NUWARD SMR Safety, Security and Safeguards Approach Preparing for International Deployment

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Abstract – Drawing on the deep experience and understanding of the principles of nuclear safety, security and safeguards as well as many years of nuclear power plant design and operation, the EDF led NUWARD SMR Project is developing a design for a Small Modular Reactor (SMR) of 340 MWe composed of two 170 MWe independent units. This concept will supplement the offer of high-output nuclear reactors, especially in response to specific needs such as replacement of fossil-fuelled power plants. NUWARD SMR is a nuclear power plant composed of two integrated Pressurised Water Reactors (PWRs) with a mix of proven and innovative design features that will make it more commercially competitive, while integrating features that comply with the highest international safety, security and safeguards standards.
This paper:

- Summarises the foundation principles and technological background which underpin the design;
- Contextualises the key design features with regard to the international safety regulatory framework with particular emphasis on innovative passive safety aspects;
- Illustrates the Project activities in preparation for first licensing, including forward looking technical exchanges with the French Nuclear Safety Authority (ASN) and the French Institute for Radioprotection and Nuclear Safety (IRSN), and also a wider international view via the Joint Early Review with the NUWARD SMR design as a case study, including both the Finnish and Czech Republic regulators;
- Illustrates the Project activities for early consideration of security and safeguards, in a holistic way;
- Articulates the collaborative approach to design development from involvement with the Project partners (the French Atomic Energy and Alternative Energies Commission (CEA), Naval Group, TechnicAtome, Framatome and Tractebel) to the establishment of the International NUWARD Advisory Board (INAB), to gain greater international insight and advice;
- Concludes with the focus on next steps into detailed design development, standardisation of the design and its simplification to enhance its commercial competitiveness in a context of further harmonisation of the nuclear safety, security, safeguards and licensing requirements and aspirations.

1. INTRODUCTION AND BACKGROUND

The NUWARD SMR Project has been in development for a number of years, adding partners and progressing the pre-concept design development. After a preliminary conceptual design phase carried out from 2017 to 2019, the project entered conceptual design formally in mid-2019. Delivery of the Concept Design is now largely complete and basic design launched. The concept design phase has confirmed the project technological choices and advanced the definition of the first design configuration of the NUWARD SMR product, to document it, in order to launch pre-licensing with the French Safety Authority (ASN). In July 2023 the Safety Options file (called the Dossier d'Options de Sûreté (DOS)) is due to be submitted to the French Regulator (ASN). The Conceptual Design has delivered a well-documented first design configuration, facilitating the major step change to commence the basic design development.

An integral part of the NUWARD SMR Project is not only to deliver a design suitable for France and to satisfy French regulation, but to develop a product suitable and indeed desirable, for the international market, with a first focus in Europe. In order to achieve its objectives and realise its market potential, the NUWARD SMR Project needs to define and realise its safety, security and safeguards approach within an international environment.

The NUWARD SMR design comprises a SMR of 340 MWe composed of two integrated 170 MWe PWR independent units, housed within a single Nuclear Island (NI) structure that is recessed into the ground, with a shared Spent Fuel Pool (SFP) located between the units.

A representation of the NI building internals is provided in Figure 1 below showing the two units either side of the shared SFP, a unit with a stripped side is shown at Figure 2 which shows the integrated Reactor Pressure Vessel (RPV) within it.

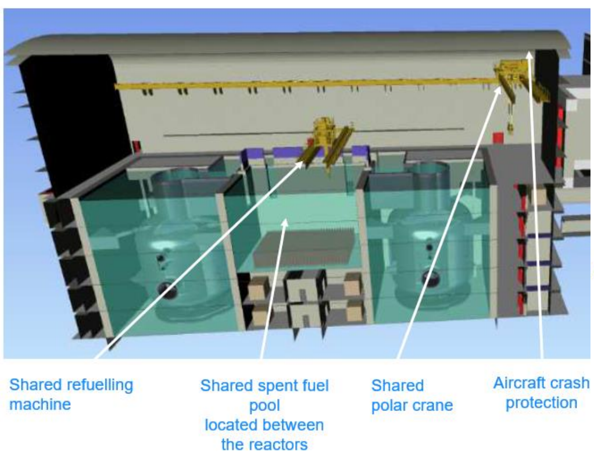

Fig. 1. NUWARD SMR Nuclear Island building internals.

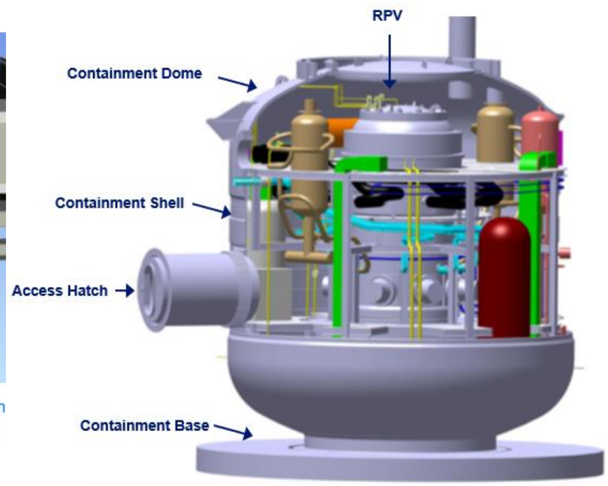

Fig. 2. NUWARD SMR unit stripped side.

Each reactor is enclosed in metallic (steel) containment, submerged under water in its own pool. The NUWARD SMR main reactor components are housed inside the RPV, this includes the pressuriser, the six Compact Plate Steam Generators (CSGs) and two Safety-CSGs (S-CSGs), the 76 fuel assemblies that make up the fuel core and the Control Rod Drive Mechanism (CRDM) that sits above them. This integrated design means there are no primary loops outside the RPV. The general composition and simple functionality of the RPV is shown in Figure 3 below.

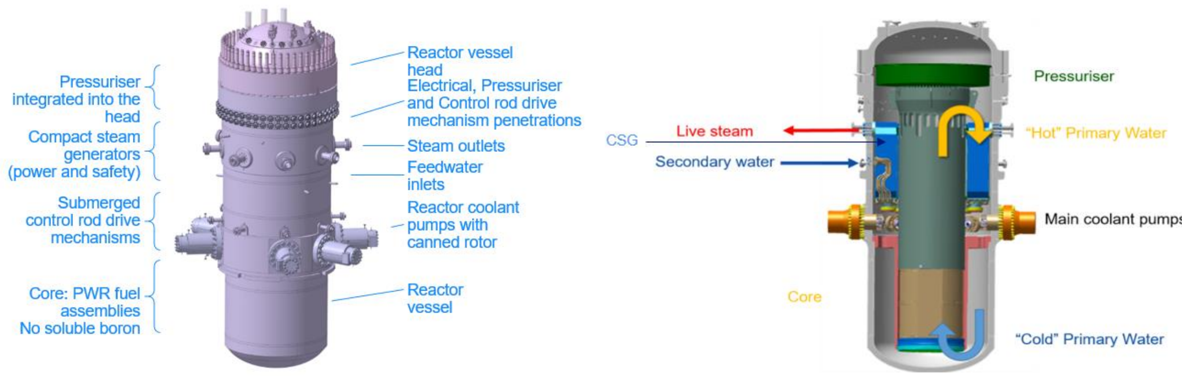

Fig. 3. NUWARD SMR RPV labelled, plus RPV basic functionality.

2. NUWARD SMR SAFETY APPROACH

The foundation of the NUWARD SMR safety approach is embedded in internationally accepted nuclear safety guidance, with positioning in relation to international recommendations, in particular International Atomic Energy Agency (IAEA) Safety Standards Series Report Safety of Nuclear Power Plants: Design (Ref.1), and Western European Nuclear Regulators Association (WENRA) reports (Ref.2), the European Utilities Requirements (EURs) (Ref.3) and applicable French regulation, in particular ASN Guide No. 22 (Ref.4). Taking WENRA qualitative objectives O2 "accidents without core melt" and O3 "accidents with core melt" as the initial objectives, the NUWARD SMR project adopts a further objective to reduce the need for protective measures for accidents with core melt, with a design target for no need for off-site protection measures.

The Defence-in-Depth (DiD) concept forms the basis of the NUWARD SMR safety strategy, its principles are implemented in the design following WENRA recommendations, design requirements for independence among DiD levels are implemented as far as practicable.

The NUWARD SMR reactor and associated safety systems are designed for:

- Passive management of Design Basis Accident (DBA) scenarios for more than 3 days without the need for an external power supply or external heat sink due to its passive systems and large water pool. Both normal (active) and safety (passively operating) cooling by the NUWARD SMR Residual Heat Removal system (called the RRP) is represented in Figure 4 below.

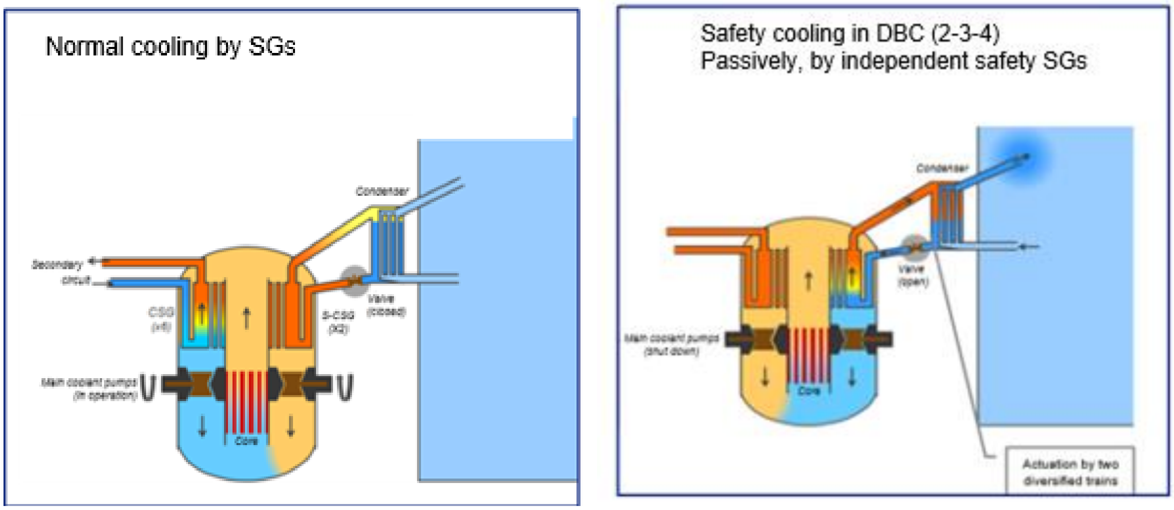

Fig. 4. NUWARD SMR RRP system shown in stand-by mode alongside in passive operation under accident conditions.

- Active management of Design Extension Conditions (DEC) (complex sequences, called DEC-A in the NUWARD SMR safety approach), with simple diagnosis and implementation of diversified systems;
- Severe accident management (called DEC-B in the NUWARD SMR safety approach) with In-Vessel Retention of the corium (IVR concept).

The safety approach for NUWARD SMR benefits from the following inherent features of the design to satisfy and maintain a safe state that requires minimum intervention from the operating team:

- Boron-free in normal operation providing large and constant moderator counter-reaction and preventing boron dilution;
- Integrated Reactor Coolant System (RCS) architecture with intrinsic and drastic reduction of the maximum Loss Of Coolant Accident (LOCA) break size (the largest primary nozzle/ pipe is limited to 30mm diameter);
- Internal CRDMs preventing rod-ejection accidents;
- Each reactor is enclosed in metallic (steel) containment, submerged under water in its own pool, providing passive cooling for several days (noting that the presence of the integrated reactor pool and the building structure itself may also further contribute to limitation of any radiological release);
- A small core in a large vessel enabling the success of the IVR strategy for DEC-B accidents.

3. NUWARD SMR SECURITY APPROACH

Within the NUWARD SMR security approach, security concerns are addressed early in the design process, including upstream exchanges initiated with the French Authority on nuclear security (SHFDS) and also preparation of a Security Options file in parallel to the Safety Options file, to be sent to the SHFDS by the end of 2023.

The NUWARD SMR security approach includes consideration of SMR specifics, with a goal to leverage potentially favourable characteristics for robust protection, for example the passive cooling of the reactors and the SFP, with a large water inventory integrated in the main nuclear building, enabling the plant to continue in a safe state for a prolonged period if needed without the need for outside resources or intervention; and the partially recessed into the ground main nuclear building, which offers a certain level of resilience to hazards (including aircraft crash),. Both physical and cyber security requirements are in development and design aspects being informed for sizing and functionality, to anticipate and take into account security demands.

The NUWARD SMR security team are soliciting wider international views in development of their approach, including but not limited to consideration of IAEA recommendations starting from INFCIRC/225 (Ref.6), participation to the IAEA CM on SMR security / TM on cybersecurity and other applicable interfaces and sources of advice and learning.

4. NUWARD SMR SAFEGUARDS APPROACH

The NUWARD SMR design approach regarding export market needs and requirements, including safeguards, encompasses early identification of additional needs (compared to the French context) and consideration in the reference design or work to foster the adaptability of the design to different contexts (e.g. through space provisions or possible additional design options).

The NUWARD SMR safeguards approach is thus developing a wider international view on safeguards by engaging in exchanges with IAEA on Safeguards By Design (interface initiated in February 2023 meeting through the FREnch Support Programme for Agency Safeguards (FRESPAS), participation in ESARDA/ INMM future exchanges, and more generally via activities to be developed as part of the basic design stage, targeting early and efficient consideration of expectations in the design process. Reference to and consideration of recommendations made in the IAEA Structure and Content of Agreements Between The Agency and States Required in connection with The Treaty On The Non-Proliferation Of Nuclear Weapons, INFCIRC/153 (Ref.7) is also being made.

Aspects such as building space allowances, accessibility for inspections and in particular anticipation of fuel management are part of the early areas for consideration. Regarding fuel management, the fuel proposed to be used for the NUWARD SMR design is classical PWR fuel, the same as currently used for the EDF PWR fleet with U235 enrichment < 5% (no use of MOX) although the fuel assemblies are shorter (220 cm active height). This fuel benefits from the already available experience feedback and established performance, production, management techniques and safeguards approach for similar Light Water Reactor (LWR) fuel. The fuel assemblies are arranged in a 17x17 square pitched array, so 76 fuel assemblies per reactor on a refuel cycle of 24 months for half the core.

Regarding the NUWARD SMR fuel cycle:

- the upstream fabrication and required process adaptation is subject to on-going studies;
- the downstream management, fuel storage and possible treatment will need to be defined according to the relevant national context;
- design provisions are already incorporated to enable fuel transport via different types of containers.

The main operations for fuel management inside a NUWARD SMR facility have been defined to facilitate fuel transfer inside the facility, and on-going basic design studies will ensure proper considerations of safeguards at each stage, including a view on:

- Fuel cask reception (fresh fuel) and evacuation (spent fuel) through a dedicated area in the nuclear auxiliary building;
- Fuel cask and fuel handling between the nuclear auxiliary building and the SFP located in the main nuclear building;
- Fuel handling between the SFP and the reactor units (reactor loading and unloading operations).

5. LICENSING PREPARATION

EDF has initiated technical exchanges with the French nuclear safety regulator, ASN, and its technical and scientific support organisation, IRSN, during the conceptual design phase of the NUWARD SMR project. The approximate timeline for progress of these exchanges is shown in Figure 5 below.

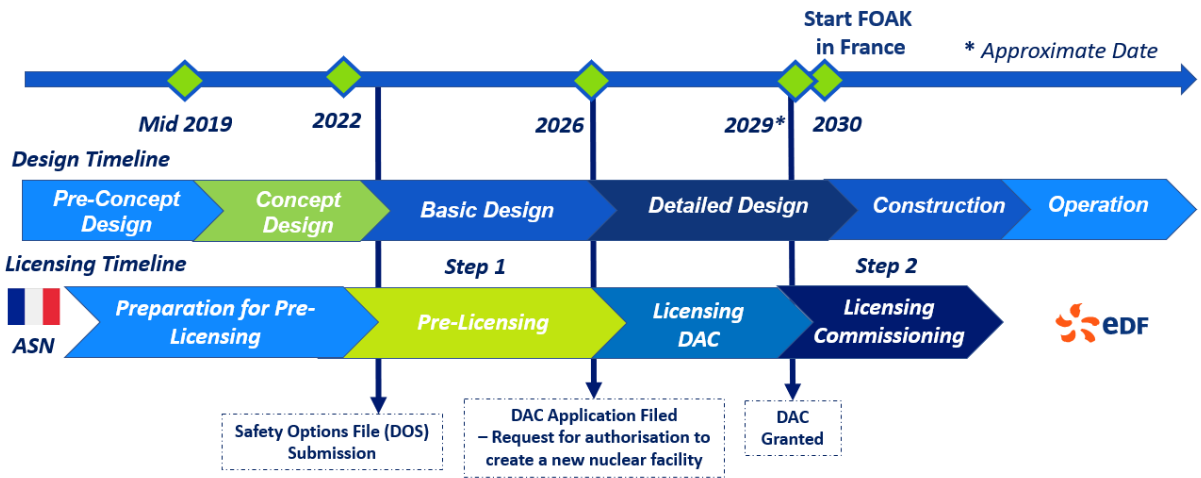

Fig. 5. Tentative French licensing timeline alongside NUWARD SMR Design timeline.

In the spirit of promoting a pragmatic effort regarding international licensing of NUWARD SMR, ASN and EDF have agreed that the Finnish nuclear safety regulator, STUK, and the Czech Republic nuclear safety regulator, SUJB, with SURO as its technical and scientific support organisation, be involved, with the objective to start identifying key enablers and conditions to be met towards potential licensing of NUWARD SMR in their respective countries. This initiative also comes at a time when many nuclear regulators are examining their internal positions and arrangements in anticipation of the advent of more advanced nuclear technologies, rendering the initiative mutually beneficial for France, Finland and the Czech Republic. Due to the involvement of these internationally recognised and experienced regulators, this Joint Early Review (JER) initiative is likely to bring benefits to the whole EU licensing approach.

6. DESIGN DEVELOPMENT - A COLLABORATIVE APPROACH

The NUWARD SMR Project is a partnership, led by EDF with significant contributions from and collaboration with our partners the CEA, Naval Group, TechnicAtome, Framatome and Tractebel. Individuals from each partner organisation are embedded in the Project Team and advance a profile of technical work placed under their charge. Via this partnership NUWARD SMR benefits from a wide scope of knowledge, experience and expertise in addition to that of EDF itself.

To support its international market aspirations the NUWARD SMR Project has launched its own advisory board, called the International NUWARD Advisory Board (INAB). Members from Canada, Finland, the Czech Republic, the US, UK, Italy and India with diverse backgrounds in business, economics, nuclear safety and nuclear technology and research, have been invited to support the Project development. Providing their own individual as well as organisational knowledge and insight into a collaborative forum of peer review, the INAB members are invited to offer their input, advice and support into the NUWARD SMR Project activities.

The Project is actively seeking to add partners, for design aspects and also future manufacturing and fabrication and for the extended supply chain, to further increase its international positioning, increase and diversify the supply chain and expand its knowledge and insight base. Considering the importance of simplification and standardisation of the design, and built-in modularity into its design, manufacture and delivery of components, the project is actively seeking expertise and insight into other areas of industry that already do this and also to move away from the bespoke niche view of nuclear manufacturing and fabrication and use more accessible and standardised SSC parts.

To further increase the knowledge and understanding within the NUWARD SMR Project and also to radiate out from it to support the advancement of SMR technology, EDF is engaged in sponsorship, cooperation and participation in various European Union and International forums, working groups and initiatives. These include, but are not limited to:

- The European SMR Pre-partnership;
- Euratom Projects (e.g. ELSMOR and TANDEM);
- IAEA Nuclear Harmonisation and Standardisation Initiative (NHSI);
- Development of IAEA safety standards;
- OECD-NEA Working Groups, including the CSNI Expert Group for SMRs;
- World Nuclear Association – CORDEL;
- European Utilities Requirements (EUR), currently developing Revision F of the EUR the main objective of which, is to be applicable to Light Water and land-based SMRs.

7. NEXT STEPS AND DETAILED DESIGN DEVELOPMENT

The NUWARD SMR design in now in the Basic Design phase and will formally enter Step 1 of the French licensing process on submission of its Safety Options file in July 2023. How the Project chooses to position itself for its design decisions going forwards has a heavy basis in the safety, security and safeguards approaches, but also the licensing expectations of the future licensing destination countries, in considering design assessment principles, safety assessment principles and how these, alongside security and safeguards aspects, are demonstrated. Many countries have specific ‘red lines’ for what should be incorporated within a Nuclear Power Plant (NPP) design and how its safety, security and safeguards should be demonstrated. Accordingly, consideration will include but not be limited to:

- The applicable legal and regulatory framework;
- Management systems employed and deployed;
- Site selection and justification;
- Access control; and
- Use of safety, security and safeguards risk informed approaches.

Work is already ongoing within the NUWARD SMR Project to gain a more specific insight into the differences between licensing regimes; to become involved and contribute where possible to working groups and international body initiatives for regulatory and requirement harmonisation; as well as continuous monitoring of progress of anticipated updates of nuclear safety, security and safeguards related international standards and good practices, and recommendations for SMR designs.

8. CONCLUSION

Due consideration has been given early in the NUWARD SMR approach to properly address specific design, with a holistic view for safety, security and safeguard characteristics ensuring a rigorous application of high level principles; a comprehensive treatment of all potential concerns; reflecting the potential benefits of design enhancements; and incorporating a risk informed approach, leveraging the potential increased potential of design enhancements against their cost and complexity.

9. REFERENCES

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