Safeguards by Design (SBD) for Small Modular Reactors (SMRs)

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ABSTRACT

Safeguards by Design (SBD) is an approach whereby international safeguards requirements and objectives are fully integrated into the design process from initial planning through design, construction, operation, modification and decommissioning of nuclear facilities. Safeguards by Design is a voluntary process which does not replace a State's existing obligations for provision of information to the International Atomic Energy Agency (IAEA) under its safeguards agreement, but which can lead to additional benefits for all stakeholders in terms of efficiency of safeguards implementation.

Although SBD can be applied at any stage or facility type of the nuclear fuel cycle, this paper has particular relevance in the development of Small Modular Reactors (SMRs), since many of these systems involve innovative technical characteristics and would require the development of new facility-specific safeguards approaches. To support the IAEA's efforts to understand these designs as early as possible, a Member State Support Programme (MSSP) task was established in 2018 to engage directly with the SMR design community through the MSSP framework. In this regard, an SBD MSSP task on SMRs was initially proposed to Member States in July 2018. Six States (Canada, Finland, France, Republic of Korea, Russia and USA) have accepted the proposal so far. In addition, development of safeguards measures for the HTR-PM plant in China has been carried out in a separate task.

This paper summarizes the Safeguards by Design efforts of the IAEA with regards to SMRs, including both external interaction within the MSSP framework, and internal interaction within the IAEA as a whole.

1. INTRODUCTION

In recent years, research and development on Small Modular Reactors (SMRs), defined as advanced reactors producing electricity of up to 300 MWe per module, has seen increasing interest in many IAEA Member States due to concerns about climate change, coupled with concerns about the economics and safety of traditional nuclear reactors. Many SMRs present attractive economic models since they are deployable as either single or multiple modules, as well as promising enhanced safety features including passive safety.

Safeguards for SMRs will be a key challenge for Member States involved in innovative SMR development, whether for domestic use or export, in parallel with safety and security (these three design considerations are often grouped as '3S' in the nuclear industry). The development of new safeguards approaches, arrangements, and technology (or modifications to existing technology), will benefit from advance discussion involving the designer, operator, State safeguards authority, and the IAEA. This process is known as Safeguards by Design (SBD).

Safeguards by Design is the integration of safeguards considerations early in the design process of a nuclear facility or component, from initial planning through design, construction, operation, modification, waste management, and decommissioning [1]. SBD is a voluntary process which does not replace a State's existing obligations under its safeguards agreement, but which can lead to additional benefits for all stakeholders through efficiency of safeguards implementation. Figure 1 shows the typical steps in providing early design information to the IAEA, and where SBD dialogue fits in this process.

With consideration for the diversity, number, and development schedule of innovative SMRs being proposed by many Member States, the IAEA Department of Safeguards initiated SBD discussions with a number of SMR designers through the Member State Support Programme (MSSP), which is elaborated in the following sections of the paper.

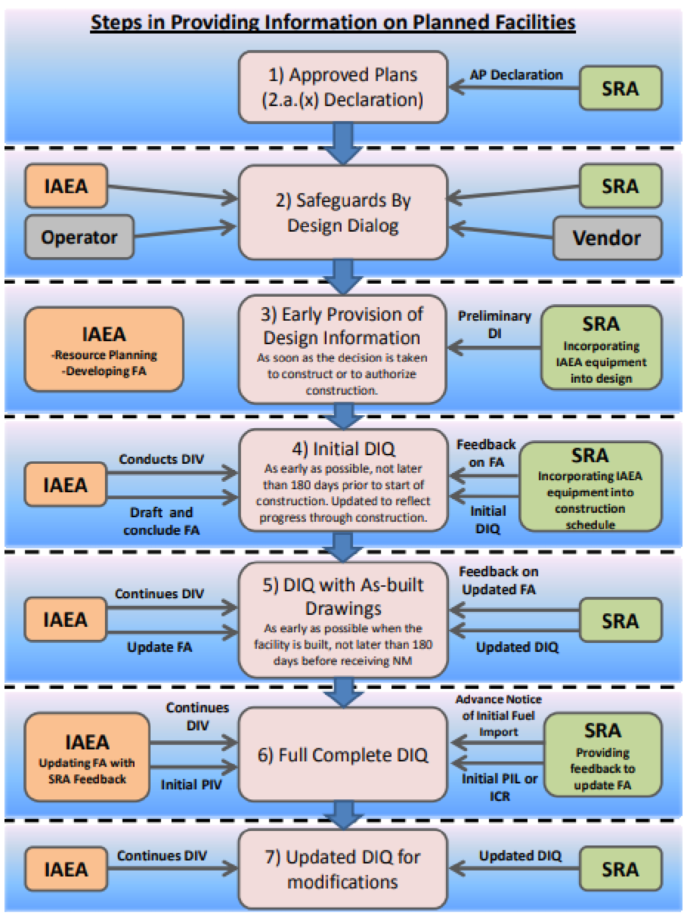


Fig. 1. Overview of steps taken in providing design information [2]

2. MEMBER STATE SUPPORT PROGRAMME (MSSP) TASK ON 'SBD for SMRs'

In order to develop, demonstrate and implement innovative and effective safeguards concepts and approaches related to innovative SMRs, the IAEA Department of Safeguards established an MSSP task on SBD for SMRs in 2018. At present, six Member States – Russia, USA, RoK, Canada, Finland, and France – are participating in this task, while China participates in a separate SBD task for its high-temperature pebble-bed SMR (HTR-PM), established earlier.

2.1. Workplan of the MSSP task 'SBD for SMRs'

2.1.1 Task objectives

The goal of the MSSP task is to identify the key technical challenges for safeguards implementation involving SMRs, and steps that can be taken to support the incorporation of Safeguards by Design principles into SMR designs. The task enables the IAEA to be adequately prepared for applying safeguards to the relevant facilities when they are constructed. Additionally, SBD interactions may contribute to better understanding and awareness of safeguards needs by Member States and the industry, enhancing future IAEA-Member State cooperation in safeguards implementation.

2.1.2. Key outputs of the task

Through the task, Member States support the IAEA in the following areas:

- Developing a model Design Information Questionnaire (DIQ);
- Developing nuclear material accountancy and control strategies;
- Evaluating and testing the technical feasibility of safeguards measures;
- Identifying technical objectives focused on enabling the IAEA to detect any diversion of declared nuclear material, and undeclared production or processing of such material;
- Evaluating of other technical safeguards aspects of potential relevance to SMRs to be constructed in Member States.

2.1.3. Implementation outlines of the task

The estimated duration of the task implementation is 24 months, but the duration could be extended on the basis of the implementation progress of the task.

Phase 1 is the development of task workplan, working with the Member State. The main activities of Phase 1 are: (1) A kick-off meeting to discuss and agree on the task workplan, including a brief introduction to the SMR design and technology. The meeting would also identify the relevant experts and participants for Phase 2 activities. Under the COVID-19 pandemic situation, the activities of Phase 1 have been carried out in a virtual mode.

Phase 2 is the development of a Safeguards Technical Report (STR) or other relevant report to address the key technical areas discussed in the task. The proposed Phase 2 activities include: provision of a Design Information Questionnaire (DIQ), technical meeting and visit (if applicable) to the SMRs, and a draft STR. A dialogue would be established between the IAEA and the SMR point of contact (POC) to address comments, questions, and feedback regarding technical information required in the DIQ. The Member State would be expected to work closely with the IAEA to draft the initial report based on information exchanged with the IAEA. The report would be subject to IAEA Department of Safeguards' internal review and approval process.

Phase 3 is an optional extension of the task, should the IAEA and Member State assess that an extension of the scope of work to other reactor designs, based on available resources and experience gained from Phase 2, is warranted.

2.2. Confidentiality of design information

All design information shared with the IAEA as part of the MSSP task is handled as IAEA Highly Confidential, and protected in accordance with the IAEA's procedure on classification of safeguards information. Access to this information is therefore strictly controlled with the Department of Safeguards, and not shared with other Departments of the IAEA. These measures are essential to respect the commercially sensitive nature of the information at this early stage of the SMR technology development process, while allowing a sufficiently detailed design review for SBD purposes by the IAEA.

3. STATUS OF THE TASK 'SBD for SMRs'

3.1. Floating nuclear power plant

The Akademik Lomonosov Floating power unit was developed for providing electricity and heat energy in Russia. The power unit has two KLT-40s at 35 MWe per unit, cooled by pressurized light water and fuelled with low-enriched uranium. The Akademik Lomonosov has been in operation in Pevek since May 2020. Figure 2 shows the general view of Akademik Lomonosov floating power unit. The IAEA received the revised DIQ for Akademik Lomonosov in April 2021 and technical discussions with the designers are pending.

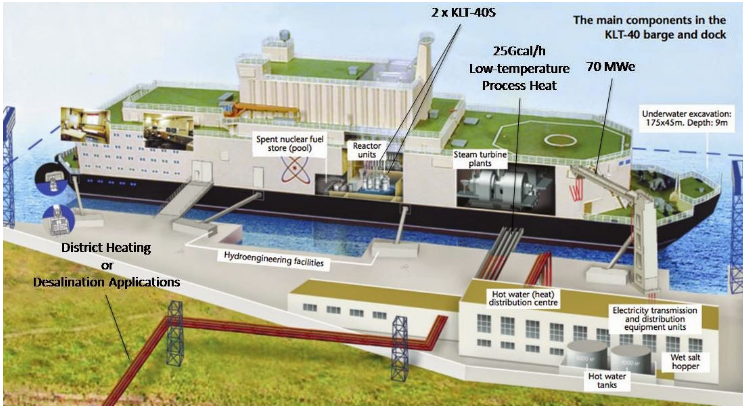
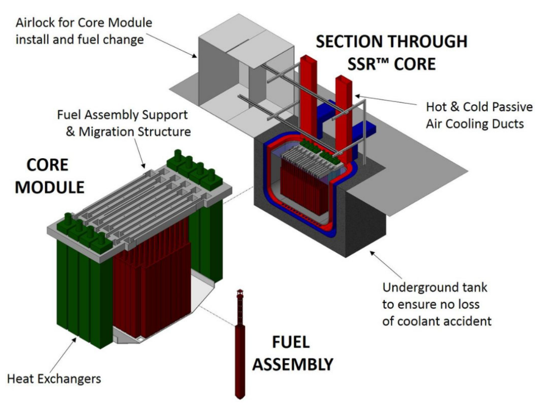


Figure 2. General view of Akademik Lomonosov floating power unit [3]

3.2. Molten Salt Reactors

Two types of molten salt reactors – the Stable Salt Reactor Wasteburner 300 (SSR-W300 of Moltex) and the Integral Molten Salt Reactor (IMSR of Terrestrial Energy Incorporated) – were proposed by the Canadian safeguards support programme. The IAEA received the preliminary design information for the SSR-W300 together with the Waste to Stable Salt (WATSS) facility in January 2021. The SSR-W300 is designed to use spent fuel from nuclear reactors, while WATSS is a pyroprocessing plant for the SSR-W300. Figure 3 shows the SSR-W300 with two reactor modules. Design information for the IMSR of Terrestrial Energy was also delivered to the IAEA in March 2021. Preliminary technical discussions with Moltex took place in June 2021.Figure 4 shows the schematic diagram of IMSR.



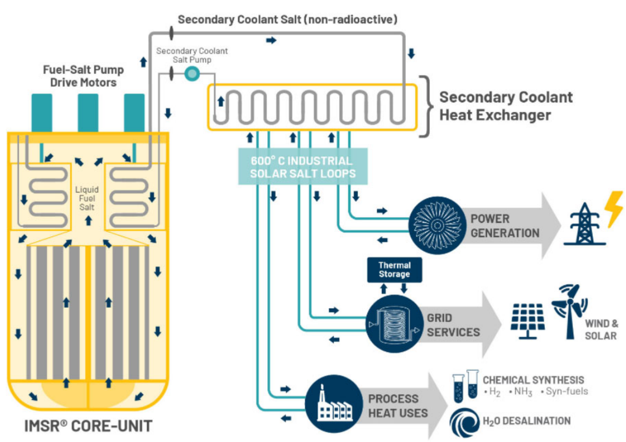


Figure 3. SSR-W300 with 2 reactor modules [4]   Figure 4. Schematic diagram of IMSR [5]

3.3. Integral Pressurized Water Reactor (PWR)

The SMART SMR design of the Republic of Korea (see Figure 5), consisting of two modular units, is an integral PWR with electrical power of 110 MW per unit. The IAEA received the acceptance letter of the task from RoK in January 2019 and a kick-off meeting for the discussion of task workplan and DIQ process was held in July 2019. The initial DIQ was provided to the IAEA in September 2019, and several progress review meetings have been held to review the revised DIQ and STR preparation. A third update of the DIQ is expected on the basis of review comments. In the third quarter of 2021, another virtual progress meeting is planned for the discussion of the final report of the task.

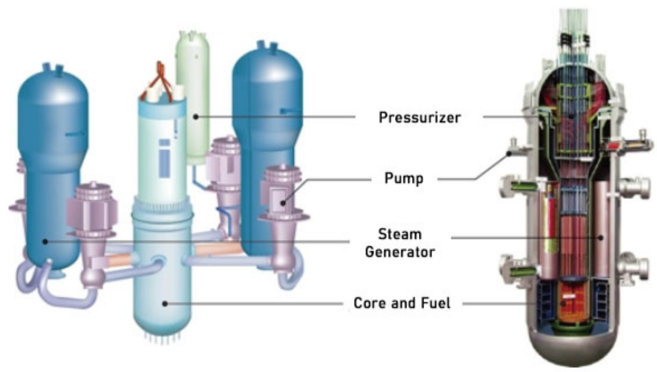


Figure 5. Schematic diagram comparing between conventional type and SMART [6]

3.4. District Heating Reactors and other types of SMRs

Finland joined the MSSP task in December 2019, and a kick-off meeting was held in a virtual mode in December 2020 owing to the COVID-19 pandemic. Preliminary DIQs of two reactors having district heating purposes were provided to the IAEA in April 2021, and another virtual meeting will be arranged once the review for the two preliminary DIQs is completed. France joined the MSSP task in in November 2020, and the IAEA looks forward to receiving the preliminary design information of a specific SMR design. A task workplan will be finalized during a kick-off meeting to be potentially held in the fourth quarter of 2021.

The USA joined the MSSP task in January 2019. The IAEA was informed during a recent MSSP review meeting that several SMR designs are under consideration for inclusion under the task.

3.5. High Temperature Gas-cooled Reactor Pebble-bed Module (HTR-PM)

China's High Temperature Gas-cooled Reactor, based upon pebble-bed fuel technology has been under development for almost 30 years. The construction of an HTR-PM plant in China is complete and the initial core loading has been prepared. The IAEA selected the current HTR-PM demonstration plant for the application of safeguards from the eligible list in order to gain experience, and to develop appropriate safeguards measures for similar types of reactors to be exported to Non-Nuclear Weapon States (NNWSs).

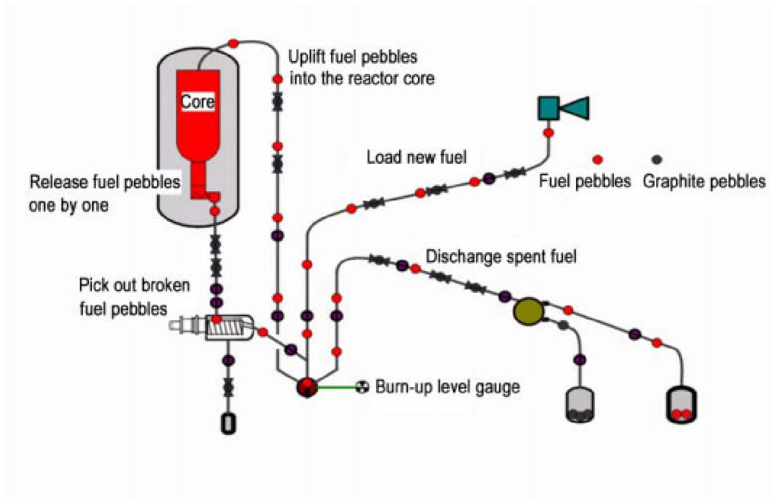


Figure 6. Schematic diagram of nuclear material flow at HTR-PM [7]

4. CONCLUSIONS

Safeguards by Design has provided a useful framework for the early discussion of safeguards needs with seven Member States involved in SMR development. Through the IAEA Department of Safeguards' Member State Support Programme, early design information is shared with the IAEA and used in the joint development of reports identifying key safeguards challenges and proposals for addressing them. SBD allows time for the development of new approaches, concepts, arrangements and (if necessary) technology, and raises awareness of safeguards needs that must be included alongside safety, security, and other design considerations. Ultimately, early and continuous voluntary interaction between all stakeholders reduces the need for retrofit of safeguards measures, and increases flexibility for future safeguards applications.

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