NUWARD SMR
Joint Early Review

Pilot Phase Closure Report

September 2023

with the technical support of:

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EXECUTIVE SUMMARY

In a context where regulators are anticipating an influx of Small Modular Reactors (SMR) projects, international collaboration is seen as an opportunity for increasing effectiveness and efficiency in licensing activities. However, although several initiatives have been launched to explore ways of cooperating effectively, the experience regarding multilateral review of a similar reactor design is limited.

From June 2022 to June 2023, three regulators ASN (France), STUK (Finland) and SÚJB (Czech Republic) and their technical support organization (IRSN for France and SÚRO for Czech Republic) have conducted a joint early review (JER) of the light water SMR developed by EDF[1], the NUWARD SMR, since energy companies from these three countries have expressed interest for the construction of such a reactor in the future.

Based on technical documents elaborated by EDF to be submitted within the framework of the French pre-licensing process, and enriched with technical meetings, this unprecedented review focused on six topics which present particular importance for the safety or for the design. The main objectives of this multilateral review were to identify key issues towards the hypothetical licensing of a NUWARD SMR in the involved countries, and to identify divergences and convergences between the regulatory frameworks in these countries. For each of these topics, feedback was addressed to the vendor (EDF) through dedicated synthesis, highlighting common and individual conclusions from the regulators involved.

The Joint Early Review was not intended to replace any future licensing review of one of the participating regulator. The results of the review achieved by individual regulators are informative and non-binding for any potential future licensing activities and evaluations.

The regulators involved in this initiative consider that this form of collaboration can provide particular benefits to all participating parties. Indeed, for the regulators, this initiative provided room for sharing of knowledge, experience and detailed national practices[2] on topics which present high stakes for the safety and which are crucial in the licensing process. It also enabled regulators to acquaint with a SMR design, and thus to anticipate main regulatory and technical challenges. For the vendor, it enabled to receive timely feedback from the regulators on topics of the highest importance for its design, when modifications are still relatively easy to be made with the objective to develop a standardized design with a level of safety consistent with regulators' expectations, and thus more likely to be accepted by several countries in the future. This exercise also showed that differences in regulatory frameworks don't always need to be addressed through design changes.

This kind of cooperation appears to be effective and efficient way to move towards an increased standardization of reactor designs, and also facilitates harmonization of regulatory requirements,

[1] Early in 2023, EDF Group has launched its subsidiary, NUWARD, a venture now dedicated to the development of its small modular reactor (SMR) technology.

[2] Beyond usual level of harmonization from IAEA standards or WENRA safety reference levels.

regulators' expectations and practices on a voluntary basis, which preserves national sovereignty and independence. Acknowledging that both regulatory and design changes can take time to be implemented, conducting this kind of review early enough is key for time and resource saving in future eventual regulatory assessments or development of a nuclear reactor. In this sense, further continuation and intensification of this initiative, following this pilot phase, could provide complementary benefits and additional savings.

This report presents the initiative and the lessons learned from the involved regulators and their technical support organization point of views.

Another document[3], which presents the lessons learned and the benefits from the vendor's point of view will also be published simultaneously by NUWARD.

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Petteri TIIPPANA,
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[3] NUWARD SMR Joint Early Review Summary Report (September 2023).

1. ANSWERING THE CHALLENGES RAISED BY THE CURRENT CONTEXT

1.1. General context

Regulators are currently observing a growing interest from the industry and policy makers regarding SMR technologies for which the licensing and operating experience feedback is limited.

In the near future, regulators may be requested to conduct safety assessments of SMR designs in the framework of a licensing process. In order to review such applications, regulators will have to address safety issues and face challenges that are specific to SMRs and might be new for them. At an international level, several initiatives have been launched to reflect on the challenges, risks and opportunities presented by SMR. However, these reflections have been usually conducted with very general perspectives. Therefore, such activities need to be applied to a specific case (specific SMR design) to go further. Focusing on a particular design could provide regulatory bodies with a more in-depth understanding of the challenges, risks and opportunities presented by SMRs in terms of safety. Considering that light water reactors are technologies on which participating regulators have strong experience, this technology was appropriate for this pilot initiative. Performing similar activity for other reactor technologies (e.g., micro reactors, HTGR, LFR…) would therefore have been more challenging.

Meanwhile, the industry promotes[4] an environment where standardized reactor designs could be internationally deployed without major changes at a country level. Proposing standardized design and safety demonstrations would notably enable standard manufacturing, thus potentially save costs that could be induced by early design or safety demonstration adaptation addressing specific regulatory requirements or expectations.

Within this context, harmonization initiatives that are on-going, such as WENRA, whose mission is to develop a common approach to nuclear safety, may facilitate harmonization and standardization, although their main objective is – and shall be – to promote the best achievable level of safety. Nevertheless, it should be noted that there are several layers of harmonization, as harmonization does not imply equivalence of detailed expectations notably regarding the safety case. Moreover, it should be noted that harmonization and standardization doesn't rely on regulators only, as the industry but also governments have a role to play.

For the purpose of enhancing these aspects, other initiatives, such as the European SMR Pre-Partnership[5], or the IAEA NHSI[6] have been launched. In particular, in the framework of NHSI,

[4] See for example the report n° 2020/012 from WNA CORDEL, in cooperation with CANDU Owners Group (December 2020).

[5] Initiative launched in 2022 with the objective to identify enabling conditions and constraints towards safe design, construction and operation of SMRs in Europe in the next decade and beyond in compliance with the EU legislative framework in general and to the Euratom legislative framework in particular.

[6] Initiative launched in 2022 which aims to facilitate the safe and secure deployment of SMRs to maximize their contribution to reach net zero carbon emissions by 2050.

three working groups composed of Member States regulators were created with a focus on different topics connected to harmonization in regulatory processes. The working group nº 2 aims to develop a voluntary joint pre-licensing process for larger group of regulators using the administrative support of centralized organization. Whereas the working group nº 3 aims to describe the process of how to leverage the reviews of other regulators and how regulators can work together during ongoing regulatory reviews (for this process, the NUWARD SMR Joint Early Review initiative was taken as an example).

Although being members of WENRA, and thus having the objective to develop a common approach for safety of nuclear reactors, Czech Republic, Finland and France have different regulatory frameworks in general. They also have different contexts, including regarding SMR technologies, as developed in the following sections.

1.2. The Czech context

In the Czech Republic, some of the industrial companies engaged in energetics, public heating, heavy industry and chemical industry are considering SMRs as a possible future source of energy for their needs. The strongest interest was announced by the current NPPs operator, which is planning to start the operation of one SMR unit placed in the near location of its NPP in 2032 and more in the regions where coal power plants are planned to be decommissioned after 2034. There are also some R&D activities related to SMRs in the Czech Republic, both LWR and non-LWR. Besides that, construction of new large units is under preparation at two sites.

The SMR roadmap "*Plan for small and medium-sized reactors in the Czech Republic - utilization and economic benefit*" and the new "*State Energy Policy*" are going to be published in 2023. It is expected that the concept will clearly indicate the Czech Republic interest in development of SMRs and thus in their construction.

The Czech nuclear regulatory authority (SÚJB) has not established a specialized SMR licensing department or new builds licensing department yet. This may change once a particular SMR project is launched in the country. At present a SMR working group is active and dedicated to dealing with the SMR related topics at both national and international level. Similarly, the SÚJB´s technical support organization SÚRO does not include a dedicated SMR licensing department, nevertheless there is a group of experts responsible for dealing with SMR related questions.

The Czech licensing process and relevant regulatory framework is described in the appendix.

1.3. The Finnish context

Fortum – utility that owns and operates Loviisa power plant – is conducting a feasibility study to construct new nuclear power plants in Finland or in Sweden. Their study covers small reactors as well as large reactors. TVO – owner and operator of Olkiluoto power plant – is also following development of SMR technologies but they have not publicly expressed any specific plan. There are also other organisations and companies that have expressed interest in SMRs: for example,

companies that are currently using coal or natural gas to produce heat for local district heating networks. No official licensing process has been started yet. Current Nuclear Energy Act (990/1987) states that before sending actual license application, anyone planning to use nuclear energy can request STUK to check their plans and give instructions on what should be taken into account with respect to safety, security and emergency arrangements. Up to now, this type of an official request has not been made to STUK.

Renewal of legal framework – including Nuclear Energy Act, Nuclear Energy Decree and all Regulations and Guides – is ongoing and the target is that it is ready during the current electoral term of Parliament. In this context, licensing process is also reviewed and could possibly change; for example, adding a separate site licensing step and a pre-licensing phase are considered.

The Finnish licensing process and relevant regulatory framework are described in the appendix.

1.4. The French context

In 2022, the French government has announced its will to launch a new nuclear program including the construction of some SMR and, at the same time, to subsidize SMR projects through a call for projects on innovative reactors.

In response to this first part of this announcement, EDF has expressed its intention to start the construction of a NUWARD SMR facility in 2030, and has submitted a safety options file in July 2023.

The second part of this announcement led to the arrival of new projects of diverse technologies, carried by new companies without extensive experience in the nuclear field. This could change massively the landscape of commercial nuclear reactors in France, as French fleet of commercial nuclear power plants is currently composed of pressurized water reactors operated by EDF.

Considering this context, ASN and IRSN have engaged reflections on their own organizations to be prepared to review these projects, with resources and processes commensurate with their maturity.

The French licensing process and relevant regulatory framework are described in the appendix.

1.5. Common decision to engage a joint early review

In this context of industrial and political support toward SMR technologies and reassessment of national regulations, and considering that EDF has approached several European regulatory bodies with the objective to have an early regulatory involvement, in countries where industry has expressed interest for the construction of its NUWARD SMR project, a joint early review of some key topics has been identified as an opportunity.

To conduct this work, ASN, STUK and SÚJB have decided to launch an initiative to conduct a joint early review of the NUWARD SMR preliminary design and safety approach, with the support of IRSN and SÚRO, and with a focus on topics with high stakes for safety or for the design.

This review was based on the current set of each national regulation, WENRA's safety objectives and reference levels, and up to date knowledge and practices. This review was not part of any licensing process, and therefore its results are not binding.

For each of the reviewed topics, a joint synthesis has been written by the working group and sent to EDF. Each joint topical synthesis notably highlighted the main convergence and divergence points identified throughout the review for the selected topic.

The format of the Joint Early Review enabled the involved regulators to derive different benefits, consistent with their different contexts.

2. PRESENTATION OF THE JOINT EARLY REVIEW

2.1. Objectives of the NUWARD SMR Joint Early Review

This initiative had for objective to enable participating regulators:

1. to acquaint with a SMR design and identify the potential challenges that it raises prior to the beginning of their respective licensing process;
2. to share their expectations, knowledge and practices about the identified topics;
3. to increase knowledge transfer about regulatory practices and expectations;
4. to provide EDF with early feedback about its design and possible associated regulatory challenges.

These objectives were confirmed by the working group from the beginning of this initiative, considering:

- the added value of the review for each stakeholder. Indeed, according to NUWARD[7], from the industry side, there is an opportunity to identify the potential major regulatory issues, at a stage where it can be addressed more easily through design adaptations or complement to the safety case. On the regulators' side, and as illustrated by the work of the SMR Regulators' Forum[8], the arrival of SMR brought a lot of questions, including questions on the approach to ensure adequate compliance with the regulatory requirements and expectations (e.g., expectable safety objectives, comparison with large NPPs for the implementation of safety principles, accidents to consider and strategy to manage them, passive systems and functions, shared systems, emergency preparedness…), which can be more easily answered with concrete cases;
- that the resources available for projects before the start of a licensing process are limited, as regulators, with the support of their TSO, are already involved in other activities;
- the level of information available. One key element to consider when defining the objectives of the initiative was the level of maturity of the NUWARD SMR design, which has begun its basic design phase in 2023. Hence, the depth of the review and its outcomes were commensurate with the level of information available.

Finally, knowing that international cooperation usually requires time and effort, and that the initiative was innovative, the involved regulators found beneficial to limit the scope to topics consensually considered as the most important ones (see II.3), and to set an ambitious pace of work from the beginning. This enabled the working group to complete its work in one year, and to assess, at the end of this phase, the strength and weaknesses of this form of collaboration.

[7] NUWARD SMR Joint Early Review Summary Report (September 2023).

[8] Forum of regulators created in 2015 whose purpose is to identify, enhance understanding of, and address key regulatory challenges in emerging SMR regulatory discussions.

2.2. The NUWARD SMR project

NUWARD SMR is a 340MWe SMR plant with two independent reactors (170MWe each). Each reactor is a compact integrated Gen III+ Pressurized Water Reactor (PWR), with full integration of the primary circuit (including primary pumps, pressurizer and compact steam generators) within the reactor pressure vessel. Both reactors are immersed and housed in a single nuclear building, which also houses a shared spent fuel pool.

To support the inherent safety of its SMR project, EDF puts notably forward NUWARD SMR's autonomy, as no system nor resource (including heat sink) outside the nuclear island is required to ensure the safe-state for at least 3 days. Indeed, it is claimed that the nuclear island is self-reliant for at least this period due to the adoption of a pool (named "water-wall") in which each 3rd barrier, the steel containment vessels, are immersed. This autonomy is key as EDF claims that all DBC scenarios can be passively managed, with no need of operator's action, external heat sink, boron injection or external electrical power supply for at least 3 days.

Although PWRs are a technology with which both EDF and the regulators in the Joint Early Review have strong experience, the NUWARD SMR presents innovative features on which there is no operating experience.

According to EDF plans, the construction of a first of a kind is expected to start in 2030 in France. NUWARD SMR is being designed to target replacement of fossil fuel power plants around the world, as well as supply energy-intensive industrial sites. In addition, NUWARD SMR is developed to support cogeneration of electricity and either heat (for industry or district heating), hydrogen production or water desalination.

2.3. Definition of a program of work

Before the beginning of the initiative, the working group agreed on a working process and a program of work. The scope of the program of work was limited to the most important topics, as it was considered not feasible nor "cost-effective" to review the whole design at this stage, especially using an innovative form of international collaboration.

The program of work was initially composed of 5 topics. These topics were selected because they fulfilled at least one of the conditions below:

1. it is a topic which brings answers on the level of safety that could be expected, and on the approach to meet this level;
2. it is a topic with SMR specificity on which there is no or very few safety requirements, recommendations or guidance, or significant information and experience feedback;
3. it is an important feature of the safety demonstration which requires a lot of time to be developed and assessed, due to its complexity or novelty. Starting the review of this topic as early as possible could help reducing the timeframe of the licensing process;

4. it is a key topic for the NUWARD SMR design, in a way that a late change on this topic would have an important impact on the design or the safety demonstration. Providing feedback as early as possible can enable the vendor to meet regulators' expectations more easily and timely.

In addition, one key condition to consider a topic in the program of work was that the topic was mature enough and the related documentation was available.

Finally, it was possible to add an additional topic during the initiative, if it fulfilled the conditions above, had limited impact on the timeframe of the initiative, and was agreed by consensus within the working group.

Based on these conditions, a proposition of list of topics was proposed, discussed and agreed. The initial program of work consisted in the following topics:

- topic 1: definition of safety objectives. This topic covered general safety goals, main safety requirements and approach, the implementation of the defense in depth into the design, and the study rules for "Design Basis Conditions" (DBC) and "Design Extension Conditions" (DEC). This topic fulfills conditions 1), 2) and 4);
- topic 2: identification of DBC. In this topic, a preliminary list of DBC, the general process for DBC identification and the way the list of DBC would be consolidated throughout the project were presented. Also, the overall approaches for DEC conditions and practical elimination were presented. This topic fulfills conditions 1), 3) and 4);
- topic 3: use of cooling passive systems. In this topic, EDF presented the cooling strategy for the reactor and the spent fuel pool. Safety classification approach was also presented, as it could help understanding some aspects of this topic. This topic fulfills conditions 1), 2), 3) and 4);
- topic 4: development plan of scientific computing tools. In this topic, EDF presented the list of major scientific calculation tools expected to be used in support of the NUWARD SMR design and transient studies, and the associated validation program. This topic fulfills conditions 2) and 3);
- topic 5: twin modules integration. This topic covered the safety approach regarding the risk of interactions between the two reactors units, as well as the spent fuel pool, as they are all located in the same building. Some examples of shared systems were also presented. This topic fulfills conditions 2) and 4).

During the technical meeting on the safety objectives, it was observed that Probabilistic Safety Assessment (PSA) should be discussed. Hence, and considering that this topic fulfills conditions 1), 2) and 3), this topic has been added to the program of work (topic 6). In this topic, EDF presented how PSA would be used to support the design process, and the methods and tools for PSA development.

The review was based on preliminary extracts from the safety options file. This level of details corresponds to the beginning of the basic design phase. The technical meeting provided additional information through presentations and discussions between experts.

2.4. Working methodology

The working group, composed of staffs from ASN, STUK, SÚJB, IRSN and SÚRO was structured as follows:

- a chair, chosen at the beginning of the initiative, led the working group. The chair was the main entry point between the working group and EDF. He was in charge of:
  - organizing the meetings;
  - ensuring that the overall schedule is respected and that the objectives are met;
  - drafting, compiling and sharing the deliverables.
- team leaders from each participating country, who were designated at the beginning of the initiative. These leaders were involved in every topic of the program of work and were in charge of:
  - identifying relevant experts for each topic of the program of work from their organization and/or TSO;
  - ensuring continuity and knowledge transfer within their organization and/or TSO, as experts could be involved once the initiative had already begun;
  - ensuring that the schedule is respected and that the objectives are met, in particular regarding contributions and reviews from their delegations.

Team leaders were generalist inspectors, with experience in project management and licensing. Team leaders from a TSO, with a generalist background, could also be appointed if relevant.

- experts, from regulatory bodies and their TSO, who were participating to the review of the topics consistent with their area of expertise.

On EDF side, a project manager was identified as the entry point for the entire initiative.

At the start of the initiative, and once the working group had been constituted, a kick off meeting was held, during which, in particular, the NUWARD SMR design was presented. This presentation enabled the working group to have a global overview of the design and the safety approach, which is particularly valuable to facilitate the review of each topic of the program of work.

Moreover, before the beginning of the review, the working group defined the process below. The final version of the process was presented to EDF during the kick off meeting, and was followed for each topic[9]:

1. Sufficiently in advance, the chair scheduled the meetings. For each topic, a technical meeting and at least two working group meetings were scheduled. The technical meetings involved EDF and the working group, while only working group members could participate to the working group meetings. Scheduling the meetings sufficiently in advance enabled to have a shared view of the milestones of the initiative.

[9] Two topics could be reviewed in parallel, on the proposal of EDF.

2. At least one month before the technical meeting, EDF sent, through the chair, the technical documents related to the topic to be addressed. This timeframe should allow the members of the working group to familiarize themselves with the technical elements so as to be able to make the best use of their knowledge during the technical meeting.
3. At least one week before the technical meeting, the working group provided EDF, through the chair, with a list of items or questions to discuss during the meeting. This list was not exhaustive and could be completed with additional questions and requests during the meeting; however, it was a way to maximize the benefits of the technical meeting, in which experts from each side were participating.
4. During the technical meeting, EDF provided a presentation of the topic and answers the questions of the working group members. These discussions, and eventual additional answers, were captured in the minutes of meeting, drafted by EDF and reviewed by the working group.
5. If necessary, additional meetings could be set up or questionnaires could be addressed to EDF. The need for an additional meeting or out of meeting questions could be expressed by any working group member. In this case, it was expected to include the other working group members in these additional exchanges with EDF.
6. Approximatively one month after the technical meeting, a working group meeting was organized where each member shares the conclusions of its own review. Indeed, during these meetings, the regulators presented their regulatory practices and expectations related to the addressed topics which were then compared and assessed against the NUWARD SMR design. To prepare this meeting, each member involved in the initiative had internal meetings and exchanges, based on guidance provided by the chair to have a common understanding of the areas and questions to cover during the working group meeting.
7. Following this meeting, a preliminary draft of a consensus-based synthesis highlighting the main convergence and divergence points identified at this stage for the selected topic was drawn up. In particular, for a better understanding of every stakeholder, the working group was asked, when relevant, to elaborate on the reasons of these divergences. The draft was then reviewed, complemented and discussed in additional working group meetings.
8. Once the joint synthesis has been reviewed and accepted by each member of the working group, the final version of the joint synthesis is sent to EDF. In particular, a two weeks review of the final version of the joint synthesis were systematically performed before it was sent to EDF.

Every step was conducted in English.

During the initiative, the process was enriched to take into account the experience feedback that was built throughout the process. In particular:

- it was asked to EDF to highlight in the meeting minutes the key points on which EDF would like to get feedback from the regulators. The working group then made sure that the joint synthesis covered these key points, among others;
- the working group agreed to add a step at the end of the process to answer EDF comments and questions on the joint synthesis.

The technical meetings and the major part of the working group meetings were held in person, with a possibility to participate remotely. Some short working group meetings could be held virtually, even though this was not the preferred option.

A diagram of the working methodology is provided below.

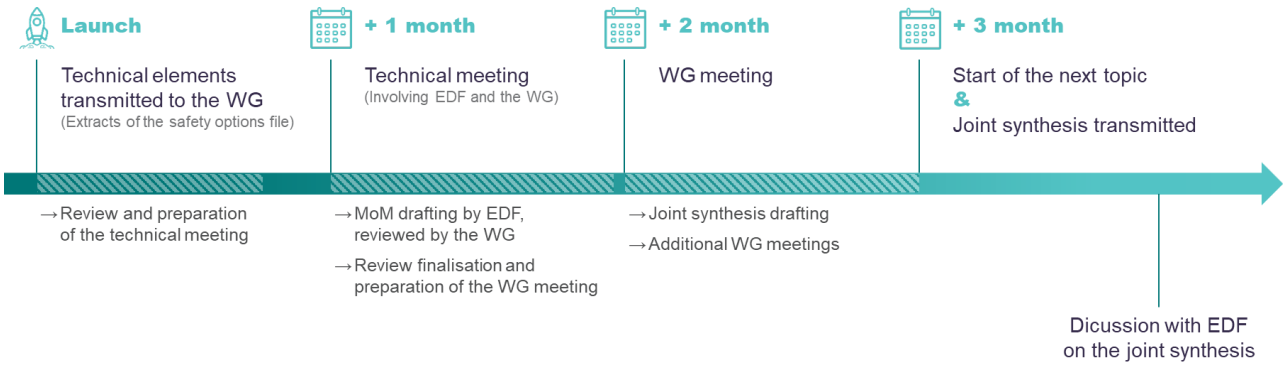

Figure 1 : NUWARD SMR Joint Early Review Process (simplified)

3. EXPERIENCE FEEDBACK FROM THE INITIATIVE

3.1. Meeting of the objectives

As defined in the section II.1 of the report, the objectives of the NUWARD SMR Joint Early Review were:

1. to acquaint with a SMR design and identify the potential challenges that it raises prior to the beginning of a licensing process;
2. to share their expectations, knowledge and practices about the identified topics;
3. to increase knowledge transfer about regulatory practices and expectations;
4. to provide EDF with early feedback about its design and possible associated regulatory challenges.

This section provides an experience feedback on the ways objectives were met and on potential improvements. For each objective, this section provides examples of the key learnings.

Regarding the first objective, the working group considers that the NUWARD SMR Joint Early Review provided highly valuable information to anticipate potential challenges raised by a light water SMR such as the NUWARD SMR in terms of regulatory requirements and existing guides. The participation of both generalist inspectors with experience in licensing, and experts of each topics provides a good balance. The technical exchanges provided valuable information to acquaint with the NUWARD SMR design and approach, commensurate with the state of development of the project.

As expected, as the design and the approach still need to be developed on some areas before engaging in a licensing process, some questions from the regulators could not be answered at this stage. However, the working group was satisfied with the selection of the NUWARD SMR design experts participating to the meetings, who were most of the times able to provide meaningful and detailed explanations. Also, the NUWARD SMR Joint Early Review enabled to identify some key regulatory issues that should be addressed by an adaptation of the NUWARD SMR design and approach and/or complement to the regulation; some examples are listed in the section IV.2 of the report.

Regarding the second and third objectives, the working group considers that the working methodology adopted for the NUWARD SMR Joint Early Review provides an adequate room for sharing information, knowledge and practices. In particular, practices from foreign regulatory bodies are a very valuable input when one regulator intends to reassess its own regulatory framework or practices. Again, the participation of both generalist inspectors, with a global overview of the regulatory frameworks, and experts, with sharper knowledge on international standards and guides, national practices and operating experience, was very beneficial. The comparison of the regulatory frameworks and approaches mainly focused on the nature of the requirements and their significance in the regulatory framework. For some specific requirements, the rationale behind them was explained.

Regarding the last objective, the working group provided feedback to EDF on every topic of the program of work through the different joint synthesis, and has completed its feedback by answering EDF's questions and comments on these documents. According to NUWARD[10], the Joint Early Review provided fruitful outcomes, and enabled EDF to better understand each regulator's requirements, expectations and approaches. Some examples of the feedback developed in the joint synthesis are listed in section IV.2 of the report.

Limiting the scope and the depth of the review enabled to achieve early results. It should be noted that the goal of the NUWARD SMR Joint Early Review was not to carry out a full-scale independent regulatory assessment of the safety demonstration of the NUWARD SMR, nor to review in detail selected characteristics and functions of individual structures, systems and components of the NUWARD SMR based on national regulatory requirements being in force in the countries of the participating regulators. The resources allocated by the participating regulators to perform the joint review and the generic nature of the documentation provided by the vendor corresponded to that ambition.

Consensus amongst regulators on a specific proposal from the vendor can be reached through harmonization of regulatory requirements, expectations and approaches, but also through the development of a standardized design and safety approach that would satisfy all regulatory requirements, expectations and approaches.

Reaching full harmonization from regulators' side was not the objective of this initiative as it requires a lot of time, effort, and often a political commitment. Indeed, depending on the level of the requirement, expectation or approach (law, decree, guide, internal procedure…), the change of a national practice requires a varying level of time and effort, and may not be decided by the regulators themselves. Moreover, the change of a national practice may not be decided only on the basis of such a review but may require a more in-depth assessment involving more experts and also in some cases dedicated advisory committees. However, sharing information and experience can motivate regulatory changes and harmonization of requirements, expectations and approaches on a voluntary basis. Some examples of changes and lessons learned from regulators' side are provided in section IV.1 of the report.

Instead, the Joint Early Review initiative aims at facilitating standardization, as it provides information on key safety issues at a stage where the design can still evolve to satisfy each regulatory requirement, expectation and approach. However, it should be noted that meeting all the different national practices with one single proposition from the vendor/licensee may sometimes not be feasible nor beneficial for the global safety of the reactor.

[10] NUWARD SMR Joint Early Review Summary Report (September 2023).

3.2. Committed time and resources

In the current context, regulators and their TSO are particularly attentive to the allocation of their resources. International collaboration can be time and effort consuming, and is not always a priority compared to the regulation and licensing of national projects even though it can be a very valuable investment for future activities. Hence, it is important to assess the benefits of the initiative against the effort deployed.

For the Czech side, SÚJB and SÚRO considered that the workload was higher than expected at the beginning of the project (the administrative support of the project is not included in the estimation), despite the limited scope and rather unofficial setting of the project outputs (with exception of this report). The SÚJB and SÚRO participation in the Joint Early Review required the cooperation of ten experts for the reviewed topics. SÚJB found advantages when more than one expert per topic was participating, enabling greater lessons learned from the participation (e.g., senior + junior) and an overall multiplicative learning effect.

For the Finnish side, six people have been involved in the NUWARD SMR joint early review, and a couple more were involved in the review of the joint synthesis. STUK considers that the resources committed were just about adequate to meet the objectives. More resources might have enabled to increase STUK contribution, but STUK considers that it may not have been cost effective.

Finally, the French participation required the involvement of several staffs from both ASN and IRSN. The multilateral aspect of this initiative required more resources than what would have been required at a national level, as multilateral discussions increase learning but also workload. In addition to the chair, one to three ASN staff members were usually participating to technical and working group meetings. From IRSN side, in addition to the team leader, for each topic, a couple of experts were involved in the meetings and in the review of the joint synthesis. Some topics, such as the development plan of scientific tools, involved several areas of expertise (neutronics, thermal-hydraulics, severe accident management…).

One can observe that regulators committed different numbers of resources for the NUWARD SMR Joint Early Review. This can be explained by the fact that regulators adopted different strategies and roles:

- SÚJB/SÚRO tried to involve several experts per topic to increase the learning experience;
- ASN/IRSN also usually involved several experts, in addition to more generalist staffs to better anticipate the assessment of the safety options file. In addition, the chairmanship of the working group has been time consuming, as the chair was in charge of organizational aspects, and was highly involved in the elaboration of the different deliverables;
- STUK considered that the active participation of the team leader and a single expert per topic was sufficient to meet the objectives.

Regarding the size of the working group, gathering three regulators and their TSO was adequate considering the objectives of the review, its scope, its timeframe and the resources to commit. These aspects, but also the ways of working and interactions would need to be reassessed should an

increased number of regulators be added. Also, care must be taken to ensure a similar level of involvement from all members.

Regarding the schedule, the working group managed to meet its initial objective. Indeed, the program of work was covered in 12 months, while the initial objective was to cover one topic every 3 months. The merging of topics helped to save a substantial amount of time. In addition, the quick dynamics of the working group helped to avoid losing the track of exchanges and to readily reach conclusions. On the contrary, some delays, mainly due to working group participants' availabilities, could have been avoided if the dates of the meetings had been defined even earlier.

At the end of this pilot phase, the working group considers that the Joint Early Review was highly beneficial because, in addition to meeting the objectives (see section III.1 of the report), it enabled the evaluation of the necessary workload and timeframe of pre-licensing assessment, joint evaluation and joint discussion between regulators as well as testing of the tools used in the project. It appeared that the most challenging and time-consuming part was the discussions on the joint synthesis and answering EDF questions on these joint synthesis.

4. LESSONS LEARNED AND REGULATORS' VIEWS

4.1. Lessons learned on the initiative and the working methodology

This pilot phase of the initiative enabled to identify lessons learned on the initiative and the working methodology.

On the objectives and the outcomes of the initiative:

1. Reviewing a same design together with other regulators helps identifying possible challenges related to this design at a very early stage, as was the case of this JER initiative. This cross-view can enhance nuclear safety, as each regulator may look at a topic from slightly different angles, influenced by their regulatory frameworks, expectations and practices, which have developed over the years and by their own experiences.
2. The JER initiative strengthens knowledge sharing and provides valuable inputs to the regulators to review, on a voluntary basis, their national regulatory framework, guides and practices.
3. The JER initiative provides substantial room for discussions between the vendor and the regulators. It enables to better understand the design and safety approach of a reactor, as well as each regulator's national legal requirements, expectations, approaches and experience.
4. The JER initiative enables to provide timely feedback to the vendor on topics considered as amongst the riskiest and the most impactful for the project, from a safety or a design point of view, at a stage where design changes are still possible with limited impact on the project. This approach facilitates the development of a standardized design more likely to meet expectations in terms of safety and to be licensed in different countries.
5. The scope of the review should be limited to the most important topics for safety or for the design.
6. There are differences in the participating countries' regulatory frameworks, how safety requirements are distributed across the different levels of regulations and how requirements are understood. For example, some requirements are set out in decrees in Czech Republic, and thus are binding requirements, but are only mentioned in guides in Finland and France.
7. International standards (IAEA, WENRA) can represent a harmonized evaluation basis; thus it can facilitate the understanding of each other's national legal requirements, guidance and practices. However, from a national point of view, these international standards are in general not sufficient to provide a position other than an in-principle acceptability of a design or a safety approach.
8. A good practice to facilitate joint reviews for the vendor is to refer to international standards and practices, and to explain how the design and/or the approach is compliant with these international standards and practices. Another good practice is to use internationally known terms (e.g., originating from IAEA Safety Glossary) and abbreviations and to remind their meanings in each document.
9. The vendor is to provide clear and complete information for a successful review to be carried out, as quality feedback cannot be given if the necessary information is incomplete or imprecise. If

the design is not finalized yet and the information provided for review is still preliminary, the review is likely to be partial and preliminary. For example, within the framework of the NUWARD SMR Joint Early Review, certain parts of the review came to the conclusion that additional information would be required to conclude on the compliance of the project with the regulatory and para-regulatory frameworks. Hence, early discussion between the regulators and the vendor should be held to identify topics that are mature enough to undergo a review, and what could be the limits of this review.

10. The JER initiative preserves each regulator's independence and sovereignty, as the joint synthesis enables to carry both common and individual views. The fact that the review was based on national regulatory frameworks, instead of a list of common acceptance criteria did not constrain the review and contributed to the independence and sovereignty of each regulator.

11. As the JER initiative does not lead to regulatory binding decisions, it enables to have more open discussions between the regulators and the vendor. Also, it enables to provide timelier feedback to the vendor through the joint synthesis compared to official processes in each country.

12. The JER initiative gives the working group useful insights on each other regulatory approaches and thus the opportunity to consider evolutions of their national regulatory framework including the regulatory safety guides. For example:

a) Based on the experience from this initiative, the SÚJB is considering enabling some official pre-licensing evaluation, both for new projects in various phases of the life cycle and for the changes to existing plants. This might be implemented in the next revision of the legislation, which is currently prepared.

b) The good results obtained with the NUWARD SMR Joint Early Review working methodology led ASN to a reassessment of its practices regarding pre-licensing activities with other prospective licensees.

c) In the renewal of Finnish legal framework and licensing process some type of pre-licensing step is considered to be added. At the same time Finnish legislation (Nuclear Energy Act, Nuclear Energy Decree), regulations (STUK regulations) and regulatory guides (YVL guides) will also be revised and this project has given good input for that work; for example, how to consider a reactor which has mainly passive frontline safety systems.

d) Based on the experience from discussion with the other regulators involved in the initiative and EDF, SÚJB considers further clarification of some requirements on the nuclear facility design at the decree level or in the guidance documents, such as: sharing of SSCs among units, redundancy of safety systems, inclusion of the containment system in the design for nuclear facilities with low power output, refining of the requirements on the independent shutdown system, decision on Emergency Planning Zone setting up, etc.

e) ASN has received an official application for the French pre-licensing process from EDF for its NUWARD SMR in July 2023, and had already identified, within the safety options file submitted, topics on which the NUWARD SMR proposes a different approach from the one recommended by ASN in published safety guides and usually adopted by EDF for power

reactors. The knowledge sharing from this initiative will be a valuable input for the technical dialogue that will take place during the pre-licensing.

13. From the regulators' point of view, participation of experienced counterparts with an established legal framework and experience in reactor licensing maximizes the benefits from the JER initiative. Participation of embarking countries may bring new benefits, opportunities and challenges.
14. Comparing requirements and their rationales takes less effort than comparing the methodologies to assess compliance by the applicant. Comparing the methodologies could be worthwhile, but should be limited to specific cases with high stakes as it can be very time and resource consuming.

On the scope of the initiative and the resources it requires:

1. The scope of this kind of initiative should be commensurate with the maturity of the design, and the resources and time available.
2. The resources required to lead the review and manage organizational aspects throughout the initiative should not be underestimated: a leader of the review should be duly identified with adequate dedicated manpower.
3. Considering the rhythm of work and the objectives defined at the beginning of the initiative, involved countries should be ready to commit appropriate resources, but also prioritize the initiative at an appropriate level. In some countries, priorities depend on the political and/or industrial commitment at the national level.
4. The broader the scope is, the longer the initiative. Hence, changes in the working group team can occur, but continuity and knowledge transfer should be ensured by members. Maintaining a core group of people throughout the review should be favored, as understanding the other members' frameworks is both essential and long to acquire.
5. The number of countries involved should be taken into account when defining the objectives, the scope and the working methodology related to the initiative.

On the working methodology:

1. The terms of reference of the initiative, agreed by all participants, should define the objectives of the initiative, and the working methodology. It should be sufficiently flexible to welcome consensus-based changes and adaptations during the initiative. It should be also sufficiently informative to describe the methodology of work and provide guidance for participants.
2. Questions related to the access and sharing of information should be addressed before the beginning of the initiative. This includes the outcomes and deliverables of the initiative, as the regulators may be willing to share them with the public and the international community.
3. The funding of the initiative, associated with the resources to commit and the targeted objectives should be defined before the beginning of the initiative.
4. Continuous improvement and adjustments of the process to better meet the objectives should be sought, through discussions between the working group and the vendor, especially during the pilot phase of an initiative. The continuous adjustments could notably be necessary regarding

the level of detail of the review: a balance should be sought between an overall review of a topic – which helps to quickly achieve worthwhile conclusions – and more a detailed review by technical experts – which provides more added value. This balance should be defined before the beginning of the process.

5. Before each working group meeting, the chair should prepare a list of items (regulatory requirements and practices, conclusions and feedback on specific questions…) to cover and should share it with the working group. Each regulator should cover these items, but should be able to add any relevant item to the discussions. This is a good practice that facilitates the comparison of regulatory frameworks, approaches and conclusions, and ensures that each presentation is relevant, with adequate information. A way to go further could be to share questions and topics for discussions within the working group that should be prepared before the working group meeting.
6. The review and approval process of the deliverables by the working group should be commensurate with the stakes of the positions carried by these deliverables to be in capacity to provide them timely. Indeed, once the joint synthesis is approved by the working group team, addressing an additional comment from one regulator would require a review by the whole working group in order to ensure that the final version of the deliverable suits every regulator.
7. For larger working groups, the use of online platforms to share documents could be a way to improve efficiency.

4.2. Main common and individual views on the different topics of the program of work

Through the joint synthesis, the working group addressed their conclusions on the NUWARD SMR. These synthesis also compare Czech, Finnish and French regulatory frameworks, guides and practices between each other and with NUWARD SMR design and safety approach. Some high-level examples of the findings are provided below as, per EDF's request, the synthesis are not publicly available for intellectual property reasons.

On the safety objectives, the working group considers that, in line with WENRA's statement in 2021, "*safety objectives for new nuclear power plants are still up-to-date and constitute a minimum to be achieved by SMRs*". Hence, although the current approach of the NUWARD SMR adheres with the French expectations for the design of large light water reactor, ASN and IRSN consider that the NUWARD SMR should take advantage of the possibilities offered by its design to aim for a further reinforcement of safety objectives, by, for instance, confirming its target of ensuring the absence of off-site protective measures and only minor radiological impact in case of accidents with core melt (hence targeting for accidents with core melt the WENRA O2 objective currently applied for accidents without core melt). Also, it was noted that the frequencies and dose boundaries associated with the different categories of incidents and accidents are not the same as those applied in the Czech and Finnish approach. This should pave the way for further verification and consideration in the NUWARD SMR basic design studies.

Moreover, during the discussions on the safety objectives, it has been observed that the implementation of the single failure criterion was different between ASN, SÚJB and STUK. Indeed, Finnish regulations stipulate that N+2 criterion shall be applied to systems necessary to reach controlled state while the other regulators can accept N+1 with appropriate justification. This difference, specific to the Finnish approach, could create quite significant changes to the current NUWARD SMR design. In the ongoing renewal of regulations, STUK is seriously considering changing this requirement.

Regarding DBC and DEC, the working group observed that the Czech, Finnish and French approaches for the categorization of these events were different. Also, it has been observed that the definition of DEC in the Finnish approach was different, as DEC without significant fuel degradation is divided into three subgroups. Even if the approach proposed for the NUWARD SMR would require further assessment, the general process to identify DBC scenarios to be considered in the safety demonstration of the NUWARD SMR reactor looks globally consistent with the regulators' expectations.

Regarding the use of cooling passive systems, which play an important role in the safety demonstration[11], the working group considers that the designer should highlight the specificities of passive systems that may require to adapt the methodology of implementation of safety principles in the safety demonstration. Also, the working group highlighted the importance of the reliability assessment of passive systems. It appeared that the strategy proposed for the NUWARD SMR regarding the cooling of the reactor pools and spent fuel pool is different from the one currently used in the French fleet of nuclear power plants and recommended by ASN for the design of these reactors. The discussions held with the working group and NUWARD SMR will pave the way for further assessment of this strategy in the framework of the safety options file assessment.

Regarding the classification process, it was observed that further verification and work to ensure compliance with the Czech regulatory framework should be conducted early in the licensing process.

Regarding the qualification of the computer codes, it was observed that the approach and development plan proposed for the NUWARD SMR are generally consistent with the regulatory frameworks of the three countries involved. However, as computer codes shall be qualified for each application, they shall be reviewed to assess their validation over the whole range covered by the safety demonstration. A particular attention will be given to the experimental validation matrix, which should be consistent with the specificities of the NUWARD SMR reactor.

On the integration of two modules inside one NUWARD SMR installation, the working group reviewed NUWARD's preliminary strategy for the staffing of the control room and considered that this strategy could meet regulatory expectations with adequate justifications. Regarding the use of shared systems, the working group reminded EDF that, even if none of the Czech, French and Finnish regulatory frameworks and practices generally forbid to share systems between different

[11] Compared to some designs of existing large pressurized water reactors.

users, sharing of systems should be beneficial for safety. This benefit for safety can be justified by design simplification, but other aspects must be considered as well such as the impacts on operation and control of accidents both within and beyond the design basis.

Regarding the probabilistic safety assessment, even if no major issue has been identified at this stage, the working group shared with EDF its expectations regarding the work still to be done for the development of its PSA. Moreover, the working group members shared their approaches regarding large and/or early release and long-term sequence management, and the link between releases and emergency planning zone. In particular, SÚJB pointed out that some of the requirements connected to EPZ could be changed in the near future.

APPENDIX

Description of the Czech, Finnish and French licensing processes and regulatory frameworks

I. Czech licensing process and regulatory framework

Licensing process of NPPs consists of the following authorization phases: siting, construction, first physical start-up, first power-generation start-up and operation. Individual phases of decommissioning as well as modifications affecting safety are also subject to a permit process allowed. A part of the most important documentation for operation of the nuclear facility (OLCs, list of selected equipment, program of operational checks, physical protection assurance plan, decommissioning plan, etc.) is approved by SÚJB. There is no regulatory pre-licensing assessment process embedded in the current Czech nuclear legal framework. The current framework enables the stakeholder to ask SÚJB relevant questions and, if agreed by both sides (SÚJB and the future license applicant), official statements on the subject can be published.

The Czech national nuclear legislation has following levels:

1. Law (the Atomic Act) – top level document, full legally binding;
2. Decrees (20 decrees in nuclear safety, radiation protection, security, emergency preparedness, etc.) – specialized documents, full legally binding;
3. Safety guides (issued by SÚJB) –detailed and specialized documents, partially legally binding – they are considered to describe "good practice" and "state-of-art" requirements and/or explains how to fulfill the requirement of particular decrees.

The Czech legal framework does not include specific parts adjusted to licensing SMRs. As for the reactors, the current nuclear legal framework primarily fits the LWRs and it origins from the experience of regulating the 2nd generation of PWRs, more specifically the VVER type reactors. Currently (as for 2023), SÚJB has launched an analysis, which should lead to the preparation of the amendment to the legislation, which will take into account specific needs of the new nuclear builds including SMRs and the research reactors. In consistency with the current situation, the amended legislation will include all types of nuclear facilities (NPPs, research reactors, nuclear material processing/handling facilities, nuclear fuel managing facilities, radioactive waste processing, handling, storing and disposing facilities) and for the NPPs it will primarily cover the LWRs including the SMRs. The amended legislation is going to be published in 2025.

Besides the legal framework, SÚJB publishes regulatory safety guides describing the design requirements more in detail to ease the license holder the process of application. This tool is expected to be used also for SMRs.

II. Finnish licensing process and regulatory framework

Licensing of a new nuclear power plant consists of three main steps: Decision in Principle, Construction License and Operating License.

First step, Decision in Principle, is mainly dealing with energy policy; is construction of a new nuclear power plant "in line with the overall good of society" (Nuclear Energy Act 990/1987, section 5). Following an application of a utility, the decision is taken by the Government and Parliament ratifies (or rejects) it. Environmental Impact Assessment must be made before applying for DiP. In the DiP application several different reactor designs can be mentioned and STUK is asked to make a preliminary safety assessment of these. Following Decision in Principle utility may choose reactor design and may start conventional site preparation works.

Second step, Construction License, deals with nuclear safety. Decision is taken by Government. At this stage, utility has chosen a reactor design and vendor and together they are preparing necessary documentation for CL application. Nuclear Energy Decree (161/1988) defines in section 35 documents that are sent to STUK for its safety assessment; most important ones are preliminary safety analysis report (PSAR), probabilistic risk assessment of the design stage (PRA), proposal for a classification document and description of quality management during construction of the NPP. Also included are preliminary plans for security and emergency response arrangements and a plan for arranging safeguards. During construction detailed design is approved by STUK and STUK also oversees construction to verify that principles and requirements that were approved with Construction License are implemented.

Third step, Operating License, deals with nuclear safety of the plant as built. Decision is taken by Government. Nuclear Energy Decree (161/1988) defines in section 36 documents that are sent to STUK for its safety assessment; mostly they are the same as for Construction License application but supplemented and updated to reflect the NPP as built. Attention at this stage is also paid on the utility's organization and its readiness to begin safe operation of the NPP.

Regarding the regulatory framework, the Parliament decides on the Nuclear Energy Act (990/1987), which is Finland's highest-level regulation. It set general requirements for the use of nuclear energy and high-level safety requirements. Government decides on Nuclear Energy Decree (161/1988) which provides administrative details for licensing and regulatory oversight. Radiological acceptance criteria for different event categories are also given here. Third level consists of STUK Regulations on safety of NPP, on emergency preparedness, on security and on nuclear waste management. These are decided by STUK. Fourth level consists of STUK Guides (46 guides) that give detailed technical requirements. Requirements of the first three levels are binding. Requirements in STUK Guides are such that license applicant or license holder can propose an alternative solution that fulfills the higher-level safety requirements.

III. French licensing process and regulatory framework

The French licensing process is composed of three steps:

1. the safety options file is an optional pre-licensing step in which the applicant – the prospective licensee – can ask ASN's opinion on its design. At this step, the objective for the applicant is to get a statement from ASN, at an early stage of its project, on the main issues that need to be solved to undergo a licensing process successfully. The scope of the safety options file is decided by the applicant, but it is usually the fruit of a dialogue with ASN and IRSN.
2. the construction license is delivered by the Government. The authorization decree delivered by the Government is usually complemented with an ASN resolution which sets additional regulatory binding requirements. At this stage, a safety demonstration as well as an environmental impact assessment are expected, based on a detailed design including site specific issues.
3. the commissioning license is delivered by ASN. At this stage, the safety case shall notably be complemented with evidence on the reactor as built.

After the commissioning, other authorizations are required by the Law for other major steps of the plant's lifecycle (periodic safety reviews, final shutdown, decommissioning…)

The French regulatory framework is composed of several layers. The Law, voted by the Parliament, and the decrees and orders adopted by the government are technology neutral and objective based. They provide high level requirements applicable to every kind of nuclear installation, including SMR.

In addition, ASN can enact regulatory binding resolutions which provide requirements for specific installation or type of installation, on specific topics.

Finally, ASN can publish guides which provide recommendations and state of the art acknowledged practices on the way to meet higher level regulatory requirements.

LIST OF ABBREVIATIONS AND ACRONYMS

ASN	French nuclear safety authority
DBC	Design Basis Conditions
DEC	Design Extension Conditions
EDF	Electricité de France – French vendor and operator
GEN III+	Evolutionary development of the 3rd generation of nuclear power plants
HTGR	High temperature gas cooled reactors
IAEA	International Atomic Energy Agency
IRSN	French technical support organization
JER	Joint Early Review
LFR	Lead Fast Reactor
LWR	Light Water Reactor
NHSI	Nuclear Harmonization and Standardization Initiative
NPP	Nuclear Power Plant
OLC	Operational Limits and Conditions
PSA	Probabilistic Safety Assessment
PWR	Pressurised Water Reactor
R&D	Research and Development
SMR	Small Modular Reactor
SSC	Structures, systems and components
STUK	Finnish radiation and nuclear safety authority
SÚJB	Czech state office for nuclear safety
SÚRO	Czech technical support organisation
TSO	Technical support organisation
TVO	Finnish operator
VVER	Pressurized water reactor design
WENRA	Western European Nuclear Regulators Association