European SMR pre-Partnership Reports

Workstream 4 – Supply Chain Adaptation

SMR European pre-Partnership

Workstream 4

Supply Chain Adaptation

Contents

ACRONYMS

Abbreviation	*Expansion*
AFCEN	Association Française pour les règles de conception, de construction et de surveillance en exploitation des matériels des chaudières électronucléaires
AMR	Advanced Modular Reactor
ATF	Accident Tolerant Fuels
BPVC	Boiler and Pressure Vessel Code
BWR	Boiling Water Reactor
C&S	Codes and Standards
ESG	Environmental, Social and Governance (Criteria)
HTGR	High Temperature Gas Reactor
HTR	High Temperature Reactor
LFR	Lead-cooled Fast Reactor
LTSA	Long Term Service Agreements
LW-SMR	Light Water Small Modular Reactor
MRL	Manufacturing Readiness Level
MSR	Molten Salt Reactor
NEANH	Non-Electric Applications of Nuclear Heat
PWR	Pressurized Water Reactor
RCC-M	Design and Construction Rules for Mechanical Components of PWR Nuclear Islands
SDOs	Standards Development Organizations
SFR	Sodium-cooled fast reactor
SNETP	The Sustainable Nuclear Energy Technology Platform
SSCs	Structures Systems and Components
TRL	Technology Readiness Level

1. THE FEATURES OF THE SMR DEMAND

Decarbonization and energy independence have come to the forefront of EU priorities, reinforcing the urgent need for emission free sources of electricity and heat. The energy market demand is multi-dimensional:

- Flexible electric power production on a European grid with steadily increasing penetration of intermittent renewable energy
- Clean hydrogen production and use that should not mostly rely on imports
- High temperature heat for industrial applications
- District heating and cooling.

Small Modular Reactors (SMR), including Advanced Modular Reactors (AMR), offer new possibilities to address the market demand in all its dimensions. The time to deployment however depends on a number of factors that are not in the scope of this development work.

The SMR Business model, largely based on research of competitiveness through a series production approach to the deployment, and then to the construction, represents quite a change to the traditional way to build Nuclear Power Plants, which in turn was very often based on a project-specific customised delivery model. The model has many effects on the Supply Chain both in terms of quantity and quality requirements for products and even in terms of management of the relationship between Vendor and Suppliers.

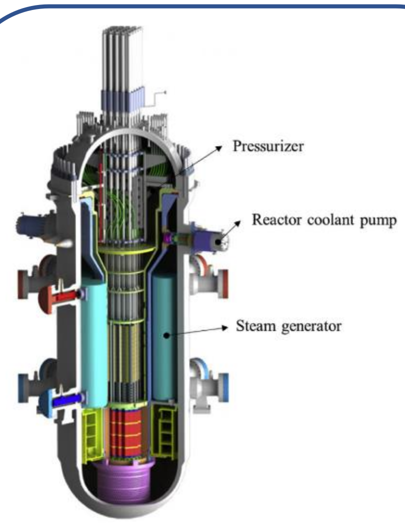
1.1 Specific challenges imposed by the SMR Business model

In terms of quantities, the reduced reactor size of the SMRs could imply per se the need for the Supply Chain to manufacture more components for a given power growth rate. This effect will be affecting all components, including the more conventional ones, like valves, piping, fittings etc. However, it could be less relevant for those plant designs focusing on simplification as a means to reduce costs, as in this case at least the safety relevant systems could require less components. Nevertheless, since the opportunities for SMR are not only related to the power generation needs but could also come from decarbonization of industrial and district heat production, it is reasonable to say that the Supply Chain would be requested to increase its capacity as long as the SMR business model would deploy all its potential.

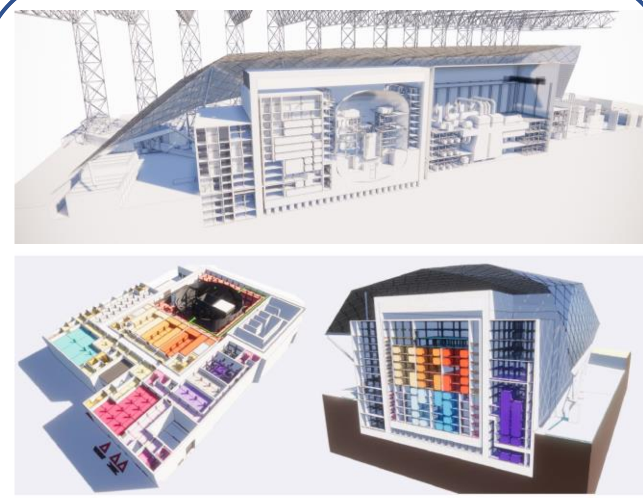
Among the qualitative challenges, the most recurrent ones associated to SMRs in the literature are:

a) **Need to standardize the product at all levels**, starting from system design to be licensed, but possibly going down up to the construction design of the single components and structures, to massively benefit from the replica effect both in terms of costs and time to build. In such respect, an obstacle to standardization could be represented by different Codes and Standards in use in different national markets. This is particularly relevant for Europe, due to the limited size of national market and the ambition to support, through this partnership, the timely deployment of SMRs in Europe with the contribution of Suppliers from several EU countries.

b) **Modularization**, in order to reduce site construction time and to achieve the needed quality standards with less burden. Not all SMR designs include the same approach to modularisation within their designs. The approaches to modularisation range between; (1) '**integrated module**' SMRs, where the reactor core, primary cooling loop, steam generators and any required emergency cooling are contained within a single reactor vessel or 'module' and (2) '**whole plant modularisation**' SMRs where the complete nuclear power station is designed, delivered and assembled as series of modules, as described in the following figure. Some SMR designs contain elements of both these approaches. The different approaches to modularisation can deliver different benefits and risks so it is important to understand which type of SMR is being proposed when deciding on a solution to mitigate any risk.



(1) Example of an integral reactor module
©K. Ahn et al. Nuclear Engineering and Technology



(2) Example of full modularisation power plant
©Rolls-Royce SMR Ltd

Figure 1. Different approaches to Modularisation.

c) 'Integrated module' SMR are envisaging quite innovative designs, possibly requiring dedicated factories with multiple skill and improved quality management techniques. It is likely that those integrated modules will remain as "proprietary items" produced by the Vendor at a centralized facility.

d) **Site construction** largely based on assembling of prefabricated modules, already adopted in some countries (e.g. Japan) and/or in some Gen 3+ design (e.g. AP1000) looks particularly promising when dealing with SMRs, i.e. with components/buildings possibly smaller. Nevertheless, the need for quality certification of the plant construction can make modularization of an NPP quite different from other industrial sectors (e.g. marine platforms, shipyards, etc.), claiming for significant testing at the shop.

e) Factory manufacturing is set to bring the **focus of the future licensee and the regulatory body from the site to the Vendor's manufacturing facilities**. This situation may be a challenge in cases where the Vendor and future licensee are geographically far apart from one another, or when the working language of the Vendor is not well understood by the future Licensee and Regulator's personnel. The concentration of assembly and construction activities in the factory also represents an opportunity to concentrate oversight activities in a controlled environment different from the temporary structures and evolving situation at the site of a future nuclear facility. Additionally, this is an area where national Regulators or their accredited inspection agencies ("notified bodies") could successfully collaborate to perform oversight activities in local factories on behalf of other Regulators.

f) The **logistic** of transporting large, long-lead SSCs for large nuclear power plants has always been a unique challenge, but one which has been successfully managed by road, rail, sea and air, often with the requirement for new infrastructure construction to facilitate this. SMR modules will need to leverage the experience and expertise of service suppliers capable of the safe transport of sensitive and complex parcels. Additionally, certain types of modular plant design will simplify the transport requirements through standardization of module size, weight etc. to ensure these can be transported using existing infrastructure. In all cases, the planning of transportation of SMR modules to the site, including means to monitor and accept those modules once they arrive at the site, will be an increasingly important activity for highly modularized SMRs.

Last but not the least, the SMR 'series production' approach could, and should, imply an **active involvement of Suppliers in the progressive cost/price reduction**, considering that large part of the savings from replica manufacturing and erection will emerge in the Supply Chain. Therefore a "win-win" relationship could be pursued, where Vendor and Suppliers cooperate to accelerate the achievement of one-of-a-series price levels, which in turn will foster further penetration of the SMR in the market, granting further volumes and even long-term business planning for all the industrial partners.

1.2 The questionnaire for SMR Vendors

As an initial step to analyse the features of the future European Supply Chain supporting SMR deployment, opinion from Vendors was sought. A questionnaire was distributed to several of them already engaged in one or several European countries to actively promote projects based on their own design: our intent was to collect issues pertaining to the impact of SMRs on the Supply Chain over and above those listed previously and mainly derived from literature and WS members' opinions. The initial distribution list was including both Light Water SMR designs and Advanced SMR of several GEN IV technologies (HTGR/LFR/MSR) and was extended to non- EU companies, however active on the European market.

The questions were strictly focused on the business model the Vendors have identified to reach competitiveness of their SMR design and on challenges for the Supply Chain. The detailed questions are attached in Annex A.

Not all the invited companies were providing answers, mainly claiming that at this stage of their projects there is not yet enough focus on Supply Chain, or even, in a few cases, there was limited interest to share information on their own business model.

We received 6 answers (out of the invited 13) from the following organizations:

- EDF — NUWARD (PWR)
- FALCON Cons. (ANSALDO-ENEA-RATEN) — ALFRED (LFR)
- GENERAL ELECTRIC – HITACHI — BWRX 300
- ROLLS ROYCE — RR SMR (PWR)
- VTT — LDR 50 (Low Temp. Heat prod. PWR)
- WESTINGHOUSE — W-LFR

The answers are summarized in Appendix 1.

1.3 SMR Business Models

The answers from the Vendors clearly show a substantial common approach in areas like:

- Standardization: all of them underline that this is not only a matter of design, but should be the key priority in all the following phases, namely in procurement and construction (see below)
- Harmonization of the safety demonstration: while the licensing process could be difficult to harmonise among the national regulations of some countries in Europe, safety demonstration should hopefully be based on principles, and even on criteria, largely shared among the Safety Authorities, so avoiding modifications on the design when trying to deploy it in a new country
- Series effect: in general, there is consensus that the learning curve (by unit) for SMR should not be different than for large units. It is worthy to underline that this opinion confirms an expected benefit of the SMR model, i.e. minor overall expenditure needed to achieve one-of-a-series costs
- Modular construction as the main means to keep construction costs and times under control
- Tendency to enlarge the Supply Chain, both to foster competitiveness and to promote local content; this is leading most of the Vendors to look for flexible approaches to Codes and Standards (e.g. through reconciliation) and even more to show interest for use of Commercial Grade Dedication and then enlargement to non-nuclear Suppliers.
- In the concepts planned to be delivered first, the Vendors are clearly inclined to utilize fuel technology already in use and well proven, and therefore more readily licensable, instead of innovative fuel types. However, the Vendors recognise the potential benefits that new fuel types may offer, and some have R&D programmes in place to address this.

However, there are also some areas where significant differences emerge, even among the proponents of LW- SMR:

- Simplification: this is considered by some Vendors (e.g. NUWARD, BWRX300) a relevant feature to achieve competitiveness, and even to differentiate the product vs larger reactors. It goes hand in hand with a certain degree of innovation, mainly focusing on passive safety issues. Others prefer to place the focus on consolidated designs plus enhanced manufacturing (e.g. RR-PWR) in order to optimize costs
- Design approach to modularization: emphasis is given in some cases to the use of standardized modules throughout the plant vs specially designed, large modules; furthermore, modularization of civil structures seems not to be unanimously pursued.

Furthermore, as could be expected, the Advanced Modular Reactors (i.e. non-light water SMRs) show a much higher degree of special components, then posing more challenges to the Supply Chain. It is worthy to note, however, that Generation IV technologies are aiming to maximise the use of inherent/passive safety concepts, and this should result, in many cases, in integrated designs minimizing the number of safety related components.

2. THE EUROPEAN OFFER

2.1 SMR Product Categories

When examining the adequacy of the Supply Chain to support the deployment of SMR, it is important to identify the correct Product Category structure. This will allow for identifying which categories could represent so called weak points, for example in terms of limited availability of Suppliers with respect to most critical technical items. For this purpose, the classification used in the Nuclear Engineering International (NEI) Buyer's Guide was utilized, as it has dense mesh that was considered to represent the Product Categories well. The database considers, in fact, 383 different Product Categories ranging from specific technical services (engineering, testing, QC, site services etc.) to categories of semi-finished products, equipment or systems.

In order to focus the analysis on the specific features relevant to most SMR, each activity was given a qualitative *relevance ranking* (decreasing relevance from “1” to “3”) with the following assumptions:

- *Rank 1* is assigned to Product Categories that are considered to represent a criticality for SMR concept development and engineering (including specialized analyses and services with limited available workforce across Europe) and/or to have a limited number of qualified suppliers (mainly for components for the nuclear island and its auxiliary systems).
- *Rank 2* is assigned to Product Categories which may represent either a specificity for some of the SMR concepts or may suffer from large volumes requested to the Supply Chain. However, most pieces equipment are not subject to stringent nuclear requirements (e.g. balance of plant components) and/or are considered to be supported by a sufficiently large Supply Chain in the non-nuclear field which could quite easily be qualified.
- *Rank 3* is assigned to Product Categories that are not considered to pose specific challenges, neither in terms of specificity in relation to SMR designs nor in terms of volumes potentially deriving from a serial production. Also, generic engineering services and analyses are assigned a Rank 3.
- Services not directly related to the supply of equipment, but more linked to the subsequent stages of the NPP life cycle (commissioning, maintenance, decommissioning), are not included (ranked as “N/A”).

Considering, as a relevant target, the identification of possible major criticalities or bottleneck for an effective Supply Chain, we have focused mainly on Rank 1 Product Categories (73 on an overall of 383 Product Categories, refer to Annex C). The 73 Product Categories with relevance Rank 1 are grouped into a larger categorization, based on the nature of the supply either because of analogy in the manufacturing route or due to the possible grouping into an integrated system of components/services. This broader categorization has substantially been used for the entire SMR Supply Chain analysis process and considerations described in following paragraphs.

2.2 The analysed Supplier data

In order to have a well-covered overall view of existing European Supply Chain, the collection and analysis of information was conducted by two different routes:

- an examination of answers received to a questionnaire distributed via Nuclear Europe’s member associations

- an analysis of publicly available information to have a more comprehensive view of existing Suppliers in Europe for the different Product Categories

Altogether the data examined included 200 companies. A large majority of examined suppliers are already experienced on Nuclear Sector. More than 70 % of them have worked with more than one customer in the nuclear industry.

3 Supplier questionnaire

With the goal to collect relevant non-confidential Supply Chain specific information related to SMRs, a questionnaire was prepared and distributed via Nuclear Europe's members to the potential suppliers.

The questionnaire (see Annex B) consists of three areas: General overview, Capability, and Capacity. It was formed in WS4 workshop meetings and contained 32 questions considered essential and indicative in examining the general capability, capacity and adaptation ability of the potential SMR Supply Chain in a comprehensive but still respondent-friendly way.

The questionnaire was answered by 91 suppliers located in 10 European Countries. It was estimated that among all of these 10 Countries more answers could have been received, especially e.g. in Spain, UK and Czech Republic. Also, from some Countries where there are potential companies for SMR Supply Chains, no response to the survey was received, e.g. Germany and Belgium.

Nevertheless, in terms of product range, the respondents cover more or less all sectors readily included in the questionnaire (see Figure 2). Summary of analysis of the Supplier questionnaire answers is presented in Appendix 2.

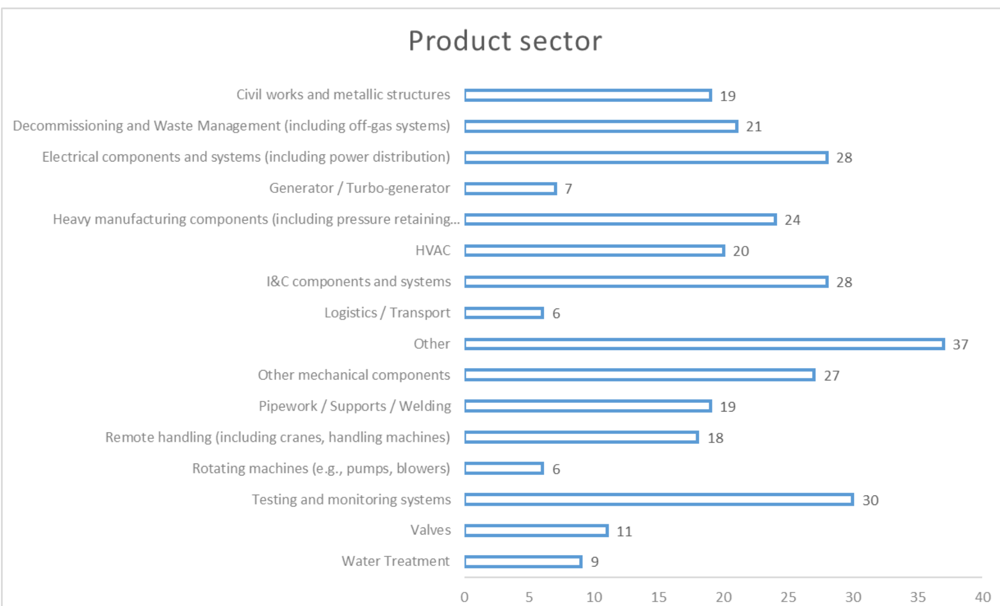


Figure 2 Company product sectors indicated by the respondents.

The size of the examined Companies varies from small and very specialized ones (with turnover of less than 3 M€) to very large and wide-ranging ones (with turnover of hundreds of million euros), typically depending by the sector of competence. The range of respondents varies similarly in terms of number of employees from small Companies to very large global organizations. The data base collected through answers to the questionnaire cannot be considered statistically relevant, but certainly represents a significant sample of the European nuclear industry, adequate to derive qualitative conclusions on a large portion of the issues examined in this study.

4 Database of Nuclear Engineering International

The publicly available database of European contractors kept by Nuclear Engineering International (NEI) /i/ was also utilized in order to complement and affirm the results gained by the questionnaire, especially concerning the potential bottle necks of the future SMR Supply Chain. Even though it was noted that the information in the NEI's database was not necessarily been updated by the Companies and doesn't include all organizations acting in the field, it was considered to be a good addition to the information freshly gained directly from the Companies through the questionnaire. After screening, a sample of 118 companies from NEI database were included in the analysis.

4.1 Supplier's Capability to meet the SMR challenges

5 Experience with different technologies and fields of specialty

A globalized nuclear market has meant that many Suppliers to the nuclear industry have experience with different technologies and end-users in different jurisdictions. This is beneficial for future SMR deployment, which will likely see Vendors, their Supply Chain, and the future SMR licensee developing projects in more than one country. Global deployment of nuclear power technology has typically come with expectations to utilize local industrial capabilities including manufacturing and contractors. Localization of Supply Chains has sometimes presented a challenge for large nuclear power plant projects where only a single power plant was planned to be built. In the case of SMRs the benefits of serial manufacturing and efficient deployment are compatible with localization, as far as sizeable number of reactors within the same country or region can be envisaged. Efforts to standardize SMR design (especially non-safety SSCs) around international Codes and Standards would further benefit the ability of the Supply Chain to remain competitive and competent throughout several national markets in Europe and abroad.

In order to appreciate the flexibility of the European Supply Chain towards innovative designs, we explored with the Suppliers their experience on different nuclear technologies (PWR, BWR, HTGR, LFR, SFR, Fuel Cycle Facilities, Naval Reactors, Fusion Reactors, etc.) The result is quite encouraging. More than 60% of Suppliers have experience with more than a single technology and roughly 30% of them have worked on more than two different technologies (Figure 3.). Major part of them have experience on LWR and Fusion technology, but a not negligible part of them has experience on AMR (LFR, SMR, HTGR).

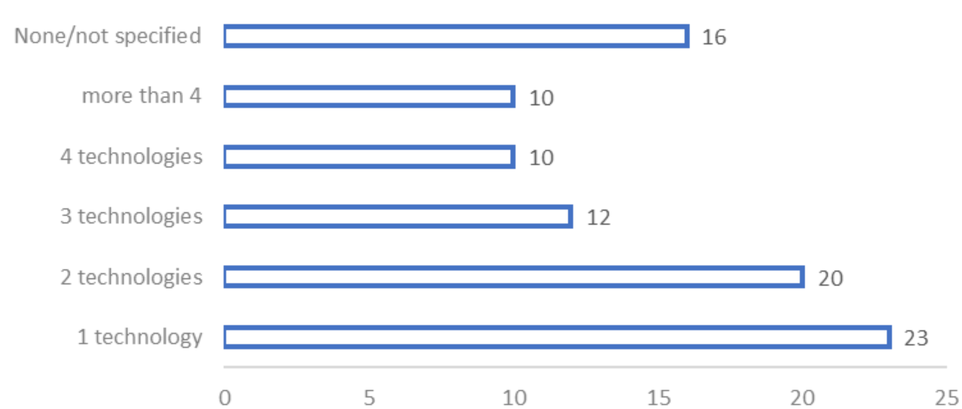


Figure 4. Supplier companies who answered having experience of one or more nuclear technology (total 91 respondents).

Still relevant to the ability to adapt to innovative designs, it can also be noted that a large portion of Companies examined in the study inform to have internal engineering capabilities varying from concept design capability to basic, detailed and construction engineering, depending on the industrial sector of each specific Company. Similarly, roughly 80% of Companies examined inform to have internal expertise to supervise site activities of their own products in the different phases of installation, commissioning and site testing. More or less the same percentage of companies can provide maintenance services after delivery, mainly through Long Term Service Agreements (LTSA).

6 Experience with Codes and Standards

The Codes and Standards experience of the examined Suppliers can be summarized as combination of international standards (e.g. IEC/IEEE/ISO), one of a handful of nuclear pressure vessel codes (e.g. AFCEN or ASME BPVC), as well as regional standards like the EN standards found in Europe. The greatest divide in Supplier's Codes and Standards experience tends to revolve around compliance with American or French practices.

Less than 15% of the respondents inform to have no experience on the use of Nuclear Quality Systems or that, due to their specific sector, experience is not required. Also, more than 50% of Companies examined have experience on more than one of the standards listed in the questionnaire. The most familiar C&S are ASME and RCC, but also IEEE and IEC seem to be well known.

It is worthwhile to note that over 50 % of the respondents inform not to have major concerns in terms of *reconciliation capability*. Approximately half of the respondents don't see major issues in qualifying their products to a different C&S, however changing qualification process from the established one naturally has a cost. This may be the case even when maintaining the same reference C&S, but moving from one national licensing procedure to another, due to differences in the way of implementing the C&S requirements by different regulatory bodies and/or notified bodies.

7 Product innovation

The supplier questionnaire had five questions that reflected innovativeness in different ways. For example, majority of Companies responded to have a good or excellent level of digitalization of their activity, *adequate to support an increase of production* at a sufficient level. This aspect should be studied further, but it does give the impression that the surveyed companies have a good understanding of the importance of digitalisation for the effective implementation of a possible increase in future production at a quality level required in the nuclear industry. Digitalisation is a wide concept and is seen as essential enabler of SMR deployment in terms of quality, certification, delivery times etc.

More specifically, many of the companies that answered the survey have given a more detailed answer of how they are implementing or are planning to implement their goal of digitalization by means of specific enabling technologies in relation to their specific product categories (Annex B, questions 20-23).

Almost 70% of the respondents indicated specific technologies such as additive manufacturing, augmented reality, autonomous robot, Big Data analysis, cybersecurity, IoT, AI, machine learning and digital twin modelling on which they are actively working or intend to invest in the next future. These innovations inherent to strong digitalisation processes exist in the Supply Chain and within the nuclear supplier organizations which have responded to the questionnaire. It is crucial that regulatory bodies, future SMR licensees and standards development organizations (SDOs) enable the utilisation of these innovations to create a virtuous circle, considering that an effective application of enabling techniques could result not only in an economic benefit, but foremost in a higher quality final product.

7.1 Capacity to support SMR fleets

In terms of quantities, the reduced reactor size of the SMRs could imply *per se* the need for the Supply Chain to manufacture more components for a given power growth rate. On the contrary, thanks to their smaller scale engineering designs and tendency to adopt passive safety systems, SMRs will rely on fewer safety classified SSCs as a fraction thereof when compared to large NPPs.

Instead, SMRs are expected to extensively utilize high-quality industrial-grade equipment for non-safety applications and some mid- and low-safety-significant applications. This means that SMR fleets can successfully leverage large industrial markets in which high quality mechanical, electrical and digital equipment is available. Furthermore, the smaller overall size of SMRs will enable a wider range of Suppliers to compete for the necessary scope of work. For example, smaller forgings will mean that more forges and steelworks will be in a position to participate in the SMR Supply Chain than was the case for the largest Generation III+ vessels and piping.

8 Adaptability of production and service provision capacity

Over 60 % of the supplier responded that their current production capacity can be expanded quite readily and most of them also give a quantitative indication of this capacity. Several Companies replying the questionnaire also indicated they had more than one production unit. These Companies include both manufacturers and service providers (engineering, consultancy, quality, testing, maintenance, etc.). However, great majority of present-day manufacturers also provide some services in the respective field of their expertise. The Suppliers' readiness to increase production capacity needs to be further studied because it is specific and strongly depends on the Product Category.

The respondents did not highlight expecting any major challenges in terms of transport logistics, laydown areas etc. but it has to be considered that probably, for manufacturers of large products or system, the actual phase is quite preliminary to highlight specific issues. However, the reduced size of SMR main components should be an advantage with respect to large reactors.

Despite the increased availability of Suppliers who are able to support SMR Vendors, as described above, the predicted market requirement for SMRs to be deployed over the coming decades indicate that capacity within the Supply Chain may become a limiting factor. This may be mitigated, in part, by the different Supply Chain requirements from different SMR Vendors. However, the identification and resolution of potential Supply Chain bottlenecks will support the accelerated deployment of SMR technology.

Additionally, the ability of the Supply Chain to deliver repeatable, standardized SMR modules and equipment for SMR plants deployed locally, regionally, and globally, rather than to a single project, will maximise efficiency and economic benefit to the Supplier and reduce cost and risk to the customer.

Special consideration shall be given to issues related to Human Resources, which appear to be considerable challenge for the Supply Chain in the near future: to select, train and qualify suitable personnel requires time and proper planning is necessary. The SMRs could potentially alleviate this general issue for the nuclear Supply Chain, due to the standardized approach to the production.

9 Manufacturing materials and resources

Materials play an important role in nuclear facilities due to the presence of neutron and high energy gamma fluxes in and around the reactor core. The nuclear industry requires standard material specifications be augmented with additional considerations related to activation and radioactivity, such as limiting Cobalt content in metals. These requirements will be augmented by other special material requirements in the case of AMR technologies (e.g. Generation IV).

There are some important aspects that emerge from the analysis related to challenges anticipated to their own Supply Chain by the nuclear suppliers that responded to the questionnaire. They anticipate supply challenges concerning:

- Raw materials availability
- Semi-finished components availability
- Specific high-tech components availability
- Specialised work force availability
- Price escalation.

All these issues, which concern not only the Nuclear Sector, should be closely monitored in the near future, as they could significantly impact an effective SMR deployment both from the CAPEX point of view and from delivery time perspective. Their dynamic behaviour is strongly influenced by global political and economic scenarios currently in place and not only in EU.

Approximately half of companies that answered the supplier questionnaire have clear view on which areas they need to invest in order to enable or enhance factory pre-assembling and integral testing, aimed at reducing site erection schedule, considering their product characteristics and required testing in accordance to C&S. Some investments may need to be directed at e.g.:

- Automatic assembly/welding
- Auxiliary systems for integrated working test
- Human resources/labour
- Inspections
- Factory laydown areas
- Machining capabilities
- Material monitoring
- Transport/logistics.

However, development and investment costs are not marginal when tailored to the current low level of nuclear business for the most part of these companies: investment plans are likely to be implemented only after there is imminent visibility on an SMR construction program and its legitimacy by public authorities.

The matter of critical products with limited number of Suppliers is discussed in chapter 4.2.

9.1 Fuel cycle issues

EU fuel cycle operators are firmly committed to contribute to the successful development of the SMR partnership. However, decisions related to both front-end and back-end challenges should be taken early in the development phase, with the active involvement of the fuel cycle industry and the support from public authorities to guarantee the competitiveness of the EU SMR Supply Chain. The optimization and validation of new concepts, taking into consideration life-cycle operating costs and long-term security of supply as well as spent fuel and radioactive waste management programs should be considered as a priority. Moreover, it is worth noting that the fuel cycle industry has a role to play in the completion of the ESG global standards and of the EU taxonomy, as it has the capability to access to the most efficient use of the fissile resources and to the most sustainable management of radioactive waste.

Depending on the type of SMR technology, fuel cycle-related challenges are different. Likewise, for the same technology, a wide variety of aspects should be considered.

The successful introduction of SMRs in the EU market will go hand in hand with the provision of new services related to fuel cycle requiring additional industrial facilities. For that reason, strong signals from policymakers are needed to incentivize investments in fuel services, as it is already the case on other parts of the world.

Once LW-SMR and AMR deployment will be successful, associated new fuel demand for LEU, HALEU or U/Pu based fuel will significantly impact the overall nuclear front-end market. Moreover, the efforts made on the development of Accident Tolerant Fuels (ATF), to comply with the EU taxonomy, is an asset for SMRs (for certain types of designs, excluding those requiring TRISO fuels and MSRs). Nonetheless, the work and associated technical choices on ATF should not hamper the treatability and recyclability of used fuels, nor interfere with the future policies related with valorisation of U/Pu resources.

On the back-end side, significant support would be needed, starting with R&D and innovation programmes. Safe, technically, economically, and societally acceptable waste management solutions must be developed for all spent fuel's types, with a specific effort for some designs, such as TRISO fuels, notably for HTR. The choice of recycling should also be considered as it allows saving natural resources (for instance 20 to 25% with current LWR monorecycling scheme compared to the direct disposal of spent fuels) and enhanced HLW conditioning ready for disposal. The savings could increase when considering multirecycling options in LW-SMR or AMR. Support will be needed for activities addressing spent fuel management from AMRs (not LWR-type) to develop processes and design facilities for recycling such reactor fuel or for treatment /conditioning prior to their disposal.

Logistics solutions will also require to be adapted to LW-SMR/AMR feed material and new forms of fresh and spent fuel. The EU will benefit from European nuclear industry capabilities and experience to develop competitive solutions across the entire fuel cycle (design, licensing, package manufacturing and nuclear transports). The challenge lies in addressing the logistics scope as early as possible to ensure that a comprehensive solution is developed, available and licensed to secure both the front-end supply, and the back-end operations in time. In particular, many logistical schemes associated with these new projects will include transports in non-nuclearized countries and therefore require strong communication with local safety authorities and possibly elongated licensing process. Competitive solutions can be developed through a combination of proven technologies and cutting-edge innovations, and by seeking mutualization among actors to avoid the multiplication of specific developments for each LW-SMR/AMR project (depending on the feed material, fuel type, quantity, and country of origin/destination).

Future LW-SMR/AMR fuel cycle will have to tackle 4 main transversal priorities: safety, non-proliferation requirements, economics and long-term security of supply.

- Safety is one of the main priorities; highest requirement shall remain compatible with economic balance and shall not degrade proliferation resistance.
- Strong reduction of proliferation risks shall remain a focus of LW-SMR/AMR designs, notably due to higher level of enrichment and considering the increased amount of fuel transport in more

different countries & sites. When assessing and considering proliferation risks, one should not only consider reactor itself but also front-end and back-end of the fuel cycles (including logistics and transport) which are often the weak points. Physical protection and security should be duly addressed, with implications on spent fuels management programme developments.

- Economics: high standards regarding safety and proliferation in all the fuel cycle, depending on options chosen, may degrade the economic balance of the project.

The security of supply has gained in importance given the current geopolitical context and the need to reduce EU's dependence towards external players. This concern has been stressed in the REPowerEU communication published in May 2022 /ii/ aiming to guarantee an affordable, secure, and sustainable energy for Europe. When it comes to nuclear power, circularity must be a key objective of the Partnership to preserve resources and to guarantee a sustainable and responsible deployment of SMRs. Strong international collaboration should be pursued in the European Union and with strategic partners. A closed fuel cycle to maximize energy production from all fissile materials contained in the fuel should be promoted to further reduce the footprint of high activity waste coming from used fuels, and to enable producing valuable isotopes for other applications. R&D programmes have been launched in the EU to develop AMR promising concepts from a sustainable point of view, such as Molten Salt Reactors and Liquid Metal Fast Reactors enabling for minor actinides and plutonium conversion, which could be envisaged as complementary of LW-SMRs deployed in the European territory. Nuclear fuel cycle operators are fully engaged in delivering the services and products needed to ensure a safe, secure, non-proliferating and sustainable deployment of LW-SMRs and AMRs in Europe. While a wide variety of services/solutions will have to be adapted to these new technologies, a comprehensive and wide support from public authorities, from a regulatory and investment point of views, will be needed in the European Union. The future SMR partnership is a unique opportunity to pool European forces to achieve these goals.

10 SPECIFIC SMR RELEVANT ISSUES

10.1 Standardization and use of industrial grade components

11 Nuclear Codes and Standards

The answers of the SMR Vendors to the questionnaire described in Section 1.2 show that they want to use existing and well established Nuclear Codes & Standards (e.g. ASME BPVC, AFCEN, …) for the design and manufacturing of safety-related structures, systems and components (SSCs) of their SMRs with some adaptions, where needed, to account for items that are not included in the established NC&S yet, e.g. new reactor materials, advanced manufacturing methods, etc. The development of new NC&S specifically for SMRs is not seen as necessary.

Manufacturing of safety related SSCs requires Vendors and Suppliers to run a nuclear quality assurance (QA) programme and having the corresponding accreditation. Vendors and Suppliers may only have the accreditation for a specific NC&S (e.g. ASME NQA-1 or RCC-M), which potentially limits them supplying components and equipment to certain reactor designs and even to specific countries, whose licensing practices or regulation refer to the use of a specific NC&S. It is relevant to note, however, that in EU countries' licensing practices there are no obligation to use a specific set or subset of NC&S, as long as the Vendors and Licensees demonstrate the differences and achievement of equivalent level of safety and full compliance with national regulations /iii/.

Codes for civil structures deserve specific attention: in few EU countries (e.g. France) C&S based on a risk informed approach, like the EURO codes, would not be considered acceptable for safety related structures, in particular for those ones limiting radioactive release to the public /iv/.

Experience and specific studies (e.g. code comparison report for class 1 mechanical NPP components published in 2012 by Standards Development Organisations (SDOs)/v/) showed that there are differences in detail between the established NC&S, but that overall they address the same technical issues in the same way. Mutual recognition of different but well-established NC&S, at least in parts (e.g. material specifications, NDE, etc.) could be beneficial in order to limit the need of the Vendor to show equivalencies. A good example in this respect is the Belgian regulator FANC that accepts RCC-M as an alternative to the ASME BPVC for safety-related mechanical components in large LWRs.

Concerning the adaption and enlargement of existing NC&S to SMRs the CEN Workshop 64 could be a useful platform. The purpose of the CEN Workshop 64 is to provide recommendations on the further evolution of the AFCEN codes and required underlying R&D. Initially focussing on RCC-MRx /vi/ in Phase 1 (2012-2013), the scope of the CEN Workshop 64 was enlarged to other additional AFCEN codes in the following two phases, first to RCC-M and RCC-CW in Phase 2 (2014-2018) and additionally to RCC-E in Phase 3 (2019-2022).

The members of the prospective groups (PGs) of the CEN Workshop 64 /vii/ involve experts from different nuclear stakeholder organisations (vendors, utilities, TSOs, regulators, R&D) allowing them to freely discuss technical issues on nuclear reactors. In practical terms the work of the PGs mainly involves comparisons of the AFCEN codes with U.S.-based NC&S (e.g. ASME BPVC, IEEE, …), German KTA and others on specific technical issues and formulation of R&D proposals on specific technical issues where limitations of the AFCEN codes have been identified. All PGs have identified SMRs as a major working area for Phase 4 of the CEN workshop 64 that will be launched in 2023. This poses an interesting opportunity for SMR Vendors and Suppliers to promote recognition of their best practices in a number of areas and thus promote harmonisation in Europe.

12 Digital devices

All new-build Gen III reactors come with digital I&C systems and SMRs will be no exception. Latest editions of NC&S for electrical and I&C systems provide rules and requirements for the design and qualification of digital I&C systems and smart devices including their software. E.g. the 2018 edition of RCC-E addresses design and qualification of smart devices in I&C systems by referring to well established IEC standards to qualify digital I&C systems of NPPs, such as IEC61513, IEC62138, IEC60880, … /viii, ix, x/ RCC-E /xi/also offers a simplified pathway to qualify digital devices of limited functionality (DDLF) based on IEC62671 /xii/. These are digital devices that can be configured according to the needs of the user, but whose software cannot be altered. Qualifying DDFLs based on IEC62671 is seen as fully sufficient for such types of digital devices and should be the norm for SMRs from the beginning.

13 Use of serially produced high-quality industrial standard components

The use of commercial-grade products and services by nuclear facilities has long been a successful practice in the nuclear industry, starting in the 1980s in the United States' reactor fleet as a means to revitalize the Supply Chain, avoid obsolescence issues and access proven high-quality products. These items are also referred as serially produced high-quality industrial standard items. The use of these types of products and services is expected to grow in the coming years and with the large-scale deployment of SMRs as a means of introducing high-quality serially produced items into nuclear facility design. This also allows further implementation of the risk informed and graded approaches, which are systematic ways of operating so that the resources used to comply with requirements are proportional to their safety significance. These products and services are defined as those which affect nuclear safety and that was not designed, manufactured or performed in accordance with specific nuclear requirements /xiii/. The use of these types of items is foreseen by nuclear quality management C&S including ASME NQA-1 /xiv/ for licensees and suppliers and ISO 19443:2018 for suppliers.

Other high-reliability industries rely on a robust framework of C&S for design, qualification and quality similar to the nuclear industry. These non-nuclear industries also place a strong emphasis on safety and risk mitigation. The use of commercial-grade items from these industries has been a success thanks to well-defined acceptance processes according to which the supplier integrating the item in their safety-related product or the licensee directly procuring the item for safety-related verifies the item's suitability for use. The suitability of commercial-grade items is a function of their design as well as confidence that the manufactured design to be installed will perform according to its specification.

The acceptance process for commercial-grade items known as dedication or commercial-grade dedication is concerned with the verification of critical characteristics of the item in order to establish confidence in the items ability to perform its safety function when in service. Due to the increasing interest in the widespread use of the dedication methodology, the European nuclear industry has published a harmonized quality assurance guideline for procuring commercial-grade items (also called industrial-grade items) based on existing good practice /xv/.

14 Fire safety

Existing national fire regulations normally address non-nuclear plants and buildings and only in some countries they are dedicated to NPPs as well. However, national nuclear regulation may mandate NPPs to follow national non-nuclear fire regulation, e.g. British Standards applied in recent nuclear new-build in the UK, such as BS 9999:2008 Code of practice for fire safety in the design, management and use of buildings, and BS 7974:2019 Application of fire safety engineering principles to the design of buildings. Requiring a SMR design to comply with different national fire regulations, wherever it is considered for deployment, could lead to costly design variations of the SMR for different countries. Instead of complying with different national fire regulations a SMR should just be subject to existing and well-established set of harmonized nuclear fire safety requirements like *NFPA 25 (National Fire Protection Association),* U.S. Nuclear Fire Regulation by U.S. NRC or RCC-F / ETC-F.

14.1 Modularisation

Different SMR technologies use different approaches to modularisation, as described in section 1.1 above and therefore the benefits and implications of these approaches will be specific to the design.

Modular construction techniques have been successfully used in other sectors, including civil construction, the oil & gas industry and shipbuilding for example, for many years. The benefits include reduced time to build, lower labour costs, lower waste, lower risk of weather delays, increased quality etc. Some elements of modular construction are successfully used today within the construction of GW NPPs. SMR Vendors have the added opportunity to maximise the benefits of this approach by incorporating this approach within the complete power station design.

Nevertheless, the need for quality certification of the plant construction can make modularization of an NPP quite different from other industrial sectors (e.g. marine platforms, shipyards, etc.). Modularisation in any of the before mentioned approaches has some implications from the Supply Chain perspective, as for instance:

- Manufacturing becomes integrated with steps of the commissioning tests, i.e. the manufacturer also becomes part of the commissioning activities, subject to quality certification requirements typical of the nuclear industry.
- The modules are complex installations, which include multidisciplinary components and systems assembled at one site. This can be achieved e.g. through tightly interconnected Supply Chain groups that provide different types of components for the integrated modules.

Special care should also be dedicated to standardising the modules, i.e. to limit the number of different types of modules (e.g. type of frame, structural design justification, etc.) foreseen for a specific design: the risk would be to force on the Supply Chain an increasing number of additional subsystems (the module types), and then a substantial additional burden to the production and certification of plant systems and components.

14.2 New tools and methods in SMR manufacturing

SMRs are designed to be standardised, repeatable and, in many cases, factory fabricated which delivers the known benefits associated with higher volume, series production including lower risk, higher quality, lower cost etc. Additionally. this approach can enable much greater use of advanced and digitised manufacturing techniques as these become cost effective to qualify and utilise.

These advanced manufacturing techniques, used in other industries today, such as automotive and aerospace, have the opportunity to improve productivity further significantly within the nuclear industry. However, many of these techniques must be proven or qualified for use in the nuclear industry by the appropriate regulatory bodies before they can be adopted.

The new types of reactors are largely based on increased use of passive safety systems. Therefore Supply Chain will also include new technologies for production, maintenance and repair, as for instance for the perspective of medium term:

- New technologies for underwater repair and inspection, mainly of robotic type, which have to be certified by regulatory bodies
- Intensive use of new digital solutions such as virtual or augmented reality techniques to prepare for maintenance and repair in harsh environment
- New human-machine-interface technologies for design and operation, like virtual reality and advanced computing
- New Training techniques for nuclear operators and maintenance personnel.

The increased use of passive safety systems also allows further adoption of graded approach in the design, reflected in:

15 Building and reactor requirements for specific qualifications (for seismic qualifications for instance)

16 Development of the licensing process due to the differing requirements of the passive safety systems;

16.1 The safety systems of passive type include less components as a whole and require less tests and verifications e.g. because operating limits for non-rotating devices require less analyses and tests. However, they present their own characteristic requirements for licensing, especially on system level.

17 Increased testing (including commissioning ones) at the manufacturer shop, with potential lower efforts on commissioning at site

18 A higher contribution of I&C, robotics and digital technologies in operation and maintenance leading to simpler operator certification process and a better human-machine interface in the Main Control Rooms.

As nuclear technology is an envelope of technologies, it is also important to consider the lifecycles and evolutions of all the technologies participating in the new modular type reactors, which are designed to operate for decades and then to be competitive in the long run. New technologies like quantum and high-performance computing, nanotechnology, AI, biology and human protection, future human generations specifics etc. are an important element that should already be considered in the design for the whole lifecycle of SMR's.

For long term evolution it is considered to develop:

- Fundamental research on improved reactor physics calculation and design, the use of quantum computing for safeguards and safety analyses mainly in severe accident conditions
- The use of nanotechnology for better material fabrication techniques
- Service inspection techniques
- Adaptation to the user profiles of new generations of specialists as technology and technological interfaces evolve (human factor).

It is important therefore to ensure that the Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) of the SMR designs and any applicable manufacturing techniques required are understood, and the risks or benefits associated with their introduction are factored into the manufacturing and delivery schedule.

EU Commission Support and collaboration between the nuclear industry and specialist R&D organisations could accelerate the approval of these advanced techniques, where required, to increase productivity.

18.1 Further challenges inherent to Advanced Modular Reactors

Advanced Modular Reactors aim at responding to the need of a more sustainable use of natural resources and minimization of radioactive waste (see Section 2.5), while offering improved capabilities for the decarbonization of hard to abate sectors of crucial importance to decarbonization and energy independence. Therefore, AMR are receiving increasing attention from EU policy makers and their nuclear "ecosystems", including Regulators and the Supply Chain.

The market demand is high, as evidenced by the widespread curtailing of industrial production in many sectors due to the current energy crisis. Advanced reactors open the opportunity for highly specialized, high value-added industrial products; it is important that the European Supply Chain does not miss those opportunities.

It is recommended to promote R&D activities that support the Supply Chain in areas such as advanced reactor fuels and materials. This includes fostering SNETP (The Sustainable Nuclear Energy Technology Platform) activities in this area and taking advantage of GIF's new focus on Non-Electric Applications of Nuclear Heat (NEANH) and on accelerated deployment of Gen IV technologies. Pre-licensing review of AMR designs from Regulators would be beneficial to accelerate time to market

A practical first step for the EU SMR Partnership could be to expose the European Supply Chain to the needs and specifications of AMR developers (whatever their country of origin), through the sponsoring of Vendor-Supplier Days or workshops.

The main challenges potentially affecting the deployment strategy of AMRs are related to maintaining and extending the current Supply Chain capabilities, defining specifications of critical components featuring innovative aspects, developing new materials and fabrication/inspection techniques, ensuring the necessary accreditation and quality for innovative aspects.

Many nuclear components (pumps, heaters, heat exchangers, electric motors, transformers, etc.) and other standard components (valves, filters, electric cabins, instruments, etc.) are in common to AMRs and LW-SMRs concepts. AMR critical components, featuring requirements or solutions not common to other SMRs and thus representing a potential challenge for the Supply Chain, can be categorised in the following groups presented in Table 1 /xvi/.

Table 1 A categorisation of AMR specific critical components and possible Supply Chain challenges related.

AMR critical component	Supply Chain challenges
Nuclear fuel	Complementary studies for new fuel licensing and manufacturing
Fuel subassemblies and racks	New designs to face new conditions considered for the new types of fuel and new coolant characteristics
Fuel handling, control rods and mechanisms	New designs adapted to new fuels, although existing suppliers have the technology to develop these components.
Reactor core and internals	Materials to support new conditions (coolants, corrosion, erosion, etc.). Innovative manufacturing techniques may be beneficial.
Reactor pressure vessel(s) and safety vessel(s)	Experience for large vessels is applicable but shall be tailored to special conditions.
Reactor coolants (e.g., sodium, lead, helium, molten salt)	Typically not produced in large quantities, experience in handling and treatment systems in the conventional sector may be beneficial.
Reactor coolant pumps	Pump design shall be implemented for new coolants.
Primary heat exchangers	Special design or innovative technologies might be required.
Primary coolant special components (filters, seals, heaters, etc.)	Complementary studies to be performed to evaluate the impact of the new fast reactor conditions in order to adapt the current equipment.
Radwaste Systems	Gaseous, liquid and solid radwaste treatment and storage systems considering new fuel and radiation source characteristics to be developed.
Instrumentation and monitoring for systems and components	Current radiation monitoring equipment to be adapted.

AMR critical component	Supply Chain challenges
Inspection tools condition monitoring and repair techniques	New fast reactors shall incorporate robotic tools and service inspection instrumentation.

The requirements for critical components and associated processes will necessitate further investments on development and qualification, thus representing a stimulus for the Supply Chain and, in perspective, a beneficial market and business opportunity for the nuclear industry to fill a niche in the growing low-carbon emission energy market, for both electricity and heat generation. Early engagement of the Supply Chain can be stimulated through the realization of mock-up, experimental facilities and prototypes, supporting the development and qualification of innovative technologies or adaptation of existing ones.

For the Advanced Modular Reactors (AMR) (as well as for some conventional LW-SMR) which are based on advanced fuel using HALEU or U/Pu type fuel, important challenges are emerging in the front-end. New technological bricks with low or no industrial maturity have to be established:

- Enrichment for High Assay Low Enrichment Uranium (HALEU: 5 to 20% U_{235}),
- Deconversion in various chemical forms and Fuel Manufacturing for U/Pu, U/Th or U/HALEU fuels feeding molten metal cooled fast reactors,
- Deconversion in various chemical forms and Fuel Manufacturing for TRISO fuels
- The complete Chloride of Fluoride Molten Salt Fuel preparation.

Securing the availability of these new fuel types, including HALEU, will be critical to contribute to the success of these AMR designs. To meet these market needs, important investments will be required, starting with R&D. However, there is a lot of uncertainties on the market (size, timing, clients) and therefore, the risk is that EU fuel Supply Chain do not have sufficient signals to implement investments. Thus, clear support from public authorities to guarantee the competitiveness of the EU LW-SMR/AMR Supply Chain will be key to provide a long -term visibility to service providers and accelerate their projects to be on time with market window of opportunity.

19 A ROBUST SUPPLY CHAIN FOR THE FUTURE

19.1 The expected market request

The market analysis conducted by Workstream 1 of the EU SMR Pre-Partnership Initiative /xvii/ indicates that the demand for SMR in Europe by 2050 would be in the order of tens of GWe, depending on the sharing of the new nuclear plants between SMR and large units, and even on the actual penetration of the SMR in new sectors like heat generation and Hydrogen production. In any case, such demand will pose a strong request on the Supply Chain to increase capacity, the effects of which have been discussed in the chapter 2.4.

However the SMR business model not only implies the need of increasing capacity over a relatively short time, but also requires to create a robust industry, able to continue to deliver new units over decades and to properly serve its customers over extended plant life. This means that the required growth shall be properly fostered taking care of:

- the risks associated to possible bottlenecks, which could become limiting factors to an orderly growth, as well as

- the foreseeable changes in the Value Chain of nuclear power induced by the SMR business model, which should suggest further areas of investment priority to consolidate the industry around the new model.

19.2 The main bottlenecks to address

Even though we didn’t go for a quantitative analysis of the available offer of nuclear components and services in Europe, nevertheless the data bases we have been using, do provide a few indications on possible bottlenecks, which are worthy to start from.

On the basis of the answers received to the supplier questionnaire, product sectors which could presently suffer from a thin Supply Chain in Europe are likely to be:

- Nuclear grade pumps, and
- Nuclear grade valves,

the criticality of which could be the required quality level, especially for body castings and forgings.

Furthermore, a product sector that could suffer because of restricted market is:

- Generator/Turbo generator

even if this criticality could be mitigated considering that, in SMR’s power range, there are more suppliers capable to comply without significant extra effort.

The NEI database of European contractors was utilized in order to complement the result. The following critical activities appear to have only few Suppliers or even just one:

- Control rods
- Cores, reactor
- Grids, fuel element
- Criticality monitors/systems
- Electronics, radiation resistant
- Uranium enrichment
- Pressuriser heaters
- Flanges, pressure vessel
- Nozzles, RPV
- Spray nozzles.

Also, among the 200 companies covered by our study, pumps, valves and generators readily manufactured to nuclear codes and standards appear to have only handful (4-7) of suppliers each.

Fortunately, on the other hand products and skills from other technologically advanced sectors can be utilized in nuclear energy Supply Chain as well, for example concerning items such as pumps and valves. Furthermore, the smaller overall size of SMRs will enable a wider range of Suppliers to compete for the necessary scope of work. For example, smaller forgings will mean that more forges and steelworks will be in a position to participate in the SMR Supply Chain than was the case for the largest Generation III+ vessels and piping.

Such a sample result suggests the possibility of dividing our considerations about bottlenecks into two parts, since the means of achieving SMR business model sustainability and resilience are quite different.

i. *Vendor specific components*

Large part of the items and components listed above are usually manufactured by the Vendor either directly or through its own, dedicated supply chain. In this regard, the goal of achieving a sustainable SMR Supply Chain in Europe should be pursued by actions aiming:

- firstly, to have more than one Vendor design available in the European market, and
- to maximize, even in the case of non-European Vendors, the local manufacturing of such items and components in dedicated European factories, to enable continuous and efficient delivery, and/or
- to foster the participation of European sub suppliers to the Vendor Supply Chain, even in terms of semi-finished items or special subcomponents.

ii. *Components procured from the broader market*

In such a case, the main path towards a robust Supply Chain is through fostering the engagement in the nuclear field of those European suppliers active in other technologically advanced sectors, through actions like:

- promoting the interaction between Vendors and potential suppliers (not only the usual ones);
- promoting the use of serially produced high-quality industrial standard components, as per para. 3.1;
- where necessary, supporting the initial investment from new entry companies in the nuclear arena (e.g. quality monitoring and testing tools).

However, bottlenecks have to be searched not only looking at items and products. On the basis of the answers obtained from the questionnaire and as anticipated in Par. 2.4, the most relevant challenge for an effective nuclear Supply Chain could be caused by the thinning, in past 20 years of human resource competence able to maintain the high quality of the nuclear systems and components even if just in specific and particular topics. Further research on the subject is recommended to avoid a situation where a significant portion of suppliers of throughout technical services, such as technical specific analysis, engineering and design activities, could represent the weak point for an effective SMR deployment. From this perspective it could be important to request a planned and structured preparatory program involving Member States universities and research centers.

19.3 Value Chain evolution

Aiming for a robust SMR Supply Chain, consideration should be given to those changes in the nuclear Value Chain which could derive from the SMR business models: they could affect the current positioning of the European nuclear industry in relation to competitors and require prioritising as well as the anticipation of the bottlenecks.

Some of these changes can be easily envisaged, others could emerge from a more specific analysis which could be better conducted on specific designs in the next phase of the Partnership.

a. *Modularisation:* Construction by modules is moving significant value from the site to the module assembly shops. Because of the need for quality certification of the plant construction, these assembly shops shall be properly organized to increase the efficiency and the productivity while maintaining full quality control.

b. *New tools and methods in SMR manufacturing*: as illustrated in para. 3.3, SMRs would largely benefit, because of their series approach to manufacturing, by new tools and methods.

   A change in the Value Chain which could be expected is the increased testing, including commissioning ones, at the manufacturer's shop (with potentially lower effort on commissioning at site). This would require to increase the capability to conduct testing at shops through specific facilities (e.g. pressure/flow testing of fluid circuits, operation testing of dedicated control systems).

c. More in general, and not specifically for SMR, the introduction of new methods able to increase productivity (e.g. electron beam welding, innovative NDE techniques, etc) would increase the value built into the shop products, and thus the competitiveness of the European suppliers.

d. *Fuel services:* SMR designs often require improved fuel performances, ranging from increased neutron efficiency and longer refuelling intervals for LW- SMR up to innovative fuel types and improved non-proliferation features for AMR. This implies an increasing value for fuel manufacturing and handling in the overall nuclear Value Chain (ref. to para. 2.5 for further discussion)

Last but not the least, the SMR business model is designed to better combine nuclear and renewables: in this respect, such a model would extend the nuclear Value Chain beyond the reactor and the associated fuel cycle, towards energy storage solutions, hydrogen production etc. Such kinds of developments should then be properly considered when focusing on EU investment priorities to favour the deployment of SMRs, and support it with a robust supply chain.

20 SUGGESTIONS FOR THE EUROPEAN PARTNERSHIP PHASE

20.1 Promoting of SMR Supplier's cooperation with the Vendors

It would be beneficial to initiate, facilitate and promote cooperation between the Supply Chain and the SMR Vendors. As mentioned in Chapter 1.1, the SMR 'series production' approach should imply an active involvement of Suppliers in the progressive cost/price reduction, considering that large part of the savings from replica manufacturing and erection will emerge in the Supply Chain. Therefore a "win-win" relationship should be promoted, where Vendors and Suppliers cooperate to accelerate the achievement of one-of-a-series price levels, which in turn will foster further penetration of the SMR in the market, granting further volumes and even long-term business planning for all the industrial partners.

The result of the study also indicates that the majority of Suppliers are ready to increase their output (Chapter 2.4) and then to cope with the increased capacity demand linked to SMRs.

Such an interaction would normally be promoted by each Vendor, possibly focusing on the first national market they are targeting. However, the European Partnership should consider to play an active role in favouring the interaction of broad European Supply Chain with the Vendors, for the following reasons:

- to give maximum visibility of SMR business opportunities to all EU suppliers;
- to maximize the European added value, by providing equal access opportunities to suppliers from different countries from the very beginning of the specific SMR development and deployment in the first country.

To such purpose, the European Partnership could promote as first step the creation, on voluntary basis, of an "EU Supply Chain database", and then organizing interactive events between interested Vendors and the suppliers participating to the database.

It is worth noting that, in order to achieve the economic benefits expected by manufacturing in series, investments in building of skills and competences should be planned carefully in advance: tight interaction between Vendors and Suppliers will be necessary to such purpose.

This would also further encourage on the excellent approach the Suppliers generally show toward product innovation and the new technologies which such a large fraction of suppliers is implementing or plan to implement the listed measures (Chapter 2.3).

When it comes to topics such as advanced techniques for manufacturing, advanced materials for non-LWR reactors, or the use of innovative technologies in general, an initiative could be taken by the EU SMR Partnership to foster collaboration between the European Supply Chain and reactor developers and Vendors through e.g. the organisation of nuclear innovation meeting days, where Suppliers and Vendors could exchange on their capabilities and specific needs (Chapters 3.3 and 3.4). The regulatory aspects should also be anticipated through active participation of regulatory bodies and national authorities.

It is important to enable the definition of one common technical specification per design. The industrial standardisation work during the design of an SMR needs to lead to a complete technical specification to be defined from start to finish: one complete design, set of technical and safety requirements and one qualification reference should be defined for each SMR design. This standardisation work should be developed by associating expert Suppliers in their field as much as possible and to secure their choice of design in terms of their feasibility and robustness.

Suppliers should be involved very early in the development of specifications, the choice of technical solutions, the analysis of manufacturing and the demonstration of conformity. At an equivalent level of safety, this approach will make it possible to resort to more robust solutions, achievable without fail with a guarantee of quality and compliance with deadlines and costs. The selection of partners by panels and medium-term joint investment (schools and training, crossed paths, industrial tools, etc.) on critical topics (such as welding, etc.) is also likely to secure project performance. In particular, decisions related to both front-end and back-end challenges, including logistics, should be taken early in the development phase. Thus, clear support from public authorities to guarantee the competitiveness of the EU SMR/AMR Supply Chain is a key to be ready on time and to provide a long-term visibility to service providers and accelerate their projects.

20.2 Promoting of discussion and cooperation on Regulatory matters

Furthermore, it would be crucially beneficial to increase the level of harmonisation of requirements, or their interpretation and cooperation between the European Nuclear Safety Regulators.

As mentioned in the Chapter 1.1, for SMRs to be deployable at scale, standard designs should be adopted at a multi-national level by a group of interested EU countries, including acceptance of the associated set of Codes & Standards used in the standard design. Mobilizing the European Supply Chain will require the prospect for group orders (economies of scale).

According to supplier questionnaire answers the existing suppliers are capable of supplying to ASME-based and RCC-based systems, and majority see reconciliation possible. However, cooperation between regulators should be recommended e.g. concerning unification of the way to implement quality requirements of codes and standards in order to better utilize the potential of SMR deployment benefits (Chapter 2.3). Benchmarking for actual differences would be the first step in this direction

Reaching a common position among regulators to recognize the equivalence between well-established NC&S, at least in parts (e.g. material specifications, NDE, etc.), would be beneficial in order to limit the need of the Vendors to demonstrate such equivalence each time they are developing a safety case for licensing (Chapter 3.1). An opportunity to such purpose could be the Phase 4 of the CEN workshop 64 that will be launched in 2023.

Factory manufacturing is set to bring the focus of the future licensee and the regulatory body from the site to the Vendor's manufacturing facilities. This situation may be a challenge in cases where the Vendor and future licensee are geographically far apart from one another, or when the working language of the Vendor is not well understood by the future Licensee and Regulator's personnel. This is an area where national Regulators or their accredited inspection agencies (notified bodies) could successfully collaborate to perform oversight activities in local factories on behalf of other Regulators.

Advanced Modular Reactors aim to respond to a market segment that is of crucial importance to decarbonization and energy independence, as well as waste minimization. It is therefore essential that the AMR track also receives full attention from EU countries and their nuclear "ecosystems", including Regulators and the Supply Chain. In particular it is recommended to promote R&D activities that support the Supply Chain in areas such as advanced reactor fuels and materials. Cooperation between Regulators in early safety assessment of AMR designs would be beneficial to accelerate time to market.

20.3 Fostering policy commitment: Suppliers urge for visibility

The lack of business outlooks in nuclear build strains companies in the sector which must make a substantial investment effort to maintain their skills and manufacturing tools dedicated to nuclear. They need sufficient predictability of business viability in order to maintain or to develop their skills and industrial capacity. Plans are likely to be implemented only after there is imminent visibility on an SMR construction program and its legitimacy by public authorities.

The successful introduction of SMRs in the EU market will go hand in hand with the provision of new services related to fuel cycle requiring additional industrial facilities. For that reason, strong signals from policymakers are needed to incentivize investments in fuel services (Chapter 2.5, Fuel cycle issues).

Decisions related to both front-end and back-end – including logistic – challenges should be made early in the development phase. For all AMRs, which could represent the best EU industry opportunity but will need the deepest supply chain adaptation (HALEU and Molten Salt Fuel), there is still a lot of uncertainties on the market and therefore, the risk is that the EU fuel cycle value chain do not have sufficient signals to implement necessary investment decisions. Thus the promotion of eligible business environment by the public authorities would be a key for the EU SMR Supply Chain to be ready on time.

Furthermore, the issue of raw material availability and cost escalation should be strictly monitored in the near future in consideration of geopolitical and economic scenarios actually in place and not only in EU (raw material availability and prices escalation). (Chapter 2.4, Manufacturing materials and resources).

As highlighted in para. 4.2, insufficient human resources are possibly the most important bottleneck for SMR deployment: it could be important to request a planned and structured preparatory program involving Member States, universities and research centers.

Finally, most of the considerations reported in para.4 “A robust supply chain for the future” should possibly influence future EU policies related to SMRs.

21 CONCLUSIONS

The goal of the European SMR Pre-partnership Work Stream 4 concerning Supply Chain adaptation was to identify inherent features of an SMR Supply Chain, analyse the existing gaps and present ways to overcome the mostly technology-independent challenges. An analysis was made on the key features of the SMR demand, including different business models, described the European offer - based on the different SMR product categories, and defined how the EU Supply Chain can meet the future challenges of the introduction of SMR in the EU territory, while considering specific SMR relevant issues.

The Work Stream 4 e.g. analysed questionnaire answer data gathered directly from both potential SMR Vendors and Suppliers during 2022. The analysed statistics were also reinforced with NEI database of European contractors. As a conclusion it can be stated that the readiness for SMR deployment, supporting it as a supplier and willingness to develop the readiness further is encouraging.

On the basis of the analysis work many possibilities to further enable the European SMR Supply Chain value chain in the future via the European SMR Partnership work were identified. The ones estimated to have the best potential for creating significant improvement at the moment via the European SMR Partnership can be structured into three main areas:

- Initiating and facilitation of SMR Supplier's cooperation with the Vendors
- Promotion of cooperation between the European Nuclear Safety Regulators and harmonisation of requirements and their interpretation
- Fostering policy commitment: Suppliers urge for visibility

Several lessons can be drawn up from the nuclear reactors build programs and with regard to the management of its supply chain. In order to develop a fleet of SMRs in Europe, it is important to learn lessons from the past experience within the nuclear sector, and even in other sectors (naval, aviation, etc). The Suppliers need also to adapt their manufacturing process by proceeding from supplying highly complex heavy components to manufacture smaller components in bigger quantity. The industrial sector must remain at the highest level of rigor, quality and operational excellence to meet the execution of a SMRs fleet in Europe. The suggestions for the European SMR Partnership phase presented in Chapter 5 cover the overall cooperation of the Suppliers, Vendors and European institutions.

Appendixes

Appendix 1 - Summary of Vendor answer analysis

Appendix 2 - Summary of analysis of the Supplier questionnaire answers

Annexes

Annex A – Vendor Questionnaire

Annex B -Questionnaire, European supply chain in the context of SMR deployment

Annex C – Product categories

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