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Start date : 2022-09-01 Duration : 36 Months

Strategic recommendations of future E&T planning in the field of Safety of SMRs andhybrid energy systems.

Authors : Gabriel Lazaro PAVEL (ENEN)

TANDEM - Contract Number: 101059479

Project officer: Angelgiorgio IORIZZO

Document title	Strategic recommendations of future E&T planning in the field of Safety of SMRs andhybrid energy systems.
Author(s)	Gabriel Lazaro PAVEL
Number of pages	15
Document type	Deliverable
Work Package	WP6
Document number	D6.4
Issued by	ENEN
Date of completion	2025-09-02 11:26:33
Dissemination level	Public

Summary

In order to support future planning of E&T efforts, an integrated analysis will also be conducted to identify the main challenges and recommendations. Expectations on future needs by industry and academia of expertise in the fields of SMR safety and hybrid energy systems will be considered and the experience collected through the implementation of the TANDEM E&T actions, including students feedback

Approval

Date	By
2025-09-02 11:27:10	Gabriel Lazaro PAVEL (ENEN)
2025-09-02 11:31:45	Claire VAGLIO-GAUDARD (CEA)

D6.4 – Strategic recommendations of future E&T planning in the field of Safety of SMRs and hybrid energy systems

WP6 - Task 6.4

August 08, 2025 [M36]

Gabriel Pavel (ENEN)

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History

Date	Version	Submitted by	Reviewed by	Comments
08.08.2028	1.0	Gabriel Pavel	Jessica Johnson	-

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Abbreviations and Acronyms

Acronym	Description
E&T	Education and Training
NPP	Nuclear Power Plant
SMR	Small Modular Reactor
AMR	Advanced Modular Reactor

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Executive Summary

The aim of this deliverable is to: 1. compile the current and expected needs with respect to Education and Training (E&T) related to Small Modular Reactor (SMR) safety including the implications of their coupling with hybrid energy systems; 2. to compare them with what currently the E&T sector offers and 3. to draft a series of recommendations that should fill this gap. Whenever mentioned within this deliverable, the SMR technology considered is the one for Generation III light water reactor types. Advanced Modular Reactors (AMR) rely on Generation IV technologies.. These reactors are planned to implement a set of upgrades in comparison with existing commercial reactors.

The current E&T landscape in Europe only partially addresses the multidisciplinary skillset required for SMR deployment. While many nuclear engineering programmes exist, their focus is predominantly on large-scale nuclear power plants, with SMR-specific content often scattered across optional modules at Master's level. Topics such as hybrid energy system integration, advanced grid coupling, and modular construction are either insufficiently covered or entirely absent. Soft skills—such as leadership, project management, and stakeholder communication—remain largely excluded from technical curricula, despite their high demand in industry. Countries with operational nuclear power plants generally maintain robust nuclear education systems to support plants operation and maintenance, while those without often orient their training toward research, regulatory functions or to serve regional or international workforce needs. In both cases, there is currently no fully integrated Master's programme dedicated exclusively to SMRs or AMRs that comprehensively addresses the skills required for development and management of these types of reactors including expertise in specialised infrastructure, stakeholder engagement at all levels and advanced managerial capabilities.

Industry and academic consultations confirm that both newcomers to the nuclear field and existing professionals from adjacent sectors, such as fossil fuels and grid management, will require targeted SMR training. This must encompass not only nuclear-specific topics but also civil, mechanical, and electrical engineering, chemistry, materials science, information technology, and cybersecurity, combined with regulatory awareness and safety culture. Gaps are particularly pronounced in hybrid energy system integration, on-site SMR-specific training opportunities, and knowledge of modular construction and prefabrication. Without addressing these gaps, the EU risks delays in developing the workforce needed for SMR deployment in the early 2030s, when the first units are expected to become operational.

The strategic recommendations set out in this document build upon the findings of the TANDEM project's E&T gap analysis and aim to ensure the timely readiness of a qualified SMR workforce.

They call for the development of dedicated SMR and hybrid system curricula at Master's and specialised postgraduate levels, supported by EU funding and designed in close collaboration between engineering, environmental science, IT, and soft-skills faculties. Interdisciplinary cooperation should extend to joint university-industry projects, simulating real-world licensing, safety, and operational challenges. Soft skills must be integrated into formal education through structured modules and project-based learning, while digital tools such as real-time simulators and virtual reality environments should be adopted to enhance experiential training.

Early introduction of SMR and hybrid system concepts at Bachelor level is recommended to accelerate readiness and broaden the pool of potential specialists. EU-wide coordination is critical, including the creation of a dedicated SMR Safety E&T Network under Euratom, a common certification system for SMR and hybrid energy system skills, and harmonised quality assurance protocols for related training programmes. Building interdisciplinary learning hubs and networks within and between universities industry and research centres would strengthen capacity, support lifelong learning, and enable the re-skilling and upskilling of existing professionals. This will require substantial investment in training the trainers, ensuring that educational institutions can meet the projected demand for qualified personnel.

An implementation roadmap is proposed in three phases:

- **Between academic years 2025 and 2026**, pilot Master's programmes and specialised postgraduate courses should be launched.
- **From 2026 to 2030**, SMR related curricula should be deployed across leading EU universities and a certification network established.
- **From 2030 to 2035**, programmes should be assessed and refined, integrating lessons learned with broader EU climate and innovation strategies.

The report concludes that the readiness of SMR technology must be matched by equally advanced and coordinated educational infrastructure. It warns that the window for action is now, as developing a skilled workforce requires four to five years of higher education and training. Without immediate, EU-wide efforts to modernise, integrate, and coordinate SMR-related education and training, Europe risks missing the opportunity to lead in the safe, innovative, and sustainable deployment of SMRs within hybrid energy systems.

Keywords

TANDEM, skills, knowledge, education, training, SMRs, AMRs, hybrid energy systems.

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1 Introduction

As Europe advances with its decarbonisation targets, the need for flexible, low-emission power generation becomes more urgent. Small Modular nuclear Reactors (SMRs) are increasingly seen as a promising solution to replace CO_2-emitting power sources such as the ones using coal or oil-derived products. The deployment of SMRs, often integrated within hybrid energy systems, is expected to play a significant role in meeting decarbonization targets given the purposes today SMRs are planned to, by providing flexible energy solutions, and ensuring energy security for various energy demanding sites, industries or even cities. However, this transition demands a robust E&T ecosystem that can anticipate and respond to evolving technological and safety needs.

In recent years, numerous start-ups have accelerated the design and development of SMRs suitable for deployment at both new sites and repurposed ones (e.g. existing power generating facilities). Although many SMR technologies adapt features from large-scale nuclear reactors, they come forward with distinct operational, regulatory, and technical challenges. These specificities necessitate a dedicated education and training (E&T) approach—one that supports not only new entrants to the nuclear sector but also retrains existing professionals from adjacent industries.

To meet this challenge, full academic programmes in Energy and Nuclear Engineering are required. However, developing and implementing such programmes is a long-term effort, similar to the timeline observed in any other high-complexity sectors. A complete SMR workforce must be shaped through multidisciplinary curricula including, but not limited to, Civil Engineering, Chemistry, technician-level disciplines and those disciplines that contribute to the soft-skills (e.g. Information Technology) so much required by the industry.

At the EU level, SMR-relevant content is currently scattered across several specialisation tracks—typically in the form of Master's-level courses, modules or optional courses within broader nuclear or energy-related programmes. These only partially meet the knowledge, and skills needed by industry. To date, there is no fully integrated Master's programme solely focused on SMRs or AMRs.

Further complicating matters is the fragmented and sometimes outdated treatment of topics such as nuclear coupling with non-electric applications, grid integration and hybrid energy systems. Sometimes this even lacks completely. Early-level engineering courses, often taught by non-nuclear experts, may not reflect the latest advancements in SMR-grid coupling or multi-vector energy strategies. Similarly, while combined heat-and-power generation is covered in

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fossil-fuel contexts, there remains a substantial gap in research and educational focus when it comes to SMRs.

Recent years have shown an encouraging increase in interest from the research community in SMRs and their potential within hybrid energy systems. Yet, more in-depth academic and practical studies are urgently needed. For example, collaborative, cross-disciplinary projects at university level—bringing together students from various engineering and (non)science backgrounds—could simulate and design next-generation hybrid energy systems with SMRs as a central element.

On the regulatory side, legislation-related know-how can be readily integrated into existing curricula. However, soft skills—essential for managing complex, multi-stakeholder projects—require more coordinated action, often best addressed through partnerships with non-nuclear educational institutions and targeted training providers.

In conclusion, while the technological readiness of SMRs is progressing steeply, the same cannot be said of the educational infrastructure needed to support their safe, cost-effective, and innovative deployment. The European Union, through projects such as TANDEM and ELSMOR, and institutions like the IAEA and OECD NEA, has identified the urgent need for E&T reforms that address SMRs and hybrid systems. This TANDEM project deliverable highlights a gap analysis that reveals insufficient coverage of specific skills, particularly soft skills, project-specific knowledge (e.g., modular construction), and understanding of integrated systems. These findings are supported by survey results from stakeholders in utilities, design, fuel cycle, and transport sectors. A comprehensive EU-wide effort is required to realign and expand education and training programmes—bridging technical gaps, modernising curricula, and fostering interdisciplinary collaboration—to meet the evolving needs of this rapidly developing sector.

This strategy document outlines key recommendations for shaping future educational frameworks with a focus on SMR safety and hybrid energy system integration.

2 Current Landscape of Education and Training

For us to issue valid recommendations on future E&T planning in the field of hybrid energy systems, first an assessment of the current E&T landscape is needed. This step was performed and presented in the Deliverable 6.1 of the TANDEM project: “E&T gap analysis on safety of SMRs & hybrid energy systems”. The main findings of this deliverable will be addressed here. In principle, the key identified deficiencies include:

- **Lack of dedicated E&T programmes.** Many of the needed disciplines by SMRs and AMRs are to be found in E&T programmes designed for traditional NPPs but there is no complete Master program that addresses the SMR and AMR particularities and their integration into hybrid energy systems, and non-electric applications of nuclear energy (hydrogen production, desalination, district heating, etc.).
- **Fragmentation**: Courses are often distributed across disciplines with no dedicated SMR focus.
- **Grid Integration**: Taught at the Bachelor level by non-nuclear experts, often lacking recent SMR developments.
- **Hybrid Systems**: Little to no academic coverage of SMRs in heat-and-power co-generation systems.
- **Soft Skills**: Leadership, project management, and stakeholder communication skills are rarely integrated into technical programmes.

2.1 Existing Curricula in EU Member States

In general, many of the E&T topics of relevance to SMRs and AMRs are covered by the existing curricula, especially in relation to SMRs based on existing reactor technology. Now, at this stage we can already divide the nuclear E&T landscape into two: countries with operational NPPs and Countries without operational NPPs.

As regards the countries with operational NPPs (e.g., France, Romania, Czech Republic, etc.) they maintain robust nuclear education programmes. In most of the cases these programmes are designed to meet their national needs. Even so, there is a noticeable mobility among nuclear experts that for general or particular reasons chose to re-locate. This information is of particular interest since it supports the idea of competence building by other institutions/countries and regional/international network of competence builders.

Countries without operational NPPs (e.g., Italy, Germany) also invest significantly in nuclear education. Sometimes these countries have research reactors but this is not a sine qua non. For these countries the educational system clearly addresses the needs of other/surrounding countries. This situation can evolve and even change as it can be noticed in Italy, where the perspective of SMR implementation revealed a huge potential in terms of available and qualified human resource in the field.

Bachelor-level programmes focus on foundational engineering and nuclear principles but the integration of nuclear power plants into the energy system is often addressed by non-nuclear

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specialists. This could be a major drawback when we address newer types of NPPs, like the SMRs with their particularities.

Master-level programmes address advanced topics but rarely focus specifically on SMRs or hybrid systems. These Master's programmes and their associated topics primarily address the general principles of SMR technologies, covering various types of SMRs as well as major challenges and recent advancements in the field. At the moment this document was redacted, there was no dedicated Master programme for SMRs implemented in Europe.

Another aspect that we should consider is the one related to the targeted human resource. The E&T needs must look into two target groups: new and existing workforce.

SMR-specific training is required both for:

- **New entrants**: Students pursuing energy or nuclear careers who need a complete and modern education path.
- **Existing professionals**: Engineers, technicians, and experts from other sectors (e.g. fossil fuels, grid management) who must retrain for SMR operations.

Both groups need comprehensive and practical training, but the pathways and timescales to readiness vary. A dual-track E&T strategy should be envisioned.

2.2 Supplementary Training Initiatives

At EU level, although there are no dedicated and complete E&T programmes for SMRs/AMRs, there are instead several types of complementary E&T actions:

- Workshops are offered by numerous institutions or E&T projects on various topics.
- Summer schools (e.g., TANDEM, ICTP/IAEA, ESTA of ENEN, etc.) offer targeted SMR-related modules.
- IAEA e-learning platforms support flexible, modular learning.
- Specializing Masters (e.g., several Italian Universities) address niche topics but face resource and coordination limitations.
- General courses which includes specific topics for SMRs/AMRs

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3 Expectations and Needs from Industry and Academia

3.1 Job Categories and Competencies

Based on stakeholder surveys and other coordinated actions presented in TANDEM, Deliverable 6.1 "E&T gap analysis on safety of SMRs & hybrid energy systems", several job categories, qualifications and other actions were identified as needed for an educational system to provide a highly qualified workforce needed to design, build and run an SMR.

To summarize a selection of those findings:

- Key job categories include engineering disciplines, project management, nuclear safety, licensing, operations, and IT. These job categories can be identified in any traditional nuclear power plant.
- Required hard skills: licensing, component and energy system performance, civil engineering, project planning, welding. These hard skills again, can be found in a regular NPP but dedicated courses that address the particularities of SMRs/AMRs are required.
- Required soft skills: communication, adaptability, teamwork, analytical thinking. These series of skills, although they seem of low importance for the nuclear educational programmes (and are rarely to never addressed in such nuclear specializations found in Universities) are identified as key skills by the industry. This is of utmost importance since a major conclusion that can be observed is that any newly developed E&T action strictly targeting SMRs must include cooperation with other institutions that can provide such topics.

3.2 Identified Knowledge Gaps

Following the consultation with the nuclear industry, several gaps in knowledge were identified. These are, of course, related to SMRs. To sum-up the key findings:

- Lack of comprehensive integration of hybrid energy systems into curricula. Considering the purpose of the SMRs, this topic is of high interest. Addressing the possibility of using the SMR technology close to industry or closer to inhabited areas , for electric and non-electric applications of nuclear energy, requires dedicated knowledge. This can be obtained by integrating relevant topics into the designed E&T curricula.
- Insufficient on-site training opportunities. Given the particularities of developing new technologies such as the one represented by SMRs, this can be partially fulfilled by trainings on current traditional NPPs. Even so, the lack of running SMRs or demonstrators cannot address the particularities of these technologies with live demonstrations.

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- Need for modular construction and prefabrication-specific knowledge. A major advantage of the technology is represented by its modularity. In the same time, this particularity can represent an important draw-back for the construction phase due to the lack of know-how.

An effective SMR workforce must be fluent in multiple disciplines, including:

- Nuclear engineering
- Civil/mechanical/electrical engineering
- Chemistry and materials science
- IT and cybersecurity
- Policy and regulatory knowledge

Only joint E&T actions across University departments/Universities can make it possible to study hybrid energy systems, enabling students to collaborate on real-world decarbonisation scenarios.

While the regulatory environment is evolving, training in legal and safety frameworks can be relatively easily integrated into existing curricula. No major structural change is required—just updates to content and delivery.

Recent growth in SMR-focused research should be supported through:

- Internships with start-ups, larger companies of nuclear design and engineering, and future pilot demonstration sites.
- Cross-border collaborative actions on hybrid systems and cost-effective deployment models.

This approach ensures knowledge transfer and workforce readiness aligned with technological readiness.

4 Strategic Recommendations

The recommendations drafted in this deliverable are based on the findings and work performed in the framework of the TANDEM project and in particular of the Deliverable 6.1 "E&T gap analysis on safety of SMRs & hybrid energy systems".

These recommendations and the following proposed roadmap are based on the fact that the most recent evaluation of the SMRs in Europe estimates that the first SMRs will start to operate around the year 2030. Given the fact that a highly skilled, educated and trained person must follow between 4 and 5 years of higher education and training period, the moment to initiate these actions is now.

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4.1 Develop Dedicated SMR and Hybrid System Educational Curricula

In order to have a consensus on the educational needs of a future employee working in SMRs, we need to launch EU-supported Master and Specializing Masters programmes focusing on:

- SMR safety design and licensing.
- Hybrid system integration and non-electric applications of nuclear energy (hydrogen, syn-fuels, heat, desalination, etc.).
- Digitalization and cybersecurity in SMRs.
- Classic nuclear engineering and physics topics.
- Soft-skills-related topics.

Promote interdisciplinary collaboration between engineering, environmental science, IT faculties and soft-skills focused faculties. On an ideal case, the development of a pan-European Master's programme focused solely on SMRs/AMRs would be of great support and it would also be in line with goals of other European Commission initiatives.

4.2 Enhance Soft Skills and Project-Based Learning

According to the responses received from the industry (presented in Deliverable 6.1 "E&T gap analysis on safety of SMRs & hybrid energy systems"), there is an urgent need to introduce mandatory modules on leadership, resilience, communication and stakeholder engagement.

It is of utmost importance to facilitate the cooperation between education, research, industry and other relevant stakeholders. In this regard, projects in collaboration with industry (e.g., mock licensing applications, simulated emergencies) are important for all the parties involved.

Establish a skills/job classification and taxonomy for SMRs in consultation with industry, regulators, academia and key stakeholders.

4.3 Expand Access to IT-supported training

Recent steep development of the IT domain created numerous opportunities for synergies between engineering skills, tools and the computer-based solutions. In this regard, it is very important to develop real time/real process simulators or virtual reality (VR) platforms for experiential learning.

Establish partnerships with research reactors and SMR demonstration projects. Numerous companies offer today simulation tools for various industries. Nuclear is one of them. Currently there are numerous actions aiming at integrating the Artificial Intelligence into nuclear processes.

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4.4 Integrate SMR and Hybrid Energy System Topics Early in Curricula

To cope with the fact that good specialists are needed in the near future, it is recommendable to include SMR related topics as early as possible in the curricula. As rightfully emphasized by the industry, presence of soft skills are needed but these soft skills can actually be already implemented in the current curricula since they are needed also for the operation of classic NPPs. As such, in order to include these technical hard skills related to, for instance, energy system modelling, sustainability, and hybrid integration scenarios, even starting with Bachelor level it is important.

4.5 Foster EU-Wide Coordination and Recognition

Establish an EU SMR Safety E&T Network/Initiative under Euratom. Having a network which is supported by European Institutions would give Europeans the chance to have a coordinated answer to the growing need of specialists. This network could be comprised of all interested parties and could also act as a dialogue and coordination unit between educational institutions, training institutions and industry.

Create a certification system for SMR/hybrid system competencies, ensuring mutual recognition across Member States. This approach would bring a standardized and widen recognition across EU countries and it would be of great support for the industry in acknowledging the quality of the educational process and the skills of the future employee that followed this career step.

Harmonize quality assurance protocols for SMR-related E&T modules. This would be supporting various institutions who wish to provide a recognized educational process across EU countries.

4.6 Fund Interdisciplinary SMR Learning Networks and Hubs Within and Between Universities And Research Centres

European Commission should facilitate the funding of a multi-purpose network dedicated to education and training both for students/researchers and for teachers. Creation of these scientific hubs would increase the competence development within institutions that can further on collaborate among themselves in the SMR educational network. The growing demand in human capital requires heavy support in actions aiming at training-the trainers. The increase in number of trainers is of utmost importance for coping with the high number of employees needed in the future in this field. With this increased number of teachers/trainers, this will contribute to the increased support for lifelong learning, re-training, reskilling and upskilling of existing professionals. By using this approach, there are several benefits that can be shared among various industries since specializations needed for the SMRs are to be found in other industrial environments as well.

4.7 Propose Implementation Roadmap

Phase	Timeline	Key Milestones
Phase I	2025–2026	Launch pilot Masters and Specializing Masters;
Phase II	2026–2030	Full deployment of SMR curricula across top EU universities; creation of EU-wide certification network
Phase III	2030–2035	Assessment and iterative reform based on deployment feedback; integration with EU climate and innovation strategies

Acknowledgement

Artificial Intelligence has been used for the preparation of the document to improve the quality and the fluency of the English language.