Small Modular Reactors Regulators' Forum

Working Group on Manufacturing, Construction, Commissioning and Operation

<u>Phase 2 REPORT</u>

June 2021

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EXECUTIVE SUMMARY

There is a sustained global interest in small modular reactors (SMRs), which have the potential to play an important role in globally sustainable energy development as part of an optimal energy mix. Such reactors have the potential to enhance energy availability and security of supply in both countries expanding their nuclear energy programs and those embarking on a nuclear energy program for the first time.

The SMR Regulators Forum was formed in 2014 to identify, enhance understanding of and address key regulatory challenges that may emerge in future SMR regulatory discussions. This is expected to help enhance safety, efficiency in SMR regulation, including licensing, and to enable regulators to inform changes, if necessary, to their requirements and regulatory practices.

The Forum entered its second phase in 2017, following up on the work carried out in previous years. This document is the Phase 2 Final report of the Working Group on Manufacturing, Construction, Commissioning and Operation Issues. Appendix A lists the abbreviations used throughout the report and Appendix B shows the list of the contributors to the report

The following four topics were covered in the second phase which was completed at the end of 2020:

- Manufacturability, supply chain management and commissioning
- Collection and Use of Experience in the Lifecycle of Small Modular Reactor facilities
- Conduct of Maintenance
- Conduct of Co-activities and Combined Activities on a Multiple Unit Small Modular Reactor Facility Site

This report was developed based on information, insights, and experience gained from the regulatory activities of the SMR Regulators' Forum members. It is considered to be generally consistent with existing IAEA documents but may deviate in some cases. This report is intended to provide useful information to regulators and industry in the development, deployment and oversight of SMRs.

Introduction

Content of the report

This report is divided into a high-level description of the main common positions of the authors of the report and four main technical chapters:

Chapter 1: Manufacturability, supply chain management and commissioning of SMRs

This chapter discusses the concept of modularity and presents common regulatory positions on manufacturing, construction, and first-of-a-kind commissioning for SMRs.

Chapter 2: Collection and Use of Experience in the Lifecycle of Small Modular Reactor facilities

This chapter presents common regulatory positions on the use of experience in activities related to the entire lifecycle of SMRs in order to enhance nuclear safety and improve performance. A primary focus in this chapter is on activities associated with design, manufacturing, construction, commissioning, and operations.

Chapter 3: Conduct of Maintenance in an SMR

This chapter presents common positions associated with the need to address the conduct of maintenance as early as possible to enable effective operation and maintenance activities through design features.

Chapter 4: Conduct of Co-activities and Combined Activities on a Multiple Unit Small Modular Reactor Facility Site

This chapter discusses safety considerations that need to be considered up front in the design of structures, systems and components (SSCs) as well as in the overall program for conducting construction, operation and maintenance.

Common Positions generated by the Working Group are provided below and listed by Section number for easy reference to the table of contents.

Common positions

Common Positions for Chapter 1 - manufacturability, supply chain management and commissioning of SMRs

<u>Modularity</u>

- The terms "module" and "modularity" may mean something different depending on the design and business model for the SMR in question. All parties need to be attentive to what is included in the terms for the particular SMR being considered.

- There are safety implications that arise from the use of modularity in building and operating SMRs, and the end-user (Licensee) needs to have the ability to address those implications to secure nuclear safety

<u>Manufacturability</u>

- Manufacturability has implications for demonstrating compliance with requirements, long- term maintainability and operability of structures, systems and components. There are safety implications that arise from these facts. The Licensee is responsible for addressing these aspects.

- The Licensee needs to mobilize adequate competence skills early in the design stage to verify that the SMR design will fulfil safety requirements. Suppliers need to be involved at an early stage in the manufacturability, inspectability, operability, and maintainability assessments of modules for the purpose of specification.

- When assessing alternative or novel configurations of structures systems and components (SSCs), such as compact modular assemblies, licensees should work directly with the SMR designers and their vendor to evaluate and address appropriate provisions to enable access for required inspections, operations, and maintenance of SSCs. These provisions should also enable licensee to conduct specific oversight activities during manufacturing and construction such as witnessing key quality assurance activities during manufacturing or conducting receipt inspections at the site.

- As standard practice, industry stakeholders and, where applicable, regulators, should work with the standard development organizations to address potential gaps in existing standards related to manufacturing and construction issues.

- If there are aspects of SMR manufacture that are not covered by an appropriate existing standard, then the SMR intelligent customer should set a tailored standard for that aspect with appropriate surveillance, third party oversight and witnessing, proportionate to the risk to nuclear safety. Good engineering practices should be used in the derivation of tailored standards, consistent with the regulatory requirements.

- Manufacturing processes, if not implemented correctly for safety significant modules, could result in potential latent issues. Hence, the development and implementation of manufacturing processes need to contain sufficient control measures to prevent latent issues. Configuration management and stability needs to be verified from the first-of-a-kind (FOAK) manufactured SMR to the Nth-of-a-kind (NOAK) SMR (including situations that involve changes in manufacturing facilities or vendors).

- SMR manufacturers need to demonstrate the capacity and capability to address nuclear safety requirements.

- Site construction and commissioning of SMRs is a Licensee activity. Licensees need to exercise oversight of in-factory manufacturing and testing to achieve an assembled SMR that is safe and meets all regulatory requirements

- Special attention needs to be paid to factory-fuelled and sealed transportable reactor modules. This is because introducing nuclear material in the factory triggers a step change in nuclear safety risk and therefore the licensing and regulatory approach need to be commensurate with any other facility that handles fissile material.

Supply Chain Management

- The Licensee needs to identify and demonstrate how to mitigate risks arising from a more diverse, new, and potentially global supply chain, particularly risks from counterfeit, fraudulent and suspect items (CFSI).

- It is the responsibility of the Licensee to establish adequate Supply Chain Management (SCM) arrangements to ensure delivery of products and services safely and right the first time (GSR Part 2 [1] Requirement 11).

- The Licensee needs to have both an organisation that is capable of providing intelligent customer capability, and a supporting management system. The Licensee needs to instil an appropriate nuclear safety culture amongst its suppliers and contractors, at all tiers in the supply chain (SF-1 [2]).

- The Licensee for the SMR needs to incorporate appropriate practices, codes and standards.

- The Licensee and its associated supply chain organizations, including the SMR vendor and suppliers, will need to be capable of managing deviations and non-conformances in a way that takes into account the characteristics of SMR build, and encourages reporting, collaboration and continuous improvement.

- The Licensee will be expected to use safety classification to support the justification of appropriate quality requirements applied to structures, systems and components for SMRs.

- Licensees are responsible for pre-qualification of their suppliers. Hence, they should recognize that supply chain companies for SMRs who have experience with modular design, manufacturing and construction, may not have experience of the nuclear sector

Commissioning

- The Licensee needs to demonstrate how the commissioning programme takes into account any uncertainties due to the lack of OPEX.
- If multiple units/modules are shared in one facility or some units/modules will be added later on:
    - there will be common SSC that may require certain commissioning activities to take place as the first modules are installed and placed into service;
    - due consideration needs to be made to common system performance when adding units or modules and whether additional or new or repeated commissioning tests may be needed (a common plant HVAC system, for example, is important to environmental qualification);
    - commissioning may have the objective to demonstrate/verify the compatibility with the existing plant.

- The Licensee is responsible for:

    - quality, transparency and independence of persons or entities directly responsible for performing the tests (the persons implementing this process

should have the appropriate expertise in terms of manufacturing, detailed design and operation of the module to meet this objective).
  - conducting a review of deviations and of how these deviations are handled;
  - the decision on the continuation of the tests, or the definition of any subsequent test programme.

- Given the importance of the Commissioning program in future plant operations, the Licensee is responsible for the conduct of the program and is expected to specify where the tests will be performed and justify the representativeness of those tests regarding the on-site configuration. A further set of on-site commissioning tests will have to be performed to check that the results obtained off-site are valid for the plant

- When commissioning tests are performed in the manufacturing premises, the Licensee needs to be involved for the purpose of gaining experience for the future operation.

- The Licensee will need to justify the representativeness of full-scale replica tests results and FPOT tests if wanting to take credit for those tests in the commissioning phase, and detail the commissioning tests to be performed on the licensed plant to check their full applicability.

International cooperation

- Information exchange about SMR activities may be affected by international agreements on intellectual property rights.

Recommendations for Chapter 1: None.

Common Positions for Chapter 2 - Collection and Use of Experience in the Lifecycle of Small Modular Reactor facilities

Importance of Experience to the safety of SMRs

- Management at the highest level should embrace and promote the use of experience by all levels of the organization, for all safety significant applications as part of an overall defence in depth strategy. The collection, evaluation (including analysis where appropriate), sharing and use of significant experience throughout the SMR lifecycle by all stakeholders is critical to safety, continual improvement and public confidence. The overall responsibility for the use and oversight of experience lies with the licensees who should impose it on all their contractors and sub-contractors performing safety significant activities. In order to make decisions, regulators independently assess safety claims being made by the licensee and verify that the safety and control provisions both meet regulatory requirements and provide a high degree of confidence that they are effective.

SMR Experience Infrastructure

- The infrastructure to manage the body of experience information for an SMR concept needs to be systematically established up-front to consider diverse experience types and anticipate and address diverse stakeholder needs which may potentially extend across international boundaries. This includes the need for mechanisms to provide appropriate and timely access to specific information for the purposes of enabling technical cooperation activities and decision-making.

Enabling access to experience data and intellectual property by stakeholders

- Designers and licensees need to establish agreements amongst stakeholders in advance, to enable sharing of nuclear safety significant experience while still assuring the protection of intellectual property.

- The organizations' measures for experience should establish roles and provisions that promote the use and sharing of experience by all stakeholders.

Establishing systematic measures for the use of experience.

- SMR stakeholders should establish systematic experience measures early in the lifecycle to be used during the entire lifecycle of the SMR. The measures should adopt and follow IAEA safety fundamentals and guides with the ultimate goals of preventing significant events and improving performance. The measures should be disseminated into appropriate tools (for example, processes, procedures, checklists, independent reviews and training), to cover all safety significant activities by all levels of the organization.

Implementing experience measures

- SMR stakeholders should establish common and effective communication channels and tools and use experience in all important safety applications. This includes access to common experience databases, technical publications, generic communications, root cause evaluations, safety evaluations, industry and regulatory groups and other fora, the sharing of data, and technical staff cooperation in evaluating complex experience. Staff training is also part of the implementation of measures.

Assessing the effectiveness of the experience measures

- SMR stakeholders should perform both periodic and reactive internal and external assessments of their experience measures including self-assessments, internal and external audits and benchmarking against IAEA safety standards and industry practices, to ensure that the use of experience continues to meet internal and industry objectives. Reactive assessments of experience for preventable significant failures should be required by the corrective action programme and actions should be taken to improve the experience measures as required. An assessment of how experience information is being systematically leveraged or developed by the licensee should be part of the regulatory assessment.

Recommendations for Chapter 2: The most effective way to produce new experience measures is to work with existing organizations as early in the project lifecycle as practicable to promote, establish and implement them. As a result, we recommend that the IAEA take advantage of the memorandum of cooperation with WANO to develop guidance for establishing experience infrastructure appropriate for deployment of SMRs. In particular:

- Infrastructure should consider the need for regulatory and licensee readiness programmes, particularly for nations completely new to the civilian nuclear industry.

- Infrastructure should consider SMR specificities that extend beyond operations and maintenance and include elements of manufacturing, construction and commissioning that may introduce challenges to lifecycle operation. For example, one noteworthy area is to examine experience interfaces between modular manufacturing organizations, which seek to produce standardized products, and the need to address site-based installation and commissioning activities in different countries.

- Existing experience infrastructure such as the International Reporting System for Operating Experience (IRS) should be evaluated to ensure that it adequately accommodates SMR experience needs.

We recommend that the SMR Regulators' Forum Licensing Issues Working Group address in their report on how national regulators might need to use existing international cooperation mechanisms to share experience and enable mutual recognition of each other's activities, through developing common positions.

Common Positions for Chapter 3 - Conduct of maintenance

Conduct of Maintenance

- The ultimate Licensee is expected to understand and approve where, how and by whom any maintenance activities are going to be done.

- The designer and ultimate Licensee should collaborate as early as possible to:
    - enable effective operation and maintenance activities through design features;
    - apply requirements for maintenance, inspection and testing in line with the national expectations of the country where the SMR is deployed;
    - consider how the design of the SMR, and any modular, factory-based approach to building the SMR, may affect subsequent maintenance activities; and
    - strike a balance between minimising risks arising during maintenance activities (to people, plant, and the environment), with ease of SMR build and aspects of the design.

- Modular construction does not necessarily mean modular maintenance unless that was the original design intent. The degree of modularity (at the outset), and the approach to the content of modules, must include thinking about future maintenance requirements, as well as the conduct of operations.

Recommendation for Chapter 3: The SMR Forum recommends that IAEA reviews existing safety standards and guides so that they give appropriate weight to the principles in this document. In particular, address whether there is appropriate emphasis on maintenance when there is modular design and construction practices being introduced in SMRs.

Common Positions for Chapter 4 - Conduct of Co-activities and Combined Activities on a Multiple Unit Small Modular Reactor Facility Site

Safety Case for multiple unit SMR facilities

- The facility Safety Case must consider all co-activities being performed at an SMR facility.

- Activities that are potentially vulnerable to co-activity risks should be systematically identified and analysed. The results of the analysis should be reflected in the safety case for the entire facility and be included in the deployment plan.

- Design the multiple unit facility with the sequence of construction, commissioning operations and co-activities in mind.

- The design of structures, systems and components for a multiple unit facility should take due account of the sequence and timing of activities and co-activities associated with construction, commissioning, and operations.

- With any increase in co-activities, a "step-wise" increase is needed in risk control features and organisational capability to match and should be anticipated in the deployment plan. Licensee capability needs to be maintained throughout any later deployment of extra modules.

<u>Safety Culture and the conduct of co-activities in a multiple unit facility</u>

- Activities between co-located units should be effectively managed by the Licensee(s) within a strong and facility-wide safety culture environment:
  - All workers should be made aware when they are conducting work in a co-activity environment and provided with the necessary tools to understand and complete their tasks within the constraints under which their work is to be conducted. For example, technical processes for activities should be sufficiently detailed to assist the workers to perform their activities to a high degree of quality.
  - The perimeters of responsibilities should be clearly established and documented, between the Licensee and parties with key responsibilities in the execution of construction, commissioning, and maintenance support.
  - An integrated set of processes and tools should be implemented to systematically identify potential co-activities, characterize potential risks and establish effective means, including "back-out" provisions to prevent and mitigate potential events that could impact on safety.
  - Particular attention could be necessary when a new module is to be installed or commissioned, or a module is underdoing maintenance in close proximity to operating units.
  - A coordinator should be assigned to manage the interface between the Licensee and the companies involved in the installation/commissioning of a new module or significant maintenance on an existing unit.
  - Another coordinator should be assigned to manage the day-to-day interface between operators and the team in charge of the installation/testing.

- The preparation of co-activities, especially before installing or withdrawing a unit or other major modular equipment, requires early systematic planning activities that involve operations staff to anticipate and prevent events that could impact on nuclear safety. Planning activities should anticipate the complexities and potential hazards of co-activities and provide realistic allowances for the impact of any delays and slippages in planning to avoid any adverse effect on quality.

- A facility operating experience program should include the study of co-activities and the analysis of lessons learned. The first unit to be installed and commissioned should be used to gather necessary operating experience to validate and verify work processes for use in subsequent units. Sufficient schedule time should be provided to accommodate these activities.

Conduct of Operations and Maintenance in a Multiple Unit Control Room

- The operations and maintenance program should give due regard for human factors considerations of multiple unit operation in a single control room.

The Commissioning Program and Plan for a Multiple Unit Facility

- The commissioning program for a multiple unit facility should encompass the entire facility in a holistic manner and incorporate the gathering and use of operating experience as new units are installed into the facility.

- In particular, commissioning activities and results for common (for example, shared) systems need to be revisited as activities within the facilities evolve, in particular as new units are added to the facility, to demonstrate that common systems remain fit for service to support safety functions credited in the safety analysis.

- The commissioning activities for newly installed units should consider past commissioning activities in the facility while at the same time ensure that sufficient testing activities are performed to demonstrate that the new units are fit for service to support safety functions.

Configuration Management in Multiple Unit Facilities

- In a multiple unit facility, a strong and systematic facility wide configuration management program is particularly important over the life of the facility to prevent the potential for human induced events and introduction of latent safety issues into the design of the facility.

- Workers planning to conduct activities should be made aware of configuration differences between units through the configuration management program and the potential safety implications of those differences. Awareness of configuration differences should be addressed through worker training as well as in all tools used to conduct work.

Recommendations for Chapter 4: None.

1. Chapter 1: Manufacturability, Supply Chain Management and Commissioning

SMRs are likely to use familiar approaches to building new reactors, but emphasize certain aspects more, such as:

- greater use of modularization,
- more construction and testing in factories and
- designs that may be replicated and supplied to a number of different operators in different countries.

Existing arrangements[1] to regulate activities involving large nuclear power plants are also suitable arrangements to regulate activities involving SMRs[2], with some adjustments and balancing to take into account novel deployment approaches under the SMR business model.

Consequently, a single organization should be responsible (the Licensee). The Licensee needs to be resourced and capable of establishing adequate oversight of the supply chain. The Licensee should have influence over the design and procurement so as to secure nuclear safety, including those aspects of nuclear safety secured by design and quality standards in the period of first supply and assembly.

The following discusses the concept of modularity and presents common regulatory positions on manufacturing, construction, and first-of-a-kind commissioning for SMRs.

1.1 Implications of modularization[3]

1.1.1 Module

In most industries, a *module* is generally understood to be a technological entity generally composed of a number of sub-assemblies that are sourced through the manufacturer's supply chain and include civil, mechanical, electrical and I&C systems and components. A module's technological complexity can range from a simple prefabricated structure to a complex arrangement of structures systems and components.

[1] Existing good practice is set out in relevant IAEA publications on NPP safety.
[2] From this point forward in this report, the term "regulating SMRs" refers to regulation of safe conduct of activities concerned with SMR projects, including manufacturing, construction and commissioning.
[3] A number of articles are available on the web for readers who want to have a greater understanding of modularity. For example: National Institute of building sciences Off-Site and Modular Construction Explained at https://www.nibs.org/page/oscc_resources

Figure 1a: Simplified Example: Petrochemical Water Treatment Module (courtesy Siemens)

Modular construction is an approach that organizes a complex construction / assembly process into discrete predictable steps using *modules*, where applicable, as the primary building blocks. The primary goal of modular construction is to improve efficiency of on-site construction and reduce the number of on-site crafts [4] needed to perform construction activities. In theory, many of the traditional on-site crafts would be moved back into the supply chain in the manufacturing facilities to ensure high quality before modules arrive at the site for installation.

All modern nuclear power plant projects use modularity in some form or another [5] but the degree of use varies from design to design. Developers of many SMR technologies are seeking to further develop these concepts and eventually demonstrate economies of scale in an effort to significantly reduce construction and commissioning times and related costs.

1.1.2 Modules in relation to SMRs

Common position

> *The terms "module" and "modularity" may mean something different depending on the design and business model for the SMR in question. All parties need to be attentive to what is included in the terms for the particular SMR being considered.*

In some SMR designs, modules may simply be smaller versions of what is already done for large Nuclear Power Plant (NPP) designs, for example:

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[4] A *craft* is a term for a highly skilled trade or profession involving a strong degree of precision and quality in design, fabrication, assembly and testing.
[5] For example, modular Instrumentation & Control platforms, turbine generator sets, back-up power platform are common technologies. The use of fully modular civil structures is less common in Nuclear Power Plant designs.

- Instrumentation & Control architectural modules
- Prefabricated civil structure modules
- Diesel generator modules

SMR designs using this type of module present the same sort of safety-management challenges associated with larger NPPs, such as Licensee oversight of procurement in a global multi-tier supply chain.

In other types of SMR design, such as integral light water, the entire nuclear steam supply system is contained within a single module and may include:

- Reactor core and control mechanisms
- Pressurizer
- Steam generator(s)
- Containment structure
- Associated instrumentation and control features installed at the factory.

In this case, additional safety management challenges may exist such as the ability to inspect during manufacturing, upon receipt at the site, and during construction, commissioning, and operation.

Another element of modular design being described by SMR technology developers is the concept of replacing one large (for example 500 MWe) reactor/process system pair with a number of smaller ones (for example, 10 SMRs of 50 MWe each) that could be installed in increments over the life of a facility as power demand increases. Sometimes a single unit SMR NPP of this type is referred to as a module. SMR vendors are also using the term module to denote the whole NPP.

One challenge of modularity is, in essence, a complete nuclear island in a single module comprising all nuclear related systems needed to support defence-in-depth. In this case, the nuclear module may or may not be re-fuellable and the majority of traditional site construction activities may be performed in a manufacturing facility that may be in a different jurisdiction under different regulatory processes. This raises the question about whether offsite manufacturing should be considered as "construction" for the project site or "procurement" or a combination thereof. Consequently, if this form of modularity is part of an SMR design, then Regulators in each member state will have to recognise that the balance between what is defined as manufacturing and what is defined as construction will differ from historic approaches, and so they may need to be aware of how their own laws might be applied.

1.1.3 Experience with the use of modularity in the nuclear sector and safety implications.

Common position

> *There are safety implications that arise from the use of modularity in building and operating SMRs, and the end-user (Licensee) needs to have the ability to address those implications to secure nuclear safety.*

Given that the number of successfully completed new build nuclear power plant projects is small, the majority of technology developers and, more importantly, Licensees of nuclear power plants currently have limited experience in the use of modularity in new nuclear power projects. This includes experience in understanding the safety implications of modularity in procurement, manufacturing, construction, commissioning, and subsequent operation. The safety implications of modularity include (for example):

- constrained space on a module skid during build leads to operational constraints in inspection and maintenance;
- ensuring proper communication between software packages, that are often sold as modules, in safety significant Instrumentation & Control systems;
- ensuring that electronic systems are integrated and function effectively;
- achieving the theoretical benefits from modularity that arise from construction in factories to consistent quality standards;
- achieving Licensee and Regulator oversight given the manufacturing location and schedule for SMR module production;
- experience from commissioning and operation of any completed new build projects will not be available to designers or vendors of SMR technologies.

The intent behind manufacturing of modules is to deliver a 'ready to install and operate' portion of the plant to facilitate efficient construction and commissioning. This increases the onus of the Licensee and its Engineering, Procurement, Construction (EPC) partner (if applicable) to perform traditional site construction inspections <u>off-site</u> and to develop additional expectations around accepting the module for shipment from the factory, site receipt, readiness for installation etc.

The above factors significantly influence the ability of an end-user (Licensee) to articulate expectations to reactor vendors and the subsequent supply chain. Expectations include:

- Quality assurance requirements to support reliability specifications (in accordance with the safety classification process results)
- Evidence to be produced by manufacturers to support the Licensee's safety analysis expectations
- Objectives to be demonstrated in both factory and commissioning activities
- Constructability, operability, inspectability and maintainability
- Ageing management considerations
- Site conditions that need to be considered in the design of modules to address, for example, external events.
- defined interfaces between the suppliers, vendors and Licensee.

1.2 Manufacturability

Common position

> *Manufacturability has implications for demonstrating compliance with requirements, long- term maintainability and operability of structures, systems and components. There are safety implications that arise from these facts. The Licensee is responsible for addressing these aspects.*

Many new SMR designs are compact and complex, and the manufacturability of some novel components may be a challenge for the industry.

Manufacturability is defined as the extent to which a good can be manufactured with relative ease, at minimum cost, and maximum reliability[6]. The manufacturability of SMRs is important to SMR reactor vendors to economically compete with other energy sources with a reactor design that meets or exceeds nuclear safety requirements.

There are a number of safety implications presented by the SMR manufacturing approach. For example, the compact nature of SMRs may limit physical accessibility to perform inspections, tests, and repairs/maintenance. SMRs may take advantage of new design features, manufacturing processes, components, and materials that have not been used previously in the manufacture and construction of nuclear power plants. Regulators should consider these elements as manufacturing requirements, licensing reviews, and manufacturing/construction oversight arrangements are developed.

The involvement of the suppliers during the design phase of components to check on manufacturability is fundamental. It may be necessary to manufacture some prototypes to test the feasibility of the design, different choices of materials, how they are joined together, and give due consideration for designs with multiple modules. The need to develop specific instruments for inspection during manufacturing and operation and maintenance needs to be assessed by the vendor, Licensee, and the supplier.

During the manufacture and construction of nuclear power plants, it is important that Licensees ensure that the necessary inspections, analyses, and tests are performed to confirm that the as-built plant is consistent with the approved design. In addition, it is important that there will be independent inspections of the manufacturing and construction activities to verify the level of quality. In contrast to the manufacture and construction of conventional nuclear power plants, the design of SMRs and their manufacturing location and schedule may affect the ability of the Licensee and Regulator to provide necessary oversight.

Licensees, suppliers, and Regulators need to be knowledgeable regarding the capabilities and limits of SMR manufacturing practices, because they will be involved in design reviews, analyses, inspections, and tests to ensure latent design issues do not arise because of manufacturing activities.

[6] Businessdictionary.com

Common position

> *The Licensee needs to mobilize adequate competence skills early in the design stage to verify that the SMR design will fulfil safety requirements. Suppliers need to be involved at an early stage in the manufacturability, inspectability, operability, and maintainability assessments of modules for the purpose of specification.*

This principle emphasizes the importance of the vendor seeking involvement of potential suppliers to ensure that their design can be manufactured, inspected and maintained throughout the life of the SMR. Once a Licensee has been established, it should be organized to ensure that safety requirements (such as inspectability and maintainability) are considered in the design stage and reflected in manufacture.

Any manufacturing requirements and acceptance criteria established by licensees, vendors and Regulators need to ensure that inspectability, operability, and maintainability will be addressed and need to be communicated in a systematic fashion to the supply chain. Regulators do not specify how a reactor should be built: it is the Licensee that specifies the overarching design criteria that the design must meet, taking into account the regulatory requirements.

Common position

> *When assessing alternative or novel configurations of structures systems and components (SSCs), such as compact modular assemblies, licensees should work directly with the SMR designers and their vendor to evaluate and address appropriate provisions to enable access for required inspections, operations, and maintenance of SSCs. These provisions should also enable licensee to conduct specific oversight activities during manufacturing and construction such as witnessing key quality assurance activities during manufacturing or conducting receipt inspections at the site.*

Most SMR designs are designed to be compact to enable their manufacture at a factory and provide for ease of transportation to the plant site. However, the compact nature of SMRs may challenge the ability to perform the necessary inspections, operations, and maintenance, not only during the manufacturing stage, but for the life of the SMR. For instance, codes and standards for welding safety-related components require inspection and non-destructive examination of the welds. Manufacturing processes would need to be properly coordinated to allow accessibility for the necessary inspections and examinations. SMR vendors would need to consider up-front, how such inspections would be performed and discuss accessibility with potential Licensees and Regulators prior to finalizing such designs.

Analysis of accessibility can be aided with the help of scale models and computer animations that accurately depict the three-dimensional space between objects. This issue is compounded when working with new materials and chemistry environments that may require additional in-service inspections to gather material performance data (for example, data on ageing).

In addition to the physical accessibility challenges for performing inspection and tests on SMRs, Licensees may also be challenged in gaining access to certain manufacturing facilities. Specifically, SMR vendors may choose to manufacture long-lead components, or entire modules, before there is a license issued to their ultimate end-user customer. Therefore, the Licensee may not have the opportunity to perform oversight of certain safety-related manufacturing processes (e.g., large component forging), for which they are responsible. The safety implication of this is that the component cannot be demonstrated to meet requirements. This is compounded by the fact that some regulatory bodies may only have access to a vendor's activities through a Licensee's new construction activities. Third party accreditation and inspection might be considered by Regulators as a method to provide sufficient independent oversight of certain code and standards activities.

The Licensee should encourage the vendor to involve the main suppliers during the design phase and in the validation of the design of safety significant components and the choice of materials. During licensing activities, suppliers, Licensees and Regulators should engage early in the process to discuss unique manufacturing processes. In addition, due to the compactness of SMR designs, Licensees and suppliers should evaluate potential manufacturing issues that may arise due to physical inaccessibility, use of unique materials, new designs/components, or use of new or alternative manufacturing processes.

Common position

> *As standard practice, industry stakeholders and, where applicable, regulators, should work with the standard development organizations to address potential gaps in existing standards related to manufacturing and construction issues.*

Industry stakeholders and, where applicable, regulators work with standards development organizations that provide more specific requirements and guidelines with respect to manufacturing and construction activities. These codes and standards may be incorporated as part of regulations or used as guidance by the Regulator. Because SMRs may use novel manufacturing techniques and new materials, the respective codes and standards may need to be updated. Industry stakeholders and, where applicable, regulators should, as a matter of standard practice, work through the standards development organizations to address potential manufacturing and construction issues. When codes and standards are modified or developed, a strong opportunity exists to harmonize practices among the standards development organizations and, as a result, enable greater opportunities for Regulators in different countries to leverage the information in their decision making.

Common position

> *If there are aspects of SMR manufacture that are not covered by an appropriate existing standard, then the SMR intelligent customer should set a tailored standard for that aspect with appropriate surveillance, third party oversight and witnessing, proportionate to the risk to nuclear safety. Good engineering practices should be used in the derivation of tailored standards, consistent with the regulatory requirements.*

In the absence of appropriate existing standards, industry stakeholders and, where applicable, regulators should work through the standards development organizations to create appropriate standards. However, it is recognized that standards development is informed by credible industry experience that takes time to develop. In the interim, regulatory mechanisms should exist to address the use of alternative practices provided that they are adequately supported by credible science and engineering information and that suitable control measures are established to address uncertainties due to lack of experience. Licensees, vendors, and Regulators should engage with standards development organizations to ensure that the necessary codes and standards are established to address the unique design and manufacture of SMRs. If any gaps are identified in the current codes and standards, they should be addressed to ensure inspect-ability, operability, and maintainability of SMRs.

Common position

> *Manufacturing processes, if not implemented correctly for safety significant modules, could result in potential latent issues. Hence, the development and implementation of manufacturing processes need to contain sufficient control measures to prevent latent issues.*

Licensees are responsible for ensuring appropriate quality during manufacture and construction, commensurate with safety importance. Suppliers have the responsibility to ensure quality requirements to the satisfaction of the Licensee. Manufacturing processes are a potential source of latent flaws if not correctly implemented in safety significant modules, e.g. lean manufacturing principles seeking to cut costs over time. Licensees need to ensure that a quality assurance process is established and implemented, including audits of their supply chain. If these processes work correctly, latent issues are less likely to occur.

For some SMR designs, the manufacturing processes may be similar to those used in the manufacture of structures, systems, and components for conventional nuclear power plants. Other SMRs, particularly advanced reactor designs, may require use of new and exotic materials. These materials may require special handling, storage, fabrication, and treatments to ensure the desired properties in the material are maintained and not lost during the manufacturing process.

There may be instances where new manufacturing processes may be used. For example, additive manufacturing, i.e., 3-D printing of metallic components, may be beneficial from a manufacturability standpoint when traditional fabrication methods are complex and/or expensive. In this case, complex metallic structures that would be difficult to manufacture using traditional machining methods could be manufactured by additive manufacturing potentially reducing cost while maintaining the desired material and structural properties. If there are aspects of SMR manufacture that are not covered by an appropriate existing standard, then the SMR intelligent customer should set a tailored standard for that aspect with appropriate surveillance, third party oversight and witnessing, proportionate to the risk to nuclear safety. Good engineering practices should be used in the derivation of tailored standards, consistent with the regulatory requirements.

Licensees, vendors, and Regulators would need to understand the technical aspects of these new processes, materials, and techniques. From this knowledge, appropriate benchmarks can be applied by vendors, suppliers, and Licensees, and inspected by the Regulator.

Common position

> *Configuration management and stability needs to be verified from the first-of-a-kind (FOAK) manufactured SMR to the Nth-of-a-kind (NOAK) SMR (including situations that involve changes in manufacturing facilities or vendors).*

One of the claimed advantages of SMRs is the greater level of standardization that can be achieved; not only with respect to plant design, but also having a consistent manufacturing process which includes procedures, equipment, and personnel. Standardization may allow for better identification and application of construction and operating experience to a fleet of nuclear power plants. If properly leveraged, the application of construction and operating experience can provide improvement upon the safety of those plants. As NOAK SMRs are manufactured, corrections could be implemented on the NOAK design based on construction and operating experience. While configuration management is not a new concept in the nuclear industry, there is a balance between configuration stability (i.e., standardization) and continuous improvements to the design. It is important that these changes are controlled in such a way to enhance the safety of the NOAK (configuration control plus evaluation of changes to ensure no unanticipated consequences). This would include consideration for implementing changes on previously manufactured SMRs. As Licensees and vendors incorporate the necessary corrections and lessons learned as SMRs are manufactured, they will also ensure the proper configuration control and design changes that result from the corrections and lessons learned.

Regulators expect quality assurance and oversight of suppliers by Licensees. Change of suppliers could happen from the FOAK to NOAK SMR. Economics tends to drive the industry to use a proven supplier, so long as the supplier can provide products in a timely and quality manner that meets cost expectations. Changing suppliers can incur certain costs, including retooling for a new supplier, establishing contractual arrangements, and other starting costs. If different suppliers are used on the manufacturing of the NOAK, Licensees would need to verify adequate quality assurance and oversight of those suppliers.

If any supplier changes are made, they would likely be at the sub-supplier level. Contracts (such as purchase orders) from the main supplier should permit lessons learned from previous manufacturing experience to be shared throughout the supply chain, and Licensees should verify that the main supplier provides adequate oversight of their sub-suppliers.

The use of test results from one SMR to the next to be manufactured could be beneficial. SMR vendors are claiming that subsequent SMRs manufactured after the FOAK would have a reduced set of required inspections and tests. This aspect has been discussed in the MDEP Common Position on First Plant Only Tests which could also theoretically be applied to SMRs. It is an important aspect of regulatory oversight that should be established during the regulatory review as to which inspections and tests could be credited from the FOAK SMR to the NOAK SMR. If the same design and quality processes are used for the manufacture of the NOAK SMR, it would be reasonable to expect the NOAK to have similar reliability to the first SMR. This is not unlike seismic or environmental qualification testing of a prototype component, for which the qualification test results on the prototype can be applied to a set of manufactured components over many years so long as the design does not change. If significant design changes occur between the FOAK SMR and the NOAK SMR, certain FOAK tests may need to be re-performed on the NOAK or, at a minimum, analysed to see if the prior test results are still applicable.

Licensees of NOAK SMRs for which the FOAK was constructed in a different country, may want to take credit for testing performed on the original FOAK. Regulators should collaborate on the potential for which SMR FOAK tests could be credited in other countries and how regulatory oversight would be applied.

Common position

> *SMR manufacturers need to demonstrate the capacity and capability to address nuclear safety requirements.*

On capacity, currently, some Licensees and vendors may not yet possess the necessary expertise to manufacture SMRs. They may compensate for this by teaming up with more experienced suppliers. However, new FOAK designs can be a challenge in achieving the necessary level of quality in manufacture and construction.

On capability, SMRs may pose challenges with new design and manufacturing features for which a workforce may need additional qualification. Once experience has been gained manufacturing new features, it is expected that the factory environment would support appropriate quality since the suppliers would be able to maintain a skilled workforce in a close proximity.

Regulators may inspect the technical expertise of the Licensee and suppliers to ensure the necessary expertise in manufacturing an SMR. This is particularly challenging for the FOAK SMR as there will likely be little to no experience with such new designs.

Common position

> *Site construction and commissioning of SMRs is a Licensee activity. Licensees need to exercise oversight of in-factory manufacturing and testing to achieve an assembled SMR that is safe and meets all regulatory requirements.*

SMRs may shift the balance of construction activity from the plant site to a factory, such as a manufacturing facility and/or an assembly facility. For Licensees, they need to make the necessary provision to gain access to important activities to verify proper quality controls at the factory. This would require, at a minimum, consideration of proper access and proper notification of activities in purchase contracts.

Shifting more of the manufacturing and construction from the site to factories may also change how and where initial plant tests are conducted, as compared to conventional nuclear power plants. Many tests that were previously initial plant tests conducted at the site may now be factory tests, conducted by the supplier. Since the Licensee remains responsible for the design and construction of the SMR, the Licensee would have to provide sufficient oversight of any factory tests performed as part of initial plant testing.

A Licensee for a SMR on a specific site involving construction and commissioning is accountable under their license for the safe and satisfactory completion of all construction and commissioning activities, including the procurement of equipment and services. The Licensee is expected to demonstrate how effective oversight of these activities will be carried out. All construction and commissioning activities should be governed by the provisions of the Licensee's quality management system.

A construction program, as defined by the vendor and Licensee, is expected to contain provisions to demonstrate that the plant has been fabricated and constructed in accordance with the design (including the procurement of equipment and services). It should also describe how the commissioning program will confirm that the equipment, structures, systems and components (SSC), and the plant as an integrated unit will perform and function in accordance with the design specifications, regulatory requirements, and as credited in the safety analyses.

Some of the factory tests may also fall into the category of FOAK tests only. Performing these tests in a factory setting has advantages and disadvantages. The advantages include the ability to have test equipment with greater testing capabilities and sophistication, a more controlled test environment, and greater access to the engineers involved with the design and construction of the components. The disadvantages include the potential lack of full integration with other plant systems and less control by the Licensee. In addition, FOAK components may require qualification testing using prototypes which can reveal design and manufacturing issues. Therefore, it is important that qualifications tests begin early and all stakeholders witness them. For the Regulators, having early access to these test activities and their results can play a role in licensing and oversight of SMRs.

Where there is significant modularity, in particular at offsite manufacturing facilities which could be offshore and out of the regulatory jurisdiction of the member state, the Licensee's oversight of manufacturing, including related test activities, extends to these manufacturing facilities. In some cases, components may be traditional long lead items due to their simplicity, and have traditional site acceptance, installation and commissioning approaches. However, as the safety significance of a module increases, the manufacturing facility needs to give proper assurances to the Licensee before shipping the module to the site for installation. This increases the number and thoroughness of inspections and tests conducted at the factory and introduces additional off-site inspection/oversight activities conducted by the Licensee and in some cases, the member state's Regulator. In addition, some of these factory tests may inform and influence the nature of the on-site commissioning activities. The construction and commissioning program should take account of these factors.

If an SMR is being manufactured in its entirety in a country different to where the SMR will be installed, then the Licensee should still ensure that they have adequate oversight of the design, construction and testing of the SMR.

Taking into account the safety significance of structures, systems and components (SSCs) within the SMR, and the use of novel features or approaches, there is likely to be a difference in Licensee oversight approaches if the procurement is under a long lead item process versus a construction program-controlled process.

Long-lead items may be procured outside of the licensing process, at the Licensee's economic risk, and some Regulator's compliance activities may be different from those performed on a construction program, which is part of the facility's licensing basis. For a SMR with significant factory testing prior to delivery to the site, then the site activities to accept, install and commission the module may vary if one process is used versus another (licensing versus construction). Additional review of whether this presents regulatory issues is needed because this influences how the Regulator organizes itself to conduct its compliance program such as placement and role of resident inspectors.

Common position

> *Special attention needs to be paid to factory -fuelled and sealed transportable reactor modules. This is because introducing nuclear material in the factory triggers a step change in nuclear safety risk and therefore the licensing and regulatory approach need to be commensurate with any other facility that handles fissile material.*

A factory-fuelled and sealed transportable reactor module is a special case because it represents a significant nuclear island component manufactured and likely tested, or even commissioned, to some degree off-site. This transfers a significant nuclear construction activity offsite, which is novel in the civilian nuclear power sector. Unlike other typical plant components, some vendors are designing the reactor module interior to be inaccessible to the site Licensee to provide further safeguards reassurances by preventing the possible diversion of fissile materials. But this presents challenges for activities such as in-service inspections. In addition, some vendors are proposing that a vendor/assembler factory may consider low-power nuclear testing of the reactor module before the module leaves the factory. The intent would be to reduce the likelihood of factory issues appearing at the site and to reduce the site's construction/commissioning times. The challenge presented in this case is that these testing activities would require an operating license in the factory's jurisdiction and the Licensee proposing to perform these tests may not have been identified. If the factory is in another member state, different regulatory requirements and licensing processes may also apply. Transportation regulations regarding transporting partially irradiated fuel would also need to be considered. Therefore, many of the principles expounded in this document will be difficult to apply to this special case. We commend the ongoing work by the IAEA in this area and recommend that the SMR Regulators´ Forum considers it when the results are in hand.

1.3 Supply chain management

SMRs may use familiar approaches to building new reactors, but emphasize certain aspects more, such as greater use of modularization, more construction and testing in factories and designs that may be replicated and supplied to a number of different operators in different countries. Hence, SMR supply chain models may place extra demands upon existing regulatory approaches.

Common position

> *It is the responsibility of the Licensee to establish adequate Supply Chain Management (SCM) arrangements to ensure delivery of products and services safely and right first time (GSR Par 2* [1] *Requirement 11)*

This IAEA safety requirement emphasizes the importance of one organization, the Licensee, being in charge of all the fundamentals that secure nuclear safety at an operating reactor, including all the fundamentals that are put in place before operation begins, through design and build.

This principle holds good for SMRs, but it has extra demands placed upon it by aspects of the SMR supply chain model. One extra demand is to ensure that there is a single organization in charge (the Licensee), given that the companies that design, market, sell and build the reactors may not subsequently operate the reactors that they design and build, and might (or might not) be licensed. Hence, the design fundamentals and the supply chain fundamentals may be under the control of organizations that are not licensed. In this situation, the ultimate operator (the Licensee) needs to be resourced and capable of establishing adequate oversight and influence over the design and procurement so as to secure nuclear safety, including those aspects of nuclear safety secured by design and quality standards in the period of first supply and assembly.

Common position

> *The Licensee needs to have both an organisation that is capable of providing intelligent customer capability, and a supporting management system.*

The primary responsibility for the safety of a nuclear installation rests with the Licensee. The Licensee should be able to demonstrate sufficient knowledge of the plant design and safety case for all plant and operations on the licensed site. The Licensee is expected to be in control of activities on its site, understand the hazards associated with its activities and how to control them, and have sufficient competent resource to be an 'intelligent customer' for any work it commissions externally.

As an intelligent customer, in the context of nuclear safety, the Licensee will be expected to know what is required, to understand the need for a contractor's services, to specify requirements, to supervise the work and be able to technically review the output before, during and after implementation. The concept of intelligent customer relates to the attributes of an organization rather than the capabilities of individual post holders.

One of the contractors is likely to be the vendor of the SMR technology.

The Licensee should have the capability to plan and organise the supply chain system from end-to-end, have appropriate qualification standards for suppliers in use, realistic metrics set for performance, and an effective quality assurance programme in place covering factory based, as well as site-based, construction. "Capability" should include, in particular, sufficient numbers of qualified and experienced people for activities novel to SMRs, such as new materials that are challenging to produce, test and certify. The Licensee should inspect safety aspects that are delivered by suppliers in factories as well as overseeing transport to site and assembly at site.

There should be proportionate arrangements for intelligent customer oversight by the Licensee of all organizations in the supply chain based on the risk they present to nuclear safety.

The Licensee management system should include the resources necessary to oversee new suppliers and novel approaches, and cope with SMR manufacture in multiple locations. The system should set a capability standard expected of suppliers, particularly those who are new to nuclear, and mandate inspection by the Licensee to check that suppliers meet these standards. The system should include targeted inspection of quality compliance, together with checks of quality assurance arrangements and the management of deviations. The SMR supply chain model emphasizes the repeat production of modular assemblies, incorporating a variety of components, to a consistent design, so the Licensee management system should include oversight on the interfaces between components, the quality of repeat modules, and on the management of changes and configuration control.

The SMR supply chain model may mean that there is deployment of the same reactor design after the FOAK reactor is operating. In this case, the Licensee that is deploying a replication of the original reactor design may be able to use the supply chain that was set up for the FOAK, and consequently adjust their intelligent customer activities over this supply chain in proportion to risk and experience. A focus for this second Licensee would be on establishing a competent design authority who can access the design through a controlled process and a programme of work to manage knowledge transfer from the vendor to the Licensee.

The supply chain may evolve as SMR deployment occurs over time and hence the oversight of the chain needs to be reviewed by the Licensee on a periodic basis. In some jurisdictions, this will also lead the Regulator to undertake certain regulatory activities within the supply chain.

Common position

> *The Licensee needs to instil an appropriate nuclear safety culture amongst its suppliers and contractors, at all tiers in the supply chain [2].*

In common with all nuclear facilities, the Licensee of an SMR should set and sustain a positive culture working with (and through) its "extended enterprise" of suppliers and contractors. The culture throughout the supply chain should be collaborative but with a questioning attitude and encourage open reporting for the purpose of improvement. The culture should be maintained and reinforced by leaders who recognize that certain characteristics of the SMR supply chain model may push against a positive culture. These characteristics include complexity, novelty, time pressures, global sourcing and the pace expected in construction.

The Licensee should systematically demonstrate understanding of its supply network and the risks presented to nuclear safety from the products or services each supplier provides [3].

Common position

> *The Licensee for the SMR needs to incorporate appropriate practices, codes and standards.*

The Licensee, in its role as the SMR intelligent customer, should specify manufacturing codes and standards for products and services that the SMR should comply with as they are procured through the supply chain. The codes and standards should be acceptable in the country where the SMR and Licensee will be located. If there is more than one code or standard to be used, then this should be documented. If there are aspects of SMR manufacture that are not covered by an appropriate existing standard, then the SMR intelligent customer should set a tailored standard for that aspect with appropriate surveillance, third party oversight and witnessing, proportionate to the risk to nuclear safety. Good engineering practices should be used in the derivation of tailored standards, consistent with the regulatory requirements.

Common position

> *The Licensee needs to identify and demonstrate how to mitigate risks arising from a more diverse, new and potentially global supply chain, particularly risks from counterfeit, fraudulent and suspect items (CFSI) [4].*

The Licensee and their associated supply chain should manage CFSI mitigation, and other product risks, to the same level as currently expected for other new build and operating nuclear plant [5]. The challenge to achieving this objective arises from the need to have more, and differently skilled, personnel and systems to take account of SMR supply chain characteristics, such as more use of modular techniques, factory-based production and international suppliers. This means that additional management attention and resources may be needed to achieve the same level of CFSI mitigation as is expected for current new build, due to the characteristics of the SMR supply chain model. Detection and prevention activities will need to be tailored to the characteristics of each organization in the supply chain for an SMR.

Common position

> *The Licensee and its associated supply chain organizations, including the SMR vendor and suppliers, will need to be capable of managing deviations and non-conformances in a way that takes into account the characteristics of SMR build, and encourages reporting, collaboration and continuous improvement.*

As now, for current new build, unplanned departures (deviations) from the Licensee's requirements will need to be properly managed. For example, where activities related to manufacturing, construction and commissioning of SMRs are occurring away from the Licensee's site, then communication of non-conformances between the Licensee and suppliers is likely to be more challenging. Licensees, SMR vendors and their suppliers will need to have more robust and integrated management systems to deal with deviations found after physical work is underway, and changes (to specification) requested prior to work starting, which are proportionate and targeted on nuclear safety risks inherent in the particular SMR design. The management systems should include notification of deviations and non-conformances and encourage sharing of OPEX. Sub-contractors should be involved in the OPEX process.

In the field of mass manufacturing of components, there is a balance to be struck between lean manufacturing practices and nuclear safety quality management, so as to have a clear understanding of what constitutes a non-conformance or deviation from specification.

There needs to be clarity on when manufacturing companies should notify the Licensee of changes to the manufacturing practices

The risk of CFSI needs to be considered in selecting alternative procurement paths for components, which may require additional management attention.

Some suppliers may be less likely to produce components that meet the nuclear specification, especially if they produce the majority of those components for other industry sectors' quality standards. This requires targeted oversight by the Licensee to ensure the supplier is meeting the specifications.

Common position

> *The Licensee will be expected to use safety classification to support the justification of appropriate quality requirements applied to structures, systems and components for SMRs.*

As now, with current new build, the extent to which "off-the-shelf" commercial items are to be used should be identified, and proven in the design, relative to achieving nuclear safety.

The SMR vendors may propose greater use of commercial items[7]. There are a number of reasons for this approach, including economic considerations, and taking credit for any inherent safety characteristics in SMR designs. Safety classification permits the safety characteristics of any items to be considered and (if proven) allow the use of commercial items.

The Licensee, as intelligent customer should accept the outcome of safety classification and pay particular attention to commercial items to ensure that regulatory requirements are met. Similarly, with commercial services in design and testing, the intelligent customer should evaluate the design and testing protocol relative to nuclear safety, perhaps assisted by specialists in the field.

Particular attention should be paid to commercial items incorporated into assemblies of wider importance to nuclear safety functions. The Licensee should manage the extent of commercial items and services relative to nuclear safety in a way that takes into account the characteristics of the SMR design.

Common position

[7] Commercial items refers to items that are purchased "off the shelf" and should not be confused with the US NRC definition of commercial grade item defined in *10 CFR [6] Part 21*, Section 21.3, Definitions. (Other countries may have similar legal definitions).

Licensees are responsible for pre-qualification of their suppliers. Hence, they should recognize that supply chain companies for SMRs who have experience with modular design, manufacturing, and construction, may not have experience of the nuclear sector.

SMR technology developers have different levels of competence in nuclear design practices ranging from start-up companies working with more senior nuclear design partners to established design companies who are adapting their design practices to produce SMR concepts. A number of these companies are working jointly with others who have experience with modularity from other industrial sectors such as shipbuilding, defence, or aerospace. At a strategic level, this approach brings together nuclear design and modular design to yield technological improvements in SMR concepts, as part of the SMR supply chain model. However, the degree of nuclear supply chain experience by these partner companies can vary from extensive military sector experience to no relevant experience of applying nuclear quality assurance requirements. Consequently, the Licensee should ensure that the vendor and supply chain have the competencies and processes in place commensurate with the safety significance of the product or service, very early in their design program to, amongst other things:

Articulate properly the specifications to their partner companies and suppliers, and also to obtain the necessary information from them to support ongoing iterative design and safety analysis processes;

Evaluate, qualify, and oversee their partner companies and the supply chain such that the specifications will be met and

Within the supply chain, instil nuclear safety culture and relevant technical knowledge of the final end use of the components and modules being designed, manufactured and tested, to prevent the introduction of latent design flaws into the overall SMR.

1.4 Commissioning

Commissioning of a nuclear installation contributes to the demonstration "that the plant meets the design intent as stated in the safety analysis report" [7].

The Licensee is responsible for the entire commissioning programme.

Commissioning aims to verify:

- the capability of structures, systems and components (SSCs) to perform the functions accordingly to the safety studies (ECCS flowrate, time for control rods drop etc.),
- operating procedures, including those for operational periodic tests, and, to the extent possible,
- the emergency operating procedures.

The commissioning phase is also used to further train operating personnel and maintenance personnel.

Commissioning traditionally address the following key activities [7]:

- Non-nuclear[8] testing, which includes:
  - Individual pre-operational tests of systems and components;
  - Overall pre-operational systems tests;
  - Structural integrity tests, integrated leakage rate tests of the containment and of the primary system and secondary system.

- Nuclear testing, which includes:
  - Initial fuel loading;
  - Subcritical tests;
  - Initial criticality tests;
  - Low power tests;
  - Power ascension tests.

By testing different system configurations, commissioning contributes to validation of the overall operation of the plant (from normal operation to abnormal transients and some incidental operating conditions[9]).

1.4.1 Implications for commissioning of FOAK SMR plants using evolutionary or innovative design features

For evolutionary or innovative design, commissioning tests are of the utmost importance due to the lack of operating experience and uncertainties on the models used during the design. The type and nature of activities will be commensurate with novelty of features to be "proved" in the design. Then, commissioning tests will be used to collect data, performing measurements that will be used to validate and improve calculation models and sometimes, for instance for passive systems that could not be fully validated by R&D activities, the fulfilment of safety requirements. Moreover, when safety relies on inherent characteristics, some complementary elements can only be available after the first core loading.

For NOAK plants, a minimal set of commissioning activities, including tests, will still need to be performed relative to FOAK plants to confirm that the plant (or the module), as built, is compliant with safety requirements.

The way that any commissioning programme is developed will be influenced by the desire of some SMR vendors to provide 'ready to install and operate' sections of the plant or modules. Hence, some important aspects of non-nuclear testing are likely to be done off-site. The Licensee will need to justify how representative these off-site tests are, because physical and functional interfaces may differ from the integrated configuration on site.

The commissioning phase is a unique opportunity to train operation and maintenance personnel. On large NPP, commissioning lasts several months during which the vendor and the Licensee will be on-site together, preparing for the transfer of responsibility. The transfer is progressive, system-by-system or part by part. For SMRs, some commissioning tests may be performed at manufacturer premises, at least unitary systems tests and pre-loading tests.

[8] This refers to activities prior to first fuel load
[9] Loss of Offsite Electrical Power (LOOP) for instance

Consequently, there may be an impact on the understanding of future plant operators and maintainers. The Licensee would need to manage the safety implications of this situation.

Common position

> *The Licensee needs to demonstrate how the commissioning programme takes into account any uncertainties due to the lack of OPEX.*

The commissioning approach has to take account of the lack of OPEX and the novelty of the design, for both FOAK SMRs and for NOAK SMRs where sufficient OPEX is not yet available.

An objective of proving the design and understanding the uncertainties could be assigned to the FOAK tests, even if partial testing needs to be made prior to the commissioning to validate the concept. This is generally because these tests may not be possible or practicable during R&D activities. In any case, the Licensee should clearly specify the contribution of the commissioning tests in the safety demonstration from the initial plant tests to physical start-up tests. This may in particular have an impact on the licensing process, for innovative designs, to support effectiveness of safety provisions in the operating license.

The commissioning approach should propose a very wide-ranging programme of validation of the design, rather than a programme of verification of the compliance of the plant regarding safety requirements. For some SMR designs, there may be multiple units inside common structures, and so the commissioning programme should encompass the whole intended facility. Other SMRs may be deployed as very separate units, and so the commissioning programme can reflect this approach.

For FOAK SMRs, specific measurement devices may be installed for the commissioning tests, to tackle uncertainties and understand the behaviour of the plant during operation. All the possible configurations have to be tested, as far as possible, including performance of SSCs during accident conditions. First Plant Only Tests (FPOT) can be considered as they may provide adequate basic data on the operational properties of SSCs for use as a basis for operation.

Common position

> *If multiple units/modules are shared in one facility or some units/modules will be added later:*
>
> - *there will be common SSC that may require certain commissioning activities to take place as the first modules are installed and placed into service;*
> - *due consideration needs to be made to common system performance when adding units or modules and whether additional or new or repeated commissioning tests may be needed (a common plant HVAC system, for example, is important to environmental qualification);*
> - *commissioning may have the objective to demonstrate/verify the compatibility with the existing plant.*

Common position

> *The Licensee is responsible for:*

- *quality, transparency and independence of persons or entities directly responsible for performing the tests (the persons implementing this process should have the appropriate expertise in terms of manufacturing, detailed design and operation of the module to meet this objective).*
- *conducting a review of deviations and of how these deviations are handled;*
- *the decision on the continuation of the tests, or the definition of any subsequent test programme.*

Common position

> *Given the importance of the Commissioning program in future plant operations, the Licensee is responsible for the conduct of the program and is expected to specify where the tests will be performed and justify the representativeness of those tests regarding the on-site configuration. A further set of on-site commissioning tests will have to be performed to check that the results obtained off-site are valid for the plant.*

For SMRs, it is likely that the commissioning tests may be partially performed at the vendor and relevant supplier premises. Communication and contractual arrangements between the Licensee and the vendor and relevant suppliers regarding the preparation, conduct and analysis of the commissioning tests have to be clearly set up in the commissioning programme.

The Licensee is expected to provide, in the general commissioning programme, for each SSC, safety requirements and identify tests or test sequences that will enable verification of each of these requirements and the location of the premises where the tests will be performed. The representativeness of the different tests should be justified, introducing some complementary tests to be performed on-site with the objective to check the validity of tests performed off-site for the commissioning of the plant.

The commissioning organization set up should clearly define:

- who develops the commissioning tests procedures,
- who plans and performs the commissioning tests,
- who analyses the results of the tests, including any deviations,
- how the Licensee ensures that the people preparing the test procedures, conducting the tests, or analysing the results have the necessary skills,
- who determines the impacts of the commissioning tests results on the continuation of the testing programme,
- who ensures the processing of all deviations identified during the commissioning tests,
- who ensures the traceability of the final results for each commissioning tests?

For SMRs, where commissioning activities may be performed off-site, the process should anticipate the need to repeat or perform additional tests on-site or off-site, to modify the conditions for conducting the commissioning tests planned in the following phases or to adapt the operating envelope to address the results of the commissioning test.

The Licensee needs to justify the representativeness of the tests regarding the site configuration. In particular, justify any impact that the transportation and storage of the module, and the works to be done on-site to install it (connection to the I&C, or to the turbine for instance) is identified and that it still complies with safety requirements.

Commissioning tests results may result in engineering design change for NOAK SMR and modification of the FOAK one. For SMRs, the balance between the desire for a standardized design over time may be challenged by the need for modifications due to commissioning results. As a minimum, commissioning results should be used to further validate calculation codes supporting the safety demonstration.

Commissioning tests results should be shared by all interested parties, including regulators, and the vendor should justify any lessons learnt by the commissioning of a FOAK plant for the NOAK designs. For the NOAK plant, the Licensee should review the safety demonstration and the commissioning programme accordingly.

Common position

> *When commissioning tests are performed in the manufacturing premises, the Licensee needs to be involved for the purpose of gaining experience for the future operation.*

In factory commissioning, the operator should have a role in the conduct of commissioning tests for the purpose of training operating and maintenance personnel on plant systems in preparation for plant operation. Off-site commissioning presents challenges to the license in this regard particularly when manufacturing facilities are remote from the site.

Common position

> *The Licensee will need to justify the representativeness of full-scale replica tests results and FPOT tests if wanting to take credit for those tests in the commissioning phase, and detail the commissioning tests to be performed on the licensed plant to check their full applicability.*

Several SMR designs rely on passive systems, and so the performance of SSC may not be fully testable during the commissioning tests, especially for protection and safeguard systems that are not used during normal operation or for systems that are not used in the same configuration in normal and accident conditions. Therefore, the Licensee should provide alternative tests to 'prove the design' and determine parameters that can be checked on the plant to demonstrate that the performance obtained on any full-scale replica is applicable to the module/plant.

The Licensee is responsible for:

- assessing the potential use of each FPOT results for its unit(s) and to conclude such FPOT results can be credited in the commissioning process before formally presenting the case to the regulator.
- assessing the similarity of the unit on which the test was conducted and the one which will credit the FPOT (and have access to all necessary data for this purpose).
- Justifying why any possible differences in design, manufacture and installation of the FPOT component or system, in the environmental and operating conditions and practices, or the codes and standards applied, do not affect the validity of the FPOT results to other unit(s).
- giving reasons for taking credit from certain FPOT tests (severity of loadings for instance).

The Licensee needs to justify that:

- the design, implementation, and plant conditions are so similar that the possible existing differences do not affect the applicability of the results to the unit where the test will not be performed.
- the test is adequate to verify the requirements and acceptance criteria that may differ from one country to another.

The Licensee commits to:

- giving full access to data; and to
- document the performance and results of any tests performed in another jurisdiction.

This data and documentation could be used to design and validate a less complex or alternative test that may be used during commissioning of follow-on units to characterise the performance or behaviour of the component or system and thus help validate application of the FPOT data.

The Licensee has then to document its role during the definition of the tests, the performance and the analysis of results and that it has the information needed to check the representativeness of the test.

The Licensee has to ensure the adequacy of the quality assurance programme of tests for the FPOT unit, considering the quality assurance requirements of the unit where FPOT may be credited. This includes ensuring the adequacy of the quality assurance programme for instrument calibration.

1.5 International cooperation

There is a worldwide interest in small modular reactors (SMRs) because of their safety claims and role in global energy development as part of an optimal energy mix. The new reactors that are defined as SMRs are very diverse and use innovative technologies including passive safety systems. Despite their novelty and variety in designs, the proposed SMR are within the existing international nuclear safety and legal framework.

Common position

1. *SMRs are NPPs and are expected to comply with existing international conventions [8, 9]*
2. *The IAEA General Safety Requirements are applicable to SMRs which contain provisions for use of alternative approaches as well as the use of risk informed decision making.*
3. *Bilateral and multilateral cooperation of national nuclear Regulators within the SMR licensing procedure is good practice to be pursued as far as legal constraints will allow. National Regulators may be able to use as evidence (or leverage) the outcome of activities performed by another national Regulator in their jurisdiction. The SMR industry are encouraged to facilitate the sharing of information.*
4. *Like any new reactor technology, most SMR technologies will contain innovative features or may apply proven technologies differently and consequently there will be areas of limited practical experience. Hence, an ongoing mechanism of cooperation between national nuclear Regulators for SMRs will be beneficial at*

the international level. This cooperation could extend to more detailed and technology specific cooperation, so as to share experiences where detailed technology specific assessments or licensing processes between countries align well.

5. *More work is needed to understand how transportation of fuelled reactors is covered by existing international conventions.*
6. *Design and manufacture of SMRs in different jurisdictions increases the need for cooperation between national Regulators, particularly in areas involving on-site inspections [10].*
7. *Information exchange about SMR activities may be affected by international agreements on intellectual property rights.*

2. Chapter 2: Collection and Use of Experience in the Lifecycle of SMR Facilities

This chapter presents common regulatory positions on the use of experience in activities related to the entire lifecycle of SMRs in order to enhance nuclear safety and improve performance. A primary focus in this chapter is on activities associated with design, manufacturing, construction, commissioning and operations

2.1 What is experience?

In the context of this report, experience refers to the entire body of knowledge collected by academia, industry, and regulatory entities that is applicable to a specific safety significant activity. In addition to operating experience, this includes the results of verified analytical and testing studies, observations, and data analysis.

The use of appropriate experience information is an integral part of demonstrating confidence in an overall defence in depth strategy; but the use of experience is complementary to systematic engineering in order to support a safety demonstration. In addition, the development and implementation of a defence in depth strategy is both a technical and a human endeavour. Therefore, the use of experience should be integrated within the management system, including detailed licensing and design bases, and risk management. For example, when experience is lacking or insufficient, risk management should identify safety significant single point vulnerabilities by performing among other things, failure modes and effects analyses, and probabilistic risk assessments. Preferably, single point vulnerabilities should be eliminated or minimised by design, and by providing redundancy, diversity and independence. Where this is not practicable, expanding testing, using more reliable equipment, increasing monitoring and surveillance testing provides assurance in support of reliability claims.

The gathering and use of experience information within an organization's management system needs to be systematically executed within a quality assurance framework commensurate with safety significance. This means that enabling tools are necessary including, among other things, sufficiently detailed procedures and processes, requirements for staff qualification and continuous training, internal and external management and management system oversight, and independent verifications including quality control, self-assessments and audits.

The integration of experience into the defence in depth strategy is a two-way relationship. On the one hand, experience should inform and improve defence in depth activities. On the other hand, defence in depth activities should supplement the use of experience in varying degrees depending on the quality, the applicability, the availability and the completeness of related experience. An example of the latter includes experience originating from one technology being applied to a different technology or experience used in one system being applied to a different system.

Information derived from experience used to substantiate safety and performance claims (particularly for a design and licensing basis) needs to have a traceable pedigree that demonstrates that the information was derived following appropriately proven practices. Practices need to be demonstrated to be consistent with recognized codes and standards, regulatory national and international safety standards. In addition, practices need to be compatible with the information needs of risk informed decision-making tools such as safety analysis.

2.2 Sources and Types of Experience

The sources of experience include internal, external, nuclear and applicable non-nuclear experience. In addition to the familiar OPEX implemented by the current stakeholders of the operating fleet of NPPs, experience used in the context of this report covers other forms of relevant experience. Table 1 below provides some experience examples.

Table 1: Examples of Experience Lessons for SMR Consideration

Experience Type	Covers	Example of Experience Databases Managed within the Nuclear Sector
Existing Facility Operation and maintenance OPEX databases and reports	Traditional OPEX Experience from commissioning activities, plant operation, maintenance, in service inspection and R&D supporting operations and maintenance	NEA-IAEA NEA Report No. 7482 [11] IAEA IRS [12] WANO OPEX Database Specific Vendor/Technology Owners Groups (e.g. Westinghouse Owners' Group, CANDU Owners Group, etc)
Industry and Regulatory Verified Research and Studies	Different topics on important to safety activities and event evaluations	European Environment Agency (EEA) reports; WANO Significant Operating Experience Reports (SOERs); Regulatory studies and research by IAEA and other regulatory bodies contained in such documents as IAEA standards; Generic communications published by various regulators.
Siting	Lessons learnt from site investigations, site characterisations and evaluations of external events	IAEA External Events Safety Section (EESS Portal) Research and Development publications from Academia, regulators and external entities such as geological organizations.
Manufacturing and Supply Chain Management	Experiences from supply chain events/lessons learnt	Typically covered under databases for each of the other areas in this table [13] and other publicly available databases that contain equipment defect notification reports.
Construction	Experience from site-based construction projects	NEA-CNRA Working Group on the Regulation of New Reactors (WGRNR)

		[14] Construction Experience (CONEX)[10] Nuclear Engineering International [15] IAEA [16]
Transport	Experience from the transport of: radioactive materials complex long lead items used in nuclear facilities	IAEA [17] OPEX tends to be manufacturer specific
Decommissioning	Experience from the conduct of decommissioning activities	OCED/NEA Working Party on Decommissioning and Dismantling (WPDD) [18]

2.3 Importance of Experience to the safety of SMRs

The following common position highlights the importance of the use of experience by all stakeholders, including contractors and sub-contractors, to the safety of SMRs.

Common Position

> *Management at the highest level should embrace and promote the use of experience by all levels of the organization, for all safety significant applications as part of an overall defence in depth strategy. The collection, evaluation (including analysis where appropriate), sharing and use of significant experience throughout the SMR lifecycle by all stakeholders is critical to safety, continual improvement, and public confidence. The overall responsibility for the use and oversight of experience lies with the licensees who should impose it on all their contractors and sub-contractors performing safety significant activities. In order to make decisions, regulators independently assess safety claims being made by the licensee and verify that the safety and control provisions both meet regulatory requirements and provide a high degree of confidence they are effective.*

The systematic development and management of experience information throughout the lifecycle of an SMR facility is just as important as that for any other NPP. Because experience factors into the demonstration of safety which, in turn, impacts confidence in the performance of the design and the operator, effort to develop adequate measures should not be underestimated. Although experience measures and databases already exist for the various types of research reactors and NPPs that operate around the world, particular attention needs to be paid to the establishment and support of infrastructure that is tailored to new technologies such as SMRs.

[10] The information contained in this report has been rolled into the IAEA's IRS database. Note that the information contained in the ConEx database has been merged into the IRS.

Experience leverages lessons learnt to enhance safety by avoiding previously identified significant events and collecting, evaluating, and sharing new experience. Effective use of experience improves performance, increases efficiency, and minimizes redesign and rework by encouraging the use of best practices. The OPEX portion of experience should include actual or potential safety significant events, near misses, breakdowns of the quality assurance program (at licensee or vendor facilities), failures with generic implications, latent defects and human performance issues.

The use of experience in guiding and informing a specific SMR activity should be justified by taking into account such considerations as the experience verifiable pedigree, its extent of applicability, and its limitations. The extent of the justification effort should be commensurate with the safety significance of the activity and the quality of the experience. There are well managed databases and industry and regulatory publications available for most types of lessons learnt. Confidence in the experience being considered varies depending on its source. Generally, experience generated by well-established and independent industry and regulatory bodies are more reliable than other sources such as experience generated by a single licensee without independent verification or non-nuclear generated experience. However, regardless of the confidence level, the extent of applicability of the experience to the activity in question should always be verified and if required, supplemented by additional actions to reach a reasonable assurance of safety.

The operation and maintenance of nuclear power facilities around the world is generally recognized to be mature with an extensive infrastructure in place for collecting, evaluating, sharing, and learning from experience. OPEX is a subset of the greater body of experience. Nation states embarking in the establishment of a nuclear power program are strongly encouraged by organizations such as the IAEA, the Nuclear Energy Agency (NEA) and industry peer review organizations such as WANO to seek timely support to prepare infrastructure and capabilities for safe operation. An example of this is the Regulators' Cooperation Forum (the RCF) which promotes collaboration among member states for regulatory infrastructure development in order to achieve and maintain a high level of nuclear security.

Effective experience (OPEX) measures are an integral part of a nuclear organization plant management system for safety. The importance of establishing and implementing effective OPEX measures became evident following significant nuclear power plant events such as the Three Mile Island accident in the United States and the Fukushima Dai-Ichi events in Japan. In response, IAEA established safety standards and requirements, guides, technical reports and other publications that require, and provide guidance for, the use of OPEX as an essential tool to improve nuclear safety in the quest for protecting people and the environment from radiological hazards. These publications include:

- Safety Fundamentals (SF1) Principle 3: "Leadership and management for safety" [2];
- General Safety Requirements, GSR-Part 1, "Governmental, Legal and Regulatory Framework for Safety" [21];
- General Safety Requirements, GSR-Part 2, "Leadership and Management for Safety" [1];
- Safety Guide, NS-G-2.4, "The Operating Organization for Nuclear Power Plants" [22];
- Specific Safety Guide SSG-16 "Establishing the Safety Infrastructure for a

Nuclear Power Programme" [23];
- Specific Safety Guide SSG-50, "Operating Experience Feedback" [24]

In 2020, the NEA published a joint report (NEA Report No. 7482 [11]) with the IAEA entitled: Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System (IRS) 2015-2017. The IRS is an essential element of the international OPEX system for nuclear power plants. IRS reports contain information on events and important lessons learnt that assist in reducing the recurrence of similar events at other plants.

Although the NEA report focuses on OPEX from operating facilities, it is important to note that lessons learnt were broadly placed into three main categories: human performance, equipment issues, and management oversight. With the exception of equipment issues which in some cases may be applicable to design specific plants, these categories generally apply to all types of nuclear power plants and are therefore, expected to apply to SMRs. In the development and deployment of new reactor technologies such as SMRs, it stands to reason that the lessons learnt from OPEX are being reflected in the strategies and technologies for design, manufacturing, construction, commissioning, operation planning for decommissioning. Existing OPEX applicable to SMRs should therefore be a part of the experience measures to be used throughout the entire SMR lifecycle.

The experience measures should be integrated into an overall defence in depth strategy that is part of a Management System that includes detailed licensing and design bases, and risk management strategies.

The Management System program should require, among other things, detailed procedures and processes, minimum staff education and qualification requirements, continuous training, and independent verifications. Independent verifications include design verifications, quality control, self-assessment and audits.

The licensing and design bases should require consideration of applicable experience along with the use of recognized codes and standards, regulatory national and international safety standards, and accident analyses.

Risk management should identify safety significant single point vulnerabilities by performing among other things, failure modes and effects analyses, and Probabilistic Risk Assessments. The effects of single point vulnerabilities should be mitigated such as by modifying their design, using more reliable equipment, and providing redundancy and independence.

The integration of experience into this defence in depth strategy requires a two-way relationship. On the one hand, experience should inform and improve defence in depth activities. On the other hand, defence in depth activities should supplement the use of experience in varying degrees depending on the quality, applicability, availability and completeness of related experience. An example of the latter includes justifying and supplementing the use of experience originating from one technology that is being considered for a different technology or experience used in one system being considered for application to a different system.

The above points highlight the importance of the use of experience as a critical element to the defence in depth strategy for an SMR. The following section discusses the need to address obstacles that could hinder the effective use of experience by SMRs.

2.4 SMR Experience Infrastructure

The following common position highlights the importance of establishing an infrastructure that enables the effective use of experience information by stakeholders. That is, a framework must be established to anticipate and remove potential obstacles that could hinder the sharing and effective use of experience information.

Common Position

> *The infrastructure to manage the body of experience information for an SMR concept needs to be systematically established up-front to consider diverse experience types and anticipate and address diverse stakeholder needs which may potentially extend across international boundaries. This includes the need for mechanisms to provide appropriate and timely access to specific information for the purposes of enabling technical cooperation activities and decision-making.*

Actual and proposed SMR designs include a high number of new technologies that in many cases are significantly different from existing technologies and from each other. This presents varying degrees of challenges and obstacles that should be removed and/or managed including the following:

2.4.1 Experience Types

Current operating experience measures have demonstrated that a body of experience needs to be organized in consideration of types of experience. In some cases, the organizations responsible for managing each type of experience may vary:

"General type" experience

Existing industry and regulatory OPEX databases, such as WANO's and the IAEA's IRS, focus on operating large-scale nuclear power plants utilizing mostly water-cooled reactor technology. Therefore, they include some OPEX that may or may not be related to the SMR lifecycle. However, they also include general type OPEX that may be applicable to some or all SMRs such as OPEX related to siting, safety culture, special processes (welding, non-destructive examination), digital instrumentation and control, commonly used equipment, operator errors, training and qualification, personnel safety and pandemic response. SMR stakeholders should review such OPEX for applicability to their activities. In addition, there are plenty of published lessons learnt regarding this general type of experience especially for the major industry events such as the accidents at Three Mile Island, Chernobyl and Fukushima. The main challenges for SMR stakeholders with this type of experience can be overcome by accounting for it in their designs, imposing it on designers, contractors and sub-contractors, making it accessible to staff, training and dissemination into related processes and procedures.

"Current Technology specific" experience

Current technology specific experience applies to all similar technologies regardless of their size and therefore, would be applicable to SMRs utilizing that same technology. This subset of experience includes

(1) experience related to traditional PWRs, AP1000 PWRs, BWRs and CANDU; and
(2) experience related to new technologies.

A wealth of data and lessons learnt already exist for existing technologies and designs. This type of experience applies to a small subset of stakeholders, namely those that utilize similar technologies and designs. Associated challenges can be overcome by accounting for this type of experience in the SMR design, imposing it on designers, contractors and sub-contractors, making it accessible to staff, training and dissemination into related processes and procedures. The level of data and lessons learnt that already exists will vary from technology to technology and the number of facilities that have been or are currently being operated.

The relevance of such information to specific SMRs will need to be justified in consideration of technological differences and the effects of scaling (i.e. if the new design is smaller, bigger or deployed in discrete modules/units in a multiple unit facility.)

Because technology specific experience is generally used by a smaller group of users (user groups and their supply chain), the main challenges for management with this type of experience can be overcome by user groups establishing processes that facilitate access, by the supply chain, to the information. This may require specific training to interpret information, determine its relevance and the need to organize the information into different access levels to preserve commercial sensitivity.

"Site Specific" Experience

Site specific experience draws from the body of siting practices and methodologies used around the world. In general, the existing siting body of experience remains relevant to land based SMR projects; however, some more novel specific facility configurations may require development of more detailed data:

a) Deeply embedded civil structures (e.g. seismic resilience, chemical degradation, uplift pressures
b) Arctic and sub-arctic environments involving permafrost as well as harsh environmental conditions that may also present challenges to emergency planning.

More noteworthy is a limited experience database for siting marine based nuclear facilities (floating, fixed platforms, and potentially submerged facilities). In some cases, experience databases from other sectors may provide some information necessary to characterize safety important siting considerations such as:

- Extreme weather and other external events
- Potential for human induced external events
- Site chemistry (soil, water, rock etc.)

In these instances, validation activities will need to be conducted to confirm such information is of the quality and substance necessary to support safety substantiation. Uncertainties will need to be addressed in the defence in depth safety provisions.

In addition, due to their smaller size, SMRs are more likely to be used near densely populated areas and/or in remote areas. Emergency response experience related to NPPs located near densely populated areas may be very limited requiring stakeholders to better plan emergency response. On the other hand, SMRs located in remote areas may limit or delay access to needed expertise and accident mitigating equipment. Therefore, this should be planned for in advance and drills should be performed periodically to ensure that emergency response during an accident is adequate.

"Related Non-Nuclear" Experience

Related non-nuclear experience should be collected, evaluated and disseminated to all impacted levels of staff. When applicable, it should also be incorporated into processes and procedures and imposed on contractors and sub-contractors. This is especially true for first of a kind (FOAK) SMRs discussed below and other applications where the availability of experience is limited. Experience leveraged from non-nuclear industry sectors needs to be assessed for impacts on nuclear safety especially when:

- Some or all of the impacted technology is utilized for components important to safety such as certain modular construction;
- Some of the impacted equipment is commonly utilized in facilities such as certain pumps, valves, switching equipment and electronics;
- The underlying causes are applicable to nuclear power such as safety culture, conservative decision making etc.;
- Geological suitability and hazards (seismic, flooding, weather, climate change, etc.) for SMR siting is limited;
- Seismic experience is limited to justify the seismic ruggedness of equipment; and
- Nuclear reliability is either absent or limited.

The use of non-nuclear experience in guiding and informing a specific SMR activity should be justified by taking into account such considerations as the experience verifiable pedigree, its extent of applicability, and its limitations. The extent of the justification effort should be commensurate with the safety significance of the activity and the quality of the experience.

2.5 Enabling access to experience data and intellectual property by stakeholders

The following common positions highlight the need to address obstacles and challenges that could hinder the sharing and use of experience.

Common Position

> *Designers and licensees need to establish agreements amongst stakeholders in advance, to enable sharing of nuclear safety significant experience while still assuring the protection of intellectual property.*

Common Position

> *The organizations' measures for experience should establish roles and provisions that promote the use and sharing of experience by all stakeholders.*

Some experience information can be considered as intellectual property. In some cases, this could be privately held and in others from historic government activities or from academic institutions. There may be specific impediments to access depending on which type; or specific measures that ease access. This can make the sharing and availability of such information a significant challenge for all stakeholders that need timely access to such information for decision making. In some cases, the experience data may be 'owned' by one organization but required by other organizations for the purposes of conducting their activities. Experience from non-nuclear sectors may have additional restrictions imposed by intellectual property owners depending on which industries they are already being used for.

Depending on the stakeholders and their information needs, the sharing of experience information, for a global fleet of SMRs of the same design, will be constrained by:

- the necessity to maintain non-proliferation export control provisions.
- the types of nuclear cooperation agreements that exist between nation states.

Stakeholders should remove all obstacles hindering the access to and sharing of information by promoting cooperation between all stakeholders national and international and engaging industry leaders such as WANO to help set up central databases and minimum standards for evaluating and sharing experience.

Certain new nuclear technology specific experience is almost non-existent at this time making the safe and successful launching and operation of a FOAK design challenging. In addition, the collection, evaluation and sharing of experience to be used by both the FOAK and future SMRs become that much more important. In addition, new technologies used in SMR designs utilize significant proprietary information the handling of which, if not addressed, could hinder the sharing of related experience. Therefore, this type of experience or lack thereof, presents the highest level of challenges and require very careful management oversight and intervention. The FOAK facility experience measures will require additional structure and content in consideration of the need to collect experience from FOAK activities. Such information may need to be disseminated to other countries in preparation for their own projects.

Special attention should be given to establishing a plan early in the design process that seeks to resolve experience gaps between the FOAK facility and subsequent projects leading to an Nth of kind mature experience model. One key objective in the plan should be resolution of key safety experience gaps for the life of a fleet of the same design by using the FOAK facility.

Focus Area:

Experience related to advanced proprietary designs.

Experience related to events involving advanced proprietary designs may include underlying causes such as safety culture, special processes, design control and operator errors that may be of a sensitive nature yet could benefit other designs. The originator of such experience should make every effort to repackage the information so that it can be shared externally in whole or in part, with other stakeholders. Reports should be de-personalized and proprietary information may be redacted such that information being shared remains useful. For example, the causes of failure of a unique piece of equipment may include non-unique contributing causes such as a defective welding process, inadequate maintenance or operation. The information originator would be expected in this case to share this information in a way that doesn't compromise their proprietary information. Conversely, designers and licensees of a FOAK facility are expected to review experience from different designs and projects for applicability to their own project activities. For example, lessons learnt should be incorporated into procedures and training as required. Experience can be obtained from reviews of design reviews, pre-job briefs, maintenance, operation and post event evaluations. FOAK facilities may still use common equipment such as pumps, valves, breakers and relays and therefore, there may be plenty of relevant experience to consider. Other non-design specific experience includes activities such as draining and venting which apply to almost all fluid systems. The same goes for equipment deficiencies, maintenance, operator errors, safety culture issues. In addition, even uniquely designed equipment may benefit from experience related to equipment of the same class. For example, the investigation of a uniquely designed pump failure from excessive vibration may still be informed by general OPEX related to vibration failures of different pumps.

Use of data from academic institutions needs to be of verifiable quality, commensurate with safety importance of the information.

2.5.1 What are Experience Gaps?

Experience gaps can refer to a spectrum of conditions:

Experience from nuclear facilities currently in operation that needs to be demonstrated to be relevant to specific SMR and advanced reactor concepts. There may or may not be experience information from other facility lifecycle stages before or after the operational phase.

Historic experience from past operating nuclear facilities/prototypes (such as advanced fuel testing in the 1960s) but this experience needs to be:

- demonstrated to be relevant to specific SMR design and
- supplemented by additional activities to meet modern standards of substantiation or quality, commensurate with importance to safety.

Some experience exists from other industries that operate in a similar risk profile, such as aerospace, or chemical manufacturing. This type of experience needs to be:

- demonstrated to be relevant to specific SMR design
- demonstrated to include consideration of nuclear specific considerations of quality and safety; and supplemented by additional activities to meet modern standards for quality of substantiation commensurate with importance to safety.

Special attention should be given to establishing a plan early in the design process that seeks to resolve experience gaps between the FOAK facility and subsequent projects leading to an Nth of kind mature experience model. One key objective in the plan should be resolution of key safety experience gaps for the life of a fleet of the same design by using the FOAK facility.

2.6 Establishing systematic measures for the use of experience

The following common position highlights the need to establish formal auditable experience measures and defines their elements.

Common Position

> *SMR stakeholders should establish systematic experience measures early in the lifecycle to be used during the entire lifecycle of the SMR. The measures should adopt and follow IAEA safety fundamentals and guides with the ultimate goals of preventing significant events and improving performance. The measures should be disseminated into appropriate tools (for example, processes, procedures, checklists, independent reviews and training), to cover all safety significant activities by all levels of the organization.*

Management should define specific and measurable goals for the use of experience during the lifecycle of SMRs with the ultimate objectives of reducing safety significant events (especially those that are preventable) and continual improvement. Continual improvement should include internalizing the use of experience, improving safety culture, continuous training and effectively addressing near misses, lower level events and their precursors. Formal audits and self-assessments described in Chapter 5 below will gauge how well the experience measures deployed meet these goals and address findings to improve the measures.

2.6.1 Establishing systematic measures for the use of experience

There are two key principles that need to be considered:

- Designers and ultimate Licensees should have experience measures. The most effective way to enhance their measures to account for SMRs is to work with existing organizations (e.g., WANO) as early in the project lifecycle as practicable to promote, establish and implement them.
- Experience measures [19] should consider both the collection and use of new experience, as well as the use of historic experience, and be:
    - established using proven practices such as methodologies developed for existing OPEX measures
    - centrally coordinated by an organization that is responsible for its implementation
    - captured and retained within a systematic structure that considers the needs of all stakeholders, their ability to add their information to support the measures and their ability to use information to support their individual objectives.

Effective experience measures:

- Should be consistent with, and adopt and achieve, IAEA safety fundamentals and guides.
- Include (or be focused on) design specific experience.

- Should account for the highly diverse nature of licensees, stakeholders and the nuclear supply chain across countries and industries.
- Should (apply a graded approach for handling experience based on safety significance) focus on nuclear safety related challenges.
- Should apply to all technical staff (not just OPEX staff) performing technical reviews, operational, maintenance and licensing functions since they're the ultimate end users of the experience in question composed of sufficiently skilled staff capable of interpreting experience information to determine its relevance even if the reactor technology and siting conditions are different.
- Have objectives to ultimately cover the full lifecycle of a design and projects, and include enhancing nuclear safety, avoiding significant safety problems, using best practices and enhancing personnel safety.

In the development and deployment of a new technology, there are many different stakeholders with their own expertise and experience information that can be integrated within the systematic experience measures framework. Existing OPEX collection frameworks and methodologies (such as that used within WANO) exist and are being used successfully. They can be adapted to include broader experience; however, the coordination of stakeholders should be considered in light of the deployment model for the SMR design concept.

To implement systematic experience measures, a good practice would be for the SMR designers and licensees to make their experience requirements and measures needs known to their suppliers and be prepared to verify the performance of the supply chain in the handling of experience information. This includes modular fabricators, constructors, nuclear safety related providers of engineering, testing and software services, and major equipment suppliers which may be new to the nuclear industry.

Designers should establish processes and means to turn over to licensees' relevant information related to their designs that was collected prior to a licensee taking over operation. Designers should also continue to be involved in experience evaluations, developing root cause analyses and lessons learnt and proper dissemination to all licensees. This is especially important for licensees new to the civilian nuclear industry. Both designers and licensees should provide relevant experience to other stakeholders as required to incorporate into future designs, fabrication and construction.

The experience measures should be tailored to account for differences in size, technology and operation and designed to cover all phases of a facility lifecycle including research and development (R&D), design, fabrication, construction, commissioning, operation and decommissioning.

For FOAK technology or its application the lead designer (typically a vendor) should be responsible for driving the experience measures during the research and development, conceptual, proof of concept, initial design and fabrication phases. Although the Licensees are not likely to achieve the levels of experience and expertise of the designer, the Licensees should acquire sufficient information from the designer, prior to operation, to enable them to continue to use and develop the experience throughout their facilities lifecycles to further nuclear safety. The experience measures at the FOAK stages should address the need to:

- Review existing experience for applicability to the size, technology and operation of their design.

- For non-general experience, group, flag and share new experience based on size, technology and operation.
- Establish owner groups to handle technology specific experience.

Focus Area: Lessons Learnt from Traditional OPEX measures
General versus specific experience.

Experience can be grouped into two types: general, specific, or a combination of the two.

General OPEX is not specific to size, technology or operation. It includes experience related to safety culture, special processes, general training, communication, and commonly used equipment issues.

Specific OPEX has limited application that is related to such characteristics as size, technology, operation, siting. Since SMRs can vary greatly in size, technology, application, location and operation, there is a greater need to group and flag specific OPEX accordingly.

Size related OPEX can affect siting, access to expertise, emergency preparedness, security and operation. For example, the application of existing OPEX related to emergency preparedness and security does not apply to a very small SMR in a significant way because the smaller release potential, the smaller amount of nuclear fuel, the ability to easily address potential meltdowns etc.

Combined OPEX includes both specific and general causes and lessons learnt. For example, a complex event may be caused by technology specific design issues compounded by an inadequate software verification and validation, inadequate testing required for proof of concept or an inadequate safety culture. In such a case, the entity responsible for developing the root causes, corrective and preventative actions, and lessons learnt should package, flag and share the various lessons learnt accordingly.

These categories can be more broadly applied to any experience measures.

However, as deployment plans move forward for any design of SMR, the experience measures need to be sufficiently adaptable to be able to draw in other users such as R&D partners, specialized equipment providers, engineering, procurement and construction (EPC) contractors etc. As more stakeholders become involved in deployment activities, multiple experience databases may evolve to serve specific objectives. Connectivity between these databases should be considered when designing the experience measures.

Organisations that are stakeholders in effective experience measures include:

- Technology developers (e.g. vendors) - research and development R&D programs require access to information to understand the nature of any technological gaps and decide how to address those gaps in an appropriate manner in design decision making.
- R&D service providers require access to information, for verification and validation purposes.
- Future operators require access to information to inform their strategies for establishing operator requirements to be used in procurement, technology

evaluation methodologies and preparatory work for the licensing process and eventual conduct of activities. Ultimately, they require access to sufficient information to inform adequacy of their safety and control measures on an ongoing basis as they conduct their activities.

- EPCs and other construction and commissioning partners will need access to experience to plan their work.
- Depending on the regulatory processes being used, regulators require access to experience information commensurate with both importance to safety and the nature of the regulatory decisions being made. For licensing, the regulator may require access to the same information available to the applicant for a licence and may need assurances that the licensee will be able to maintain access to that level of information as they conduct their authorized activities.
- Government and commercial decision makers require access to sufficiently credible information to meaningfully understand the uncertainties associated with gaps in experience.

In most cases, the designers stay involved with evaluating, disseminating, and applying experience related to their designs after the SMRs are operational. However, there is no guarantee that this remains the case in all circumstances. This introduces challenges to licensees to ensure that they can function safely in the absence of the original designer. Therefore, licensees should collaborate to make provisions for such eventualities. SMR designers may continue to drive OPEX in cases where the licensees do not have a mature nuclear programme.

As the number of facilities being placed into service increases and licensees develop sufficient experience with operating and maintaining their facilities, licensees may assume increased responsibilities for driving the experience measures by contributing their own site experiences. This includes contracting with their suppliers to participate in the implementation of the OPEX measures.

Certain aspects of the experience measures may be driven by an industry group (such as WANO) or an owner's group. However, choosing this option does not absolve designers, licensees, and their vendors from actively participating in the implementation of the experience measures.

2.7 Implementing experience measures

The following common position discusses the implementation of the SMR experience measures which include collection, evaluation, sharing and applying experience throughout the SMR lifecycle.

Common Position

> *SMR stakeholders should establish common and effective communication channels and tools and use experience in all important to safety applications. This includes access to common experience databases, technical publications, generic communications, root cause evaluations, safety evaluations, industry and regulatory groups and other fora, the sharing of data, and technical staff cooperation in evaluating complex experience. Staff training is also part of the implementation of measures.*

2.7.1 The role of the licensee in supporting the use of experience in safety claims

One important principle that needs to be considered is that the licensee (or applicant if an authorization has not yet been granted) should support proactively the search for and use of experience in demonstrating the adequacy of their safety and control measures to be used in the SMR. The use of experience should enhance nuclear safety throughout the SMR lifecycle. This implies that an applicant/licensee should source experience information and be able to assess its use as an intelligent customer.

This principle applies to all stakeholders in the nuclear industry. However, it is especially important for stakeholders such as licensees and their supply chain that are new to the commercial nuclear industry, who should:

- develop the necessary competencies to effectively work within a nuclear experience program and leverage the use of experience in decision making commensurate with importance to safety
- seek out and obtain access to relevant experience databases and tools.

Focus Area: IAEA Fundamental Safety Principles, Principle 1 (SF-1)

The licensee retains overall responsibility for the SMR and should use experience to enhance nuclear safety throughout the SMR lifecycle.

Clause 3.5 of SF-1 states:

The licensee retains the prime responsibility for safety throughout the lifetime of facilities and activities, and this responsibility cannot be delegated. Other groups, such as designers, manufacturers and constructors, employers, contractors and consignors and carriers, also have legal, professional or functional responsibilities with regards to safety.

Clause 3.6 states:

The licensee is responsible for (amongst other things):

- *Establishing and maintaining the necessary competences*
- *Establishing procedures and arrangements to maintain safety under all conditions*
- *Verifying appropriate design and the adequate quality of facilities and activities and of their associated equipment.*

Stakeholders should seek assistance in the development of the experience measures.

Stakeholders new to the commercial nuclear industry could develop relevant experience rapidly either by hiring staff with experience working with OPEX or by subcontracting with a knowledgeable consulting firm. Joining an industry based OPEX database and using tools such as those operated by WANO could be beneficial. In addition to IAEA documents, some regulators have publicly available generic communications and other OPEX related guides that can be use.

2.7.2 State of completeness and maturity of experience data

There are two key principles that need to be considered:

- Design decision-making processes and subsequent deployment activities should take due account of the state of completeness and maturity of experience data commensurate with importance to safety and establish provisions with a sufficient level of confidence to address any uncertainties; and,
- Designers and ultimate licensees should as early in the project lifecycle as practicable, establish and implement processes to evaluate the quality and applicability of experience information. Decision making processes should contain systematic provisions to:
    - classify and use information commensurate with importance to safety;
    - understand gaps in knowledge and the nature of uncertainties;
    - determine which activities may be necessary to address gaps and uncertainties.

One of the most obvious challenges facing technology developers and the companies that may choose to build and operate these concepts is addressing gaps in experience (Appendix 3). New design's experience measures may be challenged by significant differences in facility size, technology and concepts of operation and maintenance which could make certain existing experience such as those associated with siting, emergency preparedness, security and operator training, more relevant to some technologies than others. Gaps in experience can also exist if the technology is being used for a new application (i.e. non-electrical generation uses, or off-grid, deep-load-following applications).

Focus Area: Non-electrical applications of SMR and advanced reactor concepts

The IAEA has noted that SMRs are being developed for alternative uses that may involve combinations of multiple processes such as:

electrical generation
heat storage (thermal capacitors) for load following
process heat for district heating and industrial applications offsite
desalination and hydrogen generation

SMRs used for alternative purposes may present experience gaps that could impact nuclear safety because a significant body of the experience on facility transients that could impact performance of nuclear island structures, systems and components comes from the analysis of feedwater/main steam/turbine-generator transients.

Where other process or combinations of processes are to be introduced to the facility design, experience on transient behaviours may need to be addressed on a design by design and case by case basis. Combinations of end-uses used in a single facility can add complexities to transients.

The safety significance of experience will be design specific. Inputs to the safety significance of a specific experience include, for example, a review of the PRA, its FMEA and its accident analysis. The safety significance should be based on both quantitative (e.g., an increase in the core damage frequency) and qualitative (safety culture and novel failures with potential generic implications) measures. Guidance from IAEA, regulatory bodies and industry (INPO/WANO) should be utilized for consistency. In addition to including highly safety significant OPEX, other OPEX involving near miss, use of cost benefit analyses and personnel safety can also be considered.

Because certain design specific experience will be scarce for some time as operating experience is gained and analysed, designers and licensees must account for that lack of experience in the design of their experience measures.

Designers should establish measures of claims on plant integrity and performance validation. The measures should consider the novelty of the new design when determining the checks and inspections required during the lifecycle of operation. The operating experience obtained should be shared with owners of Nth of a kind plant. The measures should consider:

- Equipment qualification, surveillance and testing to simulate actual as-built installation should be emphasized. This should include consideration of accelerated ageing.
- Enhanced testing to simulate system response and system interfaces should be included to the extent practical to obtain valid data.
- Validate test results should be established to provide a feedback mechanism for qualified life, operational limitations and maintenance schedule.
- Qualified life is typically established in a conservative way because specified operating and accident conditions typically consist of maximum values. Actual operating data may be utilized to change the life accordingly. Operational limitations must be established to avoid equipment premature failure.
- Operating at or near natural frequencies must be minimized to avoid premature equipment damage. Calculated frequencies may have to be validated and adjusted by operational monitoring.
- A maintenance schedule should be informed by actual inspection schedule that should be relaxed or tightened based on the results of the inspections. All obtained information must be included to build up the experience database and shared with other stakeholders and licensees.
- Nuclear facilities require certain specialized equipment that must meet rigorous qualification requirements to ensure that it can survive the consequences of an accident to accomplish its intended safety function.
- Proposed material substitutions must undergo equivalency determinations that include analysis and/or testing to ensure that it can still perform its intended function.
- Equipment failures from both nuclear and non-nuclear applications must be analysed for the existence of defects that could be generic potentially impacting other applications and/or reactor facilities.

2.7.3 The importance of challenging the use of experience in supporting safety claims

Regulatory authorities need both the capacity and capability to critically assess the use of experience supporting any of the safety claims and any evidence that underpins those safety claims.

To achieve this, regulators need to develop knowledge and experience appropriate to enable them to critically assess the outputs of those involved in SMRs, such as licensees, applicants and designers. For example:

- a detailed understanding of the bases underpinning the expectations in the regulatory framework
- access to detailed experience information to be able to judge its adequacy and applicability on a case- by-case basis
- the ability to conduct timely regulatory research to inform both assessment and decision-making
- the internal technical assessment competencies or, at least, sufficient internal competencies to oversee external technical support activities.

This is supported by IAEA Fundamental Safety Principles, SF-1 [2], which states that regulatory authorities are established by member states to independently judge the safety case proposed by an applicant/licensee.

IAEA document, GSR-Part 1, expands on these fundamental safety principles and includes:

Requirement 15: Sharing of operating experience and regulatory experience.

The regulatory body shall make arrangements for analysis to be carried out to identify lessons to be learnt from operating experience and regulatory experience, including experience in other States, and for the dissemination of the lessons learnt and for their use by authorized parties, the regulatory body and other relevant authorities.

Such arrangements include:

- Timely reporting of experience for the purpose of corrective actions;
- Sharing regulatory information across Member States, so that lessons can be systematically analysed, applied as appropriate and any improvements implemented, commensurate with safety importance;
- Maintaining a regulatory framework for the purpose.

There is strong evidence that the number of new SMR technologies, coupled with diversification of the international supply chain, places challenges on national regulators to effectively challenge the use of experience supporting any of the safety claims and any of the evidence that underpins those safety claims for SMRs. This suggests that national regulators need to use existing international cooperation mechanisms to share knowledge and enable mutual recognition of each other's activities, through developing common positions.

2.8 Assessing the effectiveness of the experience measures

The following common position highlights the periodic and reactive assessment of the effectiveness of the experience measures.

Common Position

SMR stakeholders should perform both periodic and reactive internal and external assessments of their experience measures including self-assessments, internal and external audits and benchmarking against IAEA safety standards and industry practices, to ensure that the use of experience continues to meet internal and industry objectives. Reactive assessments of experience preventable significant failures should be required by the corrective action programme and actions should be taken to improve the experience measures as required. An assessment of how experience information is being systematically leveraged or developed by the licensee should be part of the regulatory assessment.

Reactive and periodic assessments, both internal and external, should be performed to make sure that the experience measures meet their goals and objectives of preventing significant events and continuous improvement. Benchmarking against IAEA safety standards and industry practices should also be utilized. Corrective and preventative actions should be defined and implemented for significant findings to improve the experience measures as necessary.

2.8.1 Reactive Assessments

Significant issues entered into the corrective action programme should be reviewed by the stakeholders to see if they could have been prevented by the experience measures. If preventable, the causes of the failure to prevent should be identified and corrective and preventative actions should be taken. In addition, the issue should be considered for sharing with the industry. Corrective and preventative actions may include revisions to the experience measures, strengthening of procedures, and processes and training.

2.8.2 Periodic Internal Assessments

The experience measures should specify periodic internal assessments the periodicity of which could be adjusted according to how well the measures are being implemented. The assessments should include self-assessments and independent audits by the Management System organization with support by subject matter experts. The assessments should cover among other things the following:

1. The use of experience to make sure that it is being applied correctly and effectively in accordance with the experience measures to contribute to a defence in depth strategy that maintains the design and licensing bases of the SMR and meets the requirements of IAEA standards.
2. Significant issues entered into the corrective action programme to see if they could have been prevented by existing experience. If so, was that adequately identified and evaluated as per the previous reactive assessments section above?
3. Significant unexpected issues entered into the corrective action programme to see if they presented novel problems or if they were self-revealing. If so, did the corrective action programme recognize these problems and properly evaluate the need to share them with the industry?

4. Significant external nuclear and non-nuclear events to make sure that they were properly evaluated and applied to the SMR as required.
5. Interviews and polling of staff to gauge the effectiveness of their training and understanding of the importance of experience. Suggestions for improvement should also be collected.
6. Attendance of pre-job briefs of safety significant activities to gauge how well related experience is being covered.

2.8.3 Periodic External Assessments

In addition to the information in the previous section, this section covers assessments by industry organizations such as WANO to make sure that the SMR experience measures for evaluating and effectively sharing experience related information are being met. The evaluations of experience should cover external and internal experience. External experience includes incoming experience like applicable SOERs and owners' groups recommendation to make sure that their recommendations are being implemented correctly. Significant internal experience should also be reviewed to make sure that its root causes and corrective actions were identified correctly and communicated properly to the rest of the industry.

2.8.4 Regulatory assessments

Regulators have the responsibility to assess safety claims being made by the licensee and to verify that the safety and control provisions both meet regulatory requirements and provide a high degree of confidence they are effective. An assessment of how experience information is being systematically leveraged or developed by the licensee is part of the regulatory assessment.

3. Chapter 3: Conduct of Maintenance

This chapter presents common positions associated with the need to address the conduct of maintenance as early as possible to enable effective operation and maintenance activities through design features.

3.1 Introduction

In SMR design configurations, including those that involve shared civil structures, certain operations (like fuel loading, maintenance, outage management or addition of Units) are dictated and foreseeable by the design. Ideally, the designer and the ultimate operator/Licensee should consider those operations together in a systematic fashion, so that they can collaborate on the design of safety features that are maintainable.

Collaboration should aim to provide as much as possible of the safety capability through the plant design. The use of human performance tools such as Human Factors Engineering (HFE) as well as operating experience should inform the design configuration, particularly to reflect differences in legal, operating and maintenance environments in different countries.

For example, in the case of maintenance requirements that arise from any plant design, there will be opportunities to alleviate maintenance risks by considering:

- the need for a maintenance task in the first place, because some tasks could be eliminated through changes to design or to specification;
- whether certain maintenance tasks could be substituted by others that are, on balance, safer for the plant or for the operators; and
- how particular tasks drive requirements for the qualification and skills of maintenance staff that can result in:
  - tasks that should be performed at specialist premises, rather than on site, because of the expertise and facilities required to do them;
  - specialised training, and refresher training, and certification requirements that are more onerous than those needed for alternative maintenance tasks.

As a fleet of SMRs develops over time, there will be operational experience (OPEX) from the first of a kind, and subsequently from later Nth of a kind, which should be gathered, collated, and analysed for the purpose of:

- adjustments to the plant, operations, and maintenance arrangements for the FOAK;
- driving any design changes for subsequent new builds;
- devising any necessary modifications to SMRs already built; and
- making any changes to maintenance or operational practices for SMR's in use.

A comprehensive OPEX management system will mean that Licensees for subsequent SMRs in a fleet can be assured that the design for their Nth of a kind will take account of OPEX from existing sites.

The challenge in OPEX management arises from the many different organisations that would need to be involved, each with a different role, such as designer, vendor, supplier, owner, operator, and maintainer. For example:

- a "fleet" of SMRs may be owned by more than one organisation, or one organisation may own many of the SMRs;
- the vendor of the SMR technology may be separate from the operation of any of them; or closely involved, depending on its choice of business model; and
- maintenance may be conducted by many organisations across an extensive supply chain remote from any SMR site or carried out by a single organisation intimately involved in operations.

Nevertheless, the Licensee, vendor and designer roles are essential to implementing learning from OPEX, and they will need to exercise authority according to their individual role to ensure that other organisations, who are also important in the chain that delivers the purposes, play their part. For example:

- Different Licensees across a fleet should:
    - Gather OPEX on operations and maintenance at their respective SMR sites;
    - Require suppliers and contractors to report OPEX to them;
    - Expect maintainers to provide OPEX;
    - Collate and analyse their own OPEX, and that reported to them;
    - Collaborate and exchange OPEX information with other Licensees who have SMRs of the same generic design, irrespective of country;
    - Arrange for collated OPEX information to be shared in a timely way with the designer and vendor;
    - Decide whether, and to what extent, they may adopt modifications proposed by the vendor and designer.

- Designers and vendors for a fleet should:
    - Maintain core competencies to understand any OPEX information and to consider the implications for the design of new plant and the modification of existing plant;
    - Take account of all collated OPEX and make timely decisions on it in consultation with Licensees, and ideally in consensus with all Licensees;
    - Collaborate with Licensees on implementation and be aware of the extent of implementation that has been achieved for modifications in the existing fleet.

3.2 Common Positions on Conduct of Maintenance

Common Position

The ultimate Licensee is expected to understand and approve where, how and by whom any maintenance activities are going to be done.

Common Position

The designer and ultimate Licensee should collaborate as early as possible to:

- *enable effective operation and maintenance activities through design features;*

- *apply requirements for maintenance, inspection and testing in line with the national expectations of the country where the SMR is deployed;*
- *consider how the design of the SMR, and any modular, factory-based approach to building the SMR, may affect subsequent maintenance activities; and*
- *strike a balance between minimising risks arising during maintenance activities (to people, plant, and the environment), with ease of SMR build and aspects of the design.*

Nuclear processes are designed on the premise that the facility and equipment in use will retain the reliability claimed in the facility Safety Case, thus ensuring that the hazard presented by, and the risk associated with the process is kept at an acceptably low level.

The reliability of the facility is generally assured through the facility's full lifecycle by a process of maintenance, which may include refurbishment or replacement of Structures, Systems and Components (SSCs), and is generally set out in a maintenance programme.

This process must be based upon a sound understanding of the facility, the identification of SSCs important to safety, knowledge of the equipment's ageing mechanisms and the support of a programme of examination, inspection, maintenance, and testing.

The approach chosen to plan and execute a site-specific maintenance program versus a vendor's generic maintenance approach is important to safety, so, for SMRs, Licensees must understand the consequences to maintenance that arise from, for example:

- the SMR design constraints, including reliability requirements and how those might differ between the Licensee and the SMR designer, and how they might differ depending on the ultimate use and location intended for the SMR;
- the way in which the SMR is built, using modular assemblies and in-factory construction;
- differences in configuration between different sites for SMR's of similar design (older units may be different to newer ones; site use may be different and site differences may exist, such as topography, weather conditions).
- the issues that may arise from SMR vendors requiring that Licensees adopt common approaches to maintenance using only the vendor's suppliers;
- the issues that may arise from Licensees' access to appropriate maintenance support services at the right time with the right competencies;
- access to, and awareness of, SMR configuration from site to site by maintenance providers;
- resilience of the design, from a safety perspective, to the potential for significant interruptions to the planned maintenance programme, particularly for multi-unit facilities that share common SSCs and
- any proposals for additional maintenance that arise from feedback (proposing such maintenance) from other SMRs of the same design.

The paragraphs below consider some of these examples in a little more detail.

Looking first at how the use of modular assemblies and in-factory construction affects SMRs. These factors will have implications for the maintenance strategies and their execution.

Chapter 1 of this report notes:

"Modular construction is an approach that organises a complex construction / assembly process into discrete predictable steps using modules, where applicable, as the primary building blocks. The primary goal of modular construction is to improve efficiency of on-site construction and reduce the number of on-site crafts needed to perform construction activities. In theory, many of the traditional on-site crafts would be moved back into the supply chain in the manufacturing facilities to ensure high quality before modules arrive at the site for installation".

From this, we derived the second common position below:

Common Position

> *Modular construction does not necessarily mean modular maintenance unless that was the original design intent. The degree of modularity (at the outset), and the approach to the content of modules, must include consideration of future maintenance requirements, as well as the conduct of operations.*

The implications for maintenance of SMRs from modularisation and in-factory construction include:

- Maintenance access may be constrained (or enhanced) by the lay-out of the module;
- Maintenance activities on one item in a module may require work on (potentially unrelated) systems located on the same module;
- Modules may have to be "swapped out" in their entirety, with provision for this to be done within the civil engineering;
- Maintenance on the module may occur at a site away from the SMR (such as maintenance suppliers' premises). This may be beneficial, in allowing specialisation of skills in that type of maintenance, thus improving maintenance quality, or give rise to additional risks, such as those arising from transportation of modules;
- On-site expertise would be needed in connecting, and disconnecting, the modules (or individual components on a module) as they come up for maintenance, and this may change outage regimes;
- The ability to achieve high quality may be affected if some maintenance of plant is performed in an on-site environment for equipment that was originally built in a factory environment; and
- On-site expertise in some crafts may be lost, as those skilled people move to the maintenance supplier premises remote from the SMR site. Furthermore, the expertise may only be developed by, and retained by, a maintenance supplier (which is maintaining numerous units in different locations/countries or in its own factory). There is also a possibility that some expertise might not be developed, if some unexpected maintenance needs arise that the supplier/vendor has not foreseen (for example, there might be maintenance demands unique to the SMR unit location, if that location is subject to adverse weather). Finally, if maintenance is bought "in bulk", the Licensee might not even know what kind of expertise or on-site expertise is needed, and this poses a challenge if the maintenance supplier is changed. Overall, it is important for the Licensee to obtain information from the

vendors on the anticipated capability and expertise required for maintenance activities.

Looking next at the Licensee's choice of maintenance programme delivery model. The SMR vendor may offer different models depending on their approach to providing oversight to a fleet of SMRs, and their own commercial strategy. The option chosen by the Licensee has a major impact on the management of safety, and their choice should be in full knowledge of the pros and cons of each model. For example, the SMR vendor may offer an option that requires the Licensee to use only the vendor's suppliers. The implications for maintenance of SMRs from a requirement (on Licensees) to use only the vendor's suppliers include:

- Greater likelihood of good quality maintenance from specialisation at the maintenance suppliers;
- Fewer specialised people available on site in the case of safety significant event;
- Reduced authority of each Licensee to require (and check) maintenance performed on its behalf;
- Specialised maintenance companies may require real time remote monitoring data concerning the SMR to be sent to them by the Licensee. There may be security implications.
- Improved availability of the SMR to generate electricity whilst maintenance of modules is being carried out elsewhere and (new/refurbished/already maintained) modules replace the one undergoing maintenance;
- Prompt inclusion of OPEX (from other SMRs in the fleet) into maintenance activities for all the SMRs;
- A culture of "assumption" (that maintenance has been done properly) can grip the Licensee, as they are remote from the actual, hands-on maintenance activity.
- Licensees may need to pool intelligence from their individual oversight of maintenance at suppliers to avoid contradictory requirements arising from each.
- Modules may be maintained in different countries to the SMR location. The Licensee, and the maintainer, must know the legal requirements for maintenance in the country where the SMR is located. This may lead to conflicts between the requirements being followed by the maintainer for one module arriving from a certain country when compared to another from a different country.

In summary, the Licensee must understand how maintenance on their SMR is going to be done, where it is going to be done and by which suppliers. The Licensee should have the capability to exercise control over maintenance and have good communication with all maintenance organisations to secure this knowledge.

Looking finally at the implications arising for an SMR Licensee who receives proposals for additional maintenance as a result of feedback from other SMRs in a fleet of the same design. The implications for maintenance include:

- The configurations of each SMR over time may mean that the additional maintenance proposal is not directly transferrable to all;
- Licensees will need to be in control of whether such proposals are adopted for their SMR, and have the capability to do so;

- The Licensee might choose to assign its responsibility or authority over proposals for change to maintenance on to an organization which monitors the fleet and holds fleet wide OPEX;
- SMR sites could become mere "takers" of maintenance for their plant, rather than specifiers of maintenance.

4. Chapter 4: Conduct of Co-Activities and Combined Activities on a Multiple-Unit SMR Facility Site

This chapter discusses safety considerations that need to be considered up front in the design of structures, systems and components (SSCs) as well as in the overall program for conducting construction, operation and maintenance.

4.1 Introduction

4.1.1 What might a Multiple Reactor SMR Facility look like?

One feature commonly associated with the concept of an SMR facility is the notion of a single 'facility' on a site containing multiple operating reactors or power modules. For the purposes of this paper, the words "unit" or "units" will be used to represent a discrete reactor set of structures, systems and components in a configuration even if multiple reactors supply energy to a single facility that will use the process heat for an end-use such as generation of electricity.

There are a number of arrangements of configurations possible for such a facility and the legal definition of facility may have different definitions from one-member state to another. The following figures illustrate different arrangements that are possible but also how SMR arrangements may share some similarities with larger NPP facilities already in operation.

Arrangement #1: Multiple discrete and separate reactor units in separate civil structures

A number of SMR concepts are being specifically developed to be situated on a site as discrete self-standing units as illustrated below in Figure 1. This is the most common arrangement in the existing global NPP fleet.

Figure 1: Flamanville 1,2 (1300 MW) and the new Flamanville 3 (EPR 1600MW)

Characteristics of this type of arrangement include:

- Each unit has its own SSCs to support safety functions as well as production provisions including discrete control rooms in each unit.

- Units are intentionally separated from another by space that provides separation from the effects of single unit events as well as site-wide events. The space may include separate or common physical security provisions.
- Units may use common site services such as maintenance support, security response, emergency/fire response, switchyard, waste management, site administration support. In addition, the site organisation may also coordinate external contractors.
- Sharing of operating and maintenance staff between units can range from no sharing to strictly controlled access due to configuration and/or operational differences between units.
- Conduct of operations and maintenance is addressed on a per-unit basis but may involve coordination of activities between units such as outage planning.

Arrangement #2: Multiple discrete and separate reactor units in shared civil structures

Figure 2 depicts three possible conceptual arrangements for multiple unit reactor facility concepts:

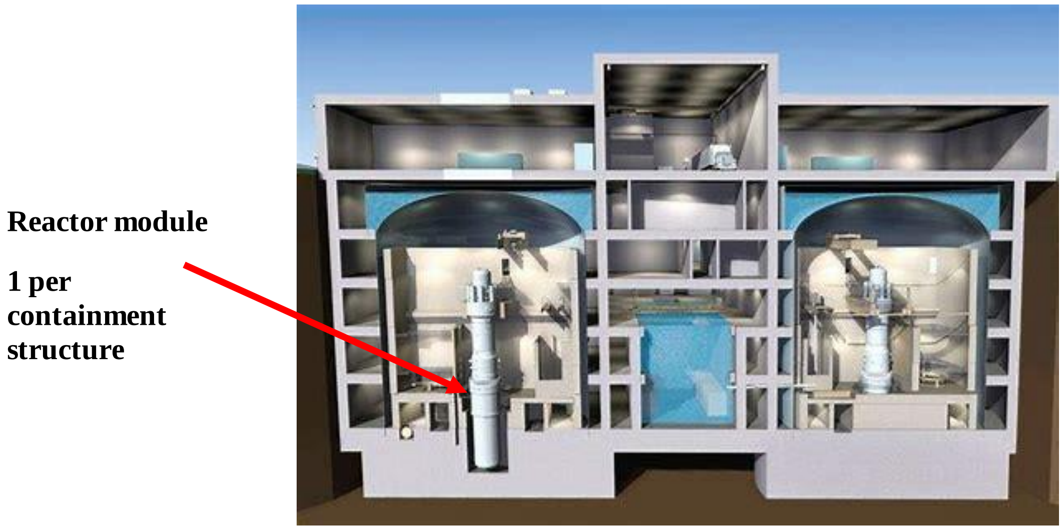

Figure 2A: B&W mPower Twin Unit SMR Concept – 2 x 200 MWe – Diagram Source OakRidgetoday.com

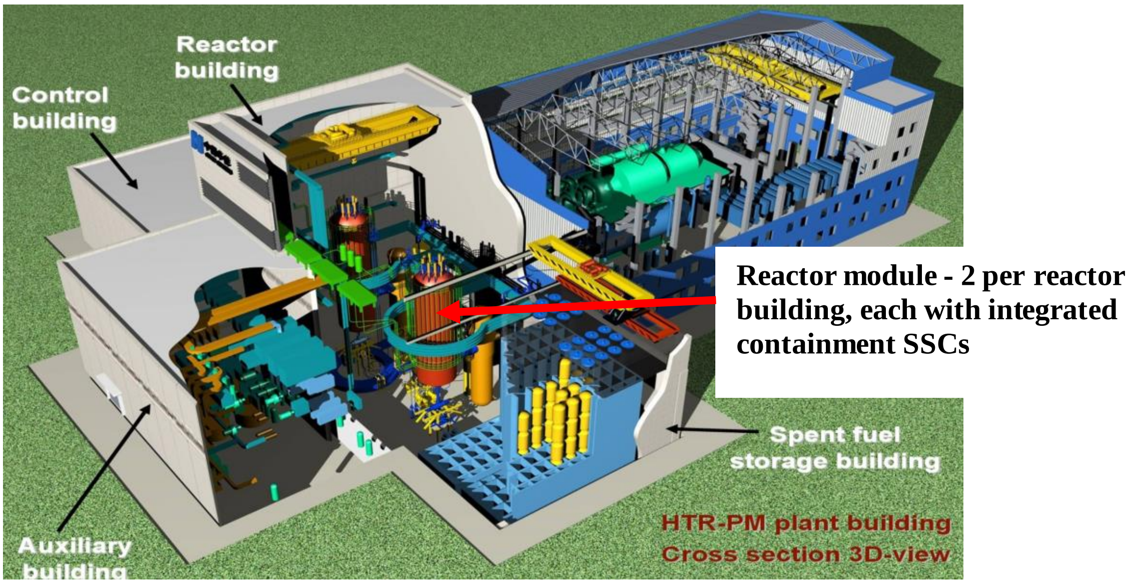

Figure 2B: HTR-PM Twin Unit Concept – 2 x 250 MWth – Diagram source: GIF 2018, Tsingghua University China

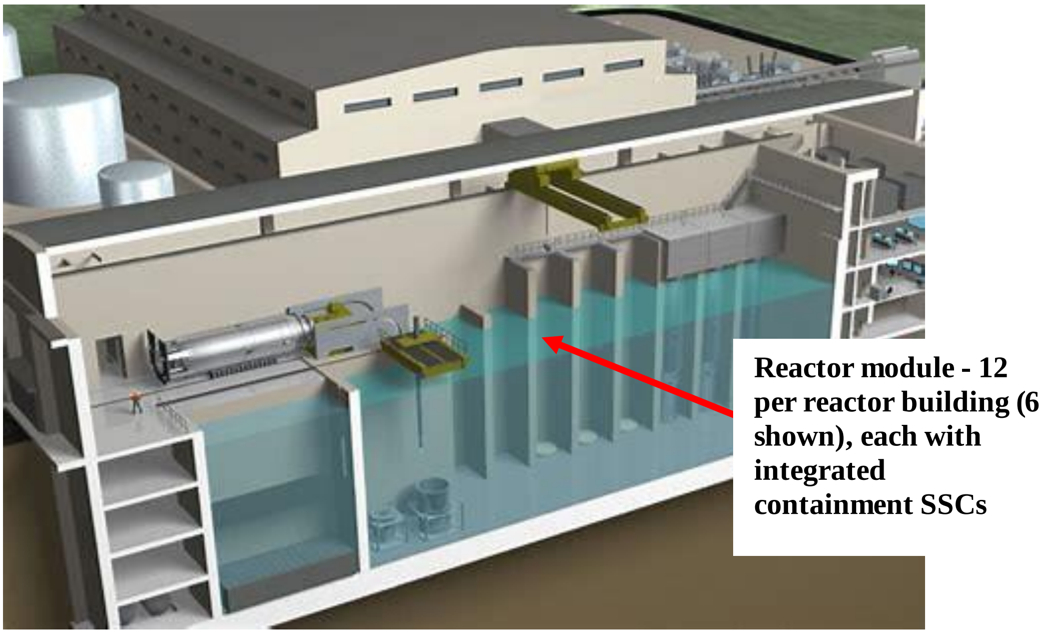

Figure 2C: NuScale SMR Concept – 12 x 60 MWe – Diagram Source: IAEA ARIS Database

Characteristics of this type of arrangement include:

- Each unit is composed of self-supporting SSCs to support safety.
- Common plant SSCs may be provided in the concept to support:
  - additional defence in depth provisions for all the units in the entire facility;
  - various degrees of multiple unit operation including shared or partially shared control rooms;
  - Facility-wide security and emergency response;

  - common services such as fresh and spent fuel handling, maintenance facilities, waste management etc.
  - common non-safety plant functions including secondary side (turbine generator, feedwater systems) and Balance of Plant systems.
- Units are separated from another by physical in-plant barriers providing separation from the effects of single unit events as well as site wide events.
- Units use common services within the facility such as maintenance support, security response, emergency/fire response, switchyard, site administration support.
- Sharing of operating and maintenance staff between units can range from extensive sharing between units to strictly controlled per-unit access due to configuration and/or operational differences between units.
- Conduct of operations and maintenance is addressed on a facility-wide basis.

Operating and maintenance experience with these arrangements is less common but exists in some countries such as:

- United Kingdom – Advanced Gas Reactor (AGR) fleet as depicted in Figure 3A; and,
- Canada – multiple unit CANDU stations as depicted in Figure 3B

Figure 3A: Heysham 1 (2 x 600 MWe) and Heysham 2 (2 x 615 MWe) Nuclear Power Station, Lancashire, UK – Advanced Gas Reactors. Diagram Source: eDF

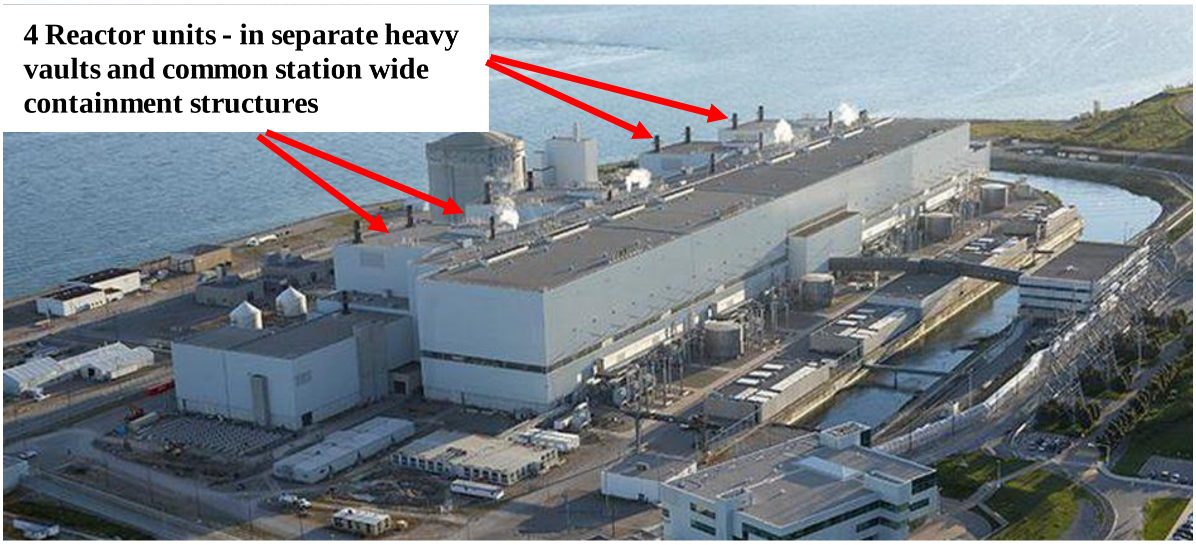

Figure 3B: Darlington Nuclear Generating Station, Canada 4 X 880 MWe CANDU, Diagram Source: Ontario Power Generation

If multiple unit NPP Conduct of Operations and Maintenance experience already exists, what is it that may make an SMR facility different from a traditional multiple unit NPP facility?

The conduct of activities associated with multiple unit facilities introduce an additional level of complexity over the conduct of activities for a single unit facility. That is, simultaneous conduct of different activities on the site in different unit operating states requires an additional measure of coordination and attention to detail by the licensee to anticipate, prevent and mitigate events that could lead to safety issues. In this report, these are called "co-activities" and examples of co-activities include:

- Specific operating and maintenance tasks (including outages) on one unit in close proximity to another unit

- Site preparation, construction, and commissioning activities in close proximity to another unit
- Security and safeguards activities that can impact on conduct of other activities.

Of particular interest are co-activities with potential to impact on safety of operating units.

Some SMR concepts may introduce new technologies and construction, commissioning, and operational approaches/methods that further amplify some of the challenges already being addressed in existing multiple unit facilities until the concepts have been fully demonstrated. In the long-term as experience is gained, these new approaches are likely to reduce these challenges.

Multiple unit facilities introduce safety considerations that need to be considered up front in the design of SSCs as well as the overall program for conducting construction, operation and maintenance. Examples include:

- Sequence of multiple unit construction, commissioning and operation including the addition of new units to increase plant capacity.
- Conduct of operations and maintenance with units in different operating states and/or in the presence of plant events.
- Staffing of operations and maintenance personnel in consideration of technological features and their maturity.
- Conduct of maintenance and/or major plant evolutions (e.g. refurbishments/equipment replacements) with other units in operation.

As discussed earlier, decades of operating experience exist in demonstrating safe conduct of activities with multiple unit nuclear power facilities. Licensees of these facilities have undergone a large number of peer reviews via processes offered by:

- Industry organizations such as the Institute of Nuclear Power Operations (INPO) and the World Association of Nuclear Operators (WANO)
- IAEA review missions and advisory services (e.g. Construction Readiness Review (CORR), Operational Safety Review Team (OSART))

SMR vendors, designers and Licensees have early opportunities exercise leadership to seek out and leverage this body of experience to inform the development of design features and key aspects of programs to oversee and conduct their activities safely such as:

- Implementation of safety culture within a project's management system
- Human performance management (e.g. minimum staff complement, training and certification etc.)
- Operating performance (including configuration management)
- Emergency management.

4.2 Generic Lessons Learned from Existing Multiple Unit NPP Facilities and Common Positions for Consideration in SMR Facilities

4.2.1 Safety Case for multiple unit SMR facilities

Common Position

> *The facility Safety Case[11] must consider all co-activities being performed at an SMR facility.*
> *Activities that are potentially vulnerable to co-activity risks should be systematically identified and analysed. The results of the analysis should be reflected in the safety case for the entire facility and be included in the deployment plan.*

The potential conduct of co-activities - such as installing and commissioning new units next to operating units later in the life of the facility - needs to be anticipated in advance, in consideration of applicable operating experience, and addressed in the safety analysis. The licensee should then establish appropriate control provisions to ensure activities will be conducted within the safety case parameters established for the facility.

Accumulated experience from the conduct of activities needs to be reconciled with the safety report on a periodic basis to maintain a realistic understanding of the effects of co-activities and the measures being used to prevent and mitigate the effects.

The safety case needs to demonstrate that the lay-out of the plant is adequately addressing all of the different activities to be performed during the plant life including co-activities such as construction, installation and commissioning of new units while other units are operating. The safety case should also include consideration of human factors associated with the conduct of activities to reduce potential for human induced events. For example, the safety case should contain a detailed analysis of activities in the field with the involvement of the actors carrying out these activities during the first stage of the design and comply with relevant ergonomic design standards. Use of 3D models may be particularly helpful in this regard. The use of operating experience is particularly important to understand how tasks will be performed and the qualifications needed to carry them out.

These activities should be optimized from the point of view of workers radiation protection security. The safety case is also expected to consider the potential hazards that may result from co-activities (dropped loads, projectile, fire, flooding…) and how they may impact safety of adjacent units in different operating states (e.g. operating, shutdown for outage, new unit under installation etc.).

The closer the proximity of the units and/or sub-modules associated with the units and the more compact the arrangement of SSCs, the more detail is needed in the safety analysis to inform the stringency of the provisions needed to predict, prevent and mitigate possible impact of human induced events, including deliberate attacks. Likewise, the more credible the potential for co-activities to impact those units. The Licensee should provide a justification in the safety

[11] The definition of safety case may vary from member state to member state; however, it generally refers to the sum of safety and control provisions and supporting evidence being established by a licensee/authorized party to assure safe conduct of licensed activities.

analysis to demonstrate that the impact is not adverse or there is adequate provision to predict or prevent.

In particular, installation of a new adjacent unit will require both design and management provisions to not only protect the new module from installation events but also to protect the operating modules that may be impacted by installation events such as dropped equipment.

Common Position

> *Design the multiple unit facility with the sequence of construction, commissioning operations and co-activities in mind.*
> *The design of structures, systems and components for a multiple unit facility should take due account of the sequence and timing of activities and co-activities associated with construction, commissioning and operations.*

When several units will be sharing civil structures and systems, the designer, vendor and the ultimate Licensee should establish an overall facility deployment plan, under the authority of the Licensee, for all the units before the first is installed. The deployment plan should document the sequence and timing of all activities and include plans to address impacts on the facility in the event of potential deferral of installed units.

The safety case for the SMR should inform, and be informed by, the deployment plan. Risks for combining operated modules with a new module being installed or commissioned should be carefully assessed and considered from the design phase in that plan.

Common Position

> *With any increase in co-activities, a "step wise" increase is needed in risk control features and organisational capability to match and should be anticipated in the deployment plan. Licensee capability needs to be maintained throughout any later deployment of extra modules.*

For multiple unit SMRs, in particular those with shared civil structures and systems, the vendor and Licensee should have a deployment plan for increasing (or decreasing) the number of units in the shared structures over time. The plan should be drawn up at the design stage because the activities to increase or decrease the number of units will impact upon operations on the plant as a whole. Depending on the deployment plan, certain operations may (or may not) be required, or may need to be revised, and thinking about these aspects at the outset will improve safety.

A multiple unit facility may involve activities such as simultaneous Construction/Installation, Commissioning and Operation activities. Each of these activities may be conducted by different parties and needs to consider:

- Risks to the unit from the activities are being carried out on that Unit;
- Activities associated specifically with declaring as "in-service" common plant systems needed to support future activities on each of the units;
- Risks to adjacent units while the activities are being conducted;
- How handovers between different organizations will occur as each unit is transferred from construction through commissioning to long term operation.

Addressing the above involves a combination of carefully considered design of facility features with sequencing of activities in mind as well as a series of administrative and managerial provisions to control transfer of activities between parties. Contingency plans should be established to address potential complications during transfer from unforeseen events.

The Licensee should identify planned transfers and handovers between organizations for the purpose of further optimizing the sequence and conduct of activities and co-activities as the deployment plan is being established for the site. The deployment plan should take account of the potential impact on other operating modules from activities like high pressure tests or pipe welding on equipment installed later. Actions should be planned to limit the potential impact on operating modules. A process of integrating human factors into the design of the premises and equipment of the installation should be detailed in the safety case and then adequately implemented.

4.2.2 Safety Culture and the conduct of co-activities in a multiple unit facility

Common Position

> *Activities between co-located units should be effectively managed by the Licensee(s) within a strong and facility-wide safety culture environment:*
>
> - *All workers should be made aware when they are conducting work in a co-activity environment and provided with the necessary tools to understand and complete their tasks within the constraints under which their work is to be conducted. For example, technical processes for activities should be sufficiently detailed to assist the workers to perform their activities to a high degree of quality.*
> - *The perimeters of responsibilities should be clearly established and documented, between the Licensee and parties with key responsibilities in the execution of construction, commissioning and maintenance support.*
> - *An integrated set of processes and tools should be implemented to systematically identify potential co-activities, characterize potential risks and establish effective means, including "back-out" provisions to prevent and mitigate potential events that could impact on safety.*
> - *Particular attention could be necessary when a new module is to be installed or commissioned, or a module is underdoing maintenance in close proximity to operating units.*
> - *A coordinator should be assigned to manage the interface between the Licensee and the companies involved in the installation/commissioning of a new module or significant maintenance on an existing unit.*
> - *Another coordinator should be assigned to manage the day-to-day interface between operators and the team in charge of the installation/testing.*

The conduct of activities associated with multiple unit facilities introduces an additional level of complexity over the conduct of activities for a single unit facility. That is, co- activities on the site in different unit operating states requires an additional measure of coordination and attention to detail by the licensee, when different organizations are conducting different activities within the facility.

The conduct of construction/commissioning may be under a different organisation and under different rules than the conduct of operations. For multiple unit SMR designs, it will be difficult to create completely enclosed workspaces that are independent of each other to avoid co-activity event likely situations, especially between the work-site area and the nuclear operation areas. The interfaces between these activities presents important safety culture issues and safety challenges. For example, different rules / laws governing conduct of construction versus operation may exist in a country because hazards are different (e.g. health and safety regulations/standards which would include conduct of activities such as equipment isolation (e.g. tag-out/lock-out), equipment testing. In addition, the trades (also known as 'crafts') and associated qualifications may not be the same for construction as they would be in conduct of operations.

Common Position

> *The preparation of co-activities, especially before installing or withdrawing a unit or other major modular equipment, requires early systematic planning activities that involve operations staff to anticipate and prevent events that could impact on nuclear safety. Planning activities should anticipate the complexities and potential hazards of co-activities and provide realistic allowances for the impact of any delays and slippages in planning to avoid any adverse effect on quality.*

Common Position

> *A facility operating experience program should include the study of co-activities and the analysis of lessons learned. The first unit to be installed and commissioned should be used to gather necessary operating experience to validate and verify work processes for use in subsequent units. Sufficient schedule time should be provided to accommodate these activities.*

The intensity of co-activities may have an impact on the safety of the plant. In particular, the intervention of a third party or an unexpected presence in a workspace or specific activity creates a break in the continuity of the activity which can introduce unanticipated risks or even trigger an event. This is particularly true to activities being conducted in close proximity to operations and operators such as installation of control systems and facilities in a common control room. Thus, planning of co-activities must include consideration of all activities being conducted regardless of the organizations doing them.

The Licensees need to implement procedures in place for ensuring that construction activities do not affect the operation of already installed modules. The operating organisation has to confirm that the lead contractor has controls in place in order to prevent events on the operating island. There are a number of designs where close proximity of units to one another may pose both jurisdictional and practical working challenges when performing adjacent construction and operation.

Even if anticipated in the vendor's technology deployment plan, the organisation of the Licensee may differ from one country to the other, or from one Licensee to the other. The impact of the operation organisation should be carefully examined before the installation of a new unit or major module.

Focus Area:
Installation of a new unit or major sub-module into the facility.

A strong safety culture should be instilled into all the persons involved in the installation of a new unit and sufficient time has to be devoted to this preparatory phase. The closer the proximity of the units and the more compact the workspaces, the greater the preparation time and associated event free tools needed to prevent and mitigate potential human induced events. Consideration must be given to constantly changing work conditions and associated risks and the potential for evolving new co-activities that can emerge. This requires a strong degree of effective oversight and supervision and the licensee must also be aware for the purposes of managing safe facility operation.

Preparation time is necessary for the teams in charge of the introduction of a new module to take ownership of the workspaces before starting work. An opportunity exists during this time to raise again awareness on the risk due to the proximity to existing operating units and to become familiar with the Licensee's organisation and operational constraints.

All the actions to be performed must be prepared, the technical process carefully described. Even if the team in charge of the installation of a new module is well-trained, it is nevertheless essential that they take time to understand how the Licensee is organized, who is in charge of the interface with the Licensee, the control room.

Then, during the installation and then the commissioning tests of the new module, regular meetings need to be organized during which the vendor reports on the past activities and details the actions that will be performed during the next hours. Consultation meetings around schedules participate in a shared space allowing different companies to coordinate and adjust to changes in the work environment. The organization and format of these consultation meetings are therefore decisive in supporting planning of co-activities.

Experience has shown that supervisors must have more direct oversight of the trades in particular where the trades have limited knowledge on nuclear issues and regulation. Share of responsibilities has to be strictly defined and the whole activity over the plant should be handled carefully. It implies that:

- adequate documentation should be shared,
- best practices should be used for the identification of activities by module,
- a prompt system of alert should be in place in case of event occurring during the construction or commissioning that may impact the operation of existing modules – it implies that the construction supervisor be aware about what may impact the safety of operated modules. Stronger communication provisions and protocols should be in place. Particular arrangements may be developed in the frame of the on-site emergency plan. Hence, for SMRs, the emergency plan may alter as co-activities come and go.

Focus Area:
The Concept of a "Construction Island" in an Operating Facility

In Canada, specifically, licensees had successfully established the concept of a "Construction Island" as a specific sub-jurisdiction within the nuclear facility with physical boundaries ranging from controlled entry and exit points for personnel to construction termination points in systems to prevent inadvertent handling of equipment by unauthorized staff. Although the licensee continues to have overall control and oversight of activities within a construction island, the construction organization is responsible for the safe conduct of activities within the island until transferred to the operating organization as part of a systematic turnover process. In a multiple unit facility, the construction island jurisdiction boundaries and controls are shifted from a completed unit to the next unit to be constructed/installed as part of the handover to operations. Where the construction island also involves common plant systems, terminal points on common systems for the operating unit are established to permit construction to proceed on common systems for the next unit. Commissioning activities for common systems would ensure that in-service units will be properly supported and that construction activities will not adversely impact plant operation. This approach has also been successfully used for major facility refurbishments, which are conducted on one unit at a time.

Experience has shown that the identification and use of terminal points between a construction activities and operation activities requires a system of formal agreement and configuration control between the parties responsible for conduct of activities both in the construction island and the operating facility.

"Operating Ponds" within a "Construction island"

Depending on the configuration of the facility, there is a possibility that some Common facility systems and structures may exist within a Construction Island. Operations may require access to the Construction Island to access that equipment for operational purposes. Because that equipment is being utilized for facility operation, said equipment will also be subject to the operator's rules and processes as opposed to the constructor's. These are referred to as "Operating Ponds" because they form a distinct area of operations jurisdiction within the Construction Island. As discussed above, the system of formal agreement and configuration control between the parties responsible for conduct of activities needs to establish both physical barriers and management control provisions to:

- prevent unauthorized access or inadvertent damage to equipment important to facility safety operation that could initiate an adverse event.
- permit controlled and efficient access by operations to support operational needs

4.2.3 Conduct of Operations and Maintenance in a Multiple Unit Control Room

Common Position

The operations and maintenance program should give due regard for human factors considerations of multiple unit operation in a single control room.

Figure 4A depicts an existing multiple unit control room for a 4-Unit CANDU facility with:

- Common Systems Control Panels – back of room
- Common Fuel handling systems – foreground
- Unit 5 (hidden to left), Unit 6 (far left), Unit 7 (far right), Unit 8 (hidden to right)

Figure 4A: Main Control Room Bruce Nuclear Generating Station B, Canada: source Brucepower.com

As an example of a multiple unit SMR facility, Figure 4B depicts a multiple unit control room simulator for a 12-Unit NuScale facility

Figure 4B: Main Control Room NuScale Power, USA: source NuScalePower.com

A multiple unit control room requires both design and control (i.e. management) provisions to be established to:

- Establish the number of operators relative to the work demands of the control room in normal running and emergency situations;
- Establish the number of Operations and Maintenance staff relative to the number of units they oversee
- Establish whether the number of operators needs to be increased when co-activities are planned and carried out;
- Support defence in depth in the face of common fault events;
- Prevent inadvertent operation of equipment (e.g. wrong unit);
- Coordinate communications between control room operators and the field;
- Control communications and evolutions of facility systems between Common Systems and Systems in each unit;
- Manage outage activities in the presence of operating units;
- Respond to events in a timely manner while limiting impacts on adjacent units.

Where a Construction Island exists within a common control room, special design and management provisions will be necessary to:

- control movement of personnel and access to equipment (including security);
- prevent distractions to operating personnel

The conduct of operations program must be planned and executed with all of the above in mind and include specific protocols for behaviours[12] of staff in a multiple unit control room environment and expectations of staff performance in all operating states.

4.2.4 The Commissioning Program and Plan for a Multiple Unit Facility

Common Position

> *The Commissioning Program for a multiple unit facility should encompass the entire facility in a holistic manner and incorporate the gathering and use of operating experience as new units are installed into the facility.*

Common Position

> *In particular, commissioning activities and results for Common Systems need to be revisited as activities within the facilities evolve, in particular as new units are added*

[12] For example, communications protocols designed to reduce distractions and relay infomation effectively between operators

> *to the facility, to demonstrate that Common Systems remain fit for service to support safety functions credited in the safety analysis.*

Common Position

> *The commissioning activities for newly installed units should consider past commissioning activities in the facility while at the same time ensure that sufficient testing activities are performed to demonstrate that the new units are fit for service to support safety functions.*

For a multiple unit facility, in particular those facility concepts under arrangement #2 as discussed in Section 1 (multiple discrete and separate reactor units in shared civil structures), commissioning activities must be considered within the greater context of the overall facility, in particular where there are units in operation.

The integrated commissioning program should also include any consideration of ancillary facilities[13] either added to the facility from the outset or at a point a later in the facility's life.

Because some concepts may involve installation of new units over a long period of time[14] the Commissioning Program will need to continually be maintained to be used as the need arises over the life of the facility.

Focus Area:
Common Systems to Support Facility Safety and Operation

Common systems can include structure and systems such as:

- Major building structures
- Common Heat Sink Systems
- Station wide electrical supplies (normal operations and emergency)
- Fire Protection
- Heating, Ventilation and Air Conditioning Systems (HVAC)
- Service Water
- Control Facilities

As Common Service Systems are brought into service, some commissioning activities may be directly tied to units that are in operation at the time. For example, if only a few units are initially in service, a series of commissioning activities may be conducted to verify common systems can complete their safety functions in the presence of those units, such as:

- Heat removal capabilities (HVAC, heat sinks)
- Electrical power supply support to systems in service for those units (Main Control Room)

As new units are installed, certain parameters such as electrical power demand, heat sink removal rate will change and may challenge the common systems' performance. As a result,

[13] For example, a cogeneration facility, hydrogen production facility, isotope production systems etc.
[14] The facility may choose deferring installing all units until an external need exists for those units, such as increase in power demand.

additional commissioning activities, over and above those for the new unit(s), may be necessary to verify that common systems will meet their safety functions in accordance with the safety analysis.

First Unit commissioning versus commissioning of subsequent units.

The Commissioning activities for the first unit may have specific objectives, including "First Unit Only" Tests (FUOT), Similar to the concept of First Plant Only Tests (FPOT) addressed by MDEP in common position document CP-STC-01 [20], that could include:

- Verification of integrated design performance against assumptions in the safety analysis (performance under various normal and abnormal operating conditions)
- Supporting ongoing Commissioning of Common Systems
- Performance verification of specific novel equipment in a realistic setting
- Verification of operator and control system performance

The first unit should also establish and exercise a systematic program for operational experience gathering and lessons learned for consideration in the commissioning of subsequent units and Common Systems.

Results from commissioning activities may be used to support and decide the adequacy of the scope and depth of activities for subsequent units. For example, a case could be made to credit FUOT tests on subsequent units; however, some verification activities may be required to support that the subsequent units are being commissioned under the same conditions as the First Unit.

4.2.5 Configuration Management in Multiple Unit Facilities

Common Position

> *In a multiple unit facility, a strong and systematic facility wide configuration management program is particularly important over the life of the facility to prevent the potential for human induced events and introduction of latent safety issues into the design of the facility.*

Common Position

> *Workers planning to conduct activities should be made aware of configuration differences between units through the configuration management program and the potential safety implications of those differences. Awareness of configuration differences should be addressed through worker training as well as in all tools used to conduct work.*

Experience has shown that although standardization of the plant configuration as well as standardization of the operating and maintenance approach across the facility was a strong objective in the development of multiple unit facilities, a number of factors emerged that slowly introduced configuration differences between units over time:

- Optimization of design features based on lessons learned during manufacturing, construction, commissioning, and operation. These may have been implemented on some, but not all units.
- Operating modes of units may differ – e.g. some may support load following and others may support base load. Experience also exists in co-generation operation (e.g. production of electricity + generation of process steam).
- Slight differences in configuration introduced during construction (e.g. piping runs, I&C layouts).
- Change of equipment suppliers during construction or over the life of the units that are introduced to units one at a time as part of Engineering Change Control.
- Maintenance discovery issues (e.g. aging management, materials performance) over the life of the units may lead to differences in operational performance/limitations of individual units.
- Unexpected behaviours or compatibility of common/shared systems with specific units (for example, there may be differences in common HVAC system performance on units farthest away from the HVAC equipment. I&C signal speed may also vary with distance from the control room and the presence of equipment that may introduce signal noise).

Slight physical configuration or operational differences over time may introduce complexities in the conduct of operations such as procedural differences and the issues can become magnified over the life of the facility as the units age. The main concern with these differences over time is the potential of operating and maintenance errors leading to near misses and events such as:

- Loss of situational awareness if an operator/maintainer is assigned to a different unit;
- Performing the wrong activity on the wrong unit;
- Discovering that the operation of a specific component leads to an unexpected behaviour or result;
- A contractor not being aware of configuration differences when performing assigned tasks;

Generally speaking, activities conducted between units or on different units present significant human factors considerations that requires carefully planned and orchestrated coordination between tasks and communication between teams. The Licensee needs to consider with the vendor whether a commensurate step wise increase is needed in risk control features and organisational capability to match.

Experience from these events has led operating organizations to develop additional administrative defence in depth provisions within their Conduct of Operations and Maintenance programs to prevent events and mitigate the effects of errors that may result from long term configuration drift. Included in these provisions were specific programs to manage facility and operation more stringently in the face of configuration differences such as:

- Unit specific operations and maintenance procedures;
- Additional work planning controls and physical interlocks where needed;
- Unit specific training and qualification of staff;
- The use of so-called Event Free Tools such as briefings, working in pairs (cross-checking), three-way communications, colour coded equipment in each unit.

Vendors of SMR technologies have a major opportunity to work with future operators to address these potential issues up front in design considerations to anticipate long term configuration changes in multiple unit facilities to the extent practicable. However, the licensee still needs very strong configuration management and control provisions in place as a defence in depth measure.

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Appendix A: Abbreviations Used in This Report

CFR:	United States Code of Federal Regulations
CFSI:	Counterfeit, fraudulent and suspect items
CNSC:	Canadian Nuclear Safety Commission
EPC:	Engineering, Procurement, Construction
ECCS:	Emergency Core Cooling System
FOAK:	First of a Kind
FPOT:	First Plant Only Tests
FUOT:	First Unit Only Test
HVAC:	Heating, ventilation and air conditioning
IAEA:	International Atomic Energy Agency
I&C:	Instrumentation and control (also commonly known as C&I)
IRSN:	Institut de Radioprotection et de Sûreté Nucléaire (Technical Support Organization to the nuclear regulator for France)
LOOP:	Loss of Offsite Electrical Power
MCCO-WG:	Manufacturing, Construction, Commissioning & Operations Working Group
MDEP:	Multinational Design Evaluation Programme
MWe:	Mega-Watt, electrical
NOAK:	Nth of a Kind (where N is any number above 1)
NPP:	Nuclear Power Plant
ONR:	Office for Nuclear Regulation (The nuclear regulator for the United Kingdom)
OPEX:	Operating experience (from events)
R&D:	Research and Development
SCM:	Supply Chain Management
SMR:	Small Modular Reactor
SSC:	Structures, systems and components
STUK:	Säteilyturvakeskus -The Radiation and Nuclear Safety Authority (The nuclear regulator for Finland)
US NRC:	United States Nuclear Regulatory Commission

Appendix B: Contributors to the Report

The Manufacturing and Construction, Commissioning, and Operations Working Group (MCCO – WG) was established to develop common position statements and areas of enhanced cooperation where practicable to inform near term SMR projects being undertaken by member states for:

This working group is composed of volunteer representatives from the following IAEA member states who are also members of the SMR Regulators' Forum:

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