1], in Phase 2 preparatory works are undertaken for the contracting and construction of an NPP after a knowledgeable commitment to a nuclear power programme has been made. The State is now ready to invite bids and negotiate a contract marking the achievement of Milestone 2. The three meta-activities identified to be caried out in this phase are as follows:

4.1.2.1. Development of a legal framework

The Milestones approach [1] identifies three main elements in the legal framework: the international legal instruments that the country is expected to adhere to, the national nuclear law, and the identification of other laws that may impact the implementation of the nuclear power programme.

Among these three elements, INIR missions identified that issuing the nuclear law or amending existing laws are time consuming and challenging activities which are ideally anticipated during Phase 1.

The issuance of a nuclear law is one of first activities expected to be implemented in Phase 2 as it constitutes a prerequisite for starting the establishment of the regulatory body.

4.1.2.2. Development of key organizations

The Milestones approach [1] identifies three main organizations in a nuclear power programme: NEPIO, operating organization and the regulatory body (or regulatory bodies depending on the legal framework of the country).

The operating organization and the regulatory body are established in Phase 2. This implies hiring, developing the required competencies and establishing the management systems for these organizations to become operational.

The regulatory body staffing increases steadily in Phases 2 and 3 but it needs to be operational early in Phase 2 with the issuance of regulations that will be necessary for the project development (some examples are the siting regulation, design regulation and management system regulation). During Phase 2, the regulatory body needs also to prepare its staff (and the eventual external support) to review the safety documentation that will be provided by the future operating organization for several steps of the licensing process and to prepare a programme to oversee construction.

During Phase 2, the operating organization will be established as a small organization and will develop the capability to select the site, prepare a site application and establish technical specifications for the NPP to be included in the bid invitation or to guide negotiations with a preferred vendor. The newcomer countries are likely to need one or more TSOs early in Phase 2 to develop the specification and strategy for engagement with vendors. Early in Phase 3, the operating organization will need to assess offers, place contracts, begin a steady expansion of its capability to prepare a construction licence application and oversee construction activities. Towards the end of Phase 3, it will need the competence to prepare an application for an operating licence and be ready for commissioning and operation. The operating organization will need to be an organization that is able to operate (with certified operating personnel) and maintain the NPP, with competent staff and management systems that are suitable for operating an NPP. The operating organization is to be encouraged to develop design authority capabilities at an early stage, and specific requirements need to be incorporated into bid invitation specifications and subsequently contract negotiations. Furthermore, the concept of readiness reviews applied to the operating organization to make sure it is fit for purpose and scaling during the specification and procurement are also encouraged.

The objective of reducing the licensing and the construction time in the case of SMRs (i.e. a shorter Phase 3), requires more to be done by the regulatory body and the operating organization in Phase 2 to respond to the project needs.

4.1.2.3. Implementation of site related activities

The site selection and characterization activities are to be implemented in Phase 2 considering the results of the site survey conducted in Phase 1.

INIR missions observed that several countries hired external support services to conduct site characterization, as not all competencies were available in the NEPIO.

The characterization of one or more sites requires time and financial resources that need to be considered in Phase 1. Normally this is under the responsibility of the future operating organization as the results of this characterization will be part of the technical specifications for the reactor. However, a preselection may have been conducted in Phase 1 by the NEPIO or the future operating organization.

Prior to starting the site selection, it is important to have the siting regulation issued by the regulatory body; the NEPIO then monitors and ensures the coordination between both the regulatory body and the operating organization as well as other governmental entities that may have a role in the site selection process.

Another important element is the identification of upgrades that may be needed on the existing physical infrastructure such as roads, ports, transmission lines and which organizations will be responsible for their implementation.

4.1.3. Phase 3

Phase 3 outlines activities to implement the first NPP. When those activities are implemented, then the MS is ready to operate the first NPP. Thereby achieving milestone 3. The 3 meta-activities identified to be caried out in this phase are as follows:

4.1.3.1. Bid evaluation and contract negotiation

The approach to select a technology provider varies between embarking countries. Some countries have established an early intergovernmental agreement with a technology provider country and others have issued a bid invitation specification, evaluated offers and concluded a contract. In another approach, some countries go for competitive offers with two or three vendors and finally decide on the vendor at the end of the process. When the vendor selection is done, they might first sign an inter-governmental agreement (IGA, see Section 5.1.1) and then start contract discussions.

This activity starts in Phase 2 and, ideally, is concluded in the first two years of Phase 3. In Phase 2, the country will need to decide on its contracting strategy and may therefore involve the NEPIO. Developing the technical specifications for the bid invitation or vendor discussions is the role of the operating organization. The Government is likely to have some involvement in the final selection of the technology provider, as well as in the financial agreement, such as the provision of a sovereign guarantee.

The number of technology providers for LNPPs is very limited, which limits the selection process to a few designs. In the case of SMRs there are a much larger number of technologies being offered with very different characteristics and deployment models. The levels of maturity of those technologies are also very different. All this makes the technology selection more difficult and will require a more detailed technical specification by the operating organization.

4.1.3.2. Licensing

The licensing approach varies from country to country but typically consists of stepwise authorization of siting, design, construction, commissioning and operation [19]. Most countries also require the conduct of an environmental impact assessment early in the project that is reviewed by an environmental regulatory authority. Marine-based water cooled SMRs also need a nuclear ship certificate in compliance with International Convention for the Safety of Life at Sea Convention [20].

It is the responsibility of the operating organization to prepare and submit the required documentation for each licence application to the regulatory body. In the case of design specific information, the operating organization reviews the information provided by the technology provider and develops the additional information required to complete the application.

The responsibility of the regulatory body is to establish the licensing process (ideally in Phase 2), issue the necessary regulations that will guide the operating organization in the preparation of the licence applications, review the applications, and issue the corresponding licences.

Typically, issuance of the first construction licence takes 18–24 months from the date of application for commercial LNPPs based on water cooled reactor technologies. For SMRs there is an expectation that the time needed for the licensing process can be reduced, but this will require early regulatory engagement (e.g. pre-licensing activities between the operator and the regulatory body), and a robust project to develop the safety case to the level of maturity to proceed to ensure this is smoother. Regulator bodies and designers are working in ways to accelerate the licensing process for SMRs without compromising safety and security. For example, pre-licensing process are being considered as an approach to de-risk SMR projects. Furthermore, regulatory bodies are cooperating more closely to jointly evaluate SMR designs and to potentially leverage other regulatory reviews. The NHSI initiative of the IAEA is an example of a platform for efficient communication between international experts' communities for defining the pathway for licensing process acceleration. The NHSI Regulatory Track effort has developed processes to support this cooperation, including a multinational pre-licensing joint regulatory review process that is described in Ref. [8].

4.1.3.3. Construction and commissioning

The operating organization will oversee the activities of the prime contractor and its suppliers to confirm that the contract requirements are met, to review non-conformances, and witness the manufacture of critical equipment and assembling activities. The operating organization may also be required to submit to the regulatory body an oversight programme for safety related activities and for safety classified equipment. It is useful for the operating organization to develop an independent oversight function to ensure the safety of the NPP at all stages.

The regulatory body will develop its own independent oversight programme focusing on safety classified structures systems and components and will review the oversight programme of the operating organization and follow its findings.

Neither the operating organization of an embarking country nor the regulatory body have all the necessary competencies to inspect the prime contractor, or its supply chain to ensure compliance with the industrial codes and standards that are adopted for the project. For that purpose, it is expected that both organizations will have the support of expert organizations.

For SMRs, for which a high level of standardization and serial production is expected, the way of implementing oversight programmes may differ from what is currently done for LNPPs.

4.2. ASSESSMENT OF SMR IMPLEMENTATION ROADMAP

Based on the above consideration, the following points may be highlighted regarding the implementation roadmap for SMRs:

- In most countries, a positive government decision to proceed with a nuclear power programme is expected to be taken before significant funds can be spent. This constraint makes it difficult to start substantial implementation in Phase 1. Phase 2 is the earliest start for such activities.
- However, development of national policies and strategies on the key issues and laying out a practical roadmap in Phase 1 will support timely implementation in Phase 2.
- The initial infrastructure activities in Phase 2 by the government, the regulatory body, and the operating organization are prerequisites for starting project implementation activities related to siting and development of bid specifications.
- The earliest start time for construction is thus determined by the sequence of activities, from the development of bid specifications to vendor contracting, preparation, submission, and review of the licence application.
- The development of the operating organization (beyond the significant level needed to progress the construction licence) and the preparation and review of the operating licence application can be conducted in parallel with construction. However, the shorter construction period expected for SMRs means it is possible for these activities to enter the critical path and delay the startup date.

Based on the foregoing assessment, and as shown in Fig. 3, currently available SMRs could shave approximately three years off the timeline presented in the Milestones approach [1] for the first NPP, for a total estimate of 12 years from initial consideration to operation. The reduction is primarily in Phase 3 due to the shorter estimated construction period for an SMR, and downsizing of some infrastructure activities. An embarking country would have difficulty in dramatically speeding up this schedule due to the necessary sequence of infrastructure development and preparatory activities for the first NPP project unless some activities are started in anticipation, often at risk, such as site investigations or preparation of bid specification.

More significant schedule reductions would flow from subsequent project(s) as in the following scenarios:

— When the enabling infrastructure, in the form of the legal and regulatory framework, etc., already exists in a country, licensing, constructing and commissioning an additional SMR of a mature design could be done in approximately 6–8 years depending on the construction time.
— If a series of SMRs of a standardized design are licensed for construction on the same site, or even on different sites with common conditions, units could follow each other in service at short intervals after an initial lead time, leading to a rapid ramp-up of generating capacity.

More detail on the above scenarios above is provided in Annex III.

SMR features may enhance the economic competitiveness and support the achievement of economies of scale as compared to LNPPs. Achieving the economies of scale would help amortize the initial infrastructure costs, serial deployment of standard designs. In these circumstances, supply chain efficiencies are also realized as teams move from one unit to the next, learning from experience and retiring project risks. Setting the conditions for such a scenario of series deployment is part of the promise and the puzzle of SMRs.

5. INTERNATIONAL COOPERATION

International cooperation between countries and organizations is fundamental for the success of nuclear power programmes in embarking and expanding countries and is to be implemented from the outset of the programme.

Depending on the phase of the nuclear power programme, international cooperation can be implemented under different mechanisms and for different purposes:

- Familiarizing decision makers and leaders on the specificities of nuclear power at earlier phases of the programme;
- Information sharing on best practices in the areas of safety, security and non-proliferation with peer regulatory bodies, operating organizations and international organizations;
- Technical support and capacity building to regulatory bodies, operating organizations and other relevant organizations including in the supply chain in areas where not all competencies are available in the embarking country.
- Developing a talent pipeline with specialized nuclear education curriculum implemented in the host country.

SMR technologies are showing a greater trend in international cooperation, globalization of nuclear power technologies and methodologies, and in some cases, deployment projects. This offers significant opportunities to use cooperation and information sharing between countries to inform regulatory processes and refine them to improve efficiency. Vendors and regulatory bodies are interested in collaborative reviews, pre-licensing and exchange of licensing documents between regulatory bodies internationally and are ready to provide support, for example by sharing proprietary information under appropriate non-disclosure agreements.

However, undertaking this proactive work requires both sufficient funding to be in place for both the regulatory body and the industry with the confidence that this proactive work will effectively address the framework requirement and result in more efficient project deployment.

5.1. GOVERNMENT TO GOVERNMENT COOPERATION

5.1.1. Inter-governmental agreements

Inter-governmental Agreements (IGAs) are a mechanism to enhance cooperation in areas of interest of both countries. An IGA creates a framework for two countries to work together and it is generally signed at the highest levels of the governments involved.

An IGA will identify areas of cooperation at a high level with detailed implementation normally set out in complementary agreements, such as memoranda of understanding, signed by the organizations involved.

Typical areas covered by IGAs signed by embarking countries include:

- Promotion of nuclear energy;
- Infrastructure development;
- Promotion of safety, security and non-proliferation;
- Regulatory processes and licensing;

— Research and development;
— Capacity building;
— Others.

5.1.2. Bilateral agreements

Many advanced nuclear power countries have made agreements with newcomer countries to support their development of nuclear power programmes. These arrangements have the capability to develop the basic human resource and the needed understanding in the development of a nuclear programme. These agreements further strengthen the IAEA efforts in supporting newcomer countries in the development of their nuclear programme and can support acceleration of their infrastructure development.

Key support newcomer countries receive under bilateral agreements include:

— Energy planning;
— Human resource development (usually Master's and PhD scholarships);
— National nuclear infrastructure development planning;
— Support in evaluating specific infrastructure issues;
— Workforce planning;
— Stakeholder engagement success;
— Technology identification and selection;
— SMR financing and localization;
— SMR siting and early works;
— Pre-feasibility and feasibility studies;
— Training the future operating organization;
— Managing procurement and the supply chain;
— Nuclear safety and licensing approaches for SMRs;
— Nuclear security;
— First supply;
— Nuclear non-proliferation;
— Commissioning and operation support;
— Spent fuel management.

5.2. TECHNOLOGY PROVIDER SUPPORT

Technology provider or reactor vendor support to the future operating organization depends on the nature of the contract used for the reactor or the nuclear steam supply system procurement. Although several contracting approaches exist, embarking countries have adopted, in most cases, turnkey or engineering, procurement, contraction (EPC) contracts. Other, less common contracting approaches are the split package and the build-own-operate models. In the EPC approach, the main contractor is responsible for the engineering, procurement of equipment and the construction of the reactor or the nuclear steam supply system.

In the EPC model, the technology provider is expected to have experience in design as well as in commissioning and operation. Some activities under the responsibility of the EPC contractor include:

— Adapting the plant design to the requirements of the operating organization and to the specific site conditions;
— Managing procurement;
— Managing construction;
— Managing the schedule and the interface between the various suppliers;
— Training the future operating organization based on technology provider inputs.

The role of the future operating organization remains relevant in this type of contract and it consists of preparing the safety documents requested by the regulatory body based on the inputs provided by the technology provider, applying for licences, defending the safety cases in the licensing process, overseeing construction and preparing for operation.

All the arrangements described above occur in Phase 3 after a contract is signed. However, some technology providers support embarking countries during the earlier phases of the programme to support the development of the infrastructure that is necessary for the development of the project.

5.3. SUPPORT FROM INTERNATIONAL ORGANIZATIONS

5.3.1. International Atomic Energy Agency

To help accelerate the deployment of SMRs, the IAEA developed a strategy based on the following elements:

— Supporting embarking and expanding countries to become knowledgeable customers and make an informed decision on whether to embark on or expand nuclear power based on SMRs;
— Supporting industrial preparedness for SMRs and their applications, including related fuel cycles;
— Promoting, supporting, and developing research and innovation;
— Supporting establishment of institutional, legal, and regulatory frameworks for the safe and secure deployment, operation, closure, and decommissioning of SMRs, including the management of spent fuel and waste;
— Preparing effective and efficient Agency safeguards;
— Supporting international cooperation on SMRs;
— Providing effective knowledge/technology transfer through technical cooperation.

In addition to the Milestones approach [1] and its evaluation methodology, a few initiatives deriving from this strategy are worth mentioning:

— The SMR Platform provides a focal point for the IAEA activities in relation to SMRs and offers expertise from relevant technical areas including SMR Schools for decision makers of embarking countries;
— The nuclear harmonization and standardization initiative (NHSI) which brings together policy makers, regulatory bodies, designers, vendors, and operating organizations to enhance the harmonization of regulatory approaches and the wider standardization of industrial approaches to ensure the safe and secure deployment of SMRs;
— The Atom4 NetZero initiative for energy scenario and strategic energy planning;
— The INPRO methodology and tools for Nuclear Energy Sustainability Assessment;

- The ARIS SMR Database and the Reactor Technology Assessment (RTA) tool for criteria-based comparison between different technologies;
- The interregional Technical Cooperation project on SMRs provides training courses and workshops oriented to SMRs technology and infrastructure.

5.3.2. World Association of Nuclear Operators (WANO)

WANO, an organization focussed on commercial safety and reliability maximization, offers a New Unit Assistance (NUA) service to ensure that new nuclear units operate safely and reliably. This new service offers tailored support to members during the transition from project phase all the way through to the operating phase of a company. With 18 modules under the NUA service, WANO members receive support to achieve safe and reliable startup of their new power plants thereby significantly reducing the risk of a delay to startup or a setback during the construction phase [21].

Provision of the NUA modules can be tailored to members' specific needs, and the delivery methods are varied to ensure the member receives the right information for them in the most effective way via sharing of industry best practices, benchmarking, the use of operating experience, and the delivery of targeted support missions and training.

5.3.3. Nuclear Energy Agency (OECD-NEA)

The NEA has developed an SMR Dashboard that can complement the IAEA ARIS database reflecting the milestones achieved for FOAK development, deployment and commercialization. The dashboard not only consider milestones but looks beyond the technology readiness level [22].

Furthermore, the Multinational Design Evaluation Programme coordinated by the NEA established as a multinational initiative is adopted by regulatory bodies to develop innovative approaches to leverage resources and knowledge in the review of new reactor nuclear power designs. In 2024, this programme established a significant platform for addressing present challenges and regulatory expectations concerning light water and HTGR SMR designs. This involves engaging with designers to gain a deeper understanding of the obstacles they encounter.

5.3.4. World Nuclear Association (WNA)

The WNA seeks to foster growth in the nuclear sector and thus supports the nuclear industry to continuously introduce and implement technologies, policies, and practices. In supporting the nuclear industry with the development of SMRs, WNA has introduced the SMR global tracker that highlights all current and future generations based on technology, project type and status[5]. WNA regularly issue reports on SMRs, such as Ref. [23] detailing some specific challenges that the deployment of SMRs can face in the licensing process and outlines potential approaches on how to facilitate a more efficient way forward.

[5] https://world-nuclear.org/information-library/current-and-future-generation/small-modular-reactor-smr-global-tracker

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ANNEX I. INTERNATIONAL TECHNICAL SUPPORT ORGANIZATION (ITSO) CONCEPT

ITSO is an innovative concept to support regulatory bodies as a solution to address regulatory human resource constraints to enable and accelerate the ability of countries embarking on or expanding nuclear programmes to conduct nuclear regulatory activities at the highest levels of safety, while optimizing efficiency. The ITSO's activities would focus on three areas:

- Supporting the reviews of licence applications for the construction and operation of new reactors (both LNPPs and SMRs);
- Supporting regulatory inspections, both during construction and operation;
- Providing training services to supplement those already available from other sources, such as the IAEA.

I–1. THE BASIS FOR THE ITSO CONCEPT

Most regulatory bodies with mature nuclear programmes hire specific outside resources on a contract basis to complete specific tasks. This approach allows regulatory bodies to augment their capabilities to respond to various licensing needs while also having the benefit of reducing staffing costs. These temporary staff are used to assist in licensing reviews and support the development of safety analysis reports, as well as carry out inspections. Supplementary staff are typically sourced from a TSO or a consulting company to assist with technical reviews, for example, when a regulatory body is short of staff, lacks a particular expertise, or when there is a spike in demand for licensing reviews. The regulatory bodies from embarking countries, such as the United Arab Emirates and Egypt, have also used TSOs to support the discharge of regulatory functions and advise the regulatory body on the licensing process while simultaneously building up domestic capabilities.

TSOs, however, vary greatly in skills, breadth of capability and experience. While there are currently more than 50 TSOs[1], there is no global database that allows a regulatory body to assess the resources of those TSOs. Where human resources are not readily available in a national TSO, a regulatory body often has to go through a complex procurement process to find the right skill sets. The regulatory body has to define the areas where the technical support is needed and the right skill sets based on a self-assessment exercise on the available competencies and regulatory obligations identified within the nuclear power project.

I–2. ITSO DESIGN OBJECTIVES

The ITSO's defining features would be nuclear safety, independence, and efficiency: The ITSO is to uphold the highest standards of nuclear safety in every aspect of its scope.

The ITSO's charter and organization structure, which would include a board of advisors, would ensure independence from any government or private entity.

The ITSO would be an agile and compact organization of permanent staff to manage the programme while having access to a large and diverse expert pool of technical expertise available to work on a

[1] https://www.oecd-nea.org/upload/docs/application/pdf/2024-09/governmental_authorities_for_nuclear_activities_sept_2024.pdf

per-task basis. The ITSO staff would ensure that the organization is operated in a way that minimizes costs while delivering the highest value to regulatory bodies.

I–3. THE EXPERT POOL

The regulatory body would be able to draw resources from the ITSO's expert pool of international nuclear professionals. The expert pool would contain individuals with a wide and deep skill set, including such nuclear-specific topics as environmental, nuclear safety, emergency planning, nuclear fuel cycle and probabilistic risk assessment, as well as more general topics such as electrical, mechanical, materials, and civil engineering.

The ITSO would be responsible for recruiting and retaining the experts who comprise the expert pool. A process would be developed for the ITSO to evaluate potential expertise and ensure that experts have knowledge relevant to the applicable technology. The ITSO would also work to maintain consistency between experts from different countries and regulatory frameworks. These experts would be contracted to support a particular project or projects based on their competence. As the experts work with the local regulatory body, skills will be transferred and, over time, the staff of the regulatory body would develop their own expertise.

I–4. PROJECT SELECTION

The ITSO would necessarily have limited resources and funding, so it would be important to avoid unnecessary expenditure on projects that would likely never progress to the construction phase. The ITSO would need to establish a clear and objective Resource Allocation Standard in order to aid in the selection of what projects would be the subject of assistance. A country requesting assistance needs to have made a commitment to develop nuclear power and would have to meet the requirements of the Resource Allocation Standard before it would be eligible for assistance.

I–5. FUNDING THE ITSO

The ITSO would also need adequate funding to be able to meet its objectives. The ITSO's costs would be incurred in three broad cost centres. The first is the cost to maintain the direct employees of the ITSO. This cost would be minimized by keeping permanent staffing as low as possible and expanding only as needed to meet increased demand. The second is the cost of providing regulatory bodies with licensing support services for a project. The third category of costs would be for field support, such as providing regulatory bodies with compliance verification support during construction and commissioning.

The ITSO would seek to capture economies of scale and lessons learned to keep licensing costs low. A primary goal of the ITSO would be to support the regulatory body in ensuring safety and security of NPPs. Therefore, a criterion for accepting ITSO services would be for the host country to agree to adopt effective licensing processes. These would include a process that allows for design certification and provides the host country regulatory body with the ability to accept a reactor design certification from another competent regulatory body. In addition to expediting deployment and capturing cross-border efficiencies, this would allow the ITSO to focus efforts on supporting licensing rather than on repetitive design certification.

Recipients of ITSO services would include many countries with limited resources. Therefore, the primary source of funding for the ITSO would be from the governments of nations supplying reactor technologies on a grant basis. Funding commitments and ITSO governance would be structured to guarantee the ITSO remains independent of influence from the provider(s) of the funds. Another source of funding could be from charities and other entities that have an interest in the development of the host country. One example could be Power Africa, which is supported in large part by the U.S. Agency for International Development. Finally, the ITSO may charge nominal fees, while maintaining a 'fee forgiveness' programme for countries that don't have the financial capacity to pay back these fees.

The ITSO concept is summarized in more detail in a white paper titled 'Establishing the Framework to Facilitate Licensing of New Nuclear Projects in Embarking Countries' published by the Clean Air Task Force[2].

I–6. SUPPORTING THE ESTABLISHMENT OF LICENSING PROCESSES IN EMBARKING COUNTRIES

As noted above, in order to maximize its resource and meet the goal of enabling the scaling of nuclear energy to meet decarbonization goals, countries would be encouraged to meet certain criteria as part of receiving support from the ITSO.

One key criterion is that the host country would need to have its own independent regulatory staff. The regulatory body would need to agree to seek to incorporate the ITSO resources and experts' review into its licensing process but maintain its independence. This is necessary to avoid the duplication and the inefficiencies that the ITSO has been designed to avoid and ensure ITSO resources are used effectively. This does not mean that the country gives up its independence and decision making to the ITSO, but rather that it uses the ITSO to supplement its own internal resources.

Another key consideration for receiving assistance from the ITSO is the effort by the host country to harmonize its licensing regime. A key goal of the ITSO is to enhance the ability of the regulatory body to perform licensing documentation reviews. This is the approach that was used by the Federal Authority for Nuclear Regulation in its successful licensing of the 4 Barakah NPP units. This approach creates efficiency, while allowing the national regulatory body to focus its resources (including those supplied by the ITSO) on site specific licensing actions.

[2] https://www.catf.us/resource/establishing-framework-facilitate-licensing-new-nuclear-projects-embarking-countries.

ANNEX II. INTERNATIONAL BANK FOR NUCLEAR INFRASTRUCTURE (IBNI)

II–1. BACKGROUND

The International Bank for Nuclear Infrastructure (IBNI) is an initiative that entails the creation of a new nuclear energy-focused multilateral international financing institution (IFI) that would specifically target the accelerated commercialization and global expansion of existing reactors, SMRs and advanced reactors, along with supporting worldwide scaling of existing commercial LNPPs and the entire nuclear value spectrum. The initiative has been recognized as an innovative financing tool under consideration by the Nuclear Industry Pledge made at COP 28 in Dubai, December 2023, where 24 countries at ministerial level made a declaration for tripling nuclear capacity by 2050. The initiative was specifically reflected in the International Energy Agency report Electricity 2024, Analysis and forecasts by 2026[3], which states "IBNI intends to provide a wide range of financial and advisory services for the development of nuclear projects in its Member States."

The IBNI initiative contains the following important novel features:

- It will be nuclear sector specific. Focus is expected to be on new build generation programmes/projects, but upstream/downstream investments in related infrastructure would also be eligible in order to avoid supply chain bottlenecks in sectors such as uranium mining, fuel fabrication, nuclear power plant delivery supply chains, nuclear infrastructure, waste management and used fuel management to final repository and environmental remediation.
- It is intended to provide financing and support in all its Member States regardless of income levels, from technology providing countries to embarking countries (including both newcomer and expanding countries). As such it is an 'infrastructure bank', beyond the current mandate of the existing multilateral development banks.
- It is positioned to aggregate nuclear finance-specific and environmental social governance (ESG) compliant standards and criteria and support the development of expertise in nuclear finance around the world, driving market confidence in IBNI-supported nuclear financing.
- IBNI would have the specific mandate to support the rapid expansion of nuclear capacity for the explicit purpose of attaining global Net Zero by 2050, supporting sustainable decarbonization, 'just energy transition' and global energy security policy objectives.
- Specific to the accelerated global deployment of SMRs, IBNI would offer a wide range of flexible and adaptable financing and other support programmes, tools, and mechanisms. IBNI would serve as the early and patient long term capital provider that would be necessary to build market confidence incrementally and progressively through the demonstration of repeatable, bankable (and ESG-compliant) and successful SMR financing transactions across international borders and under a uniform and commonly understood and accepted set of global IBNI standards and criteria and related frameworks.
- IBNI would offer its financing and support in an open, transparent, fair, and equitable basis to project sponsors, industries, suppliers, operating organizations, and governments in all its Member States. Accordingly, it is important to note that IBNI would provide a highly diversified range of funding, financing and other support solutions aligned with the

[3] IEA (2024), Electricity 2024, IEA, Paris https://www.iea.org/reports/electricity-2024

unique needs of the IBNI Member States, which would range from embarking and expanding countries including vendor countries. IBNI's financing and support would be provided on a country, vendor and technology-neutral basis, which is intended to enable the decoupling of the selection of nuclear technology from financing, which would create a more 'fair and level playing field' on which global nuclear industry would compete based on merits of technology rather than tied to the availability of State-backed financing from vendor countries. This construct would promote greater global competition, growth, efficiency, accountability, and cost-reduction within the global nuclear industries, which is seen as a necessary pre-condition toward enabling nuclear to sufficiently scale up.

— IBNI would have two major operational arms: IBNI Ordinary Operations Fund (commercial financing operations) (IBNI OOF) and IBNI Special Operations Fund (donor-sponsored support operations) (IBNI SOF)[4].

II–2. FINANCING AND SUPPORT TOOLS TO BE OFFERED UNDER THE IBNI ORDINARY OPERATIONS FUND

The IBNI OOF would provide: direct commercial credit; risk management products; insurance; indemnification and other similar risk management products, and advisory services. For example, the IBNI OOF would also utilize proven commercial financing products and programmes, that would aim to progressively catalyse and accelerate co-financing participation from global commercial lending institutions in IBNI supported nuclear financing transactions. Through its global and regional financial markets operations, the IBNI OOF could also serve as the global nuclear 'market maker' that would aim to progressively drive global capital flows into nuclear-specific ESG-compliant equity and debt investments (both into diversified portfolios of IBNI nuclear sector holdings and into individual IBNI co-financed nuclear transactions).

IBNI OOF is envisioned to provide its financing and support in the following areas:

— Commercializing existing nuclear technologies and scaling and sufficiently de-risking SMR/advanced reactor designs.

— Attracting highest investment-grade (AAA category) credit ratings on IBNI bond issuances and achieving the lowest cost of financing for the benefit of programme participants. This minimization of capital costs would be essential toward fulfilling the aim of driving down the cost of nuclear generation and enabling it to become a competitive form of low-carbon generation across energy markets around the world.

— IBNI OOF would provide cost-efficient commercial guarantees and other risk management tools that would enable sovereign governments to progressively reduce the need for full sovereign guarantees for financing. This would allow countries to re-focus guarantees to sovereign and political risks elements (such as change in law/regulation/tax provision and a more limited set of risks relegated to government control, or otherwise outside the control of any non-governmental stakeholder, such as force majeure).

Also, in terms of driving global sustainable/climate financing into the nuclear sector, the IBNI OOF is projected to become the world's largest issuer of nuclear specific high grade and ESG compliant bonds. It is anticipated that IBNI would become a significant market maker in regard to development,

[4] https://img1.wsimg.com/blobby/go/8593b45a-4452-46ac-9e76-81839d4d582a/downloads/IBNI_IRAP_7_IBNI_Operations_and_Programs.pdf?ver=1693545510840

deepening and enabling and liquidity in global ‘sovereign and supranational’ bond markets and markets for other nuclear related financing instruments. Currently, the inclusion of nuclear in various ‘Green/Sustainable’ taxonomies and bond/financing programmes has done little to attract any institutional investor's interest in the nuclear sector. In fact, a report published by Columbia University School of International and Public Affairs (‘SIPA’) Center on global energy policy indicated that none of the 30 systematically important global banks have specifically included nuclear in their sustainable finance policies[52]. IBNI’s bond issuances would essentially drive such institutional investors to include (or not) nuclear energy within their sustainable financing policies.

II–3. FINANCING, FUNDING AND SUPPORT TOOLS TO BE OFFERED UNDER IBNI SPECIAL OPERATIONS FUND

The IBNI SOF would administer certain donor funds and programmes that would be funded, earmarked, and administered for specific programmes that are prioritized by the IBNI Member State donors and envisaged to be progressively funded by private sector donors and third-party investors and lenders. The envisaged specific IBNI SOF funds would be earmarked for providing supplementary support (in addition to current individual government support programmes) for the rapid demonstration, commercialization and scaling of new SMR technologies, and their related life cycle supply chains.

IBNI SOF is envisioned to provide the following:

— The IBNI SOF would offer a range of innovative flexible products and programmes that would, in most cases, be adapted from the many existing IFI models.
— IBNI SOF programmes would be initially funded from public sector capital (government member donor capital) and progressively co-funded through private sector donor. Global capital markets co-investment would administer specific earmarked grants and concessionary financing, enclave loans, backstop sovereign/political risk guarantees, insurance, venture equity co-funding and social impact financing programmes (specifically, outcomes-based ‘climate impact financing’ and ‘sustainability impact financing’).

These early-stage financing and support tools would be tailored to bridge the gaps between where the current enabling government sponsored programmes end and where a sufficient ‘runway’ of global financial markets products may begin. Importantly, IBNI SOF programmes would provide flexible support solutions that would accelerate capacity building on the demand side as well as the supply side. Many vendor countries’ governments have and continue to do a great deal to stimulate development and early-stage funding of national emerging SMR industries. However, their collective resources and capabilities are significantly short of what would be needed to stimulate both the demand and supply side of the industry sufficiently and rapidly enough to achieve the levels of global expansion necessary to achieve global decarbonization and policy aims. IBNI could be a complementary extension of existing governmental programmes to include FOAK and early-stage demonstration support.

[5] Bowen, M. (Columbia SIPA), ‘A Critical Disconnect: Relying on Nuclear Energy in Decarbonization Models While Excluding It from Climate Finance Taxonomies, July 6th, 2023’

It is also anticipated that the IBNI SOF would also provide a wide array of programmes, tools and solutions for newcomer/embarking Member States interested in deploying SMRs in their countries (often as their first nuclear deployment of any type). IBNI SOF would provide dedicated funding (for example to create national legal and regulatory framework), financing (for example to characterize and select a nuclear site) and other tools (for example for human resources planning) and resources to these Member States which would enable them to accelerate development of their nuclear infrastructure and become 'nuclear-ready' customers for SMRs. In such cases, the IBNI would work closely and cooperatively with the IAEA and the relevant IBNI Member State stakeholders adhering to the Milestones approach and other IAEA Support and Assistance programmes. Even though the IAEA provides a great deal of expertise, resources, and guidance to newcomer/embarking nuclear countries and their respective institutions, it does not provide funding or financing or commercial advisory and support for Member States' activities related to achievement of the respective milestones, therefore, IBNI would serve as the integral funding and financing partner.

II–4. POTENTIAL NEXT STEPS TO ESTABLISH IBNI

Similar to most of the world's existing major multilateral IFI's, it is anticipated that IBNI would be established through the ratification of a treaty amongst a coalition of aligned sovereign nations.

ANNEX III. SMR ROADMAP SCHEDULE REDUCTION SCENARIOS

The first scenario considers a new SMR project in a country with operating nuclear power plants (either SMRs or LNPPs) where all project related activities will need to be implemented, while some infrastructure development activities (namely, institutional development of the regulatory body and operating organizations) would have already been undertaken. In terms of regulation, some new or additional regulations to cover the potential new SMR reactor type need to be developed. In this scenario, the SMR is assumed to be built at a new site and is potentially a new technology to the host country. In this case, the project will begin with site selection and characterization and ends with commissioning. The overall roadmap schedule for this scenario is envisaged to be 9.25 years as shown in Figure III–1.

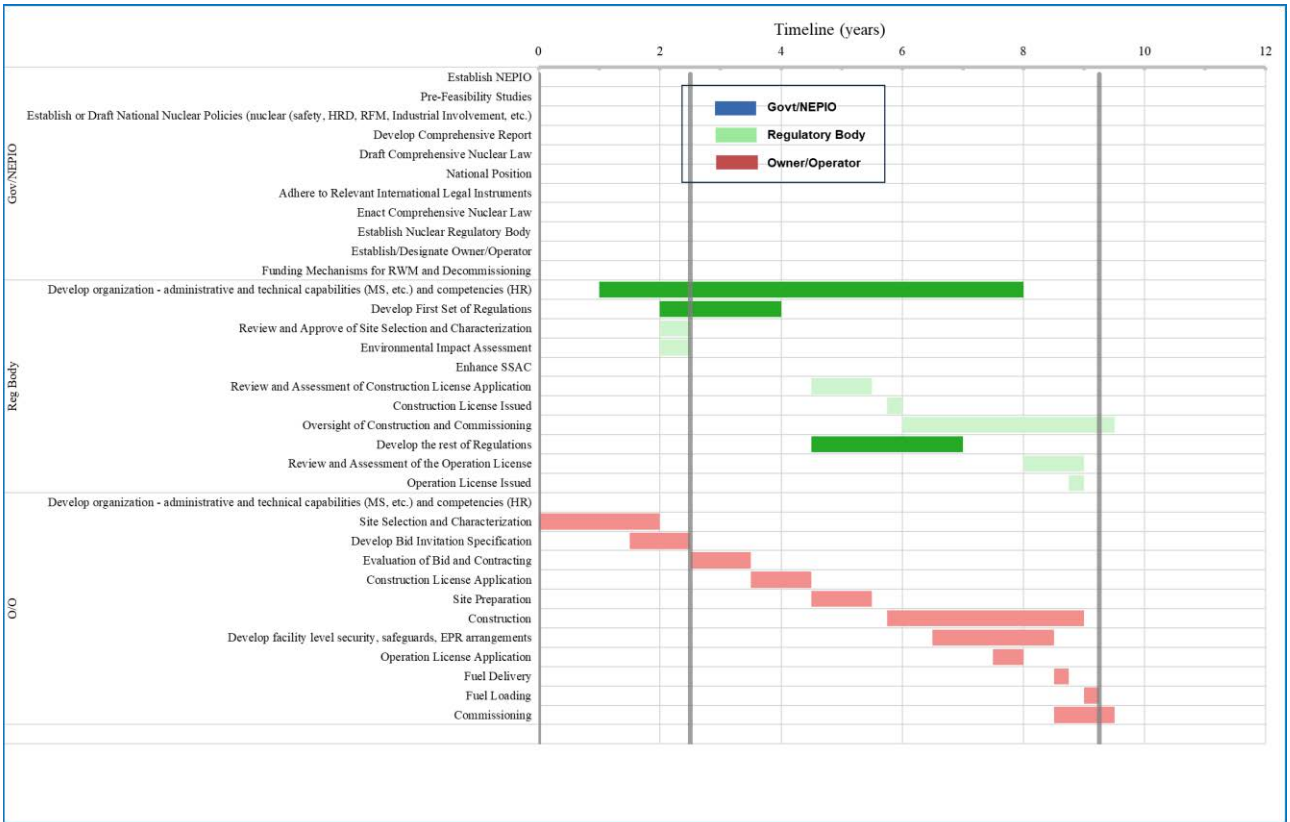

FIG. III–1. Roadmap for second SMR project showing reduced Roadmap Schedule

A second scenario, as shown in Figure III–2, considers a new SMR project that is executed at the same site with similar SMR technology already deployed. In such a scenario, it is assumed that site selection and characterization has already been performed. It is also assumed that some infrastructure development activities (namely, institutional development with the regulatory body and operating organizations) has been developed. Thus, such a scenario will start with the development of the Bid Invitation Specification and end with commissioning. Such a project is assumed to take 6.75 years.

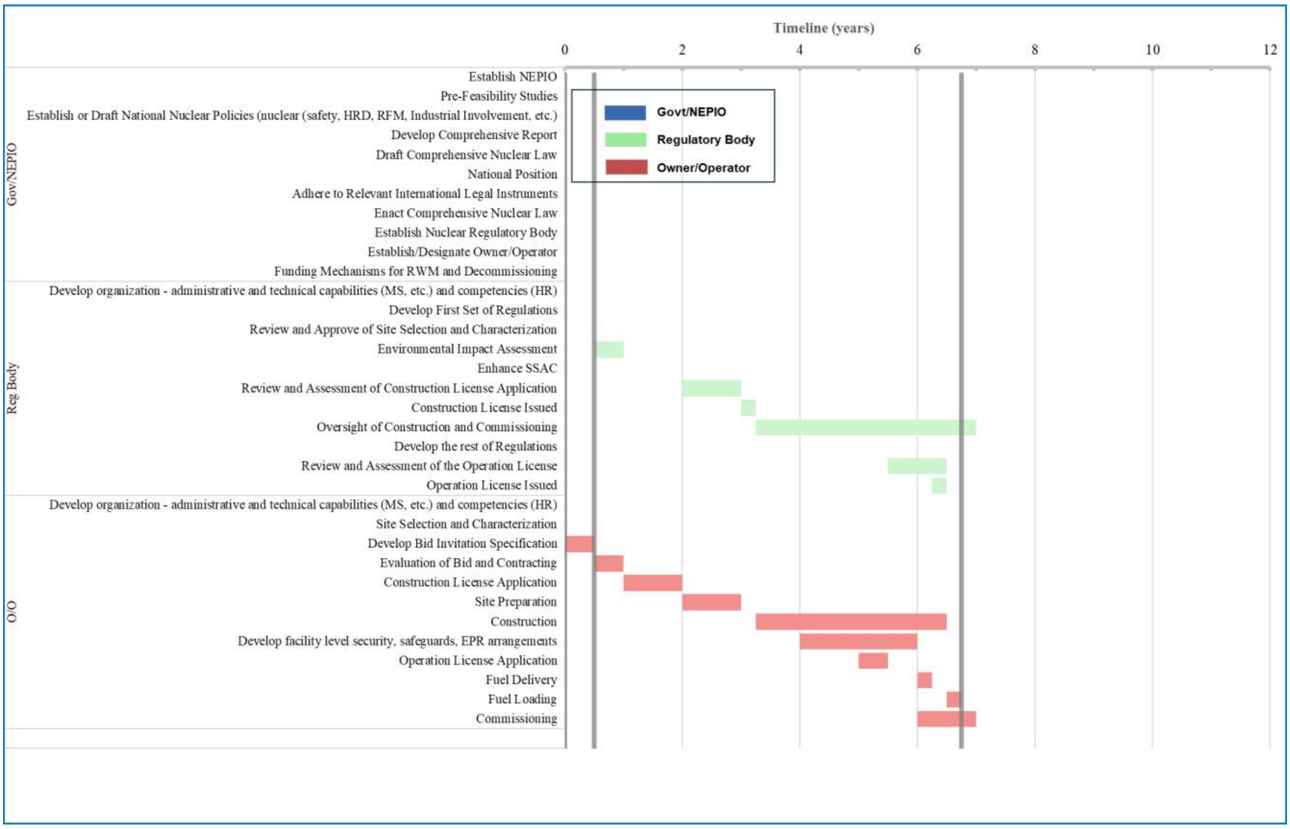

FIG. III–2. Roadmap for third SMR project showing much reduced Roadmap Schedule

LIST OF ABBREVIATIONS

ARIS	Advanced Reactors Information System
EPC	engineering, procurement, contraction
ESG	environmental social governance
FOAK	first-of-a-kind
HTGR	high-temperature gas cooled reactor
IBNI	International Bank for Nuclear Infrastructure
IBNI OOF	IBNI Ordinary Operations Fund
IBNI SOF	IBNI Special Operations Fund
IFI	International Financing Institution
IGA	Intergovernmental Agreement
INIR	Integrated Nuclear Infrastructure Review
ITSO	International Technical Support Organization
LNPP	large nuclear power plant
NEA	Nuclear Energy Agency
NEPIO	Nuclear Energy Programme Implementation Organization
NHSI	Nuclear Harmonization and Standardization Initiative
NPP	nuclear power plant
NUA	new unit assistance
SMR	small modular reactor
SSCs	structures, systems and components
TNPP	transportable nuclear power plant
TSO	technical and scientific support organization
WANO	World Association of Nuclear Operators
WNA	World Nuclear Association

CONTRIBUTORS TO DRAFTING AND REVIEW

Aparkin, F.	Rosatom/Russia Federation, Russia
Bastos, J.	Consultant, Brazil
Belyea, S.	Canadian Nuclear Safety Commission, Canada
Carson, A.	World Nuclear Association
Catts, M.	GE Hitachi Nuclear Energy, United States of America
Cherevko, Y.	JSC Rusatom Service, Russia
Chernyakhovskaya, Y.	JSC Rusatom Service, Russia
Cometto, M.	International Atomic Energy Agency
Dean, D.	Dean Capital Strategies, Austria
Debrah, S.	International Atomic Energy Agency
Delmastro, D.F.	Comisión Nacional de Energía Atómica (CNEA), Argentina
Devos, M.	Prodigy Clean Energy Ltd, Canada
Di Lizia, C.	Électricité de France (EDF), France
Gomaa, R	International Atomic Energy Agency
Grant, I.	Consultant, Canada
Herbach, J.	International Atomic Energy Agency
Hong, H.	China National Nuclear Corporation, China
Jeltsov, M.	Fermi Energia, Estonia
Khartabil, H.	International Atomic Energy Agency
Kovachev, M.	International Bulgaria
Lazerwitz, B.	International Atomic Energy Agency
Lepouzé, B.	International Atomic Energy Agency
Maliev, V.	JSC OKBM Afrikantov, Russia
Mehmet, C.	International Atomic Energy Agency
Newton, T.	International Atomic Energy Agency
Nichol, M.	Nuclear Energy Institute

Nyarko, B.J.B.	Consultant, Ghana
Oseeva, M.	JSC Rusatom Overseas, Russia
Ozerina, M.	International Atomic Energy Agency
Puente-Espel, F.	Seaborg Technologies, Denmark
Rini, B.	International Atomic Energy Agency
Samiei, M.	International Expert, Austria
Scott, M.	International Atomic Energy Agency
Scotto de Cesar, C.	International Atomic Energy Agency
Stearns, D.	International Expert, United Kingdon
Teplinsky, E.	Pillsbury Winthrop Shaw Pittman LLP
Tyndall, D.	Ontario Power Generation, Canada
Calle Vives, P.	International Atomic Energy Agency
Whitlock, J.	International Atomic Energy Agency

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