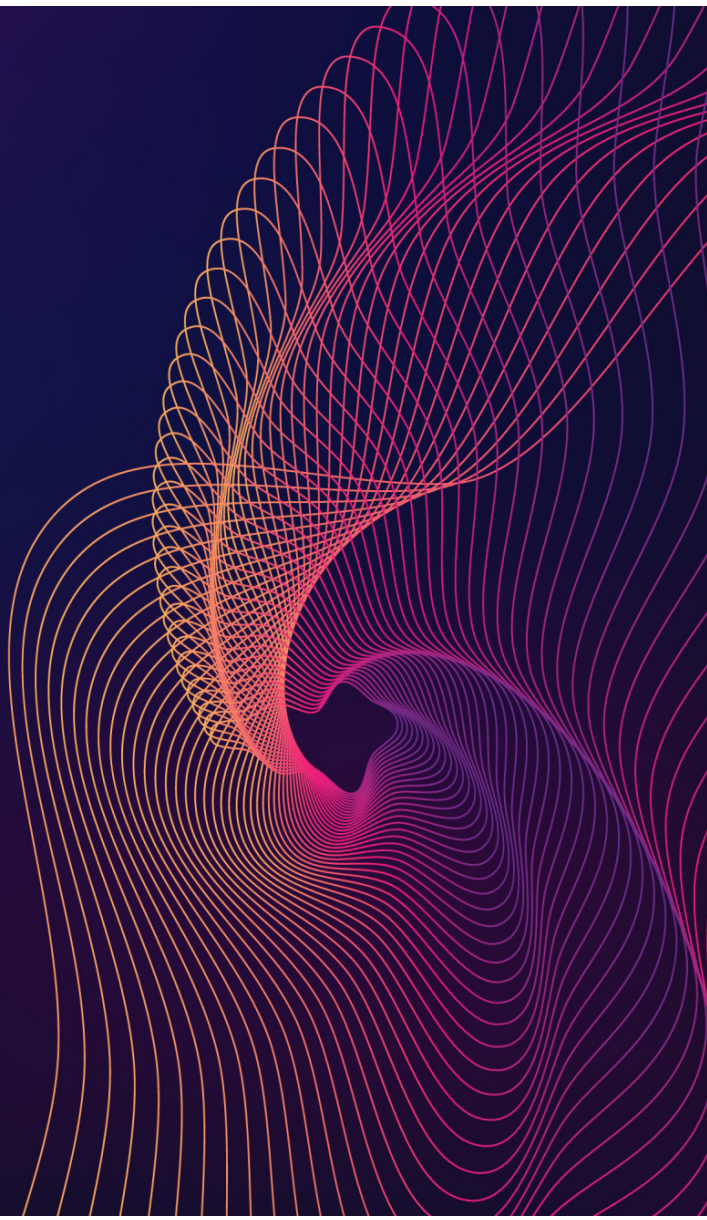
European Commission

nuclear europe

SNETP
Sustainable Nuclear Energy Technology Platform

European Industrial Alliance on SMALL MODULAR REACTORS



Strategic Action Plan 2025-2029

Towards the development and deployment of SMRs in Europe

European Industrial Alliance on SMRs 2025



The Commission Communication titled 'Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050, building a sustainable, just, and prosperous society' emphasises the necessity of utilising all technologies to achieve the EU's climate neutrality goal by 2050. It also introduced a new European Industrial Alliance to accelerate the development, demonstration, and deployment of Small Modular Reactors (SMRs) in Europe by the early 2030s.

The European Industrial Alliance on SMRs functions through specialised thematic working groups to enhance the conditions necessary for SMR development, demonstration, and deployment, including revitalising the nuclear supply chain. Its activities are designed to support specific SMR projects and their introduction into the European market.

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European Industrial Alliance on SMALL MODULAR REACTORS

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01 Introduction



> The European Industrial Alliance on Small Modular Reactors (SMRs) aims to facilitate and accelerate the development, demonstration, and deployment of SMRs in Europe by the early 2030s.

In an era characterised by ambition and determination to advance the European policy agenda on **industrial competitiveness** and **decarbonisation**, there is an urgent need for **Small Modular Reactors** (SMRs) as a part of the response to the demand for **reliable low-carbon energy** solutions that will enable the European industry to remain strong and competitive while driving the **energy transition** towards a **carbon-neutral** future **by 2050**. Maintaining the competitiveness of the European industry is crucial for **economic, strategic**, and **social reasons**. The nuclear landscape of Europe has significantly evolved in recent years. Amidst a renewed interest in nuclear energy and technologies, many EU Member States that use nuclear energy, including France, Slovakia, the Czech Republic, the Netherlands, Sweden, Romania, and Bulgaria, as well as newcomers such as Poland, have decided to launch ambitious programmes to support **new nuclear build**. Most of them also consider the integration of SMRs into their future nuclear fleet.

SMRs, encompassing both Light Water SMRs and Advanced Modular Reactors (AMRs), are anticipated to complement the current and future fleet of large nuclear power reactors and other **low-carbon energy sources**. They are expected to provide a versatile and efficient solution to meet increasing energy demands. This demand is primarily driven by the need to replace coal-fired plants, the anticipated electrification of various economic sectors—including energy-intensive industries, e-mobility systems, hydrogen and e-fuel production, and data centres—and the expanded use of low-carbon heat by industry and urban districts. AMRs based on fast reactor technologies also present promising perspectives for limiting Europe's import dependency on fresh uranium and reducing the long-term radioactive waste inventory that will have to be disposed of in deep geological repositories.

The renewed focus on nuclear energy and the growing interest in SMR technologies go beyond the EU. At the World Climate Action Summit, part of the 28th Conference of the Parties (COP 28) to the U.N. Framework Convention on Climate Change, more than 20 countries from four continents launched the Declaration to Triple Nuclear Energy. The Declaration aims to promote the use of nuclear energy as a low-carbon energy source to aid in mitigating climate change. Nuclear energy is increasingly considered a **complementary source** to renewable energy, enhancing the overall **grid stability** and building a **resilient and cleaner energy system**. SMRs and AMRs can enable more flexible deployment and integration with other energy sources in the energy mix, thereby achieving **sustainable development** in the future.

Support for their development is taking shape worldwide. The UK has a government-backed initiative to develop and deploy a new generation of nuclear power plants. Its Advanced Nuclear Fund of up to £385 million includes up to £215 million for SMRs and up to £170 million for a research and development programme to deliver an AMR demonstration by the early 2030s. In the US, in addition to a strong push for nuclear energy from the US government, the US DOE has committed up to $3.2 billion for the US advanced reactor programme.

In the EU, the **European Industrial Alliance on SMRs** was established in February 2024 (see magenta box) , with a clear objective "to facilitate and accelerate the development, demonstration, and deployment of the first

SMRs projects in Europe in the early 2030s, by assisting emerging SMRs projects to reach the demonstration and deployment phase". This will be achieved by providing t**ailored support** to identified **SMR projects** and working on establishing **long-term enabling conditions** for their development in line with the Alliance's project-oriented approach.

In its first year of operation, the Alliance's work was mainly focused on laying the foundations and establishing the operational structure for carrying out its work. Eight Technical Working Groups (TWGs) have been established on key issues for further development and deployment of individual SMR projects in Europe. At the end of 2024, **nine SMR projects** were identified as the **first batch of projects to form the core of the Alliance** and benefit from the work of the TWGs. Each of the identified projects formed a Project Working Group (PWG) to organise the support and guidance from the Alliance for its project.

Under the steer and oversight of the Alliance's Governing Board , the TWGs have worked with PWGs to prepare the first key deliverable of the Alliance, its **Strategic Action Plan**. It is centred around **ten targeted Actions to be delivered by the Alliance through the TWGs in collaboration with the PWGs over the next five years**. The **actions** seek to address the **key challenges** to the deployment of SMRs in Europe as identified by the Alliance. They are defined in consideration of the policy context (the EU energy policy framework and the role of nuclear energy within it) as well as the technology context (SMR technologies and their characteristics).

Nuclear energy and SMRs in the EU policy framework

In line with the EU's climate neutrality objective and the REPowerEU Plan, the Commission has recently emphasised the role of low-carbon energy sources in its Communication "Securing our future. Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society" adopted in February 2024[1].

In January 2025, the Commission adopted the Communication: "A Competitiveness Compass for the EU" highlighting the importance of a stable and predictable policy framework for the EU's energy sector to strengthen the EU industrial base[2]. In May 2025, the European Commission presented the REPowerEU Roadmap[3], to gradually **phase out Russian oil and gas**, and restrict the import of uranium, enriched uranium and other nuclear materials deriving from Russia while simultaneously accelerating the transition to clean energy. At the beginning of July it also proposed an amendment to the European Climate Law[4] to set an EU climate target for 2040[5], where the **role of nuclear**, along with other technologies, was emphasised.

Furthermore, the Net-Zero Industry Act (NZIA)[6] ,adopted last year, would be instrumental in **facilitating** and **accelerating** the **manufacturing of nuclear components** within the EU and could serve as a powerful legislative tool to strengthen and revitalise the nuclear supply chain development in the coming years. The Nuclear Illustrative Programme (PINC)[7], adopted by the Commission in June 2025, provides an up-to-date, comprehensive, fact-based overview of **nuclear energy investment needs across the EU**, underlining the r**ole of nuclear** to "supply clean power, suitable for l**ow-carbon baseload electricity**, also enhancing **system integration** and providing **flexibility** facilitating further roll-out of other **clean technologies**", as announced in the Affordable Energy Action Plan[8] adopted earlier in 2025.

Against this backdrop, 13 Member States endorsed the establishment of an **Important Project of Common European Interest** (IPCEI) initiative on innovative nuclear technologies,

1 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52024DC0063

2 https://commission.europa.eu/topics/eu-competitiveness/competitiveness-compass_en

3 https://energy.ec.europa.eu/strategy/repowereu-roadmap_en

4 https://climate.ec.europa.eu/document/download/e1b5a957-c6b9-4cb2-a247-bd28bf675db6_en?filename=Proposal%20for%20a%20Regulation_0.pdf

5 https://commission.europa.eu/news-and-media/news/eu-climate-law-new-way-reach-2040-targets-2025-07-02_en

6 https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

7 Communication on the Nuclear Illustrative Programme under Article 40 of the Euratom Treaty - European Commission

8 https://energy.ec.europa.eu/publications/action-plan-affordable-energy-unlocking-true-value-our-energy-union-secure-affordable-efficient-and_en

EU Energy & Industrial Policies
Nuclear energy & SMRs

EU Climate Neutrality Objective

The EU sets a goal to achieve climate neutrality by 2050
EU climate target for 2040 proposal

Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society

Communication

Competitiveness Compass Initiative
Clean Industrial Deal
Affordable Energy Action Plan
EU Start-up and Scale-up Strategy

Enhancing the European Union's global competitiveness by closing the innovation gap, accelerating the decarbonisation of the economy, and reducing strategic dependencies

EU's strategy to remove Russian oil, gas and nuclear energy imports from EU markets in a gradual and coordinated way

REPowerEU Roadmap

Net-Zero Industry Act (NZIA)

Regulation to support the development of net-zero industries. Strength and revitalise EU nuclear supply chain

13 Member States for a project to support innovative nuclear technologies, including SMRs

IPCEI on Innovative Nuclear Technologies

Nuclear Illustrative Programme (PINC)

A programme assessing nuclear investment needs by 2050 in view of decarbonisation and competitiveness goals

As announced on the Affordable Energy Action Plan a Strategy for SMRs in Europe to be adopted in 2026

Communication on SMRs

providing a collaborative framework to develop and support ambitious R&D projects, experimental facilities and First Industrial Deployment (FID) projects in the nuclear sector.

Finally, the European Commission has launched the EU Startup and Scaleup Strategy[9]. It focuses on **fostering innovation**-friendly regulation, improving access to finance, accelerating market uptake and expansion, attracting and retaining top talent, and facilitating access to infrastructure, networks, and services.

SMRs characteristics and technologies

SMRs promise a number of inherent characteristics, such as **simplicity of design**, **enhanced safety feature**s, and the **economics of factory production**, that make them appealing to policymakers, industries, and investors. These smaller reactors, which could be built in modular units, are set to offer **flexibility** in addressing **diverse energy needs**, including district heating, industrial heat, hydrogen and e-fuel production. (Information about specific SMRs technologies is provided in Annex III of the document).

Business cases based on cogeneration (electricity and heat), or even heat only, are promising[10]. The sizes of SMRs are well-suited to meet the demands of **urban heating networks** and **large industrial facilities**. In this regard, AMR technology holds the potential to provide **high-temperature heat** (exceeding 300°C and reaching up to 600-700°C), thereby offering an **alternative to fossil fuel-based solutions**, such as natural gas, and consequently **mitigating CO_2 emissions** and **reducing reliance on imports**.

SMR/AMR projects can provide grid services to accommodate the **intermittency of renewables** or help **decarbonise specific industrial processes**, such as **hydrogen production** or **desalination**.

Furthermore, SMR development is expected to have a profound **impact on innovation beyond the nuclear sector**. These anticipated advancements include cutting-edge areas such as **modular manufacturing**, **advanced materials**, and **digital integration**. Modular construction and manufacturing techniques pioneered for SMRs can be applied to other industries, including wind turbines, battery storage systems, and emerging ammonia or hydrogen production systems, particularly when they are designed to be part of local energy hubs.

The development of advanced materials and high-temperature applications may have far-reaching benefits for the **aerospace and automotive industries**, with potential applications in turbine blades, thermal protection systems, and heat-resistant materials for electric vehicles, as well as advancements in hydrogen fuel cells. Additionally, the integration of Digital Twins and AI-driven optimisation is revolutionising smart grid development. **Predictive maintenance** is becoming increasingly essential in the automotive and electronics sectors as it drives innovation and efficiency across multiple industries.

Fast neutron AMRs are bringing **technological bricks** that are valuable for optimising the use of fresh uranium resources (and therefore minimising mining), which could strengthen the **energy security** of the EU and **reduce long-term radioactive waste**.

No high-flux fast neutron reactor is currently operating in the EU, while China, the US, Japan, and especially Russia are developing and even operating such technologies. Some of these technologies are innovative on both the reactor and fuel sides. However, the EU has substantial assets and competences in these technologies (some Gen IV reactors operated in the EU until 2010), which should be reinvigorated to support their swift development.

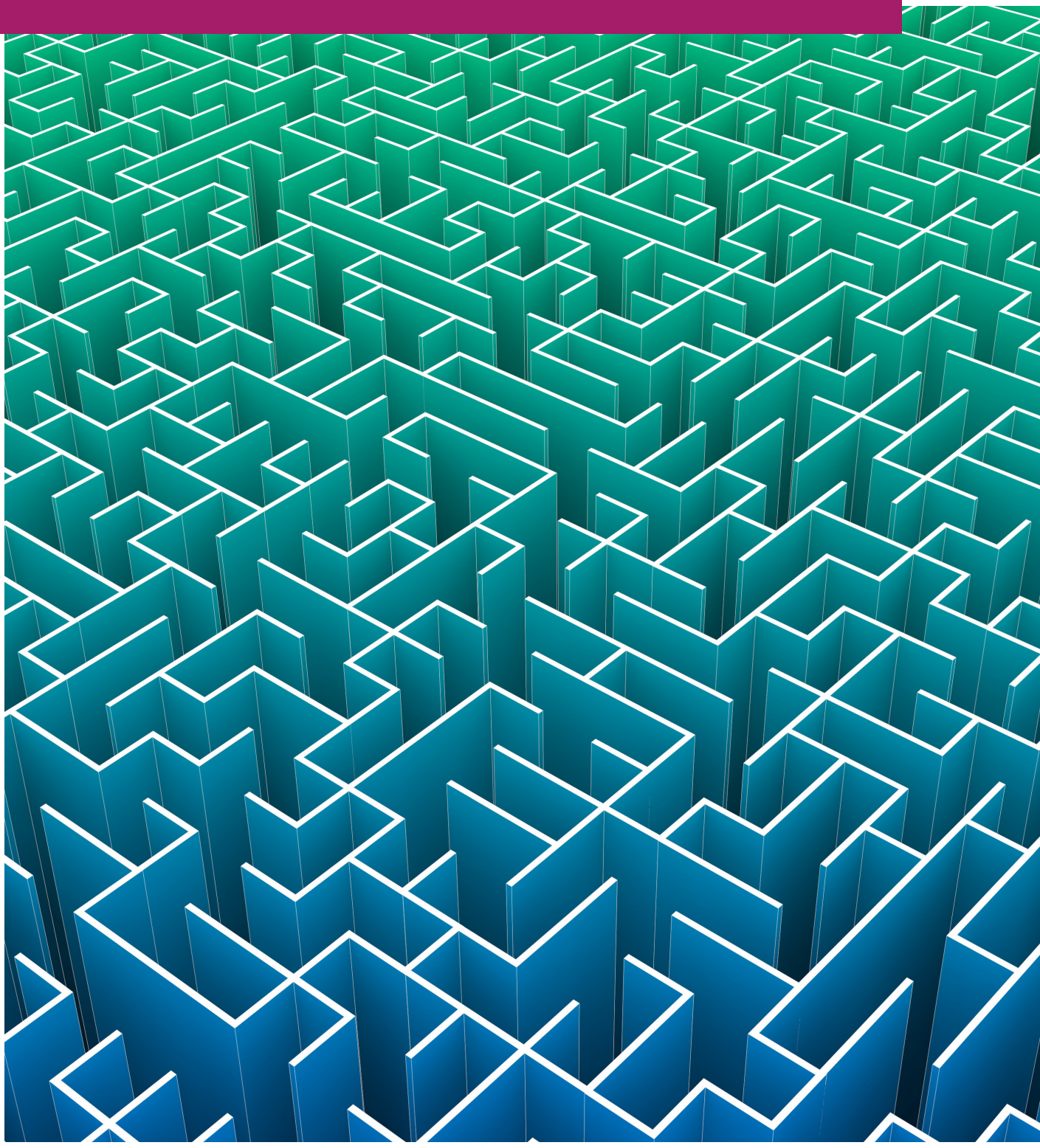
9 https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/jobs-and-economy/eu-startup-and-scaleup-strategy_en

10 A nuclear reactor produces heat, which is then transformed into electricity with an overall efficiency between 33% for light water reactors and up to 50% for AMRs. As a result, utilising heat directly rather than converting it into electricity not only eliminates conversion losses but also enhances the overall energy efficiency of a cogeneration reactor to between 60% and 80%, compared to generating electricity alone.

SMR & AMRs Characteristics



02 Key Challenges



> Coordinated progress across multiple areas is essential to enable the effective rollout and sustained impact of SMR projects in Europe over the coming decades. This **integrated approach** is critical for ensuring regulatory alignment, infrastructure readiness, public acceptance, and investment mobilisation.



The journey from developing to deploying SMRs is multifaceted and non-linear. Like other major industrial projects, it requires strong industry and public sector engagement, commitment and collaboration among diverse stakeholders, including policymakers, regulators, researchers, innovators, educators, private investors, and a broad supply chain of specialised and competent companies. This support is particularly critical as the development of SMRs is part of a **global technological race**.

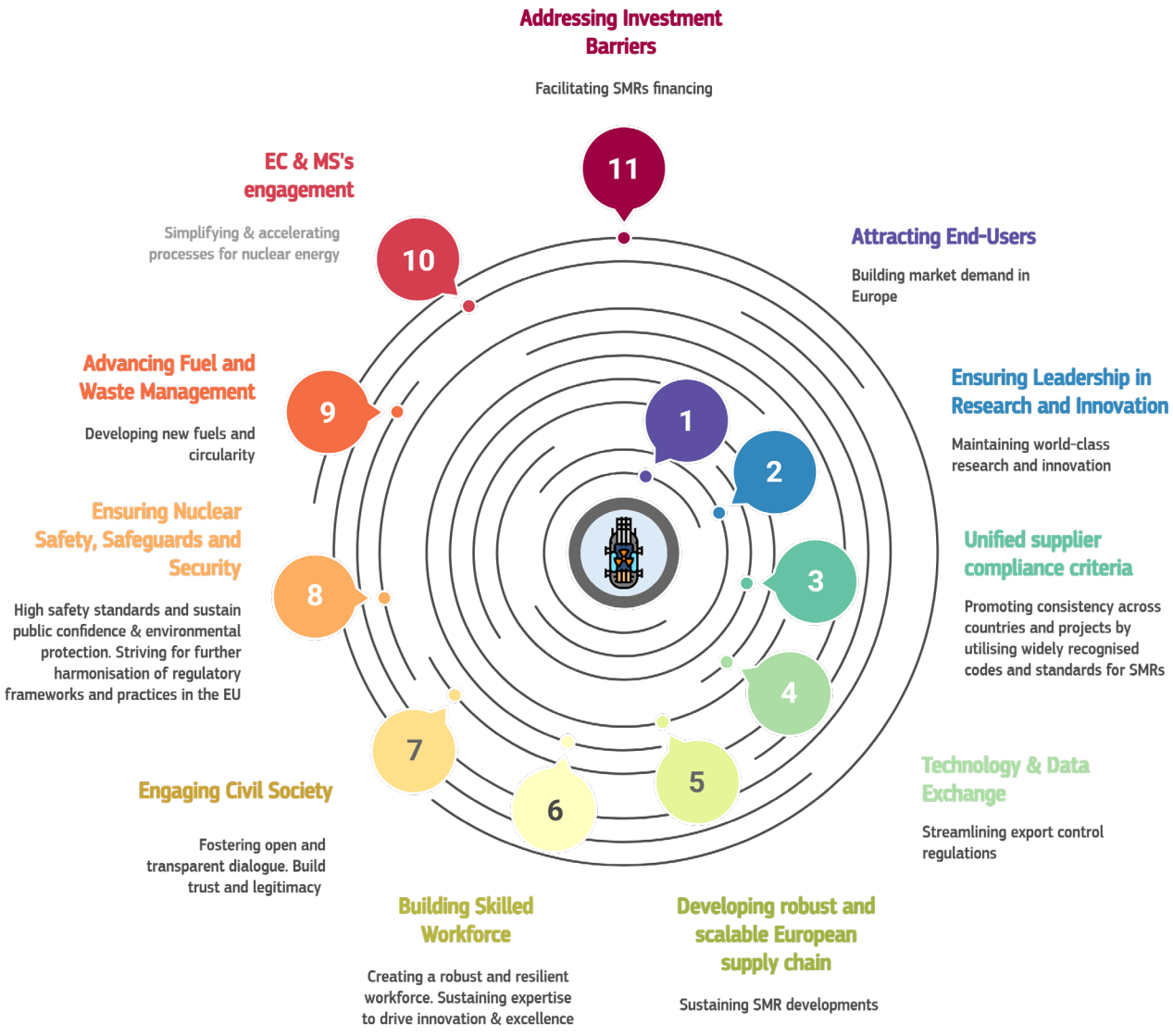
For the successful implementation of a significant number of SMRs projects in Europe over the following decades, it is essential to address multiple areas simultaneously, starting immediately by:

- Creating a **strong market demand** and business cases for SMRs to attract public and private investments;
- Simplifying and accelerating the process of obtaining **state aid** for nuclear energy, considering its ability to operate as a base load or in combination with renewables;
- Strengthening the **EU R&D leadership**, based on a strong commitment of key EU stakeholders to continue pursuing **R&I** efforts in Europe, further solidifying the EU's position at the forefront of SMR development;
- Promoting **limited sets** of widely recognised **codes and standards** for Small Modular Reactors (SMRs) developed and deployed in Europe, to be widely used for R&D and design development, equipment manufacturing and fuel supply;
- Facilitating the e**xchange of technology** and **data** between EU Member States by simplifying and streamlining **export control** regulations as far as practicable
- Developing a **robust** and **scalable** European **supply chain** fostered by a **dynamic ecosystem** of well-established firms, innovative SMEs, and specialised start-ups;
- Equipping the **European workforce** with the right **skills** and competencies, ensuring that expertise and know-how are maintained and sustainable to drive innovation and strengthen the longstanding excellence in this areas area;
- Ensuring **public engagement** and **awareness** as they help build trust and legitimacy around SMRs projects;
- Implementing safety, security, safeguards and sustainability as the cornerstone of this sensitive economic sector, ensuring that SMR projects adhere to **high safety standards** and sustain **public confidence** and **environmental protection**. Striving for further **harmonisation of regulatory frameworks** and **practices** in the EU, both on nuclear and non-nuclear aspects;

- Securing a **robust fuel cycle** approach, based on harnessing existing domestic capabilities, **waste minimisation** and **circularity**, particularly for AMRs, and unlocking **investments** sustaining the growth and viability of these innovative projects in the long term;
- Finally, by **eliminating investment barriers** and providing suitable **financing schemes** for these projects' future deployment and commercial success.

Overcoming these challenges would ensure that Europe maintains a **leading global position**, secures its **strategic autonomy**, and anchors **intellectual property** within its borders. Consequently, SMR projects should be supported to safeguard **European leadership** in the future. The backing of the European Commission and Member States is vital to enhance the likelihood of success, as the development of such projects necessitates **clear institutional**, **political**, and **financial support**.

Overcoming SMR Development Challenges



The creation of the European Industrial Alliance on Small Modular Reactors (SMRs)

To facilitate SMR development at the EU level, the European SMRs Pre-partnership, established in 2021[1] , was decisive in identifying key barriers and opportunities and assessing the required conditions for SMR development over the next decade. Following the publication of its results, the Pre-partnership proposed the establishment of a European Industrial Alliance on SMRs to unite a broader spectrum of SMR stakeholders under a shared vision and a joint plan for action to pursue this work over the next years.

The European Industrial Alliance on SMRs, established in February 2024[2], with the general objective *"to facilitate and accelerate the development, demonstration, and deployment of the first SMRs projects in Europe in the early 2030s"*, by assisting emerging SMRs projects to reach the demonstration and deployment phase". This will be achieved by providing tailored support to several identified SMR projects and working on establishing long-term enabling conditions for their development.

The Alliance organisational structure

At the inaugural General Assembly held in May 2024, eight TWGs were established, and a chair and vice-chair were appointed for each of them; both positions have a term of two years and can be extended as necessary. Their responsibilities include overseeing the coordination of the TWGs' work, approving their deliverables, and reporting to the Governing Board. Furthermore, the chair of each TWG serves as a member of the Governing Board, as outlined in the Alliance's Terms of Reference, and as a direct contact point to the PWGs.

All TWGs have established several subgroups and drafting teams to share the workload and deliver the expected outcomes. Subgroups are permanent entities, while drafting teams are ad hoc to tackle specific tasks. Drafting teams can be reactivated as needed to update their initial work. Both subgroups and drafting teams are led by a leader, who comprises volunteer TWG members. Subgroup and drafting team leaders are expected to work closely with and report to the chair and vice-chair of their respective TWGs.

The Governing Board oversees all activities conducted under the Alliance and offers guidance on its strategic priorities. It comprises the eight TWG chairs, representatives of the European Commission, which also chairs the Governing Board, and representatives of nucleareurope and the Sustainable Nuclear Energy Technology Platform (SNETP). Since its inception in June 2024, the Governing Board has been convened every 2-3 months. The European Nuclear Safety Regulators Group (ENSREG) participates as an observer.

1 European SMR pre-Partnership - nucleareurope
2 European Industrial Alliance on Small Modular Reactors - European Commission

03 The Way Forward





> The Strategic Action Plan outlines a shared vision and commitment to guide the Alliance's efforts over the next five years

The Strategic Action Plan for Alliance's way forward

This **Strategic Action Plan** outlines an ambitious **roadmap** aimed at steering the Alliance's efforts over the next five years. It embodies a **shared vision** and the collective commitment of the Alliance's members to work together to facilitate the **development, demonstration**, and **deployment** of **SMRs** in **Europe** by the early 2030s, which is the Alliance's core objective.

It aims to keep the Alliance's work focused on delivering **targeted support** to the **SMR projects** identified by the Governing Board and supporting them in their timely and successful deployment.

Following a **collaborative effort** of its members, the Alliance has identified the following **Top Ten targeted Actions outlined in the table below, which will be delivered by the Alliance through the TWGs in collaboration with the PWGs over the next five years.**

The successful implementation of these ten targeted actions will require prior or parallel implementation of **activities** detailed in this document's second part and listed under each **specific TWG** (Annexes I and II). The planning, prioritisation and execution of all these activities will be discussed between TWGs and the PWGs over the next period following the plan's endorsement in the 2nd General Assembly of the Alliance. The Alliance's **key innovative research areas** for SMRs are included in Annex III.

The Annexes have been developed through **extensive exchanges** of TWGs with PWGs and consist of the work of several hundred experts across Europe from many different stakeholders covering a wide range of disciplines, such as SMR designers, nuclear reactor utilities, supply chain representatives, finance and economics actors, policy makers, intensive users, NGOs, research, and innovation organisations. They incorporate valuable insights and suggestions from each TWG and the targeted support needs highlighted by the PWGs.

In the framework of this extensive collaboration between Alliance members, their TWGs and identified projects' PWGs, key hurdles to constitutive activities, and specific tasks to address them have been identified to enable steady progress. To facilitate effective implementation, the **plan's actions** are carefully **aligned** with the **Alliance's organisational framework**, structured around the eight TWGs, allowing for streamlined **feedback** and **rigorous progress monitoring**.

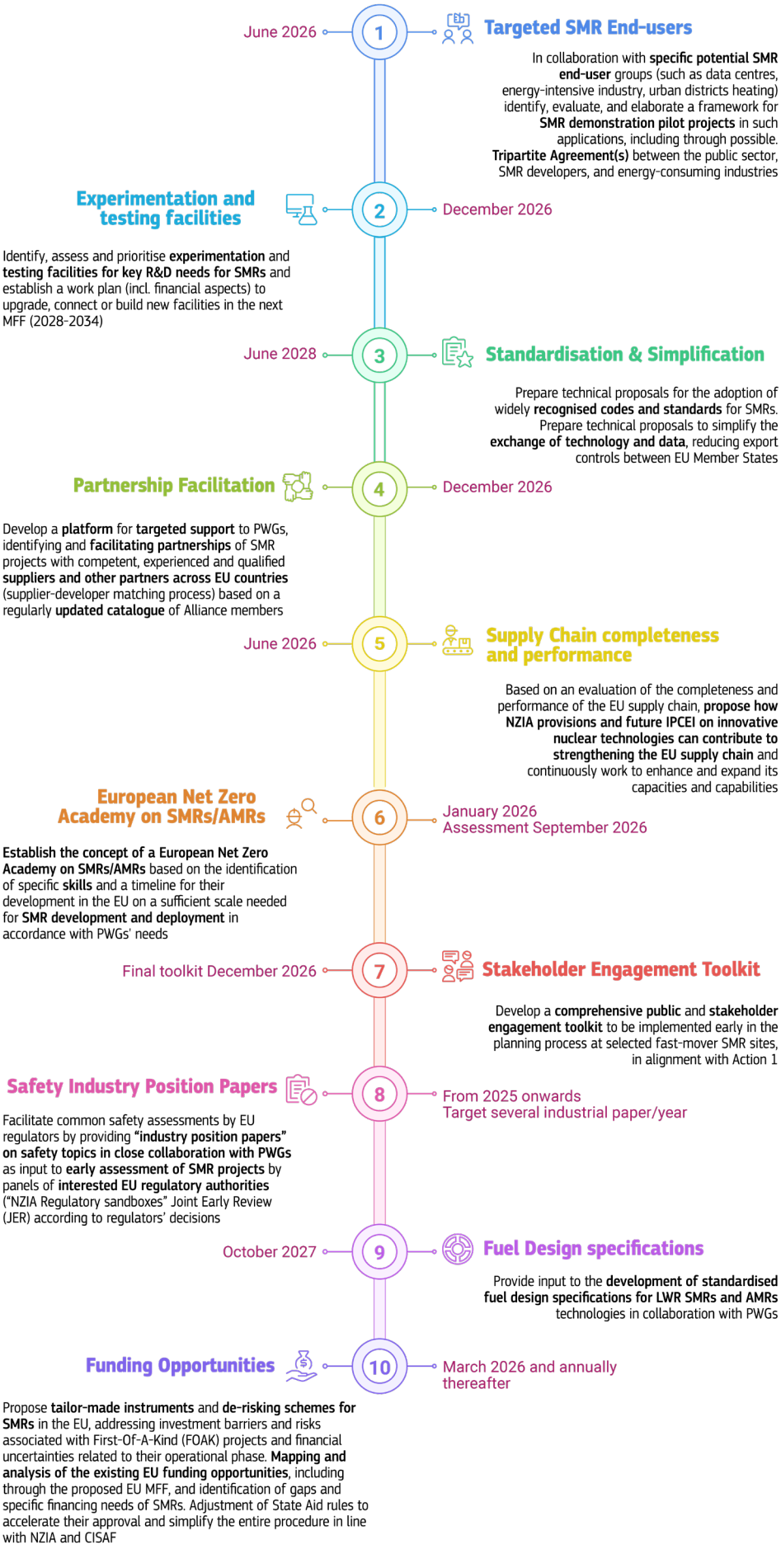


Top Ten Actions	Targeted Date
1. **In collaboration** with **specific potential SMR end-user groups** (such as data centres, energy-intensive industry, urban districts heating) identify, evaluate, and elaborate a framework for **SMR demonstration pilot projects** in such applications, **including** through possible **Tripartite Agreement(s)** between the public sector, SMR developers, and energy-consuming industries	June 2026
2. **Identify**, assess and prioritise **experimentation and testing facilities for key R&D needs for SMRs** and establish a work plan (incl. financial aspects) to upgrade, connect or build new facilities in the next MFF (2028-2034)	December 2026
3. **Prepare technical proposals for the adoption of widely recognised codes and standards** for SMRs. Prepare technical proposals to **simplify the exchange of technology and data, reducing export controls between EU Member States**	June 2028
4. **Develop a platform** for **targeted support to PWGs, identifying and facilitating partnerships** of SMR projects with competent, experienced and qualified **suppliers and other partners across EU countries** (supplier-developer matching process) based on a **regularly updated catalogue** of Alliance members	December 2026
5. Based on an evaluation of the completeness and performance of the EU supply chain, **propose how NZIA provisions and future IPCEI on innovative nuclear technologies can contribute to strengthening the EU supply chain** and continuously work to enhance and expand its capacities and capabilities	June 2026
6. **Establish the concept of a European Net Zero Academy on SMRs/ AMRs based** on the identification of specific **skills** and a timeline for their development in the EU on a sufficient scale needed for S**MR development and deployment** in accordance with PWGs' needs	January 2027 (assessment by September 2026)
7. Develop a **comprehensive public and stakeholder engagement toolkit** to be implemented early in the planning process at selected fast-mover SMR sites, in alignment with Action 1	Pilot test - March 2026 Final toolkit December 2026
8. Facilitate common safety assessments by EU regulators by providing **"industry position papers" on safety topics in close collaboration with PWGs** as input to **early assessment of SMR projects** by panels of **interested EU regulatory authorities** (through "NZIA Regulatory sandboxes" or other mechanisms such as Joint Early Review (JER) according to regulators' decisions)	From 2025 onwards (Target: several industry position papers per year)
9. Provide input to the development of **standardised fuel design specifications for LWR SMRs and AMRs** technologies in collaboration with PWGs	October 2027
10. **Propose tailor-made instruments**[1] and **de-risking schemes for SMRs** in the EU, addressing investment barriers and risks associated with First-Of-A-Kind (FOAK) projects and financial uncertainties related to their operational phase. The action will be based on a **thorough mapping and analysis of the existing EU funding opportunities**, including through the proposed EU MFF, and identification of gaps and specific financing needs of SMRs[2]. Adjustment of State Aid rules to accelerate their approval and simplify the entire procedure in line with NZIA and CISAF	March 2026 and annually thereafter

1 e.g. funding or financing opportunities for SMR projects via key European financial institutions like EIB and EIF or through European funds

2 e.g. guarantee schemes for SMR PPA´s, full inclusion of nuclear energy sources and other zero-emission energy sources under the EU taxonomic criteria for sustainability

Top Ten Actions and Targeted Dates



04 Implementation



> In late 2025, a key goal is to identify 'Fast Movers' SMR/AMR projects from the updated PWG list for targeted Alliance support

The key activities to be undertaken and the tasks assigned to each TWG in the execution of the **Top Ten Actions** of the **Strategic Action Plan** are provided in detail in the second part of this document (Annex I and II). The implementation activities may include interviews and meetings with industry experts and financial institutions to gather insights, foster partnerships, and **develop guidance** notes and **policy recommendations** on specific topics. Furthermore, webinars and thematic workshops tailored to the needs of PWGs will facilitate knowledge sharing and create new opportunities for collaboration

The successful implementation of specific actions requires **close collaboration** and **coordination** among TWGs and between TWGs and PWGs. This **inter-group collaboration** is crucial, as it would not only leverage synergies and enhance task execution but also facilitate sharing best practices, lessons learned, and expertise across groups, ultimately driving collective progress within the Alliance.

Moreover, these collaborative efforts may help PWGs identify and connect with potential partners while supporting the **development of R&D proposals** under the **Euratom Research and Training Programme**. Ultimately, the Alliance, particularly through the collaboration of PWG-TWG, is expected to **incubate ideas and projects** that could receive support under the new IPCEI (Important Programme of Common European Interest) for innovative nuclear technologies, other EU programmes, or financial institutions such as the European Investment Bank (EIB).

Although each TWG will typically operate independently, following its action plan and priorities, collaboration between TWGs with shared interests will be promoted to enhance efficiency and knowledge sharing.

Following endorsement of the Strategic Action Plan, the **collaboration between the Alliance's PWGs and TWGs** will need to become even more **regular and extensive**. Most of the **planned actions will be carried out in close partnership with interested PWGs**, who are anticipated to be the primary beneficiaries of the expected outcomes of the Alliance. To facilitate collaboration between PWGs and TWGs while maintaining confidentiality, the Alliance secretariat has prepared **Non-Disclosure Agreements (NDAs)** that have been signed by PWG representatives and Governing Board members and should be signed by all Alliance members wishing to participate in meetings and discussions with PWGs. In this context, the **PWGs** will be expected to **provide key information and take an active role in shaping the work of TWGs** on individual tasks, ensuring the efficient and effective implementation of the action plan.

It is worth noting that most TWGs have already begun developing and implementing various actions according to their scheduled timelines, through their subgroups or drafting teams that have been set up to coordinate and advance the work under each TWG.

PWGs streamlining process

Considering the **dynamic nature of SMRs** projects, which see on one side some projects developing very fast while others are slowing down or even stopping, and the need to ensure that the **resources** of the Alliance are **used most efficiently**.

The Governing Board decided to put in place a **regular reassessment process** of the PWGs.

This process is indicated in the announcement made regarding the identification of the first batch of nine PWGs, where it was noted that: *"These projects will remain subject to compliance with the 14 criteria as per annex 1 of the ToRs during the whole duration of the Alliance support and a reassessment of these projects according to the* **ToR criteria** *may be carried out under the Governing Board guidance at any time"*. All PWGs were made aware of this requirement when they were informed about the result of the identification process of PWGs.

This process will be implemented for the first time immediately after the 2nd General Assembly to ensure that all **PWGs consistently meet the criteria** outlined in Annex I of the Alliance's ToR throughout the Alliance's lifecycle. By regularly **reassessing compliance**, the Alliance seeks to maintain its commitment to fostering PWGs which uphold its core values and objectives, thereby ensuring the effective and focused use of its resources.

In this context, the goal for the second half of 2025 will also include identifying the '**Fast Movers**' among the PWGs that could be **prioritised for support** by the Alliance. Additionally, it will be essential to determine **key actions for other projects to help unlock their full potential**. This would help ensure that Alliance resources are allocated even more efficiently and effectively, considering the Alliance's objective of having first SMRs in operation in Europe by the 2030s. To do so, the governing board intends to meet each of the existing PWG in the second half of 2025 to identify with them how they match with these objectives. Commitment to safety and cross EU safety bodies analysis as identified by ENSREG, will also be considered.

Subsequently, the Alliance will also examine the opportunity to launch, before the end of 2025, a **second call for PWGs if gaps** are identified in the remaining PWGs **regarding technologie**s, applications or EU Member States' interests after the reassessment of the existing nine PWGs.

Interactions with the European Nuclear Safety Regulators Group (ENSREG) and other external organisations

Beginning of 2025, ENSREG established a dedicated **SMR Task Force** to collect and analyse input from interactions between regulators and SMR projects, with the **primary goal of integrating the highest safety standards into SMR project development and pre-licensing activities**. The Task Force will interact with the Alliance to identify technical and organisational issues, including regulatory issues, that must be addressed to streamline SMR licensing in EU countries. This will not be limited to interactions with TWG6 even if it should be the main point of entry.

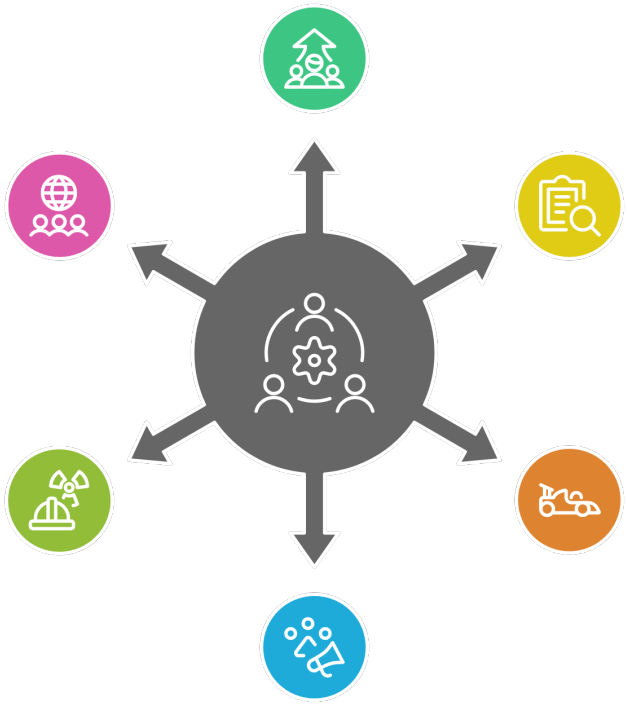
The Alliance and its TWGs will also collaborate with relevant national initiatives, civil society (through the **Alliance Stakeholder Forum** to be organised every year), and **international organisations** (e.g., IAEA, IEA, and NEA-OECD) involved in SMR policies and initiatives. The aim is to **share information**, **perspectives**, and **results**. This cooperation may include inviting external organisation representatives to workshops or conducting expert interviews.

TWGs & Collaborations with PWGs

Foster partnerships, and develop guidance or policy recommendations on specific topics. Potential partners R&D proposals, incubate ideas and projects for support

Cooperation with External Stakeholders

Sharing information and perspectives globally. Stakeholder Forum.



PWG Reassessment

Ensuring ToR criteria compliance and efficient resource allocation.

Interaction with ENSREG

Integrating safety standards into SMR projects.

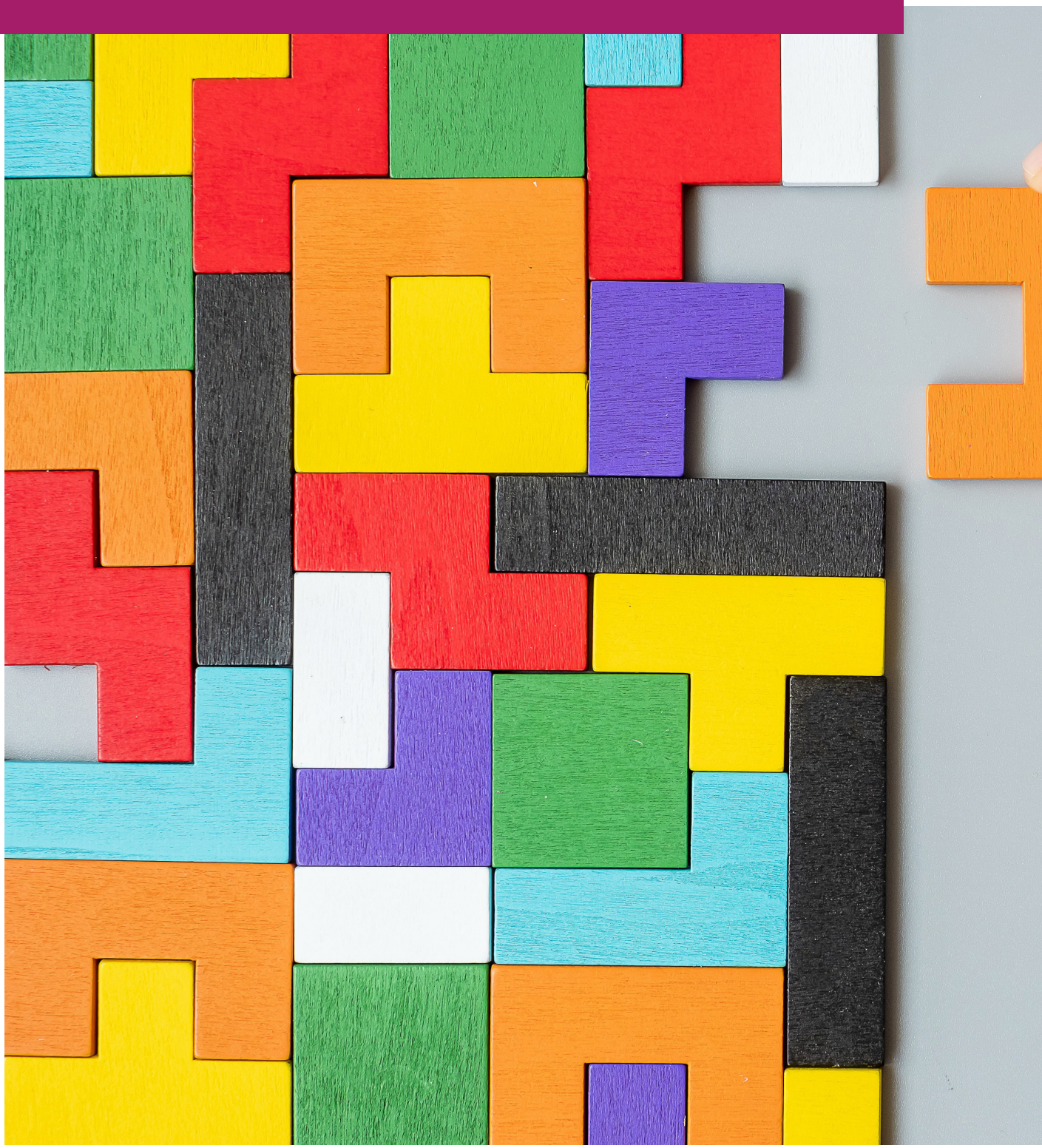
Fast Movers Identification

Prioritising SMR/AMR projects for early support and development.

Second Call for PWGs

Addressing gaps in technologies and interests.

05 Concluding remarks



> An ambitious roadmap for the Alliance's work over the next five years. A shared goal and the members' promise to work together



The **Strategic Action Plan** is an **ambitious roadmap** aimed at steering the Alliance's efforts over the next five years. It embodies a **shared vision** and the **collective commitment** of the Alliance's members **to work together** to facilitate the development, demonstration, and deployment of SMRs in Europe by the early 2030s. It is designed to **facilitate** the **progressive, pragm&atic**, and **efficient achievement of the Alliance's objectives**. Besides giving clarity on the Alliance's forthcoming work, it is meant to provide input to the Commission's upcoming Communication on SMRs in the EU announced in the Affordable Energy Action Plan[1] adopted earlier in 2025.

By providing **targeted support services** to PWGs and **"Fast Movers" SMR projects**, the Alliance will seek to address the specific needs of these projects, ultimately enabling the **successful deployment of SMRs** in the EU by the **early 2030s**. This approach will ensure that the Alliance's efforts are focused on concrete projects, provide them with effective support for their successful deployment, and stay aligned with the needs of Alliance's members and stakeholders, paving the way for a timely and successful rollout of SMR technology in Europe.

To successfully implement this Strategic Action Plan, the Alliance will actively seek and first rely on contributions from its members, but support and coordination with other key European players, such as the European Commission, the European Parliament, relevant European organisations, and all EU countries interested in SMRs, will be needed to ensure success.

At the EU policy level, besides the long-standing Euratom Research and Training Programme[2], both the Net-Zero Industry Act (NZIA), adopted last year, and the recently endorsed IPCEI on innovative nuclear technologies (including SMRs) and additional potential financing mechanisms could be instrumental in supporting their development in the years to come. The Alliance will focus on the implementation of the Strategic Action Plan on nurturing tangible project proposals that can be submitted under the new IPCEI framework for innovative nuclear technologies and the Net Zero Industrial Act, which enables the **development of strategic projects** in this field. Additionally, the Alliance will facilitate exploring the possibility offered by the Euratom Research and Training Programme for advancing R&D collaborations and skills development across the EU, ultimately benefiting the deployment of SMRs. The clear objective will be to **maximise EU content** in the **supply chain** and the anchoring of **European intellectual property** and designs/consortia to strive towards **European autonomy and competitiveness**.

Collaboration with international organisations such as the IAEA, IEA, and NEA-OECD will also be crucial. International knowledge-sharing is strongly encouraged, with the overarching objective of reinforcing the **European Union's scientific workforce** and **industrial competitiveness**.

A **mid-term review** of the Strategic Action Plan will be planned in due time (prospectively in 2027) to facilitate necessary adjustments to the initially proposed actions. Any proposed adjustments will be thoroughly justified by the relevant Technical Working Group and approved by the Governing Board. The Alliance Governing Board will conduct an **annual review** of progress on all actions using feedback reports prepared by each Technical Working Group and exchanges with PWGs.

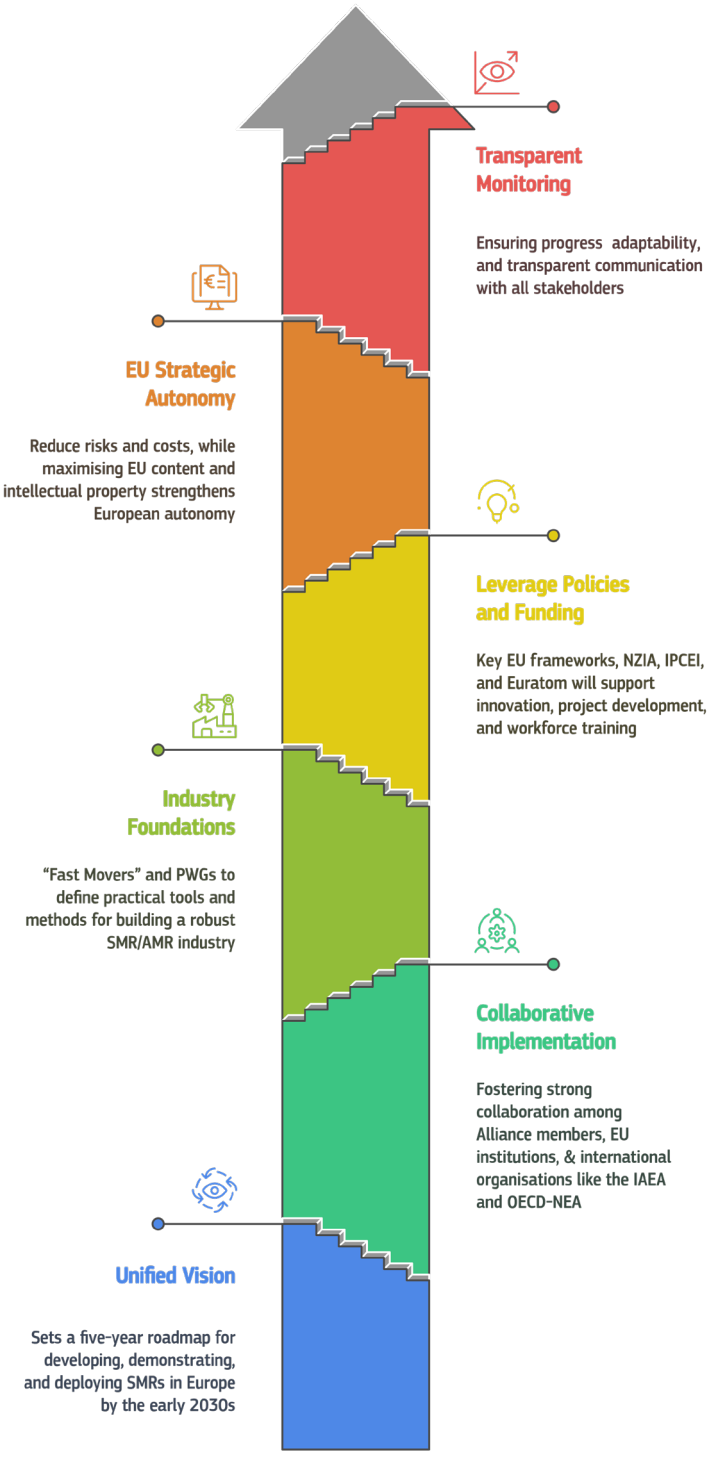
1 https://energy.ec.europa.eu/publications/action-plan-affordable-energy-unlocking-true-value-our-energy-union-secure-affordable-efficient-and_en

2 https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/euratom-research-and-training-programme_en

Key results and lessons learned from the implementation reports will be communicated to Alliance members through the **Alliance's newsletter**, **promoting information sharing and transparency**.

The Strategic Action Plan officially commences upon its endorsement by the second General Assembly of the Alliance, scheduled for September 1, 2025.

Strategic Action Plan - Key Messages




NET
ZERO

Annex I



Technical Working Groups
Specific areas for 2025-2029

Challenges, Key Objectives and Tasks

European Industrial Alliance on SMRs
Technical Working Groups

TWG1: Industrial Applications
Chair: N.Rega (CEFIC)
Vice Chair: A.Georgescu (Eurometaux)

TWG5: Public Engagement
Chair: M. Martell (GMF)
Vice Chair: M. Ilnicki (SGE)





TWG2: Technology and R&D&I
Chair: P.Baeten (SCK-CEN)
Vice Chair: M.Pasquet (Framatome)





TWG6: Nuclear Safety & Safeguard
Chair: O.Kymäläinen (FORTUM)
Vice Chair: A. Jelev (Nuclearelectrica)



TWG3: Supply Chain
Chair: V. Ramany (EDF)
Vice Chair: M.Tacconelli (Walter Tosto)





TWG7: Fuel cycle & waste management
Chair: H.Baars (URENCO)
Vice Chair: T. Louvet (ORANO)





TWG4: Skills
Chair: M.E. Ricotti (POLIMI, CIRTEN)
Vice chair: O. Bard (GIFEN)

TWG8: Financing
Chair: M.Jedlička (ČEZ)
Vice Chair: K. Abramovič (GEN energija)



TWG1 Developing a Robust Market Demand for SMRs

Challenges

In today's fast-evolving economy, energy-intensive industries, data centres, maritime sectors, e-fuel and hydrogen producers, among others, face significant barriers in transitioning to electrification, adopting decarbonisation strategies, and ensuring stable energy supplies. SMRs are expected to offer promising, economically viable, low-carbon energy solutions for these industries. SMRs could provide continuous electric power for data centres and have significant cogeneration capabilities, supplying both electricity and heat to energy-intensive industries and district heating. Moreover, their smaller size and modular construction result in a reduced footprint, which is ideal for space-constrained areas, and require a lower upfront investment, which can be particularly attractive to private investors, including the industry.

Major high-tech companies outside the EU have recently taken the lead in investing in nuclear energy projects, including SMRs, to meet their anticipated massive energy demands and ensure a reliable power supply for data centres. This forward-thinking approach sets a precedent for other energy-intensive industries to follow, demonstrating the potential of SMRs to support their operations.

However, potential SMR users in Europe are not yet fully aware of the benefits that SMRs can offer. Moreover, several issues associated with SMRs, beyond co-financing, remain to be fully addressed. These include technological risks, such as integrability-related issues, as well as legislative hurdles related to different connection modes, including off-grid and hybrid configurations. To develop this market, nuclear energy should be recognised as a net-zero energy source in the EU, enabling it to operate on an equal footing with other net-zero energy sources in terms of electricity and heat supply, as well as energy supply to produce other energy carriers, such as hydrogen.

To encourage the adoption of SMRs in Europe, energy-intensive industries and other relevant sectors should be properly informed and incentivised to explore the benefits of integrating SMRs into their energy strategies. To facilitate this, several key actions are required, such as evaluating the role of SMRs in meeting the energy needs of these industries, developing targeted awareness campaigns to inform and engage interested sectors, and conducting techno-economic analyses to assess the benefits of integrating SMRs into industrial hubs.

Key Objectives

The primary objective of TWG1 on Industrial Applications is to better assess the role of SMRs as potential providers of electricity and heat to different industrial sectors and large projects and to identify the associated obstacles and risks in actual industrial settings. Identification of needs and challenges of future energy market shall not be limited to 2030s but should also include the following decades considering the net zero goal is set to be achieved in 2050.

To this end, TWG1 will start by evaluating the **electricity and/or heat needs of energy-intensive industries**, such as steel, aluminium, petrochemical, cement, and pulp and paper industries, as well as data centres and energy utilities. In the second stage, TWG1 will work with additional sectors, including the maritime and mining industries and district heating applications. TWG1 will also seek to i**dentify the obstacles and associated risks of deploying SMRs** as energy providers across these sectors and draw up recommendations for consideration by these industries and PWGs interested in specific industrial applications.

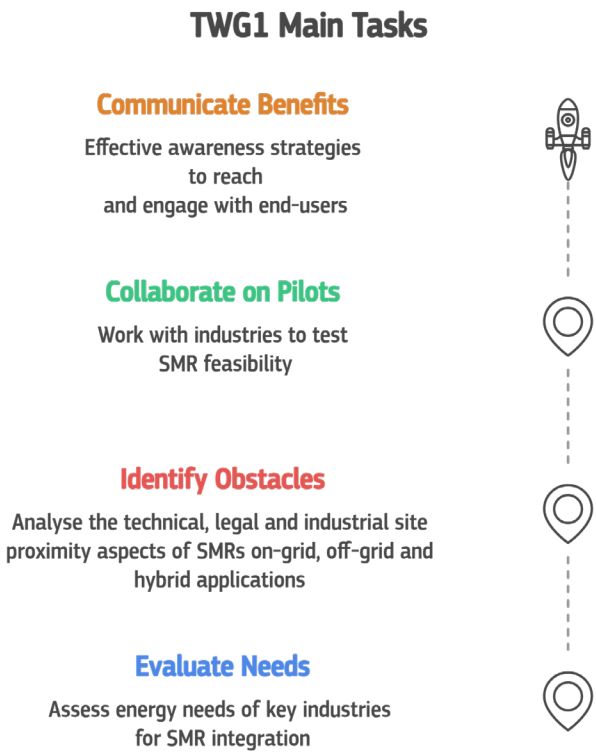
TWG1 Key Objectives



TWG1 will explore ways to engage interested end-users from the above sectors in collaboration with relevant PWGs to **develop pilot projects** that demonstrate the feasibility of SMR integration into real industrial settings. The objective is to assess all types of associated difficulties from a practical perspective.

Finally, TWG1 will develop an **awareness strategy** to reach and inform as many potential SMR end-users as possible about the benefits of SMRs and the obstacles associated with them for their sector.

The topics and activities of TWG1 are closely intertwined with the efforts of other TWGs. The most pertinent are TWGs focused on TWG2–Technology and Research & Innovation, TWG5–Public Engagement, TWG6–Nuclear Safety and Safeguards, and TWG8–Financing. Proactive collaboration with these groups will be prioritised to ensure a cohesive and coordinated approach. This strategy will ensure the active participation of all interested PWGs.



TWG1 Tasks

The following tasks have been formulated by considering the needs expressed by the PWGs and the feedback gathered from the TWG1 members.

1.1 Evaluate the needs for electricity, heat and other energy carriers of potential SMR end-users

The objective of this task is to gain a better understanding of the energy needs of key stakeholders who could become potential users of SMR outputs. The task will **estimate the needs for both electricity and heat for district heating and industrial processes** with the most substantial energy consumption, such as energy-intensive industries, data centres, and energy utilities. The task should also aim to verify the possibility of using electricity from SMRs to produce **other energy carriers such as hydrogen or ammonia**. Other high-energy industries or large-scale projects will be examined, including mining industries, maritime industries, hydrogen and battery production, desalination projects, and district heating.

1.2 Identify the challenges of potential SMR end-users and draw recommendations

This task will identify and analyse the **obstacles** and concerns, such as technical, legal, energy market and those related to proximity to industrial sites, for each of the above industries associated with using SMRs in both **on-grid, off-grid and hybrid applications**. This includes exploring technical and legal obstacles as well as issues related to proximity to industrial sites and raising awareness. The action will suggest measures to overcome these difficulties and obstacles.

1.3 Collaborate with potential SMR end-users to identify, evaluate, and prioritise the first demonstration pilot projects

This task will engage with potential SMR end-users from the above sectors to facilitate collaboration with PWGs and other relevant stakeholders, such as industrial local clusters, in developing **demonstration pilot projects**. These pilot projects aim to demonstrate the feasibility of using SMRs in industrial settings, showcasing their potential benefits as well as associated challenges, including technical, regulatory, and financial hurdles. The pilot projects will provide a platform for testing and validating specific SMR technologies, identifying and addressing potential issues, and refining solutions to meet the needs of end-users. By developing and demonstrating tailored solutions, the action will help to build confidence among potential end-users, reduce barriers to adoption, and gain experience that

would be valuable for other similar projects.

1.4 Communicate with a large community of potential SMR end-users and raise awareness

The goal of the task is to **communicate and raise awareness** of potential SMRs end-users by collaborating with European industrial associations. This collaboration aims to identify various potential approaches for engaging a diverse community of end-users across the sectors mentioned above. By collaborating with industrial associations, the initiative aims to inform potential users about the benefits and opportunities offered by SMR technology. The task will involve developing and implementing effective awareness strategies to reach and engage with these end-users. This may include organising workshops, webinars, and other events to showcase the potential of SMRs and address any concerns or questions that end-users may have.



TWG2 Excelling in Research and Technology for SMRs

Challenges

Over the past few decades, the Euratom Research and Training Programme and various national support programmes have played a significant role in driving R&I on SMRs and AMRs by providing complementary support, shaping policy frameworks to ensure safety and innovation, fostering collaboration among EU Member States and strengthening the EU leadership in the nuclear sector in terms of expertise and knowhow.

Today, there is a dispersion of codes and standards used across the EU, and gaps still exist. Gaps need to be identified in the application of current **European codes and standards** for LW-SMRs, and new codes and standards for AMRs need to be developed. To accelerate deployment across borders, one should designate and reinforce their ownership by an EU organisation. This encompasses a broad range of codes and standards, including those related to civil design and construction, mechanical and electrical engineering, instrumentation and control systems, and other generic design aspects that apply to all projects.

Data for the codes are spread over the EU, and a "European Data Source Centre" could be assessed that consolidates and makes accessible existing datasets, currently restricted by proprietary agreements. **Export control rules** hinder exchange of data across the EU

The development of SMRs requires significant investment in experimental and analytical capabilities to demonstrate nuclear safety. However, many existing **European test facilities** are facing budgetary and ageing pressures, and some are even being shut down. To support the development of SMRs and AMRs, a robust and accessible European R&D infrastructure is needed, providing new and existing data to ensure safe, efficient, and long-term operation. This includes access to materials testing reactors (especially high flux fast neutron irradiation facility) and supporting facilities, as well as specific and integral testing facilities to validate theoretical and computer simulation models. Modular construction and advanced manufacturing can help reduce costs and delivery times for nuclear components, while also enabling more efficient design. However, to ensure the qualification and standardisation of these components, the nuclear supply chain must be involved early in the optimisation and standardisation processes to ensure the inclusion of **modularity** and **advanced manufacturing solutions** within the scope of the EU nuclear codes and standards. Additionally, the development and deployment of SMRs can be optimised and accelerated by advanced **digital tools**, **Artificial Intelligence**, and **Machine Learning**, which can facilitate licensing, construction, predictive maintenance, and integration into the energy grid.

Finally, SMRs and AMRs have significant potential for **non-electrical applications**, such as industrial heat, district heating, and hydrogen production. However, a general framework is needed to address the design, safety, and performance aspects of SMRs in these non-electrical applications, which may require separate guidelines for different types of SMRs due to varying operating conditions.

Early involvement of regulators in the R&D phase is essential to align **technological innovation with regulatory expectations** from the outset.

This proactive engagement helps to identify and address potential safety and licensing challenges early, reducing time and costs in later stages. It also facilitates a smoother and faster **technology qualification process**, ultimately accelerating the deployment of SMRs in Europe. This topic will be addressed in cooperation with TWG6

Key Objectives

The primary goal of Technical Working Group 2 (TWG2) on "Technology and R&D&I" is to meet the specific research, development, and innovation needs of the PWGs. TWG2 will identify where the EU can take dedicated initiatives and will foster dialogue and collaboration on **R&D&I**-related topics **crucial for the development of SMRs**, such as establishing **experimental and simulation facilities in Europe**, defining European **codes and standards**, and **simplifying export controls** within the EU. Based on these gaps and further R&D&I topics for advancing SMR's development, TWG2 aims to **identify areas and incubate ideas that could be addressed at the EU level** through the Euratom Research and Training Programme, the recent IPCEI on innovative nuclear technologies, the EIB, as well as national research programmes, ensuring a **coordinated EU approach** that promotes **innovation and excellence** across the EU while collaborating worldwide.



Besides the close and continuous collaboration with all PWGs, TWG2 will work closely with other TWGs, particularly TWG1 on Industrial applications, TWG3 on Supply chain, TWG4 on Skills, TWG6 on Safety and Safeguards, TWG7 on Fuel cycle and waste management, and with TWG8 on Financing.

TWG2 Tasks

To identify the tasks listed below, the TWG2 conducted a specific survey among its members including the PWGs and performed a thorough review of past and current collaborative EU projects, co-funded under the European framework programmes and particularly Euratom. The research areas and topics proposed below will be further elaborated and would be addressed in the framework of EU and national initiatives and programmes for further support.

2.1 Promote standardisation and preferred European codes and standards for SMRs

The task will **identify gaps** in the application of current **codes and standards** adopted in the EU for LW-SMRs and accelerate the development of new codes and standards for AMRs, as well as designate and reinforce their ownership by an EU organisation.

As a result, the Alliance will formulate recommendations for the key design, material, and construction codes and standards to be adopted for SMRs, prioritising interoperability and flexibility to accommodate established standards used in existing SMR design. The Alliance will provide support to SMR projects that adhere to this preferred **set of codes and standards**, with a focus on promoting consistency and best practices across the industry and compatibility with globally recognised standards across the EU. This encompasses a broad range of codes and standards, including those related to civil design and construction, mechanical and electrical engineering, instrumentation and control systems, and other generic design aspects that apply to all projects.

Moreover, the task will develop a set of references for evaluating advanced safety systems for SMRs, to establish a **harmonised EU reference methodology** and a consistent **safety approach** that can be applied across all PWGs while complying with the state-of-

the-art requirements. Through this task, the TWG2 will create further links with European and international organisations to set up **best practices and guidelines** to spread the use of **innovative materials**, **methodologies**, and **processes**, ensuring the alignment with the **international safety standards**.

2.2 Facilitate the flow of SMR-related data, technologies, and components across the EU

The goal of this task is to assess the feasibility and cost-effectiveness of establishing a **"European Data Source Centre"** that consolidates and makes accessible existing datasets, respecting proprietary agreements, to promote data sharing and collaboration across EU countries interested in SMRs. In addition, the task will assess how to call upon the EU to **simplify export control** within the EU, facilitating transnational cooperation for SMRs.

The TWG2 will examine the possibilities to leverage the historical data and create new credible ones through various indigenous programs and collaborate with the existing platforms and organisations to ease their access and exploration by the PWGs, while supporting a common approach towards standardisation.

TWG2 Main Tasks

Task	Description
Standardisation	Promote codes and standards
SMRs Data Flow	Facilitate data, technologies, components flow
Experimentation	Prioritise key testing facilities
Facilities Upgrade	Upgrade/connect or build facilities
Modularisation	Advance modularisation and digitalisation
SMR Integration	Facilitate integration into applications

2.3 Identify, assess and prioritise key experimentation and testing facilities for SMRs and establish a work plan to upgrade/connect them or build new facilities

The objective of the task is to explore ways for promoting the establishment of an EU access framework to **experimental facilities**, thereby reducing barriers, fostering collaboration, and maximising the use of existing research infrastructure. The task will **identify gaps in the EU to R&D&I infrastructures** to comply with the needs of the SMR projects, and i**dentify ways to develop missing facilities**, including but not limited to those for thermal-hydraulic analysis in non-loop reactors, facilities dedicated to studying advanced safety systems, and infrastructure for assessing environmental effects (irradiation, corrosion, temperature, stresses, ...) on new materials, seeking for adequate support from EU financial Programmes.

Moreover, the task will define, in collaboration with the PWGs, the **testing requirements for each SMR design**, including the need for conducting integral, partial, or other types of tests either for qualification, validation or verification, and identify the suitable partners and facilities to perform these tests in support of the licensing process.

TWG2 will identify the **key experimental facilities** essential for the successful implementation of the first LW-SMRs by the early 2030s and of the first AMRs during the next decade. A comprehensive work plan will be developed to upgrade/connect or build new critical facilities, in close collaboration with the Project PWGs and alignment with their overall development schedules

2.4 Advanced Modularisation and Digitalisation of SMRs

Modular construction and advanced manufacturing can help reduce costs and delivery times for nuclear components, while also enabling more efficient design. The task will evaluate **advanced construction methodologies** and **innovative techniques** for optimised layout and construction of SMRs, with a focus on improving efficiency, reducing costs, and enhancing overall project delivery while ensuring compatibility with existing modular designs and standards, including those from other industrial sectors (such as shipbuilding, aerospace, ...).

Moreover, TWG2 will prioritise short-term, high-**impact digitalisation initiatives** that drive

tangible value and deliver practical benefits, focusing on innovative solutions that address pressing needs and yield swift returns on investment in SMRs.

Furthermore, **collaboration with the non-nuclear industry** should be fostered, primarily to benefit from lessons learned regarding established industry standards in product development, manufacturing, and qualification, where the nuclear industry can learn from the pioneering culture of developing innovative technology more effectively

2.5 Facilitate SMR integration into different applications and systems

TWG2 will conduct a comprehensive investigation into the **critical issues associated with integrating SMRs into other applications and systems**, such as heat-to-X applications. This investigation aims to identify and address technical, economic, security, and licensing issues, and to collaborate with end-users to define the requirements for non-electrical application demonstrators.

Moreover, the TWG2 will assess the **flexibility for dual electric and non-electric operation** of future SMRs and economic-related issues, as interest in non-electric applications of nuclear energy will be growing in the future, including desalination, nuclear hydrogen production, district heating, synthetic fuel production, maritime transport and ammonia production.



TWG3 Building a Competent and Scalable Supply Chain

Challenges

One of the primary issues is the need to assess the **capacity and capabilities of the EU nuclear supply chain** and identify bottlenecks and investment needs. This assessment is crucial for the successful deployment of SMRs and AMRs in the coming decade.

Geopolitical trade uncertainties and disruptions pose significant threats to European industrial and **economic sovereignty**, as well as **social welfare**. These challenges necessitate drastic enhancements in support for projects designed by European companies, utilising substantially the European supply chain and creating jobs, to build a stronger and more resilient Europe, while generating concrete economic value for the European Union. This implies more specific tasks, such as:

- Scaling up activities to resolve bottlenecks
- Investing in critical areas such as modularisation
- Building key partnerships where the EU currently lacks the know-how and capabilities
- Developing cooperations to strengthen the supply chain

Furthermore, the supply chain is not yet fully integrated at the European level, which can limit its ability to operate across borders and tap into a broader expertise and resource base. To overcome these obstacles, it is necessary to foster collaboration among stakeholders and explore ways to enhance the **integration of the supply chain at the European level**. This includes the development of standardised codes and regulations, and the establishment of mechanisms for risk assessment and mitigation.

To address these, a comprehensive strategy is needed to enhance the performance and build the **resilience of the supply chain**. This includes long-term vision, continuous support, diversification of suppliers, investment in critical areas, and innovation in supply chain management.

Additionally, with the guidance and insights from TWG8, it is essential to explore how instruments such as the Net Zero Industry Act (NZIA), the Innovation Fund, and the recently established IPCEI on innovative nuclear technologies, and the European Investment Bank (EIB) can contribute to **strengthening the supply chain for SMRs** in Europe. By providing customised support to SMR projects and identifying supply chain partners with the required profiles and specific technologies, it is possible to accelerate the development and deployment of these technologies in the future.

Key Objectives

The development and deployment of SMRs in Europe necessitates a **robust and resilient supply chain**, as well as sustained collaboration

among diverse stakeholders across EU countries. The primary mission of the Technical Working Group 3 (TWG3) on Supply Chain is to conduct a comprehensive **assessment of the supply chain**, evaluating its **capacity to support SMR and AMR development** in the next decades, identifying the necessary investments and capacity-building initiatives required to foster a thriving SMR and AMR ecosystem in Europe, and fostering cross-category collaboration to facilitate knowledge transfer. This work involves establishing a robust and capable supply chain that not only meets current technological demands but also remains adaptable to future innovations. The TWG3's second mission is to provide bespoke support for selected projects.



For this work, TWG3 has developed and used a "**Reference Scenario**" and “Average Quantitative Model” for the SMR market within the broader context of the overall European nuclear market. It will serve as a reference system to assess workload volumes over the study period and evaluate the consistency of the supply chain’s capacity by discipline across the European supply chain. The Reference Scenario will be regularly updated as needed to reflect new developments in the SMR market or new studies/reports. Every official release of the Reference Scenario will be shared with other TWGs and PWGs as a reference.

TWG3 Tasks

The following tasks have been formulated by considering the needs expressed by the PWGs identified under the Alliance, as well as the feedback gathered from the TWG3 members and relevant results of the work conducted by the European Pre-Partnership on SMRs in this area

3.1 Assess the nuclear supply chain in Europe

To evaluate the **current state** of the nuclear **supply chain** in Europe for the development of SMRs, this task will undertake a thorough analysis to identify and characterise existing capacities, **capabilities**, **gaps**, **bottlenecks**, and associated **risks**.

This assessment will be performed primarily via a specific questionnaire addressed to TWG3 members. The preparation of this questionnaire will be informed by a review of recent reports and studies conducted at national, EU, and international levels, ensuring a holistic understanding of the supply chain's strengths and weaknesses in Europe, including the "Supply Chain Adaptation" report, delivered by the European Pre-Partnership on SMRs. Considering the current TWG3 membership, it is expected that the outcome of this assessment will be reasonably representative, though not fully comprehensive.

3.2 Analyse the economic and sustainability aspects of the supply chain

The task will conduct comprehensive economic analyses to understand the financial implications, gaps and opportunities within the nuclear supply chain. This includes identifying **investment needs** and requirements to support the development and deployment of SMRs and assessing the potential overall cost benefits of SMR deployment, including cost savings, revenue generation, and job creation. Additionally, TWG3 will assess the **economic viability** of various supply chain scenarios, including the impact of different market and regulatory conditions, and develop business cases and financial models to support informed investment decisions and strategic planning.

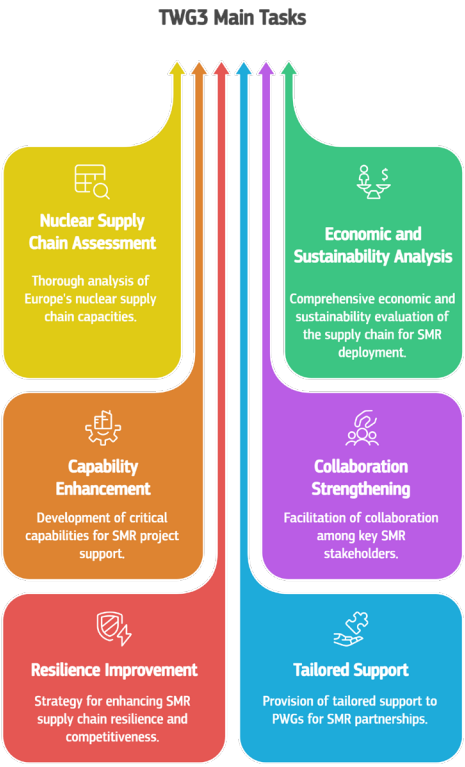
3.3 Evaluate and enhance supply chain capabilities

The goal of the task is to identify and foster the

development of **critical capabilities** essential for supporting current and future SMR projects, such as capabilities for developing and using advanced manufacturing technologies and explore how the Net Zero Industry Act (NZIA) provisions, the recent IPCEI on innovative nuclear technologies, the Innovation Fund, the EIB and other instruments can contribute to strengthen the supply chain for SMRs in Europe. To establish mechanisms for risk assessment and mitigation, particularly in domains prone to geopolitical tensions or trade disruptions (excluding nuclear fuel, which is the subject of TWG7).

3.4 Strengthen collaboration within and beyond Europe

The goal of this initiative is to facilitate **collaboration and coordination among key stakeholders**, including government agencies, industry leaders, and research institutions, to ensure a unified and efficient approach to supporting the SMR supply chain. By fostering a culture of cooperation and information sharing, the task will optimise resource use, minimise duplication of efforts, and maximise the impact of individual initiatives. The task will explore opportunities to enhance the integration of the SMR supply chain at the European level, enabling it to operate seamlessly across borders, leverage a broader expertise and resource base, and respond effectively to emerging challenges and opportunities.



3.5 Improve supply chain resilience

The goal of this task is to develop a comprehensive **strategy for enhancing** the **performance** of the **SMR supply chain**, with a focus on improving its resilience, flexibility, and overall competitiveness. This strategy will include specific tasks for diversifying suppliers, promoting investment in critical areas, and adopting innovative supply chain management practices to enhance the efficiency, transparency, and resilience of the supply chain.

3.6 Provide tailored support to PWGs

Under this task, TWG3 will provide **tailored support** to the PWGs, with a focus on identifying and facilitating partnerships with supply chain partners possessing the required profile and expertise. This support will be designed to address the specific needs of each PWG. It will include supply chain partner identification, technology Identification, partnership facilitation, and capability development needed to work with identified supply chain partners and technologies, including training, knowledge sharing, and other forms of **capacity building**. The TWG3 has also identified the need for increased visibility on tangible SMR programs in the EU to accelerate efforts and motivate continued engagement from members, who participate voluntarily.

The TWG3 acknowledges that the journey ahead remains substantial. Sustaining long-term engagement from members will be an ongoing challenge. The TWG3 will be able to draw and present a reliable picture of the European supply chain's "heat map" for SMR (i.e. a relevant mapping of the value chain for SMR development and construction in Europe) with the identifications of strengths and weaknesses. Nevertheless, a detailed and fully exhaustive assessment of the supply chain may represent a challenge for TWG3's current capabilities, while a representative evaluation is feasible. An additional scaling-up mechanism would be needed to draw a full-scale overview with accurate magnitude.

The next phase of work will involve deploying key tools and activities, including questionnaires, workshops, and interviews. These efforts will support the development of structured deliverables such as reports and comprehensive databases. The insights gathered will be thoroughly analysed, and the outcomes will be consolidated into executive reports, including clear recommendations to guide the continued

development of a robust European SMR and AMR supply chain. Promoting cross-TWG work will be critical for the success of the EU SMR IA, ensuring that all aspects are well-coordinated to have a coherent and credible roadmap. This will help build a stronger supply chain in a stronger Europe while generating concrete economic value for the European Union.



TWG4 Getting the Right Skills and Competences for SMRs

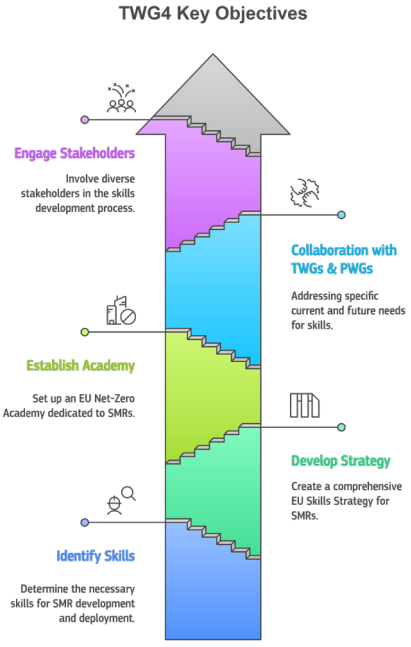
Challenges

The availability of skilled human resources is crucial for the efficient deployment of nuclear energy in the EU, but it poses a significant challenge. Decades of reduced investment have eroded supply chain capabilities and technical expertise, resulting in **workforce shortages** that hinder nuclear plant construction and operation. Moreover, SMRs face specific workforce training hurdles due to introducing new technologies, manufacturing processes, materials, and innovative reactor applications such as cogeneration. These advancements impact various sectors, including construction, operation, licensing, research and development, and finance, necessitating new or adapted education and training initiatives tailored to the unique features of SMRs.

In addition, even if the **attractiveness** of nuclear industry may have improved in the recent years, it still struggles to attract enough young talents, highlighting the critical state of Science, Technology, Engineering, and Mathematics (**STEM)** education and training. However, SMRs can leverage their innovative potential and promising market growth to attract young professionals and experts from other industries to the nuclear industry. Numerous national programs, alongside the Euratom Research and Training Programme at the EU level, have played a vital role in promoting training activities to support the nuclear sector over the years. Nevertheless, considering the sector's difficulties and the anticipated rise in skill demand, it is essential to undertake additional systematic and coordinated efforts, building on and enhancing previous and ongoing initiatives across the EU.

Key Objectives

The primary objective of Technical Working Group 4 (TWG4) on Skills is to identify and help develop and sustain the **skilled workforce** that is necessary to facilitate the development and deployment of SMRs in Europe by the early 2030s and beyond. The outcomes of TWG4's efforts will provide insights and recommendations, informing the development of an **EU Skills Strategy for SMRs**, including dedicated **upskilling** and **reskilling** initiatives and tasks. This strategy will provide the foundation and evidence for establishing an **EU Net-Zero Academy** dedicated to SMRs. This long-standing EU platform will examine the efficient and effective leveraging of ongoing and future EU and national initiatives on **skills for SMRs**, and foster a more coordinated approach at the EU level.



The range of required skills for SMRs is diverse, spanning various scientific, technical, and regulatory fields and encompassing a broad range of competences. To effectively address this complexity, TWG4 will establish close collaboration with other relevant TWGs such as those working on Research, Development, and Innovation, Supply Chain, Safety and Safeguards, Industrial Applications, and Public Engagement. Additionally, TWG4 will cooperate with interested

PWGs to address specific current and future skills needs. Furthermore, TWG4 will engage with a wide range of stakeholders and target audiences, including the **younger generation**, professionals from other sectors, and international institutions working on skills development for the nuclear sector industry, to exchange views and share best practices.

TWG4 Tasks

The following tasks have been formulated by considering the needs of the PWGs identified through a preliminary survey launched by the Alliance, and the feedback gathered from the TWG4 members.

4.1 Collect all necessary skills that are needed to develop, deploy and operate SMRs in the future

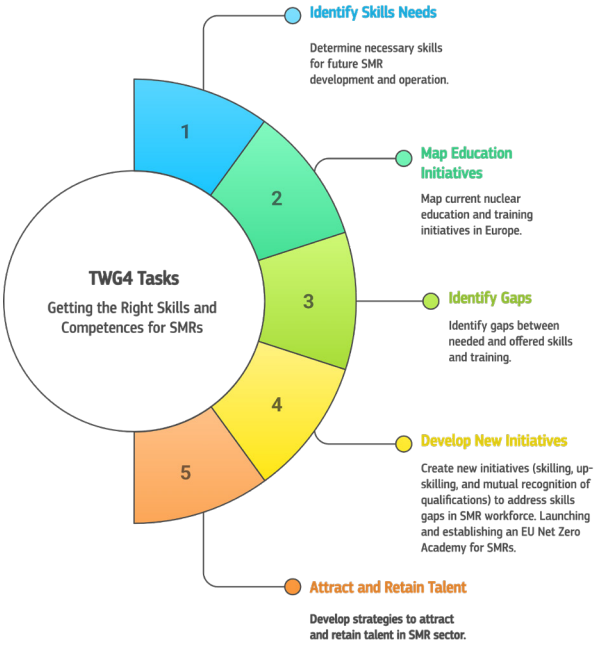
Overview of skills workforce needs for nuclear deployment in the EU: The goal is to gather and review the **main types of human resources**, such as areas, skills, knowledge, and competences, that are usually needed today to deploy nuclear power plants. These skills will encompass scientific and technical skills, regulatory competences, operational skills, and specialised expertise, such as knowledge and competences that are typically required today to deploy nuclear power plants. These skills will encompass scientific and technical skills, regulatory competences, operational skills, and specialised expertise, such as fuel and waste management.

Identify at early-stage specific skills and size for SMR development and deployment following PWGs' needs: The objective is to collect human resource needs and required expertise that is tailored to the development, operation and decommissioning of SMRs.

This task will require close collaboration with relevant PWGs and TWGs to ensure that the gathered information is precisely tailored to the unique characteristics of SMRs and their potential industrial applications. The focus will be on addressing **specific needs** that are challenging to recruit for, yet crucial for the success of the projects. To achieve timely results, this task will be initiated at an early stage, enabling the PWGs to benefit from the outcomes promptly and inform their project development.

4.2 Map current Education & Training (E&T) initiatives on nuclear at the EU, national and regional level

Identify the landscape of actors in the European Union: The objective is to identify the **key actors** in the nuclear sector, including educational institutions, professional organisations, and industry stakeholders, who play a crucial role in developing and delivering training and education programs for the nuclear workforce. These actors will be mapped and categorised to understand their roles, responsibilities, and areas of expertise. The types of training programs offered by these actors will be classified according to the European Qualifications Framework (EQF) levels 1–8, enabling a standardised evaluation of the identified competences.



Review the European nuclear training offer and classify educational programs: The goal is to **collect and review the training offers** in the nuclear sector, ensuring that the data collected is sufficient, up-to-date, and relevant to the needs of SMRs. The educational programs will be classified to identify those addressing the broader nuclear sector, those **focused on SMRs**, and those providing training and education in cross-industrial areas such as project management, digitalisation, and cybersecurity that can be

applied to SMRs, but are not exclusive to the nuclear sector.

4.3 Identify gaps between skills needed and offered E&T and develop initiatives to address them

Gap identification in workforce E&T for SMR deployment: The goal is to synthesise and compare the results obtained in the previous steps, including an analysis of workforce needs, training offers, and educational programs, to identify and assess possible gaps in the workforce specifically for the development, operation, and decommissioning of SMRs. This comparison will enable the **identification of areas** where the current workforce and training programs may not be adequately equipped to meet the unique demands of SMRs, of areas where the current workforce and training programs may not be adequately equipped to meet the unique demands of SMRs and where **targeted investments** in education, training, and workforce development may be necessary.

New E&T initiatives to address the gaps and foster the development of the SMR workforce: The objective is to identify new E&T initiatives that can effectively cover the gaps and foster the development of the workforce for SMRs. These initiatives may include a range of tasks, such as E&T programs, re-skilling, up-skilling, and mutual recognition of qualifications. The work will be leveraged by launching and establishing an EU Net Zero Academy for SMRs. This will enable the creation of a **cohesive and comprehensive framework for skills development** in the SMR sector, one that fosters collaboration, minimises duplication of efforts, and optimises the use of resources.

4.4 Develop strategies to attract and retain human resources in the SMR sector

Interact with young professionals to understand their expectations: The goal is to develop a comprehensive and inclusive approach that identifies the diverse needs and interests of various target groups, including young generations, students, recent graduates, and experienced professionals from the nuclear sector and other industrial fields. This approach aims to understand and address the specific motivations, aspirations, and concerns of each group to influence their decision to pursue a career in the SMR sector.

Strategies to support the attractiveness of the SMR sector and projects: The objective is to develop effective strategies to support the attractiveness of the SMR sector and projects in the future, and to improve the capabilities of attracting and retaining human resources over time. By identifying and implementing these strategies, it is expected that the competitiveness of the SMR sector will be enhanced, and a sustainable, skilled workforce will be ensured for the successful development, deployment, and operation of SMR projects in Europe in the future.



TWG5 Fostering Public Engagement of SMRs

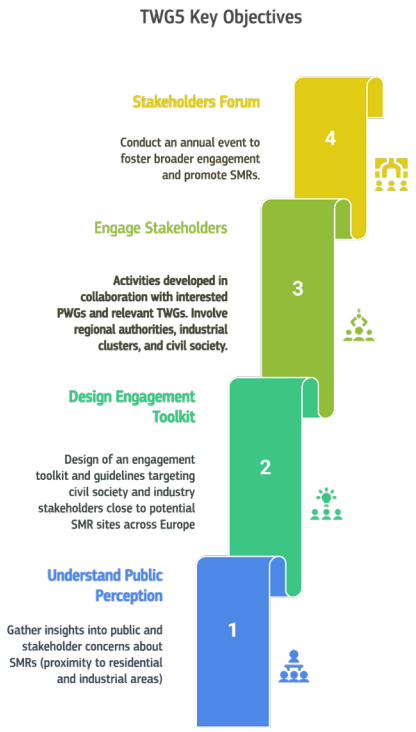
Challenges

The feasibility of SMRs projects hinges on proactively and effectively addressing public concerns and engaging stakeholders early in the decision-making process in a meaningful way. Public engagement is often viewed as a mere formality rather than a genuine participatory process, requiring a comprehensive strategy to navigate the diverse interests and expectations of stakeholders. To build trust and foster support, engagement efforts should focus on providing **open** and **transparent**, **reliable information** on **SMRs' benefits and risks**, addressing concerns, and ensuring the diversity of views is heard early in the planning stages. Incorporating **community feedback** is crucial for boosting public confidence, particularly for projects located near residential or industrial areas. In this context, it is essential to emphasise the complementary role of SMRs alongside large nuclear power plants and renewable energy sources, including their role in decarbonising district heating and hard-to-abate sectors. Highlighting their synergy underscores the importance of leveraging all available energy options to meet Europe's decarbonisation goals, while fully respecting the freedom of EU Member States to decide about their energy mix. Currently, public understanding of SMRs is limited, and historical events such as Chernobyl and Fukushima and the management of radioactive waste continue to raise scepticism and concerns. **Effective communication** of

technical information is essential for **dispelling misconceptions**, **building trust**, and fostering more informed public debate. However, the lack of specific guidelines for SMRs stakeholder engagement and the absence of a centralised EU database mapping stakeholders hinder coordination and make it challenging to develop targeted awareness campaigns. Furthermore, limited resources pose an additional difficulty, necessitating **tailored approaches** for each. Developing such approaches requires a nuanced understanding of the **local context**.

Key Objectives

The siting of SMRs is a crucial step in their overall deployment plan, and SMR public engagement plays a vital role in this process. The primary objective of the Technical Working Group 5 (TWG5) on Public Engagement is to launch an **open**, **transparent**, and **inclusive dialogue** with civil society and key stakeholders regarding the **benefits and concerns associated** with developing and deploying **SMRs**, particularly in proximity to **residential** and **industrial areas**.



To ensure effective public and stakeholder engagement, it is essential first to gain a comprehensive understanding of the potential public perception and concerns related to nuclear energy, particularly SMRs, among local communities. This understanding will be key for designing a targeted awareness campaign across EU interested countries and selected regions. The campaign should be implemented at **candidate or selected sites for hosting SMRs** by organising several activities to engage regional authorities, industrial clusters, and civil society representatives.

TWG5 Tasks

The proposed tasks outlined below are based on inputs collected through various presentations and discussions among TWG5 members and consider contributions and feedback received from several PWGs over the recent period on this topic.

5.1 Collect baseline information on societal aspects related to SMRs

This task involves **collecting and analysing information on public perception**, opinions, and concerns regarding SMRs to gain a deeper understanding of the societal context surrounding their development and deployment within EU regions, including in the context of local industrial hubs and urban district heating. The goal is to identify and address **misconceptions** and ensure that the societal and stakeholder implications of SMRs are carefully considered and integrated into the **decision-making process at the regional and local levels.**

5.2 Design an awareness and engagement approach (toolkit and guidelines)

Building on the insights gathered from this analysis, this task will entail the design of an **engagement toolkit** and **guidelines** targeting civil society and industry stakeholders who are in proximity to potential SMR sites across Europe. This toolkit and guidelines will be flexible and adaptable, providing a general framework that can be applied to any potential SMR location site. It will include all necessary elements and steps to engage stakeholders in an open and inclusive dialogue, regardless of the SMR location. This could consist of a series of **public information sessions and local workshops**. Additionally, a range of informative materials—such as brochures, fact sheets, and the **Practical Stakeholder and Public Engagement Toolbox**—

could be developed to provide accurate and impartial information about the proposed SMR project These resources would address key topics, such as nuclear safety, safeguards, and waste management, including minimising nuclear waste and reusing nuclear fuel more effectively.



5.3 Foster collaboration, outreach and networking among interested stakeholders

TWG5 will directly support the Alliance Governing Board in organising the Alliance annual **Stakeholders Forum event**, which should be an integral part of the awareness campaign. The annual Stakeholders Forum will serve as an additional **platform** for continuing the dialogue on SMRs with a **broader community** of stakeholders and promoting public and industrial engagement.

This task also aims to foster close collaboration with interested PWGs and relevant TWGs such as those focused on Industrial Applications, Skills, Nuclear Safety and Safeguards, and Nuclear Fuel and Waste Management.

If applicable, the TWG5 will host side events for civil society stakeholders, including local mayors, city councils and communities, interested in learning about the benefits and risks associated with SMR deployment in their local industrial hubs or urban district heating systems. Furthermore, TWG5 will seek cooperation with European projects to exchange opinions and share good practices.



TWG6 Fostering Safety, Security and Safeguards

Challenges

To effectively serve key sectors, SMRs must be designed and operated with careful consideration of **safety**, **safeguards** and **security** factors that vary depending on their operational mode and location. Given the need for **siting closer** to **population** centres and **industry** for non-electrical applications (cogeneration, district heat), SMRs will necessitate a high level of nuclear safety and stringent risk management.

Moreover, ensuring the security and safeguards of SMRs is essential, particularly for SMRs that are expected to operate in connection to industrial settings. This includes addressing the safe transport of nuclear materials and preventing unauthorised access to sensitive nuclear material, information and equipment. Furthermore, some SMR designs are being developed by startups or organisations with limited experience in reactor design, licensing, and intertasks with EU regulatory bodies. To support these entities, specific tasks will need to be implemented to facilitate their navigation of the licensing process and foster intertasks with both nuclear and non-nuclear EU regulatory bodies to ensure that they meet **high safety, safeguards and security standards**.

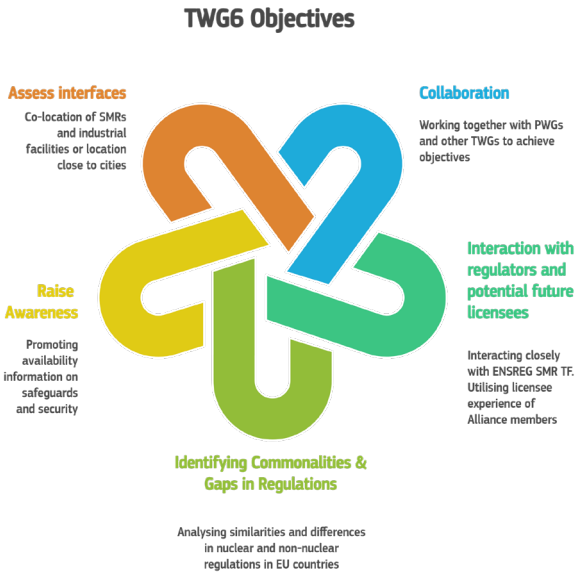
Key Objectives

A significant advantage of SMRs is related to their potential to be built closer to urban areas and regional industrial settings than conventional nuclear power plants, which would allow their easier application, e.g. for production of industrial heat, district heat or for deployment at previous fossil power plant sites. This necessitates ensuring a high level of nuclear safety, security, and safeguards. Additionally, other safety requirements related to, e.g. fire safety, occupational safety, safe intertask with industrial processes, environmental protection, and resilience to climate change and external hazards such as flooding, earthquakes, and droughts, also need to be comprehensively addressed.

At the same time, it would be important to

ensure that **national differences** in safety requirements do not lead to significant design changes from country to country, which would endanger the potential for serial production and the competitiveness of SMRs. The Technical Working Group 6 (TWG6) on Safety, Security, and Safeguards will investigate strategies to help maintain the required high level of safety for the PWGs established under the Alliance, while addressing the issues and questions posed by different national licensing requirements and practices.

To achieve this, TWG6 will initially identify and analyse the **commonalities and differences** in nuclear regulatory framework implementation among relevant EU countries, focusing on pre-licensing, licensing, and non-nuclear requirements such as fire, occupational and environmental safety issues.



Furthermore, TWG6 will conduct a **risk assessment** to determine the potential impacts of nearby industrial facilities on SMRs and vice versa, including the effects on safety design, demonstration, and emergency protection zone planning. The working group will also raise awareness among SMR developers, potential future users, and utilities about safeguards and security issues, promoting the adoption of the Safety-Safeguards-Security by-design methodology.

To achieve its objectives, the working group will establish a close collaboration with each PWG and engage with nuclear utilities and relevant EU regulators. The activities of this TWG are closely intertwined with the work of other TWGs, including TWG1 on industrial Applications, TWG2 on Technology and Research & Innovation, TWG5 on Public Engagement, and TWG7 on Fuel and waste management, with which it will maintain a strong interface to ensure a cohesive and coordinated approach.

TWG6 Tasks

6.1 Develop "industry technical strategy" on nuclear safety issues for SMRs and AMRs

The primary objective of this task is to develop a series of comprehensive position papers that describe **technical strategies for achieving safety demonstration** for select technical topics, with a focus on outlining the various acceptable methods for demonstrating compliance with converged requirements in key European countries. These position papers will provide analysis and guidance on meeting the safety standards and objectives outlined in the Western European Nuclear Regulators' Association (WENRA) Safety Reference Levels (SRLs) and Safety Objectives, as well as relevant requirements in the IAEA Safety Standards Series (SSR) and General Safety Requirements (GSR) standards. To ensure a collaborative and informed approach, this work will be undertaken in close intertask with the European Nuclear Safety Regulators Group (ENSREG) Task Force on SMRs. For AMRs, the focus will be on safety topics that are directly relevant to Lead-cooled Fast Reactors (LFRs) and Molten Salt Reactors (MSRs).

6.2 Promote early assessment of SMR projects by panels from several interested EU regulatory authorities to identify potential common safety concerns and address them in a timely manner

The development of SMR projects in multiple EU countries can benefit significantly from early assessment by a panel of safety bodies. This proactive approach can substantially mitigate the risks associated with late stage demands, thereby strengthening the development of a series of identical reactors. By c**onducting assessments early** on, potential safety concerns can be identified and addressed in a timely manner, reducing the likelihood of costly rework

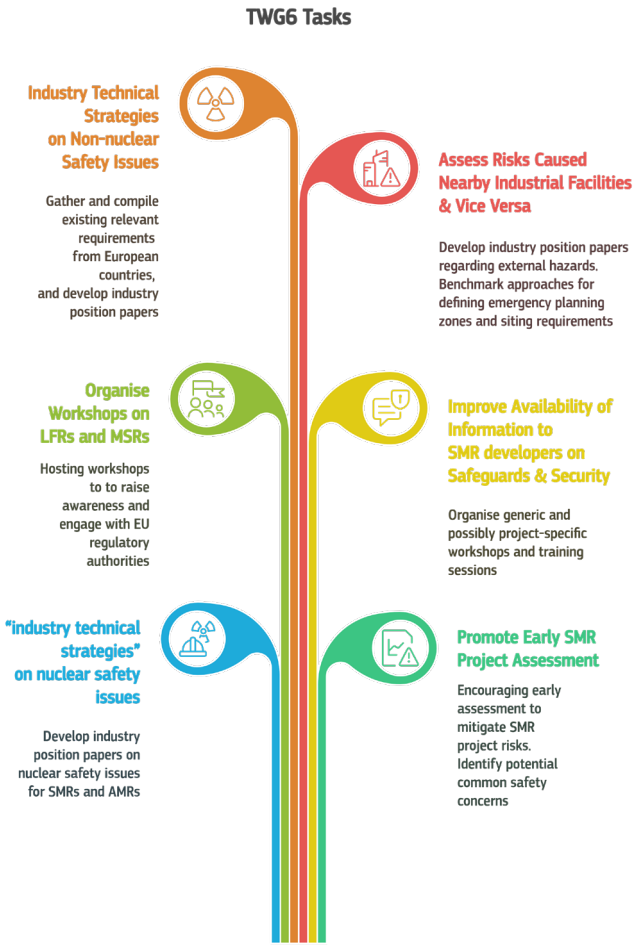
and delays. This, in turn, can facilitate the efficient deployment of SMR technology across the EU, promoting a **harmonised and robust safety framework** for these innovative reactors. In this frame and in close intertask with the ENSREG SMRs Task Force further development of SMR designs through **Joint Early Reviews (JER)** by EU regulators will be further explored, as well as setting up "NZIA Regulatory sandboxes[1]" to support SMRs' design pre-licensing.

6.3 Organise workshops on LFRs and MSRs to raise awareness and engage with EU regulatory authorities

The objective of this task is to host or coordinate technical workshops to familiarise regulators and Technical Support Organisations (TSOs) with the unique characteristics and benefits of SMRs, particularly of LFR and MSR technologies. These workshops will provide a **platform for knowledge** sharing, discussion, and collaboration among stakeholders, facilitating a deeper understanding of these innovative reactor designs. To support this effort, TWG6 will develop **comprehensive documentation** highlighting the safety features of **LFRs** and **MSRs**, as well as their distinct differences from traditional Light Water SMRs (LW-SMRs). In this context, it will be important to conduct dedicated **deep dives on key issues** such as coolant chemistry and reactivity, fire hazards, corrosion mechanisms, material ageing, etc., with the objective of producing **industry position papers** on these issues by 2027. This documentation will serve as a valuable resource for regulators, TSOs, and other stakeholders, enabling them to make informed decisions about the deployment and integration of LFRs and MSRs into the energy landscape in the future

6.4 Improve the availability of information to SMR developers regarding security and safeguards issues

TWG6 will conduct an analysis to **identify critical safeguards and security issues** associated with specific SMR technologies and applications, considering their unique design features, operational characteristics, and potential deployment scenarios. To provide targeted support, the working group will organise generic and project-specific workshops and training sessions, bringing together experts from industry, regulatory bodies, and international organisations to share best practices and address technology-specific issues. In collaboration with key partners, including Euratom, the IAEA, and the European Safeguards Research and Development Association (ESARDA), the working group will leverage expertise and resources to provide direct support to interested PWGs



6.5 Develop "industry technical strategies" on non-nuclear safety issues for SMRs

The objective of this task is to gather and compile existing relevant requirements from European countries, including regulatory frameworks, standards, and guidelines applicable to SMRs, including those related to environmental protection, health and safety at work, fire safety and other relevant non-nuclear safety issues.

1 The framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem (Net-Zero Industry Act) was adopted in 2024 (Net-Zero Industry Act) establishing a requirement for Member States to set up net-zero regulatory sandboxes in order to promote innovation and regulatory learning in the field of net-zero technologies

The work will be done in intertask with the PWGs. Based on this analysis, the working group will develop industry technical strategies through position papers that provide a clear overview of the regulatory landscape for **non-nuclear requirements**, identifying potential gaps and barriers.

6.6 Assess risks caused to SMRs by nearby industrial facilities and vice versa

The objective of this task is to assess the potential hazards and risks posed by nearby industrial facilities to SMRs and vice versa, ensuring the safe and secure operation of these reactors. Such industrial settings may include, for instance, chemical plants, refineries and petrochemical facilities as well as warehouses, storage facilities, and construction sites. The possible implications of **external hazards** caused by external facilities on safety design of SMRs will be assessed. Position papers on external hazards will be developed. Furthermore, TWG6 will benchmark the approach to **defining emergency planning zones (EPZ)** and **siting requirements** and practices relevant to SMRs in different countries to find commonalities. **Position papers on EPZ** aspects will also be developed. As siting aspects and EPZ are linked to public engagement, cooperation with TWG5 is very important.



TWG7 Securing Existing & Advanced Fuel Supplies & Waste Management

Challenges



A clear pipeline of projects alongside a stable and supportive policy and regulatory framework is essential for attracting **investment** in a **new fuel cycle capability,** which is critical for successfully deploying SMRs dependent on existing and new fuel types. While LW-SMR designs can leverage existing nuclear fuel solutions with modifications, AMRs will require **customised front-end and back-end industrial capabilities and logistics**, including **advanced fuel fabrication** and **reprocessing facilities**.

Fuel cycle sustainability is also a central component of many SMR strategies, as it enables the **reduction of waste production** and **optimises the use of resources**. Therefore, advanced reprocessing and reuse of fissile materials will be key to achieving **nuclear fuel cycle circularity** and more efficient use of ore. This includes the development of **innovative fuel cycles**, such as **closed fuel cycles**, which can **minimise waste production** and **maximise energy generation**. Additionally, implementing **advanced waste management strategies**, including **characterising** the **waste streams from advanced technologies** and focusing on areas such as **storage**, **transportation** and **disposal**, will be crucial for ensuring the **safe and responsible management of radioactive waste**.

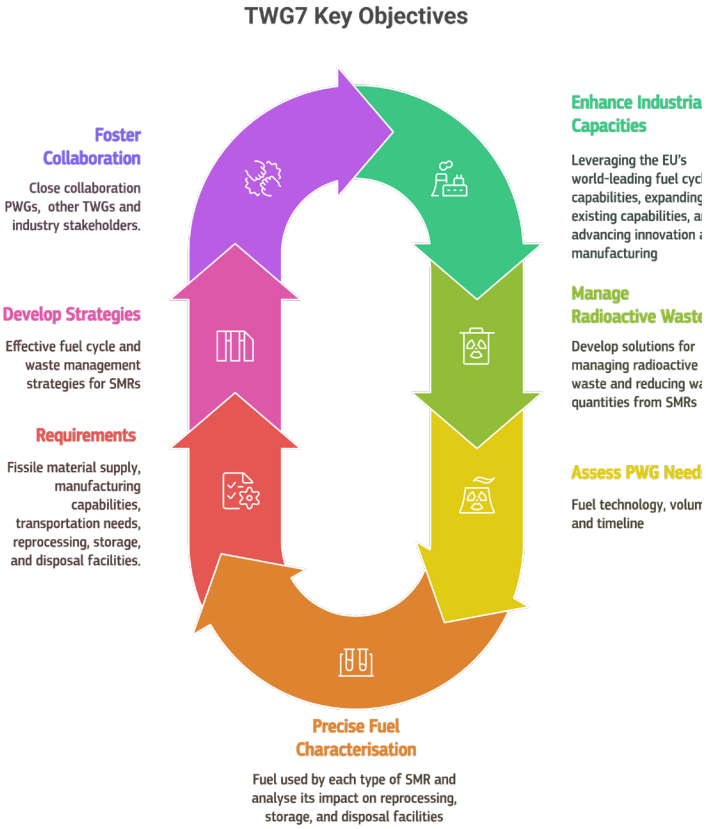
Regulatory harmonisation is equally vital, particularly concerning the **transport and classification of nuclear materials**. The SMR projects identified by the Alliance mainly rely on low-enriched uranium (LEU) or MOX fuels (mixed uranium and plutonium oxide). However, recognising that future projects may require high-assay LEU fuels (LEU+ or HALEU) and acknowledging the long lead times necessary for developing such new European fuel cycle facilities, it is essential to include HALEU in the scope of the work on advanced fuels. This will require coordinated efforts among regulatory bodies, industry stakeholders, research institutions, and public bodies to develop and implement **harmonised standards** and **guidelines** for the **safe** and **secure transport**, **storage**, and handling of **LEU+**, **HALEU**, and **MOX fuels**.

Key Objectives



The Technical Working Group 7 (TWG7) on Fuel Cycle and Waste Management will aim to explore and propose ways to **enhance industrial capacities for existing and new nuclear fuels and nuclear material supply in Europe**. It will particularly focus on leveraging the EU's world-leading fuel cycle capabilities, further expand existing capabilities and to advance innovation and manufacturing of **next-generation nuclear fuels**, including **Pu-based fuels**, **thorium**, **LEU oxide**, and **LEU+** or **HALEU-based fuels**. Additionally, TWG7 will explore solutions for **managing radioactive waste and reducing waste quantities from SMRs**. Ultimately, TWG7's efforts will contribute to a more sustainable and environmentally friendly nuclear energy sector.

To achieve this, it is crucial to assess the needs of PWGs in terms of fuel technology, volume, and timeline. TWG7 will also assess the **requirements for fissile material supply**, **manufacturing capabilities**, **transportation needs**, and **reprocessing**, **storage**, and **disposal facilities**. TWG7's work will consider the precise **nuclear characterisation** of fuel used by **each type of SMR** and analyse its **impact on reprocessing, storage, and disposal facilities**. This characterisation will also apply to activation waste resulting from these reactors.



By addressing the fuel cycle and waste management issues, TWG7 will help to ensure the l**ong-term viability and sustainability of SMRs as well as enhance public acceptance**. The group's efforts will focus on promoting innovative solutions and fostering collaboration among industry stakeholders from within the EU and with international partners. The group's recommendations will inform the development of **effective fuel cycle and waste management strategies for SMRs**.

To achieve its objectives, TWG7 will establish close collaboration with each PWG and work closely with other TWGs such as TWG2 on Technology and R&D&I, TWG3 on Supply chain, TWG6 on Safety and Safeguards, and TWG8 on Financing.

TWG7 Tasks

The proposed tasks outlined below are based on inputs from and discussions among TWG7 members, and consider contributions and feedback received from several PWGs.

7.1 Enhancing European nuclear fuel production and reprocessing capabilities

The goal of this task is to enhance existing and future European nuclear fuel production and reprocessing capabilities, thereby achieving a reliable and sustainable supply of nuclear fuel. This involves continuing to leverage and expand existing **infrastructure for uranium conversion, enrichment,** and **deconversion**, as well as **nuclear fuel production** and **fuel reprocessing**. Notably, reprocessing technologies will address, in addition to LWR fuel with low fissile content, also fuels with higher fissile content (i.e. MOX for fast reactors). By unlocking further investment to strengthen these capabilities, Europe can enhance the **competitiveness** of its existing **fuel supply chain**, **reduce dependence** on Russia, improve the **security of its energy supply**, and enhance the **sustainability** of the nuclear fuel cycle.

7.2 Foster industry-wide collaboration to develop standardised fuel design specifications for SMRs

The objective of this task is to foster synergies and **standardisation efforts in the design of nuclear fuel for SMRs**, with the aim of maximising fuel volume requirements and minimising the need for short series production linked to specific designs. To achieve this, TWG7 will collaborate with interested PWGs to identify specific features that can be harmonised in terms of fuel requirements and design. This harmonisation effort will enable the development of **standardised fuel designs** that can be applied across multiple SMR projects, **reducing production costs** and enhancing overall efficiency.

7.3 Accelerating innovation in nuclear fuels for SMRs through industrial and EU collaboration

The The objective of the task is to explore the different opportunities offered by different EU-funded programmes to **foster innovation in existing nuclear fuels** like LEU oxide and advanced fuels such as Pu-based fuels (including MOX), thorium and LEU+ or HALEU-based fuels. This can be achieved by igniting and **scaling up financing opportunities**, including, for **research**, those provided by the Euratom Research and Training Programme, the recently established Important Project of Common European Interest (IPCEI) initiative on innovative nuclear technologies, and the European Investment Bank (EIB), among others. By leveraging these funding sources, researchers, industry stakeholders, and policymakers can work together to **develop and demonstrate new advanced nuclear fuels for SMRs**, including the extension of existing **infrastructures** or the development of new ones.



7.4 Unlocking investment in advanced nuclear fuel cycles for SMRs

The objective of this task is to establish a stable and long-term energy policy framework that unlocks **private and public investment** in existing and advanced fissile material provision, as well as nuclear fuel fabrication capabilities. This includes supporting the development and production of various fuel types, such as MOX fuels, Low-Enriched Uranium (LEU) oxide, Reprocessed Uranium oxide, High-Assay Low-Enriched Uranium (HALEU)-based fuel, Plutonium-based salts, and Thorium-based fuels. A stable energy policy will provide a predictable and favourable business environment, enabling investors to commit to the development of these **advanced fuel cycles and fabrication capabilities**, which are essential for the sustainable and efficient operation of current and future nuclear reactors.

7.5 Closing the nuclear fuel cycle: consolidating European expertise and driving innovation and minimising fresh uranium needs for EU

The task will focus on reinforcing EU capabilities in **(multi-) reprocessing** and **recycling** of fissile material, whereby Europe can **reduce** its **dependence on external fuel sources** and on fresh uranium, needs to **minimise waste production** and maximise the efficient use of nuclear energy. The task will address developing MOX fuels for AMRs, innovative **Partitioning and Transmutation technologies** reducing the **radiotoxicity of nuclear waste** and **minimising** its **storage** and **disposal** requirements. Furthermore, the task will explore developing effective **waste management strategies for SMRs**, including the development of advanced storage, interim and disposal facilities, to ensure the safe and secure management of nuclear waste.

7.6 Mapping final repository needs for SMRs in Europe

The goal of this task is to develop a comprehensive **mapping of final repository needs for SMRs** in Europe, providing a detailed understanding of the requirements for final repositories, including geological, technical, and societal factors. The mapping will also facilitate the **development of fuel and nuclear waste management strategies** that align with international standards and

guidelines, such as those outlined in the Council Directive 2011/70/EURATOM.

Furthermore, the task will consider the inventory reports of radioactive waste and spent fuel present in the European Community's territory, ensuring a thorough and informed approach to final repository needs. By fostering multinational collaboration in this area, EU countries will be able to share knowledge, expertise, and best practices to develop effective and sustainable solutions for effective nuclear waste management.

7.7 Optimising nuclear material transport

The goal is to coordinate the development of solutions to ensure that nuclear materials are transported in a secure, controlled, and cost-efficient manner, respecting the requirements set by the Member States' authorities, while targeting the harmonisation of fuel cask designs across Europe. This includes **designing** and **building transport casks** and fleets that are specifically tailored to the needs of different SMR fuel types, as well as fresh and spent fuel, and various levels of radioactive waste. In this context, one of the first tasks would be assessing **current transport cask availability** and **production capacity** and identifying necessary investments to support future demands for secure and standardised transport by road and sea.



TWG8 Unlocking Investment in SMRs

Challenges

From a financing perspective, SMRs present a distinct set of **barriers** and **opportunities** that diverge from those associated with conventional large-scale nuclear power plants. On the one hand, SMRs offer several attractive features that make them a compelling option for investors and governments. As a result, SMRs promise to provide quicker investment returns, making them a more appealing option for investors seeking to minimise risk and maximise returns.

However, SMRs face significant **financing hurdles** that can complicate their development. The introduction of new designs and advanced technologies involves higher uncertainties, as these designs have not yet been widely tested or proven in commercial settings. Furthermore, limited fuel availability for certain AMR types adds an additional layer of complexity, potentially impacting operational costs and supply security in the future. The evolving regulatory landscape for SMRs, with licensing requirements still being established, can lead to delays and increased costs. Moreover, the supply chain is not yet fully mature and adapted to SMRs, resulting in logistical barriers and increased project risk.

The high risks associated with first-of-its-kind (FOAK) SMR projects, including potential technical and regulatory setbacks, pose significant barriers to investment, as investors typically prefer projects with proven technologies and predictable outcomes. These make it difficult for SMR projects to secure adequate financing and attract investors, particularly within the EU's financial and regulatory framework. To overcome these financial hurdles, new de-risking methods are essential to fully unlock the potential of SMRs. This includes innovative financing approaches and policy tools designed to mitigate risks and provide investment incentives. Mechanisms such as government-backed loan guarantees, public-private partnerships, and targeted subsidies can play crucial roles in addressing these barriers.

Key Objectives

The key objectives of the Technical Working Group 8 (TWG8) are to identify and address f**inancial barriers**, **map EU funding opportunities**, and **develop innovative financing solutions** to support the development of SMRs. The primary goal is to understand and address the financial barriers and risks associated with SMR development, demonstration, and deployment. This includes identifying financial concerns of SMR developers and end-users, mapping EU funding opportunities at the EU level and identifying potential gaps. TWG8 will conduct a thorough review of **potential revenue models** for SMRs, and how to create **innovative, tailor-made financing tools for nuclear demonstrators** and substituent commercial fleet, where necessary, combining different funding sources and instruments to provide

robust financing solutions for SMR developers. Within this framework, ways to **simplify** and **accelerate** the processes of obtaining **state aid**, as well as to provide **flexibility in support mechanisms**, should be explored. TWG8 also aims to communicate effectively with additional financing stakeholders to ensure their active participation and engagement in the activities to be undertaken in the future.

TWG8 will also engage in close collaboration with all interested Project Working Groups (PWGs), inviting them to participate in relevant activities such as expert meetings, workshops, and webinars on financing topics. Furthermore, close collaboration with other TWGs will be essential to leverage expertise and develop joint initiatives.



TWG8 Tasks

The following tasks have been formulated by considering the needs expressed by the nine PWGs supported by the Alliance and the feedback gathered from the TWG8 members. They can be categorised into four broad task groups.

8.1 Identify financial and market demand challenges, associated investment risks, and measures for SMRs

Identify the financial concerns of SMR developers, associated risks, and measures: The goal is to comprehensively gather and meticulously review the wide range of financial barriers, bottlenecks, risks, and investment barriers that SMR developers may face in the EU. This thorough examination aims to identify the specific hurdles that hinder the development, deployment, and commercialisation of SMR technologies. Upon identifying these obstacles, the next step is to propose well-informed, practical, and taskable recommendations.

Identify financial challenges of SMR end-users, associated risks, and measures: The objective is to conduct a thorough analysis to **identify and evaluate the financial barriers** faced by potential SMR users, to foster market demand for SMRs in the EU. The focus is on understanding the financial hurdles and requirements of various potential users of SMR-generated electricity, including but not limited to energy utilities companies, nuclear operators, large-scale industrial consumers of electricity, such as manufacturing facilities, chemical plants, and oil refineries, and local clusters of businesses, possibly from diverse sectors, that could collectively purchase electricity from an SMR. The next step is to propose a set of clear and taskable recommendations.

8.2 Map EU-level funding opportunities, identify gaps, and propose accessible financing options for SMR development along all development stages

The objective is to conduct a comprehensive analysis to **identify** and review **gaps in existing EU financing opportunities** that can be utilised by **SMR developers** or **companies manufacturing** components for SMRs, which are established in

the EU. This involves examining the various **EU funding programmes** and proposing solutions to address the identified gaps. Emphasis would be given to fully explore the different possibilities offered under Euratom, the Net Zero Industry Act (NZIA), the EIB, the innovation Fund, and the IPCEI on innovative nuclear technologies, as well as other State-aid schemes.



8.3 Develop tailor-made instruments and funding schemes

The goal of this task is to conduct a thorough review of **potential revenue models** for SMRs, including Power Purchase Agreements (PPAs), and suggest innovative, tailor-made financing tools where necessary, such as **structured financing packages** that combine different funding sources and instruments to provide comprehensive and **robust financing solutions** and **de-risking mechanisms** for SMR projects. These reviews will address both SMR projects that provide a mix of electricity and heat to different customers, as well as SMRs designed to provide heat for local community or industrial applications. To achieve this objective, experts from financial institutions such as investment and development banks, private equity funds, and specialised investment initiatives such as the EIB advisory hub, will bring their extensive knowledge and experience in financing complex projects.

8.4 Communicate effectively, and collaborate with other international organisations

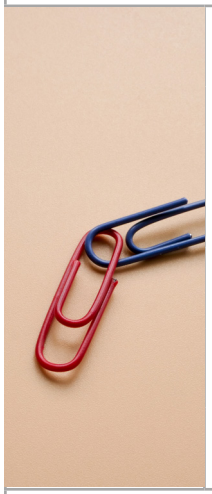
The primary goal of this task is to **inform** and **raise awareness** among f**inancial stakeholders** about the significant market potential of SMRs and to engage in collaborative efforts with international stakeholders working on SMR financing topics, such as the NEA-OECD and the IAEA. This goal is crucial for unlocking the full potential of SMRs as a low-carbon energy source, as it requires the active participation and support of the financial community. To this end, Task Working Group 8 (TWG8) will develop an awareness strategy, including specific tasks, tasks, and a timeline, with the aim of engaging the financial community in SMR development and deployment in Europe.

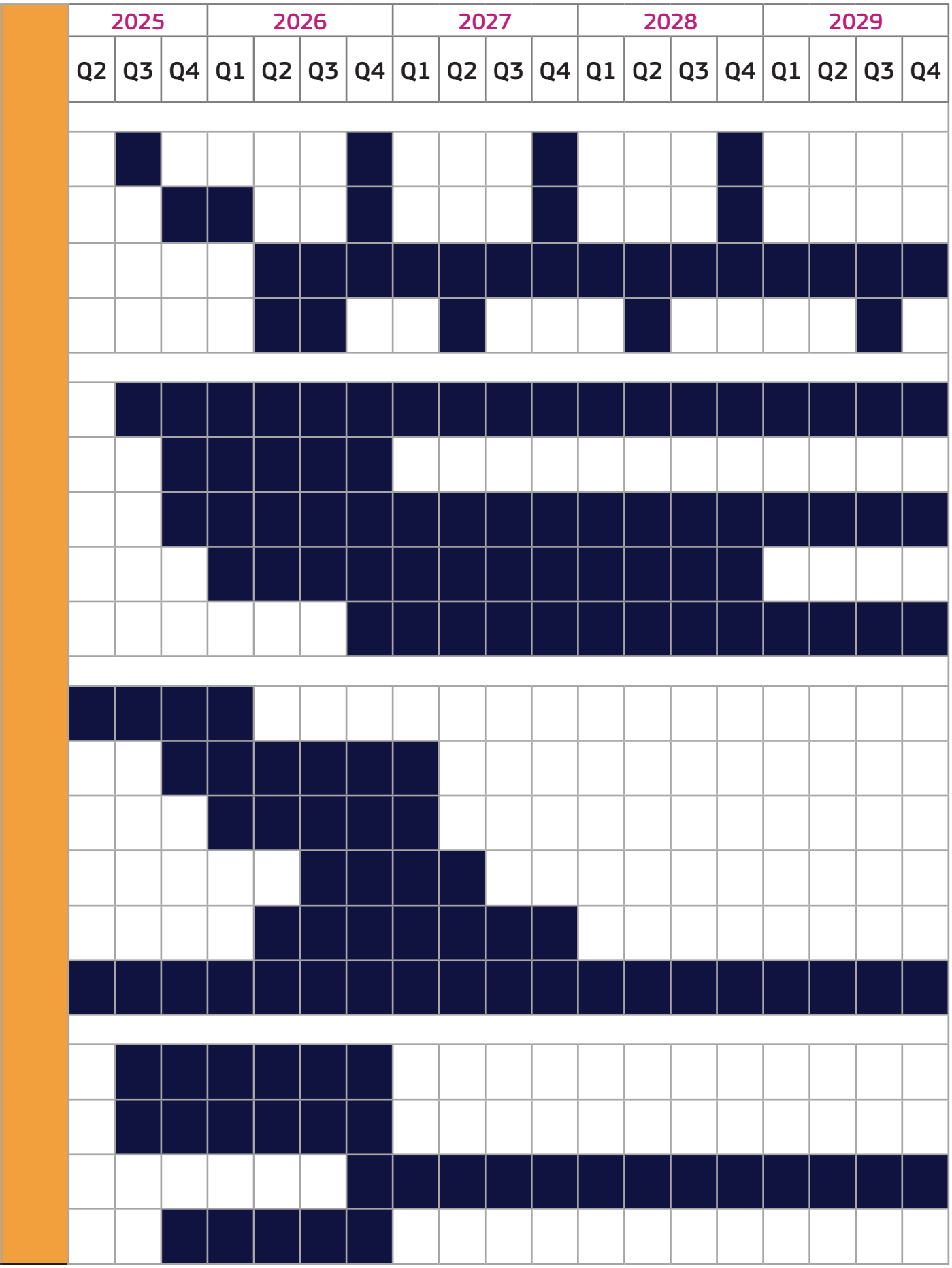
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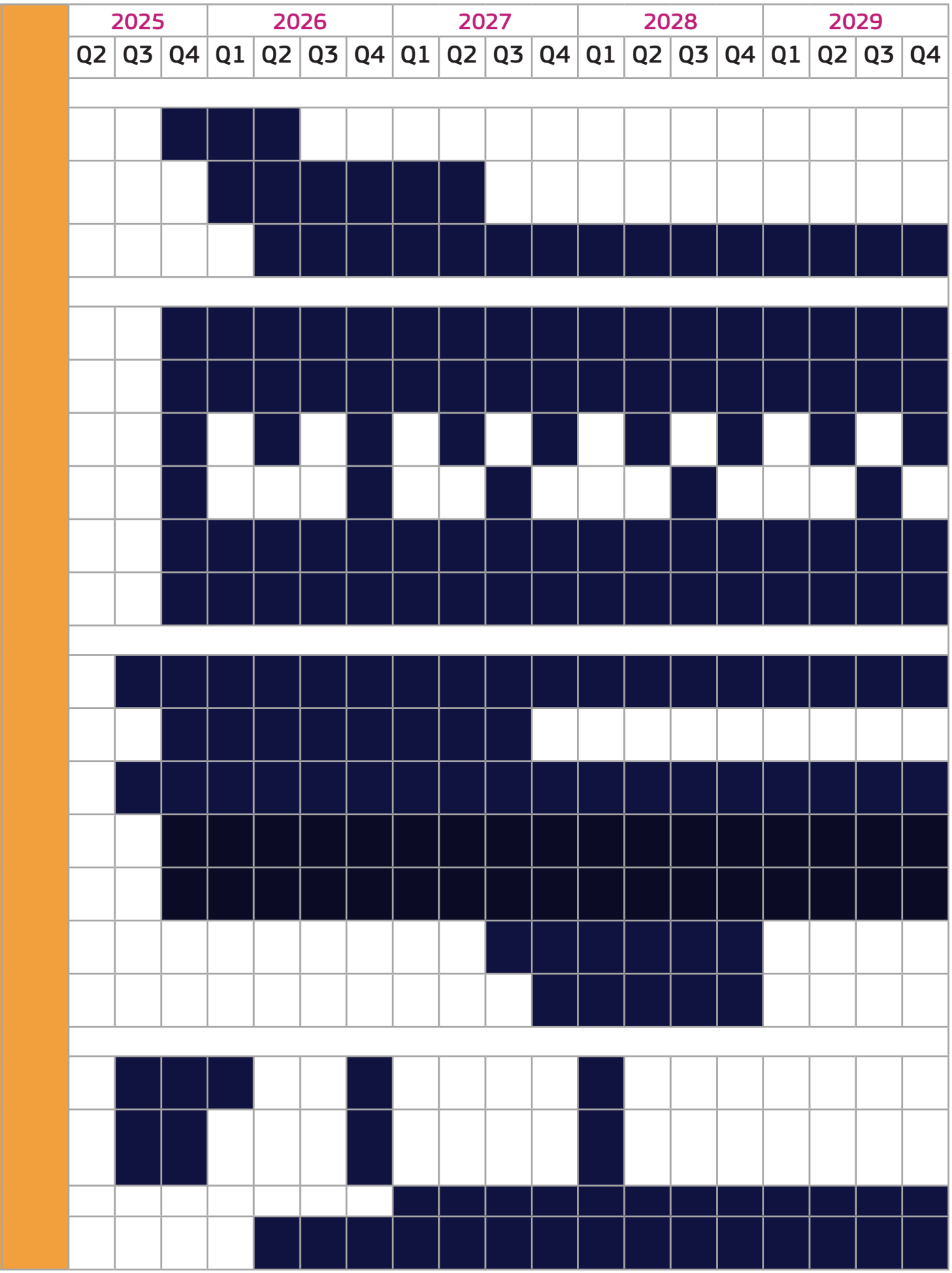
Technical Working Groups
Time schedule



TWGs	Objective	Tasks
	**Developing a Robust Market Demand for SMRs**	Evaluate the needs for electricity and heat of relevant end-users
		Identify the challenges of using SMRs by key industries
		Identify, evaluate, and prioritise the first demonstration pilot projects
		Communicate and raise awareness
	**Excelling in Research and Technology for SMRs**	Promote standardisation and preferred European codes and standards
		Facilitate data, technologies, and components flow within the EU
		Identify, assess and prioritise key experimentation and testing facilities
		Advance Modularisation and Digitalisation of SMRs
		Facilitate SMR integration into different applications and systems
	**Building a Competent and Scalable Supply Chain**	Assess the nuclear supply chain in Europe
		Analyse the economic and sustainability aspects of the supply chain
		Evaluate and enhance supply chain capabilities
		Strengthen collaboration within and beyond Europe
		Improve supply chain resilience
		Support PWGs on Supply chain topics
	**Getting the Right Skills and Competences for SMRs**	Collect needs for skills to develop and operate SMRs
		Map current E&T initiatives on nuclear at EU, national and regional levels
		Identify gaps for skills and develop initiatives to address them
		Develop strategies to attract and retain human resources for SMRs


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TWGs	Objective	Tasks
	**Fostering Public Engagement**	Collect baseline information on societal aspects related to SMRs acceptance
		Design an awareness and engagement approach (toolkit and guidelines)
		Foster collaboration, outreach and networking among interested stakeholders
	**Fostering Safety, Security and Safeguards**	Develop “industry technical strategy” on safety issues for SMRs
		Promote early assessment by several EU regulatory authorities
		Organise workshops on LFRs and MSRs to engage with EU regulatory authorities
		Improve information access to SMR developers on security and safeguards
		Develop “industry technical strategies” on non-nuclear safety issues
		Assess risks caused to SMRs by nearby industrial facilities & vice versa
	**Securing Existing & Advanced Fuel Supplies & Waste Management**	Enhancing European nuclear fuel production and reprocessing capabilities
		Develop standardised fuel design specifications for SMRs
		Accelerating innovation in nuclear fuels through industrial and EU collaboration
		Unlocking investment in advanced nuclear fuel cycles for SMRs
		Closing the nuclear fuel cycle
		Mapping final repository needs for SMRs in Europe
		Optimising nuclear material transport
	**Unlocking Investment in SMRs**	Identify financial and market demand challenges, associated investment risks, and measures for SMRs
		Map EU-level funding opportunities, identify gaps, and propose accessible financing options for SMR development along all development stages
		Develop tailor-made instruments and funding schemes
		Communicate effectively, and collaborate with international organisations


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Annex III



Key innovative research areas to support SMRs development in the EU

A. Introduction

In this Annex, the term "SMR" encompasses both Light Water Small Modular Reactors (LW-SMRs) and Advanced Modular Reactors (AMRs), serving as a collective reference to these technologies. Where necessary, the terms LW-SMRs and AMRs will be used to provide more specific descriptions and avoid ambiguity. This document defines SMRs as compact nuclear power units that generate an electrical output of 10 up to 500 MWe, and/or produce thermal power varying from 100-850°C. "SMR technologies" encompasses various technological fields, including reactors, cooling systems, control and instrumentation systems, simulation tools, digitalisation and automation, materials and manufacturing, modularisation, advanced safety systems, and fuel and waste management technologies.

Small Modular Reactors (SMRs) can be categorized into two primary groups. The first group consists of SMRs that utilize technologies analogous to those employed in Light Water nuclear reactors (Generation III+). The second category encompasses SMRs that use alternative coolants, such as gas, liquid, or molten salt-cooled reactors (Generation IV), also known as Advanced Modular Reactors (AMRs).The table on the next page summarises the main SMR types, their reactor technology, key characteristics, existing experience at the EU level (designing, building, and operating), as well as, when relevant, the corresponding PWGs identified so far for support under the Alliance.

Given the breadth and depth of these areas, this technology overview cannot be an exhaustive compendium of all existing SMR technologies within each category. Instead, it focuses on the most predominant ones. It identifies **critical innovative technologies**, associated **infrastructures**, **knowledge gaps** and areas that require **additional investigation**. The implementation of these technologies will be facilitated through a series of actions that will be launched and monitored by the Technical Working Groups of the Alliance, notably by TWG2 on Technology and R&I, TGW3 on supply chain, TWG6 on safety and safeguards, and TWG7 on fuel & waste management.

Light Water Reactors SMRs (LW-SMRs) – GEN III/GEN III+

Three types of light-water-cooled reactors are currently used in the EU:

1. Pressurised Water Reactor (PWR): This is the most used reactor technology worldwide, accounting for nearly three-quarters of all reactors. They are used in both power and marine propulsion nuclear reactors. Over 300 units operate worldwide, including over 80 in the EU. Most LW-SMRs are based on this concept.
2. Boiling Water Reactor (BWR): This is the second most widely used technology for power reactors. Over 40 are operating worldwide, and 7 are in the EU (27 units have been operating in the past). This limited deployment, particularly in the EU, has resulted in a smaller base of expertise and mastery of BWR technology among European industries than PWR technology.
3. Integrated Pressurised Water Reactor (iPWR): This design integrates the primary circuit components, such as the reactor vessel, steam generators, and pressuriser, into a single unit. The integral design inherently reduces the number of components and potential failure points. It relies on passive systems that could provide high reliability and resilience during severe accidents.

LWRs are a proven technology. Therefore, LW-SMRs are anticipated to reach market readiness by the early 2030s. This timeline positions LW-SMRs for deployment several years before the next generation of AMRs.

Advanced Modular Reactors (AMRs) – GEN IV

Over the past three decades, the EU has developed significant expertise in AMRs, which were mainly built through continuous, albeit limited, support and the operation of pioneering reactors established in some Member States, such as the Sodium Fast Reactor (SFR) in France. Additionally, several EU member states, including Belgium, the Czech Republic, Italy, Romania, Slovakia, and Sweden, have actively supported the development of these technologies through dedicated national programs. Furthermore, the Euratom Research and Training Programme has been crucial in funding safety-focused research projects on GEN-IV reactors.

The main Advanced Modular Reactors investigated at the EU level can be grouped into the following four categories:

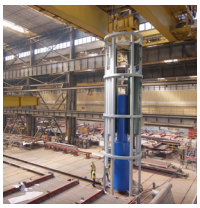
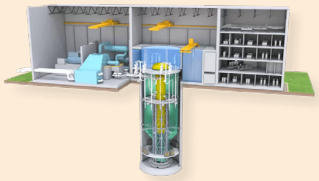
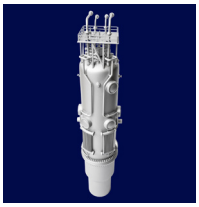
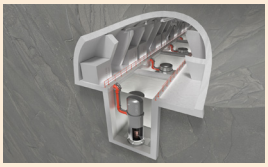
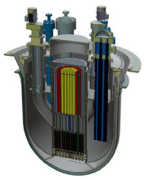
1. High Temperature Gas Reactors (HTR or HTGR)

High-temperature gas-cooled reactors (HTR or HTGR) are helium-cooled graphite-moderated nuclear fission reactors utilising fully ceramic

GEN III/III+ SMRs and GEN IV AMRs offer promising technological advancements

	Reactor Technology	Experience with technologies at EU level[1]
GEN III/III+ SMR	**PWR (Pressurised Water Reactor)** The most widely used reactor technology globally, representing nearly 75% of all reactors. It is employed for both electricity generation and marine propulsion. More than 300 units operate worldwide, including over 80 within the EU.	Very Good
	BWR (Boiling Water Reactor) This is the second most widely used technology for power reactors. Over 40 operate worldwide, with 7 in the EU (27 units operated previously). This deployment has led to less BWR technology expertise among European industries than PWR technology.	Very Good
	iPWR (Integrated Pressurised Water Reactor) This nuclear reactor integrates primary circuit components like the reactor vessel, steam generators, and pressuriser into a single unit. Compared to traditional PWRS, the design aims to improve safety, reduce costs, and increase efficiency.	Good
	Heat-dedicated LWRs This type of LWR produces only heat, not electricity, and operates at low temperatures and pressures.	Good
GEN IV – Advanced Reactors AMR	**HTR (High Temperature Reactor)** High-temperature gas-cooled reactors (HTR or HTGR) are helium-cooled graphite-moderated nuclear fission reactors utilising fully ceramic fuel.	Moderate
	SFR (Sodium Fast Reactor) Sodium Fast Reactors (SFRs) are advanced nuclear reactors that use liquid sodium as a coolant and operate with fast neutrons instead of slowing them down with a moderator. This allows for efficient fuel use and the potential to recycle nuclear waste.	Good
	LFR (Lead Fast Reactor) Lead-cooled Fast Reactors (LFRs) are fast neutron reactors using lead or lead-bismuth alloy coolant. One advantage over sodium is the elimination of chemical reactions with water or air. It could use various fuel types, including recycled nuclear waste.	Moderate
	MSR (Molten Salt Reactor) A self-regulating critical geometry uses an enriched molten salt mixture as coolant and fuel to generate heat.	Low

1 Experience based on the number of reactors and test facilities built and operated in the EU since the 80s and the number of research
2 SMRs/AMRs projects, identified by the Alliance within the first batch, corresponding to the technologies

Typical Reactor Temperature and Pressure	Projects identified by the Alliance[2]	Projects Designs
<320°C 155 bar	NUWARD QUANTUM-PWR-20 ROLLS-ROYCE	 
<285°C 70 bar	OSGE-BWRX-300	
<320°C 155 bar	ROPOWER-NUSCALE	
100-150°C <10 bar	CITYHEAT (Steady Energy LDR50, Calogena, CAL-30)	 
750-850 °C 70 to 90 bar	None for the time being	
<550°C Atmospheric pressure	None for the time being	
<550°C Atmospheric pressure	EU-SMR-LFR (EAGLES-300) NEWCLEO (LFR-AS-200)	 
<625-800°C Atmospheric pressure	THORIZON ONE	

programmes conducted at national and EU levels for these technologies

fuel[1] . The fuel is uniquely encapsulated in small pellets, which are then assembled into blocks or pebbles. Helium gas circulates between the pebbles, acts as a coolant, and is heated to temperatures ranging from 750°C to 850°C. The very-high-temperature reactor (VHTR) is a longer-term evolution of the HTR, targeting even higher efficiency and more versatile use by further increasing the helium outlet temperature to 950 °C or even higher. The fuel employed in HTGRs possesses a high mechanical strength, chemical stability, and significant resistance to irradiation, thereby contributing to the robustness and safety of these reactors. The high temperatures generated by HTGRs make them well suited for producing heat for high-temperature industrial processes and enabling high-efficiency electricity generation. In the EU, there have been a few HTRs operating in the past, such as the AVR test reactor (40 MWth) running from 1967 to 1988, and the THTR demonstrator reactor (750 MWth) running from 1986 to 1989, both in Germany. Some R&D projects have also been conducted to investigate the safety and feasibility aspects of HTGR technology; however, commercial deployment has yet to occur. Initiatives are underway in several EU Member States, including the Czech Republic, France, and Poland, to advance the technology readiness level of HTGRs.

2. Sodium Fast Reactors (SFR)

Sodium Fast Reactors (SFRs) are fast neutron spectrum reactors, where a molten metal coolant, sodium, extracts the heat generated in the core. The reactor is operating approximately at 550°C, maintained at atmospheric pressure. As the most developed fast neutron reactor technology to date under the Generation IV (GEN-IV) framework, SFRs have been commercially deployed and have been in operation for decades, particularly in France (e.g. Rapsodie (40 MWth experimental reactor), operated from 1967 to 1983, Phénix (250 MWe demonstration reactor), operated from 1972 to 2009, Superphénix (1,200 MWe, the largest SFR built to date), operated from 1985 to 1997. Over the past decade, an intensive R&D program has been underway at the EU level, in France, with the ASTRID project[2], which continued until 2019. Sgnificant international collaboration, notably with the GEN-IV International Forum (GIF)[3]. At global level, two SFR are operating in the Russian Federation (BN-600 since 1980 and BN-800 since 2016). Other countries, such as the United States (with TerraPower's Natrium project), China, India, and Japan, are developing or constructing SFRs, but none are yet operational.

3. Lead Fast Reactors (LFR)

Lead-cooled Fast Reactors (LFRs) are fast neutron reactors that utilise a molten metal coolant, typically lead or a lead-bismuth alloy. One significant advantage of using lead or a lead-bismuth alloy over sodium is the elimination of chemical reactions with water or air, which can be a substantial concern in sodium-cooled reactors. However, the primary challenge associated with LFRs is the highly corrosive nature of molten lead, which can damage the steel components of the reactor. Developing advanced materials that can withstand aggressive conditions and high operating temperatures (approximately 550°C at atmospheric pressure) is essential to mitigate this issue. Within the EU, a substantial expertise and knowledge base has been established in LFR technology, thanks in part to the support provided by the Euratom programme and national initiatives in several member states, including Italy, Belgium, Sweden, and Romania. These efforts have contributed to advancing LFR technology and positioned the European Union as a leader in this field.

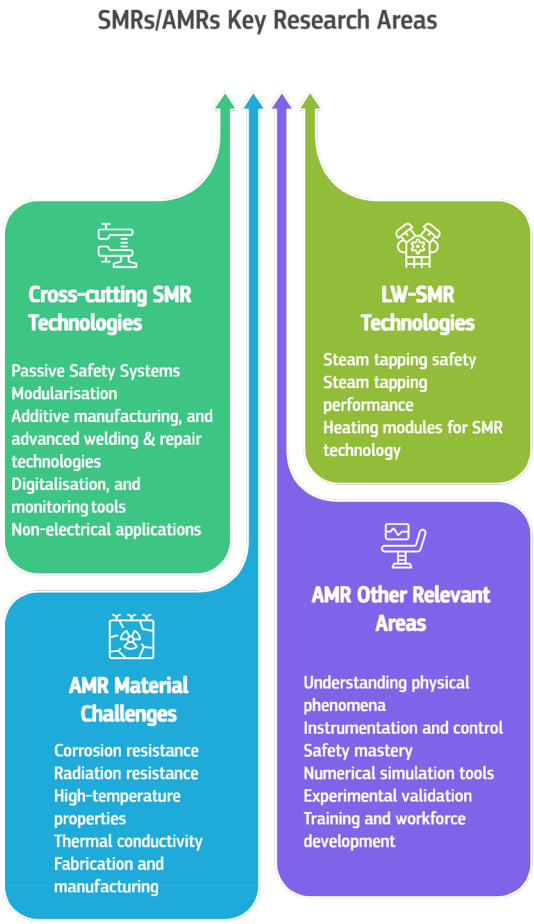
4. Molten Salt Reactors (MSR)

Molten Salt Reactors (MSRs) are nuclear reactors that utilise molten salts rather than traditional solid fuels. In an MSR, the molten salt serves a dual purpose: it acts as both a coolant and a medium for transporting the fuel within a “core” zone, where the geometry is designed to achieve criticality. The high melting point of the salt, typically sodium fluoride or chloride, enables core operation at temperatures ranging from 625 to 800°C at atmospheric pressure. Moreover, MSRs have the flexibility to operate in both thermal neutron and fast neutron modes. However, MSRs have not yet progressed beyond the experimental stage and are susceptible to complex corrosion. The primary challenge in developing MSRs is creating and qualifying materials that can withstand corrosion and irradiation, thereby achieving lifetimes that render the reactor economically viable. At the European Union level, only a few collaborative projects have been supported to address some of the R&D challenges associated with MSR technology. Nevertheless, there is a growing interest in MSRs at the international level, including in some EU member states such as France and the Netherlands, where researchers and industry stakeholders are exploring the potential of this innovative type of reactor for safety, fuel cycle improvement and economics.

1 The High Temperature Gas-Cooled Reactor - ScienceDirect
2 ASTRID project (Advanced Sodium Technological Reactor for Industrial Demonstration)
3 https://www.gen-4.org/

B. Key research areas to support SMRs development in the EU

This section aims to highlight the key research and development (R&D) and innovation domains necessary for advancing Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs) within the European Union. These domains are categorised into three distinct groups: those that are crosscutting between Light Water SMRs (LW-SMRs) and AMRs, those that are exclusively pertinent to LW-SMRs, and those that are more relevant to AMRs. Furthermore, key R&D topics related to the nuclear fuel cycle are also included. Where possible, a list of recent or ongoing projects co-funded under the Euratom Programme is provided where possible. It should be noted that the description provided here is not intended to be exhaustive, and each area and topic should be thoroughly investigated and supplemented with additional sources. The information presented in this section is based on a non-confidential consultation with the nine identified PWGs, organised by the Alliance secretariat over the past period. It is intended to provide a foundation for further analysis and development, which will be conducted with the support of the various TWGs and in association with the PWGs that will be supported under the Alliance in the next period, as outlined in the established non-disclosure agreement.



Cross-cutting SMR technologies

1. Advanced Safety Systems

Nuclear reactor design and operation prioritise accident prevention and mitigation, particularly managing decay heat after a shutdown. Some safety systems can be vulnerable to disruptions, such as a station blackout, which can compromise their ability to remove decay heat.

To address these challenges, advanced reactors, including SMRs and AMRs, are being developed with more robust and reliable safety systems.

Some of these systems are passive safety systems that utilise natural processes, such as circulation and evaporation, to maintain safety without relying on external power or operator action. These passive systems can provide a robust and reliable means of removing decay heat, even in the event of a complete loss of power. However, passive systems require further demonstration and qualification as stated in WENRA Report "Regulatory Aspects of Passive Systems"[1], such as validation of simulation safety codes, safety demonstration, human factor adaptation. Overall, combining modularisation and advanced safety systems can provide a robust and reliable means of generating nuclear power.

Some advanced reactor designs also feature enhanced containment structures, which can provide an additional layer of protection against radioactive releases.

Euratom R&D projects relevant to Advanced Safety Systems

The Euratom Research and Training Programme funded several projects on passive safety systems for SMRs. These initiatives aim to enhance reactor safety and improve the robustness of the design. Such R&D projects are described below (see box).

1 https://www.wenra.eu/sites/default/files/publications/rhwg_passive_systems_2018-06-01_final.pdf



International R&D cooperation

EU researchers and experts have been active in participating in collaborative efforts with the IAEA INPRO[2] to benchmark passive safety systems. INPRO is a membership-based collaboration platform that supports its members in their long-term planning and collaboration on innovations in reactors, fuel cycles, and institutional approaches. Similar collaboration efforts are conducted as part of the OECD/NEA Nuclear Safety Research Joint Projects[3].

Advanced Safety Systems Key Issues

The following **key topics** still need to be addressed collaboratively:

- **VVUQ of codes**: Validating, verifying, and quantifying uncertainties in simulation codes that model passive safety systems;
- **Human factor adaptation**: Understanding how operators adapt to and manage passive and semi-passive systems during fault conditions and developing guidelines to support this adaptation;
- **Passive safety demonstration**: Demonstrating the effectiveness of passive safety systems, including the performance of safety condensers and passive heat exchangers, under various operating conditions.

2 https://www.iaea.org/services/key-programmes/international-project-on-innovative-nuclear-reactors-and-fuel-cycles-inpro

3 https://www.oecd-nea.org/jcms/pl_72332/nuclear-safety-research-joint-projects

2. Modularisation

Modularisation is one of the key characteristics of both LW-SMR and AMRs that distinguish them from traditional large nuclear reactors. Although modularisation is vital, the nuclear industry lacks established and proven practices, unlike other sectors such as aerospace and shipbuilding, where modularisation is more prevalent.

Modularisation is a design and construction approach that involves building SMRs from smaller, prefabricated modules. These modules can be manufactured in a factory and transported to the site, enabling parallel construction and enhancing productivity.

Modularisation aims to standardise components wherever possible, leveraging factory fabrication and simplifying on-site installation of preassembled modules reducing site specifications. In some SMR designs, such as integral LW-SMRs, a single module can encompass an entire nuclear steam supply system, including primary systems and associated instrumentation. Alternatively, other designs may utilise integrated components for easy field assembly, such as a pre-tested and partially commissioned instrumentation and control system module.

Factory-built modules differ from traditional stick-built construction methods in that they are designed to be self-contained and incorporate mechanical, electrical, and instrumentation features. By assembling these modules in a controlled factory environment, skilled labour can work with consistent materials, codes, and standards, ensuring high-quality results. The modular approach is expected to reduce labour

costs by minimising the need for workforce relocation and allowing for serial fabrication techniques. Additionally, modularisation is predicted to yield cost savings through shorter project timelines and more efficient material usage, ultimately streamlining the construction process.

To fully leverage the benefits of modularisation, there is a pressing need to develop robust methodologies that address **key challenges** such as:

- Optimisation of the modularisation rate and factory fabrication by shifting as much construction as possible to a controlled factory environment, improving the quality and reducing costs. Model integration into the design process encourages early supplier involvement in design to ensure manufacturability;
- Definition of interfaces between modules by developing standardised module designs for reactor cores, steam generators, control rooms, etc and creating interchangeable interfaces for mechanical, electrical and control systems to simplify integration. Establishment of qualification procedures for modules by working with regulators to develop pre-licensed module designs that could enable site-independent certification of modules to reduce licensing time. Build a qualified modular supply chain with clear quality assurance protocols and promote international harmonisation of codes and standards for global deployment;
- Transport management and supply chain logistics: Develop **modular procurement strategies** to streamline sourcing and logistics;
- Adopt Best Practices from Other Industries by for instance facilitating the use of modular construction techniques, such as block assembly and outfitting before integration similar to shipbuilding and aerospace, apply modular plant design for remote and rapid installation used in oil and gaz industries and/or implement lean manufacturing, just-in-time delivery and digital twins for quality and efficiency as it is done in the automotive manufacturing.

Given the **limited experience** with modularisation in the **nuclear sector**, particularly in SMRs, it is essential to tackle these open issues and develop practical solutions to unlock the full potential of modularisation and drive the successful deployment of these innovative reactor designs.

Modularisation Key Areas

Examples of areas that would need further exploration and support are as follows:

- **Best modularisation standards**: development of practices, quality control, and tools (real-time digital twin tracking and AI-driven modular assembly platform) to integrate modularisation into standard engineering design sequences from the early stages by managing margins and identifying the optimal rate of modularisation, prefabrication, and module size;
- **Interface standardisation**: optimisation of interfaces between modules and other permanent structures;
- **Modularisation standards in civil works**: development of new standards, practices, and protocols for the design, manufacturing, and construction of civil engineering works, including modularity (steel-concrete-steel), and qualification of these new construction processes;
- **Modularisation and logistics trade-off**: ensuring the best trade-off between the logistics of exceptional transport and on-site assembly and construction.

3. Additive manufacturing, and advanced welding & repair technologie

Integrating advanced manufacturing techniques, particularly additive manufacturing (AM), is expected to play a pivotal role in enhancing SMR **competitiveness**. By leveraging AM, SMR manufacturers can significantly reduce production and execution times, automate tasks, and achieve complex designs with optimised materials. This can lead to several **benefits**, including:

- **Rapid Prototyping and Production**: Additive

manufacturing enables the rapid creation of complex components and systems directly from digital designs. This capability can accelerate the development and testing of SMR prototypes, reducing the time and cost associated with traditional manufacturing methods;

- **Increased Design Complexity**: Additive manufacturing allows for intricate geometries and structures that cannot be produced using traditional manufacturing techniques. This enables SMR designers to optimise component design, reduce material usage, and improve overall system performance;
- **Automated Manufacturing**: Additive manufacturing can automate many tasks, reducing the need for manual labour and minimising the risk of human error. This can result in increased production efficiency, reduced costs, and improved consistency in component quality;
- **Reduced Lead Times:** Additive manufacturing can significantly reduce lead times for SMR construction by producing components directly from digital designs. This can enable faster deployment of SMRs, reducing the time and cost associated with traditional construction methods;
- **Enhanced Repair and Maintenance**: Additive manufacturing can also produce spare parts and components for SMR maintenance and repair. This can reduce downtime, minimise waste, and improve overall system availability;
- **Increased Standardisation**: Additive manufacturing can facilitate the standardisation of SMR components, reducing the complexity and cost associated with traditional manufacturing methods. This can improve economies of scale, reduce production costs, and increase competitiveness;
- **Improved Supply Chain Management**: By leveraging Additive manufacturing, SMR manufacturers can reduce reliance on traditional supply chains, minimising the risk of component shortages, and improving overall supply chain resilience;
- **Advanced manufacturing development**: develop advanced and innovative manufacturing techniques such as automatic welding, additive manufacturing (3D metallic printing, HIP (Hot Isostatic Pressing);
- **Additive manufacturing and advanced welding qualification**: identify current qualification landscape by technology and gaps to close for deployment at scale.

The development of AM and Advanced Welding & Repair Technologies involves several **critical R&D** challenges and **focus areas,** such as:

- **Materials Qualification and Performance:** Ensuring that AM-produced or welded components meet the stringent mechanical, thermal, and radiation resistance requirements of nuclear environmentsInterface standardisation: optimisation of interfaces between modules and other permanent structures;
- **Process Qualification and Standardisation:** Lack of established codes and standards for AM and advanced welding in nuclear applications;
- **Design for Manufacturability:** Adapting reactor component designs to leverage the benefits of AM and advanced welding;
- **Repair and Maintenance Technologies:** Developing reliable in-situ repair methods for critical components;
- **Scalability and Component Size Limitations:** Current AM technologies are limited by build volume and component size;
- **Regulatory Acceptance:** Gaining regulatory approval for AM and advanced welding in safety-class nuclear components.

These technologies and commercial-grade dedication (CGD) processes could effectively reduce costs and simplify design. CGD enables using readily available, non-nuclear components for nuclear applications through validated approaches. This lowers costs, expands supplier options, and enhances design flexibility while maintaining safety standards.

Euratom R&D projects relevant to additive manufacturing

The Euratom Research and Training Programme funded several projects on **additive manufacturing, advanced welding**, and repair technologies to enhance the manufacturing, maintenance, and safety of SMRs in the EU. Such R&D projects are described below (see box).

M4F

Multiscale modelling for fusion and fission materials[1]

NUCOBAM

Nuclear Components Based on Additive Manufacturing[2]

INNUMAT

Innovative Structural materials for fission and fusion[3]

CONNECT-NM

Coordination of the European Research Community on Nuclear Materials for Energy Innovation[4]

1 https://cordis.europa.eu/project/id/755039
2 https://nucobam.eu/
3 https://www.innumat.eu/
4 https://cordis.europa.eu/project/id/101165375

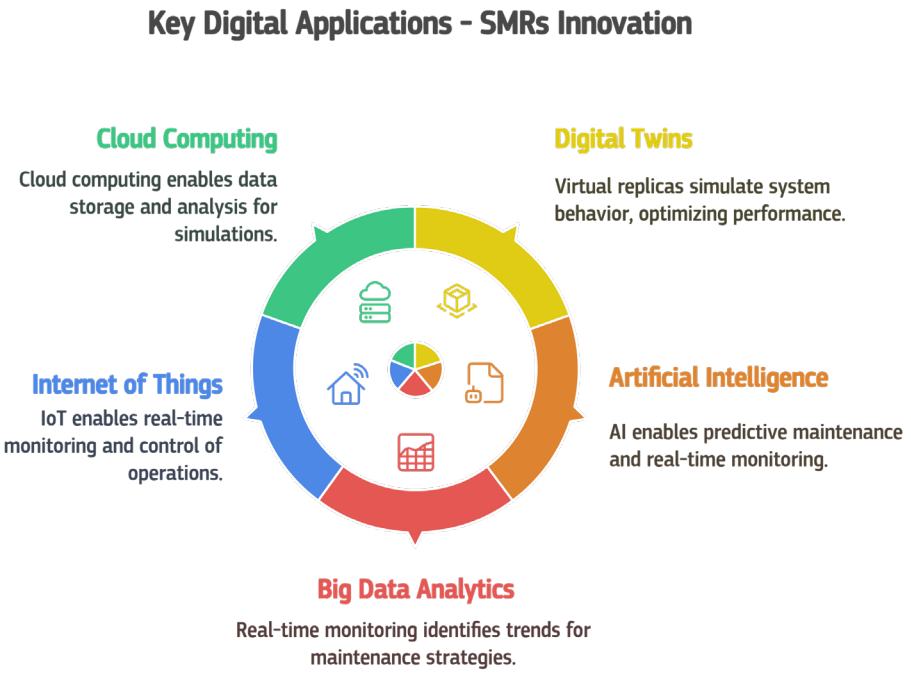
4. Digitalisation and monitoring tools

The development of SMRs is a prime example of how the nuclear industry is leveraging the potential of artificial intelligence (AI) and advanced digital technologies to revolutionise the design, construction, operation, and maintenance of nuclear installations. All reactor projects, including SMRs/AMRs, aim to utilise digital tools together with robust, physically based and experimentally validated models to simulate and optimise their operations, enabling adequate **real-time monitoring**, informed **predictive maintenance** that could enhance the efficiency and reliability of these industrial installations. Among others, digital twins that are virtual replicas of physical systems can be used to simulate and analyse their behaviour, leading to the **optimisation** of their performance.

SMRs are expected to utilise advanced digital technologies, such as digital instrumentation and control, increased automation, robotics, and remote monitoring. The adequate implementation of these technologies can enhance the **optimisation of SMR operations** and **integration**, while **reducing costs** and **improving performance**. For example, digital instrumentation and control systems can provide real-time monitoring and control of reactor operations, enabling operators to respond quickly to changing conditions and optimise performance. Increased automation can also **reduce the risk of human error**. At the same time, remote monitoring enables operators to monitor and control reactor operations from a distance, thereby reducing the need for on-site personnel.

However, the increased use of digital technologies in SMRs also introduces new vulnerabilities to cyberattacks. As SMRs rely on digital systems for operation, they are potentially vulnerable to cyber threats, including hacking, malware, and ransomware. These threats can compromise the safety and security of SMR operations, potentially leading to accidents or unauthorised releases of radioactive materials. Therefore, it is essential to implement robust cybersecurity measures to protect SMR digital systems from cyber threats, such as firewalls, intrusion detection systems, and encryption.

SMRs are the first nuclear products to be developed in the era of digitalisation and AI. As such, they are well-positioned to benefit from recent information systems. The rapid progress in digital technologies, such as cloud computing, big data analytics, and the Internet of Things (IoT), has given rise to numerous digital applications that will drive and accelerate innovation in the years to come. For example, machine learning algorithms and artificial intelligence can enable predictive maintenance, anomaly detection, and real-time monitoring of SMR operations if they are implemented adequately and in compliance with the safety requirements. Some of the key digital applications that are expected to drive innovation in SMRs are shown in the figure on the next page. Following the EU Digital Act, various projects have been initiated at the business, national, European, and international levels, which are expected to accelerate the development and deployment of SMRs. These projects aim to leverage digital technologies



to **enhance the efficiency and reliability of SMR operations while also reducing costs and improving performance**. For example, the EU's Horizon 2020 program has funded several projects focused on developing digital technologies for SMRs.

R&D areas that need to be further explored and supported could be:

- **Development of digital twins**: Implementing digital twin solutions requires access to physical facilities, such as the reactor itself, to enable computer models to accurately replicate the reactor's behaviour under all circumstances. Digital twins can generate dynamic, real-time digital duplicates of physical assets when successfully implemented. This, in turn, provides valuable insights that can enhance decision-making, optimise operational effectiveness, and reduce expenses;
- Development of **"engineering" simulators:** Support SMR design development and preliminary training of SMR operators;
- **Advanced simulator development:** Development of simulators and physics-based numerical software for training in normal and emergency situations;
- **Advanced maintenance development**: Advanced maintenance systems powered by AI and digital twins that can monitor the plant continuously and perform proactive maintenance; modules for surveillance and repair in the radiation field;
- **Cybersecurity of advanced control systems**: Ensure the integrity and security of the control systems while using advanced digital technologies.

5. Non-electrical applications

SMRs have the potential to address various energy and environmental challenges beyond electricity generation. One of the most promising non-electrical applications of SMRs is **steam production** (above 550'C) and **district heating**, which can reduce the need for fossil fuels and lower greenhouse gas emissions. Additionally, SMRs can be used for hydrogen production, which can be used as a clean fuel for transportation, power generation, and industrial processes, offering a promising alternative to traditional fossil fuels.

Other non-electrical applications of SMRs include **industrial process heat**, chemical synthesis, desalination, and carbon capture, utilisation, and storage (CCUS), demonstrating the versatility

and potential of SMRs to contribute to a **low-carbon economy** and support **sustainable development**. By leveraging these non-electrical applications, SMRs can help **reduce greenhouse gas emissions**, improve **energy security**, and promote **economic growth**, making them an attractive option for countries and communities looking to transition to a more sustainable and resilient energy future.

Although there is a significant potential for SMRs to provide energy solutions beyond electricity generation, examples of such applications are limited. The development of **tools for optimising the local energy mix**, including **integrating renewables** with nuclear power plants for non-electrical applications such as hydrogen production, district and industrial heat distribution, and water desalination, remains a significant gap. As a result, there is a pressing need for **tools and techno-economic data** to **evaluate** and **optimise** the **use of SMRs in non-electric applications**, including identifying preferred insertion locations and the optimisation of the transition towards a **defossilised economy**.

However, realising these applications requires targeted R&D efforts across several domains. Here are some of the main R&D topics to be investigated:

- **Process Integration and Coupling:** Develop safe and efficient methods to couple SMRs with non-electric systems by investigating thermal integration with desalination plants, hydrogen production units, and industrial heat processes. Dynamic modelling of load-following and heat-sharing systems, and finally, by developing Safety and control strategies for multi-output configurations;
- **District and Industrial Heating:** Replace fossil fuels in heating networks and industrial processes;
- **Maritime and Mobile Applications:** Use SMRs for ship and space propulsion and remote/off-grid power;
- **Economic and Regulatory Frameworks:** Create viable business models and licensing pathways by thoroughly investigating the techno-economic applications of non-electric SMR, the licensing and safety case development for hybrid energy systems and the public acceptance and stakeholder engagement strategies.

Euratom R&D projects relevant to Non-electrical Applications

The Euratom Research and Training Programme have funded several projects exploring non-electric applications of SMRs (see box).

GEMINI 4.0+ Research and Development in support of the GEMINI Initiative[1]	GEMINI 4.0
TANDEM Small Modular Reactor for a European safe and Decarbonised Energy Mix[2]	TANDEM

1 https://gemini-initiative.com/gemini-4-0/
2 https://cordis.europa.eu/project/id/101059479

Technologies more relevant to LW-SMRs

Some LW-SMRs are designed as extrapolations of high-power electric reactors, which can pose challenges when adapted for non-electrical applications. The initial design constraint requires additional studies to address the impact of heat extraction on steam turbine stability and reactor performance and safety.

In addition to the TANDEM project, which addresses safety issues and assesses the feasibility of SMR integration into hybrid energy systems, several key issues still need to be investigated, including:

- **Steam tapping safety:** The impact of steam tapping on nuclear safety and reactor performance is crucial for ensuring the safe and reliable operation of the SMR;
- **Steam tapping performance**: The impact of steam tapping on the behaviour of the turbine during nominal and incidental operation, which can affect the overall efficiency and reliability of the system;

- **Heating modules for SMR technology**: The development of plug-and-play steam diverters that can efficiently and safely redirect steam for heating applications such as district or industrial heating.

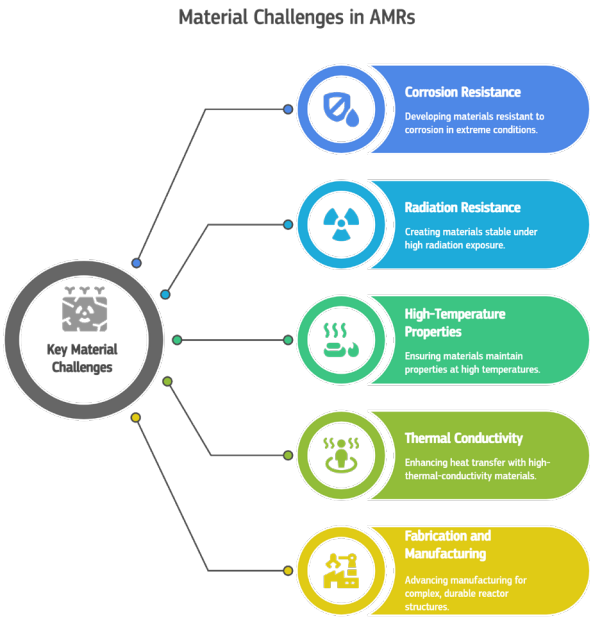
LW-SMRs are well suited for heating applications, such as district or industrial heating, but require **standardised heat interfaces** to facilitate their deployment. Additionally, flexible regulatory approval frameworks are required to enable the deployment of **SMRs in urban and industrial hubs**.

Market incentives are also necessary to promote **nuclear heat over fossil fuels**, which can help reduce greenhouse gas emissions and improve energy security. By addressing these challenges and developing standardised solutions, SMRs can significantly provide clean and efficient heat for various applications.

Technologies more relevant to AMRs

1. Material challenges under severe environmental conditions for AMRs

AMRs are designed to operate in various environments, including those with severe conditions, such as high temperatures, high pressures, and high radiation fields. However, these conditions can pose significant material challenges that must be addressed to ensure the safe and reliable operation of the reactor.



One of the primary material challenges for AMRs is the development of materials that can withstand high temperatures and radiation fields in the reactor core. The reactor core is the hottest part of the reactor, with temperatures reaching 1000°C or more. Such high temperatures can cause materials to degrade, become brittle, or even melt, leading to the loss of structural integrity and potentially catastrophic consequences.

In addition to high temperatures, the reactor core is subject to high radiation fields, which can cause materials to become radioactive and change their microstructures. This can lead to the loss of material properties, such as strength and ductility, and make the material more prone to corrosion. Some of the **key material challenges** for AMRs are described in the figure.

To address these material challenges, researchers are developing new materials and technologies that can withstand the severe environmental conditions in the reactor core. Some of the materials being developed include the following:

- **Advanced steels**: New steel alloys with improved high-temperature properties and resistance to radiation damage are being developed;
- **Ceramic composites**: Ceramic composites with high thermal conductivity, strength, and resistance to radiation damage are being developed;
- **Refractory metals**: Refractory metals, such as tungsten and molybdenum, are used in AMR designs owing to their high melting points and resistance to radiation damage;
- **Advanced coatings**: Advanced coatings have been developed to protect materials from corrosion and radiation damage.

In addition to developing new materials, researchers are improving the manufacturing processes used to fabricate AMR components. This includes advanced manufacturing techniques, such as 3D printing and additive manufacturing, which can produce complex geometries and structures without traditional manufacturing methods.

Developing and qualifying materials for AMRs encompasses a wide range of R&D topics, given the unique operating conditions and design

innovations of these reactors. Some of them are:

- **Accelerated testing protocols**: to simulate long-term behaviour in shorter timeframes under representative conditions in terms of irradiation behaviour under fast and high flux neutrons as well as corrosion in various environments (lead, molten salt, …) and high temperatures;
- **Standardisation of test methods:** to accelerate qualification, especially for novel materials subjected to various environments
- **Coolant chemistry control**: to mitigate degradation and extend component life
- **Code and regulatory framework development**: to support licensing of new materials and designs;
- **Additive manufacturing (3D printing)**: for complex geometries and rapid prototyping;
- **Powder metallurgy and HIP (Hot Isostatic Pressing)**: for producing dense, defect-free components.;
- **Advanced welding** and joining for dissimilar materials and high-integrity joints;
- **High fidelity modelling**: for predicting material performance and degradation.

Euratom R&D projects relevant to Materials

The Euratom Research and Training Programme has funded several projects focused on **advanced materials**, particularly for high-temperature, corrosive, and irradiation-heavy conditions found in AMRs like molten salt, lead-cooled, Sodium and high-temperature gas-cooled reactors (see box).

Several **critical barriers** still exist that hinder industrial deployment, such as:

- Lack of **long-term material testing data**, as most tests run for less than 5 years, but AMRs, as SMRs, need 60-to-80-year lifespans;
- **Limited industrial supply chain** for advanced alloys, as Europe relies on the US/Japan for Hastelloy and ODS steels;
- **High costs** of corrosion-resistant coatings that necessitate scale-up to high-volume coating pilot plants;
- The EU does not have **high-flux, fast neutron irradiation facilities**. It relies on Russia (BOR-60) and Japan (JOYO). While expecting the RJH-MTR by the mid-2030s, an alternative must be found.

To overcome these gaps, it is paramount to continue and strengthen the work launched within the partnership CONNECT-NM, complemented by a high level of industrial sector engagement.

MATISSE Materials' Innovations for a Safe and Sustainable Nuclear in Europe[1]	MATISSE
SAMOFAR Safety Assessment of Molten Salt Fast Reactors[2]	SAMOFAR
PATRICIA Passive and Active Systems for Thermal-Hydraulics Enhancements in SMRs[3]	PATRICIA
NUCOBAM Nuclear Components based on Addiive manufacturing[4]	NUCOBAM
IL TROVATORE Innovative Lead Technologies for Safety and Efficiency and others[5]	IL TROVATORE
CONNECT-NM Coordination of the European Research Community on Nuclear Materials for Energy Innovation[6]	CONNECT NM

1 https://cordis.europa.eu/project/id/604862
2 http://samofar.eu/
3 https://patricia-h2020.eu/en
4 https://nucobam.eu/
5 https://iltrovatore-h2020.eu/en
6 https://cordis.europa.eu/project/id/101165375

2. Other areas relevant to AMRs

The relatively lower technological maturity of Advanced Modular Reactors (AMRs) necessitates substantial advancements in several domains to ensure their safe and reliable operation.

A primary challenge involves the need for a more comprehensive understanding of the physical phenomena occurring within the reactor, particularly under more severe physico-chemical conditions. This encompasses the behaviour of materials under irradiation, their interaction with the coolant and the reactor core, and the reactor's response to various operational and accidental scenarios.

Another critical area of focus is the **development of instrumentation and control systems** that can withstand harsh reactor conditions. This requires designing and testing specialised sensors, detectors, and other instrumentation means that can accurately measure and monitor the reactor's performance, even in high temperatures, high pressures, and radiation fields. The resistance of this instrumentation to degradation and failure under such conditions is essential to ensure the safe and reliable operation of the reactor.

Furthermore, developing dedicated **numerical simulation tools** that can accurately model the behaviour of the AMRs for safety analyses is crucial to their successful deployment. This requires developing dedicated numerical simulation tools to accurately model the reactor behaviour under various scenarios, including **normal operation**, **accidents**, and **extreme events**. These simulation tools must be validated and verified using experimental data and tests to ensure their accuracy and reliability.

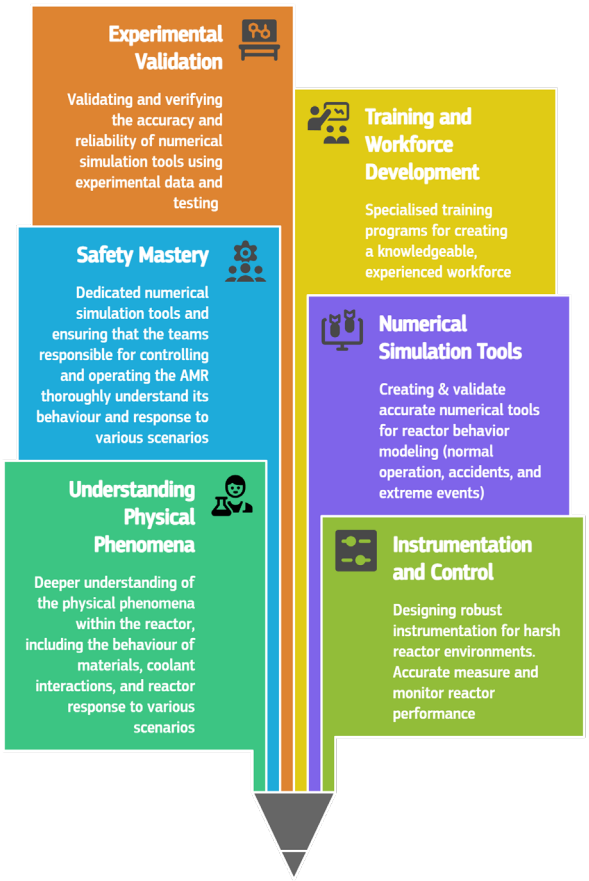
Furthermore, it is essential to ensure that the teams responsible for controlling and operating the AMRs thoroughly understand its behaviour and response to various scenarios. This requires the development of **specialised training programs** and the creation of a knowledgeable and **experienced workforce** that can safely and effectively operate the reactor.

Some of the key areas in which progress is required are described are described in the figure on the right.

Over the past two decades, the Euratom Programme has funded several initiatives to enhance the safety of advanced reactors (Gen-IV, AMRs) in close collaboration with the GENIV International Forum-GIF under the auspices of OECD-NEA. **Euratom projects** such as SAMOFAR, ESFR-SMART[4], and PATRICIA have provided a significant amount of knowledge and understanding of various technological topics, including but not limited to:

- **Safety codes qualification:** qualifying computer codes for simulating severe accident transients for AMRs;
- **Harsh environment instrumentation**: development of instrumentation and measurement techniques for harsh environments with different types of coolant and operation temperatures than LWRs;
- **Mitigation provisions**: demonstrating the adequacy of the mitigation provisions of an AMR in severe accident conditions;
- **Human factor tools**: integrating human factors in the safety demonstration of AMR reactors.

AMRs Key Areas Needing Improvement



4 https://esfr-smart.eu/

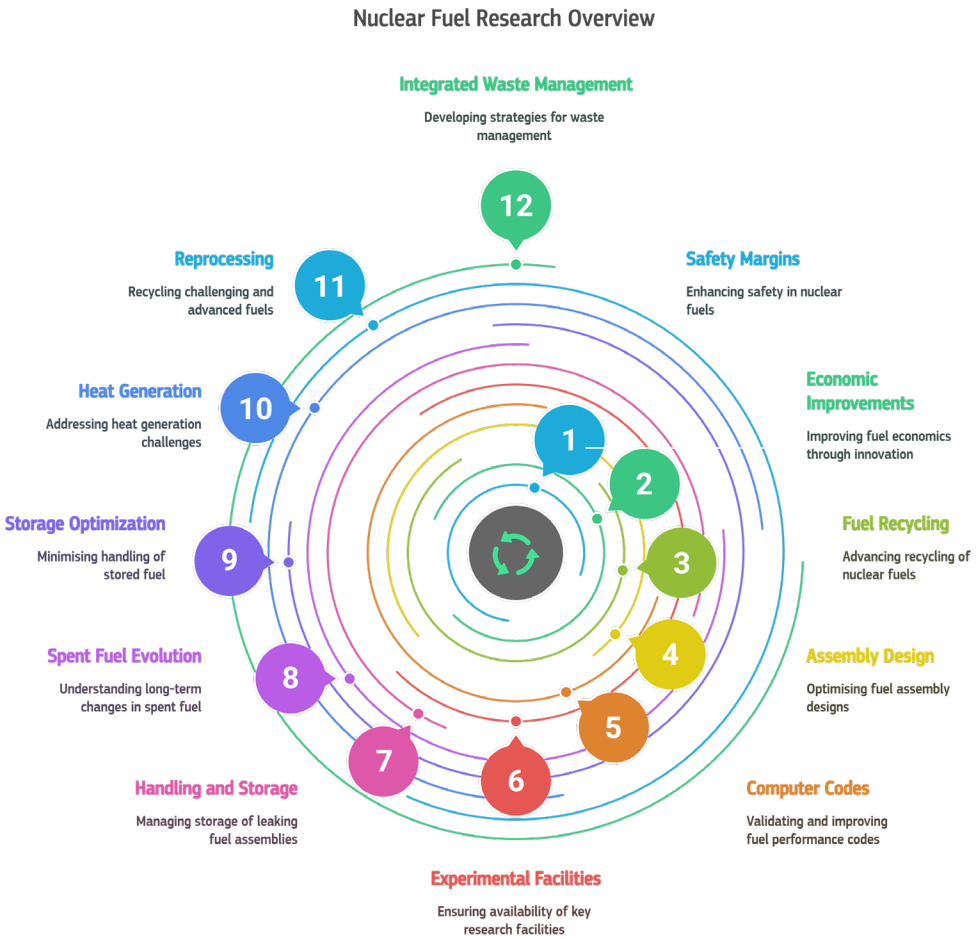
Nuclear Fuel Cycle

Regardless of the reactor technology, the fuel cycle remains a crucial consideration. Despite the extensive knowledge base on existing nuclear fuel types, mainly UO_2 and $(U, Pu)O_2$ pellets with zirconium-based alloy for cladding, data gaps still necessitate dedicated material property measurement and modelling. In addition, many challenges exist for several innovative nuclear fuel element types under development, particularly with enhanced advanced technological fuels (ATF).

The focus is first on the safety requirement criteria for the fuel rod behaviour in the core under normal, transient, and accident conditions and the fuel cycle. Of particular importance is improving the economics and sustainability of SMRs through optimising available fissile and fertile nuclear material resources, reducing fuel costs and volume, and optimising waste management while maintaining flexibility within a more varied energy mix.

Numerous R&D programmes have been conducted to qualify fuels and fuel performance codes for current fuel rod designs and operating conditions. Transposing this knowledge to new conditions requires a thorough understanding and detailed description of fuel behaviour. Physics-based validated fuel performance codes capitalising on the results of a combination of irradiation experiments, post-irradiation examinations, separate effect or integral test experiments, and multiscale modelling approaches are the way to answer these new questions. This knowledge must then be transferred to industrial simulation tools.

Spent fuel management of various nuclear fuel types from both LWR SMRs and AMRs will benefit from the accumulated knowledge and experience acquired over the past fifty years in the EU. Nevertheless, there is room for improvement in safety, security, safeguards requirements, economics, and environmental aspects.



Additionally, new challenges will arise for managing spent fuel from innovative nuclear fuel types currently under development.

Spent fuel management of various nuclear fuel types from both LWR SMRs and AMRs will benefit from the accumulated knowledge and experience acquired over the past fifty years in the EU. Nevertheless, there is room for improvement in safety, security, safeguards requirements, economics, and environmental aspects. Additionally, new challenges will arise for managing spent fuel from innovative nuclear fuel types currently under development. Spent fuel management is carefully regulated by national regulators and recommendations from international organisations, particularly Euratom and the IAEA. Within the EU, for the initial management step, a range of spent fuel storage arrangements are in place. In some countries, fuel is stored primarily at the reactor site where it was irradiated. In contrast, in other countries, centralised facilities exist for interim/long-term storage following an initial cooling period at the reactor site. Other subsequent steps must also be considered, such as transportation/reprocessing, high-level waste conditioning, development of spent fuel conditioning, and deep geological repository.

The R&D topics to be investigated can be summarised as follows:

- Increasing the safety margins of nuclear fuels and improving behaviour under operation and accident conditions, including the development of new advanced technological fuel (ATF);
- Improved economics of nuclear fuels through allowing high burn-ups, increased enrichment (beyond 5%), and potential new high-density fuel forms;
- Increased nuclear fuel recycling using reprocessed uranium and improved MOX fuels, including multiple recycled MOX, high plutonium content, and minor actinide-bearing MOX facilitating the closing the fuel cycle;
- Improvements in assembly design and optimisation, including attempted elimination of grid-to-rod fretting and the prevention or mitigation of damage by foreign objects;
- Improvement of fuel performance and safety computer codes and their validation by quantifying and reducing uncertainties, and extending qualified experimental data;
- Ensuring availability of key experimental facilities (research reactors, hot cells and hot laboratories) and expanding their capabilities to meet future requirements;
- Handling and storage of leaking fuel assemblies (spent fuel pool and interim wet and dry storage);
- derstanding the **evolution of spent fuel** and storage systems over multiple decades or even longer temporary storage and developing effective means for monitoring compliance under nominal and off-nominal conditions.;
- Optimisation of **storage** systems to minimise handling of fuel and casks after longer-term storage, including the interface to a deep geological repository;
- Spent fuel heat generation and burn-up credit challenges (code validation, uncertainty reduction, and licensing issues);
- The **reprocessing** and **recycling** of **challenging fuels** (e.g. high burn-up, multiple recycled MOX) and advanced fuels (e.g. ATF) as well as advanced reprocessing technologies (e.g. pyro-processing);
- Use of advanced integrated computational tools for the development of integrated waste management strategies:
    - ★ **new fuels** (targets) and **fuel assembly designs** bearing significant amounts of minor actinides, and their fabrication technology, thus includes plutonium and minor actinide-bearing fuels, including thorium oxide (ThO_2) matrix (thorium MOX) and inert matrix fuels for plutonium and minor actinide burning applications;
    - ★ **new recycling technologies** based on advanced aqueous and pyro-metallurgic reprocessing technologies, adapted to highly active and hot fuels containing large amounts of plutonium and minor actinides, and minimising the production of secondary wastes.

It is also critical to maintain **key experimental facilities**, particularly **experimental irradiation devices** in research reactors, hot cells, and hot laboratories, and to expand their capabilities to meet future requirements regarding **advanced characterisation techniques** or **online data**

acquisition in irradiation experiments.

Euratom R&D projects relevant to fuel and nuclear waste management

The Euratom Research and Training Programme has funded several projects related to fuel development, spent fuel and radioactive waste management, focusing on safety, disposal, reprocessing, and advanced technologies are described below (see box).

ESFR_SMART European Sodium Fast Reactor Safety Measures Assessment and Research Tools[1]	ESFR-SMART sodium fast reactor safety
INSPYRE Investigations Supporting MOX Fuel Licensing in ESNII Prototype Reactors[2]	INSPYRE
GENIORS GEN IV integrated oxide fuels recycling strategies[3]	GENIORS
PUMMA Plutonium Management for more agility[4]	PuMMA
PREDIS Pre-disposal management of radioactive waste: Focuses on innovative treatment and conditioning technologies for radioactive waste[5]	PREDIS
SITEX-II Sustainable network for Independent Technical EXpertise in radioactive waste disposal: Enhances safety assessments for geological disposal[6]	SITEX Network
EURAD European Joint Programme on Radioactive Waste Management[7]	eurad 2 European Partnership on Radioactive Waste Management

1 https://esfr-smart.eu/
2 https://cordis.europa.eu/project/id/754329
3 https://www.geniors.eu/
4 https://pumma-h2020.eu/
5 https://predis-h2020.eu/
6 https://www.sitex.network/
7 https://www.ejp-eurad.eu/

Other past and current R&D projects cofounded by Euratom that are pertinent to SMRs, AMRs and GenIV:

ELSMOR Towards European Licencing of Small Modular Reactors	ELSMOR Towards European Licensing of Small Modular Reactors
SASPAM-SA Safety Analysis of SMR with Passive Mitigation strategies – Severe Accident	SASPAM-SA
EASI-SMR Ensuring Assessment of Safety Innovations for SMRs	EASI SMR
SANE Safety Assessment of Non-Electric uses of nuclear energy	SANE
GEMINI Plus Conceptual design for a HTGR for supply of process steam to industry, a framework for the licensing of such system and a business plan for a full-scale demonstration	GEMINI+
TREASURE Towards reliable and safe GFR	TREASURE
LESTO Lead fast reactor safety design and tools	LESTO
ANSELMUS Advanced Nuclear Safety Evaluation of Liquid Metal Using Systems	ANSELMUS
ESFR-SIMPLE European Sodium Fast Reactor - Safety by Innovative Monitoring, Power Level flexibility and Experimental research	ESFR SIMPLE
MIMOSA Multi-recycling strategies of LWR SNF focusing on Molten Salt technology	MIMOSA
ENDURANCE EU knowledge hub for enabling molten salt reactor safety development and deployment	ENDURANCE
HARMONISE Towards harmonisation in licensing of future nuclear power technologies in Europe	harmonise Harmonising Fission & Fusion Reactor Licensing

European Industrial Alliance on SMRs membership as of 31 July 2025

18for0 Advocation for Clean Energy
3 HCSI SRLS UNIPERSONALE
ABB AB
Actimondo
AD Consulting Ltd.
ADKRON GROUP (EMEA) SRL
Aecon Nuclear
AEMI Atomenergia Mérnökirods Kft.
AFCEN
Agencja Rozwoju Przemysłu S.A.
AIC S.A.
AID - Agenzie Industrie Difesa
ALD-FRANCE
Alfa Laval AB
Alleima
ALRO SA
ALSYMEX
ALTEN
Amphos 21 Consulting, S.L.
ANDRITZ AG
Ansaldo Energia
Ansaldo Nucleare
APAVE NDT
APOLLTECH
Arabelle Solutions France
Associazione Italiana Nucleare (AIN)
ASSURATOME
Assystem Engineering and Operation Services
Asturfeito
ATB RIVA CALZONI SpA
Aubert & Duval
AVENTECH
Baltic Scientific Instruments
BAQ Sàrl
Baudin Chateauneuf
Baumert
Becker Technologies GmbH
Belleli Energy Critical Process Equipment Srl
Bernard Controls SA
Bertin technologies
BILFINGER NUCLEAR & ENERGY TRANSITION GmbH
Black Sea Women in Nuclear Network Association
Blue Bird Energy JSC
Blue Capsule Technology
Blykalla AB
Boccard SA
BOUYGUES Travaux Publics
Brabatech
BREMBANA&ROLLE SPA
Bulgarian Atomic Forum Association (BULATOM)
Bulgarian Energy Holding EAD
Bureau Veritas Services
CAELUS S.r.l.
CAEN SpA
CALOGENA
Campoverde srl
CANADIAN NUCLEAR PARTNERS S.A.
Capgemini
Cefic
Center of Nuclear Competencies Kozloduy
CENTER OF TECHNOLOGY AND ENGINEERING FOR NUCLEAR PROJECTS (CITON)
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
Centrum výzkumu Řež, s.r.o.
CEZ Group
CINC
CIRTEN
Clean Air Task Force (CATF)
Clextral
CoEER, Congress of European Emerging Regions
Commercio.network spa
Commissariat à l'Energie Atomique et aux énergies alternatives (CEA)
Consensus d.o.o.
Copenhagen Atomics A/S
Crescent Blue Group
Czech Power Industry Alliance
Czech Technical University in Prague
Czechatom a.s.
Dassault Systèmes
De Atoomcoöperatie
De Pretto Industrie Srl
Delmeco
DEMCON
DEMONT S.R.L.
Denetek LLC
DEXTRA Europe
DIGITAL HOUSE HOLDING
Direction Generale de l'Energie et du Climat (DGEC)
Doosan Škoda Power s.r.o.
Dow Europe GmbH
E.T.S. Sistemi Industriali srl
ECM technology
Ecole des Mines de Paris
EDF SA
Edison spa
Egis
EKIUM
ELATOS 21
ELECTROCENTRALE BUCURESTI SA
Elektroinštitut Milan Vidmar
ELIN Motoren GmbH
ELINI - European Liability Insurance for the Nuclear Industry
ELSE NUCLEAR srl
EMERSON PROCESS MANAGEMENT
Empresarios Agrupados Internacional, S.A.
ENCO (ENCONET consulting Ges.m.b.H)
ENCONET d.o.o.
ENEA
ENEA S.A.
Enel SPA
Energy Agency of Savinjska
Energy Software S.L. (ENSO)
Eneris Cleantech S.A.
Engineering Planning & Management, Inc
Eni S.p.A.
ENISS
ENTRA1-NuScale Partners
ENUSA Industrias Avanzadas S.A.
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ES Group Europe s.r.o.
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European Safety Organisations Network (ETSON)
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GenF
GENVIA
GIFEN
GNF ENUSA NUCLEAR FUEL SA.
GNS Gesellschaft für Nuklear-Service mbH
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Institute for Energy Technology
Institute Of Applied Phisics National Academy Of Sciences Of Ukraine
Institute of Environmental Geochemistry NAS of Ukraine
Institute of Power Engineering - National Research Institute
Institute of Technology and Business in České Budějovice
Instrumentation Technologies



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NGO Eco Generation
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vgbe energy e.V.
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WAVELENGTH TECHNOLOGY CENTER, LDA
weCARE
Westinghouse Electric Sweden AB
Whitecase
WIKA Alexander Wiegand SE & Co
Worley Nuclear Services JSC
WS Atkins France
ZAT a.s.

LIST OF ABBREVIATIONS

AM	Additive Manufacturing
AMRs	Advanced Modular Reactors
ATF	Advanced Technological Fuel/Accident Tolerant Fuel
BWR	Boiling Water Reactor
CCUS	Carbon Capture, Utilisation, and Storage
CEFIC	European Chemical Industry Council
CEZ	České Energetické Závody
CDG	Commercial Grade Dedication
COP	Conference of the Parties
EC	European Commission
EDF	Électricité de France
ENSREG	European Nuclear Safety Regulators Group
EU	European Union
ESARDA	European Safeguards Research and Development Association
E&T	Education and Training
EPZ	Emergency Planning Zone
FID	First Industrial Deployment
FOAK	First of a Kind
GMF	Group of European Municipalities with Nuclear Facilities
GEN III	Generation III
GEN IV	Generation IV
GSR	General Safety Requirements
HALEU	High-assay low-enriched uranium
HTR	High Temperature Reactor
HTGR	High Temperature Gas Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
iPWR	Integrated Pressurised Water Reactor
LEU	Low Enriched Uranium
LFR	Lead Fast Reactor
LWR	Light Water Reactor
LW-SMRs	Light Water Small Modular Reactors
MOX	Mixed oxide fuel
MRS	Molten Salt Reactor
NDA	Non-disclosure Agreement
NZIA	Net-Zero Industry Act
NEA-OECD	Nuclear Energy Agency -Organisation for Economic Co-operation and Development
ODS	Oxide Dispersion Strengthened
PINC	Nuclear Illustrative Programme
PPAs	Power Purchase Agreements

PWGs	Project Working Groups
PWR	Pressurised Water Reactor
R&D	Research and Development
R&D&I	Research and Development and Innovation
SRF	Sodium Fast Reactor
SMRs	Small Modular Reactors
SNETP	Sustainable Nuclear Energy Technological Platform
SRLs	Safety Reference Levels
SSR	Safety Standards Series
STEM	Science, Technology, Engineering, and Mathematics
ToR	Terms of Reference
TSO	Technical Safety Organisation
TWGs	Technical Working Groups
VHTR	Very High Temperature Reactor
VVUQ	Validating, verifying, and quantifying uncertainties
WENRA	Western European Nuclear Regulators' Association





About the European Industrial Alliance on SMRs

Authors

This document is produced by the European Industrial Alliance on SMRs Secretariat. See full list of authors below:

ALDAVE DE LAS HERAS Laura (JRC), AL MAZOUZI Abderrahin (SNETP), GOICEA Andrei (nucleareurope), IORIZZO Angelgiorgio (RTD), IVANOVA Ivelina (ENER), PANTALOS Nikos (GROW), PASCAL Ghislain (ENER), VIHANTA Jussi (ENER)

Editors

ALDAVE DE LAS HERAS Laura (JRC)

Contact

grow-EU-SMRS-ALLIANCE@ec.europa.eu

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