CONNECT- NM

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

A EURATOM Cofund Action

Co-funded by the European Union

Start date of project	01/10/2024
Duration	60 months
Reporting period	

Work Package 1 – Coordination and Daily Management

Deliverable D1.6 D1.2.5.1 First Publishable Annual Partnership's Progress Report (PAPREP1)

Author(s) name and affiliation	(1) Lorenzo Malerba	CIEMAT
Date of issue	17/11/2025	
Date of final approval	24/11/2025	

Dissemination Level		
PU	Public	X
CO	Confidential, only for partners of CONNECT-NM and the EC	

Document versions

Date	Version	Author(s) / Reviewer(s)
17/11/2025	First version already revised by ExB	L. Malerba
24/11/2025	Final version	L. Malerba

Disclaimer

This project has received funding from the Euratom research and training programme 2023/2025 under grant agreement No. 101165375.

The information contained in this document has been prepared solely for the purpose of providing information about CONNECT-NM. The document reflects only the CONNECT-NM consortium’s view, and the European Commission is not responsible for any use that may be made of the information it contains.

While this publication has been prepared with care, the authors and their employers provide no warranty with regards to the content and shall not be liable for any direct, incidental or consequential damages that may result from the use of the information or the data contained therein. Reproduction is authorised providing the material is unabridged and the source is acknowledged.

Table of contents

List of abbreviations

AI	Artificial Intelligence
AQP	Accelerated Qualification Paths
ATF	Accident Tolerant Fuel
EERA	European Energy Research Alliance
ENTENTE	European Database for Multiscale Modelling of Radiation Damage
ESNMS	European School on Nuclear Materials Science
FAIR	Findable Accessible Interoperable Reusable
JPNM	Joint Programme on Nuclear Materials
MAP	Materials Acceleration Platform
R&D	Research and Development
SNETP	Sustainable Nuclear Energy Technology Platform

Summary

The first year of the CONNECT-NM partnership has laid the groundwork for a new way of developing, qualifying, and monitoring nuclear materials in Europe. New or improved materials, designed to withstand radiation, high temperatures, and long operating lifetimes, are essential to warrant safety and efficiency of nuclear energy. CONNECT-NM, launched in October 2024, brings together research organisations, regulators, and industry to accelerate innovation in this field.

The partnership promotes a change of paradigm in nuclear materials science, from “observe and qualify”, to “design and control”. Traditionally, developing and qualifying a material can take decades. CONNECT-NM intends to use modern digital tools, such as machine learning or semantic technologies, to speed up materials discovery and design, through Materials Acceleration Platforms (MAPs), while rethinking qualification procedures through Accelerated Qualification Paths and standardised Test Beds, to be developed in close collaboration with safety authorities, with a view to ensuring fast but reliable certification. Monitoring and predictive control are also central parts of the activities of the partnership: CONNECT-NM promotes real-time materials-health monitoring using sensors and digital twins, allowing early detection of degradation and supporting predictive maintenance. Complementing this, multiscale modelling — enhanced by AI and validated through advanced characterization — is helping researchers anticipate material behaviour under reactor conditions more accurately than ever before. A major effort has gone also into starting to build a shared European knowledge base for nuclear materials, integrating existing databases through semantic technologies, to improve data quality, accessibility, and reuse (FAIR principles). This digital backbone is expected to cut testing time and costs significantly.

Collaboration has been a key focus of the first year. CONNECT-NM launched a large, two-step open call for projects, receiving 65 initial ideas and 51 full proposals. These were evaluated by an independent international committee, with the selected projects set to begin in 2026. Meanwhile, smaller pre-selected projects have already been advancing work in accelerated discovery, qualification, monitoring, modelling, and data management, ensuring that progress is continuous.

Education, training, and communication have also been prioritised. Training schools, mobility programmes, and outreach actions are helping develop Europe’s next generation of nuclear-materials experts and ensuring that CONNECT-NM’s results reach industry, regulators, and other stakeholders.

Overall, CONNECT-NM’s first year has been about building the foundations of a new paradigm: moving from simply observing material behaviour to actively designing and controlling it. With strong collaboration and modern digital tools, the partnership is positioning Europe at the forefront of safe, sustainable, and innovative nuclear-materials development.

FIRST PUBLISHABLE ANNUAL PARTNERSHIP'S REPORT

CONNECT-NM: Driving Innovation in Nuclear Materials

Nuclear Energy remains to date the main single source of electricity production in the European Union [1]: on average, about ¼ of the electricity comes from nuclear power plants in Europe. Moreover, in the framework of the global endeavour to reduce greenhouse-gas emissions, according to projections global nuclear capacity could double or even triple by 2050 [2,3]. This transformation, as well as ever increasing levels of nuclear energy safety and efficiency, will only be possible with new, smarter materials.

In this context, **CONNECT-NM** is a **European co-funded partnership** that aims to boost innovation in nuclear materials, helping make nuclear energy safer and more sustainable. Launched on **October 1, 2024**, it builds on the roadmaps of platforms such as the **EERA JPNM** [4,5] and **SNETP** [6,7], bringing together research institutions, regulators, and industry partners from across Europe and even beyond.

The initiative has two main goals: (1) to maintain today's nuclear capacity while (2) paving the way for the next generation of advanced systems, also supporting efforts towards the design and deployment of small modular reactors, both using current light-water-cooled technology, and novel technologies. By doing so, CONNECT-NM supports Europe's broader ambition to reduce its dependence on fossil fuels.

A New Way to Develop Nuclear Materials

CONNECT-NM's mission is to strengthen the safety and sustainability of nuclear energy through material innovation. Developing and qualifying new nuclear materials can currently take decades. The partnership seeks to shorten dramatically the time taken by this process, by exploiting **modern digital technologies**, including **machine learning** and **data analytics**. Among its goals are the development of **nuclear materials acceleration platforms**, **intelligent monitoring systems** and **advanced predictive methodologies**, to anticipate how materials behave over time.

To promote this, CONNECT-NM focuses on **five interconnected research lines**: accelerated development and manufacturing of advanced materials; accelerated qualification of materials and components; intelligent monitoring of materials' health; advanced predictive methodologies; and semantic-technology-based management of knowledge and data, in support of all previous activities.

From Materials' Conception to Qualification

The research in CONNECT-NM does not just study materials — it aims to design them. CONNECT-NM strives to combine data-driven and physics-based approaches to develop alloys, fuel claddings, coatings, and concrete structures that are more resistant to radiation, high temperature and corrosion. The goal is to create materials with stronger structural integrity and longer service lives, helping nuclear systems operate more efficiently and sustainably.

In this framework, one of CONNECT-NM's priorities is to introduce the use of **Materials Acceleration Platforms (MAP)**, as a means to speed up not only the development, but in fact also the discovery, or design, of advanced nuclear materials. In these acceleration platforms, researchers combine several modules, including automatized self-driven laboratories, and use advanced manufacturing techniques, together with non-destructive characterization, to optimize production procedures and rapidly screen amongst several potentially improved materials, so as to identify the few most promising ones. Computer simulations and machine learning heavily support this process, not only helping select the best materials, but also predicting how they will perform over decades of reactor operation.

Qualification — the process that determines whether a material is safe and reliable enough to be used in a reactor, as a pre-requisite to reactor licensing by the national safety authorities — is another key and related challenge. Fast materials discovery does not help if the material cannot be then rapidly brought to the market, by being proven appropriate for safe use in nuclear reactors. For this purpose, CONNECT-NM is applying the concepts of **Accelerated Qualification Paths** (AQP) and **Test-Beds**. The latter enable the performance of qualifying experiments - i.e., providing all data that are necessary for materials to be included in standard design codes - along standardized and quality assured fast tracks (the above-mentioned accelerated qualification paths). By working hand in hand with safety authorities (regulators), the partnership is helping define new benchmarks that can speed up approval without compromising safety. Importantly, accelerated qualification is not only supporting the licensing of **next generation reactors**, but also the deployment of nuclear materials technologies that are crucial for **current generation reactors**, also in connection with **Long Term Operation**. **Advanced manufacturing** is expected to make the repair and replacement of obsolescent components more affordable and ultimately safer, while **Accident Tolerant Fuel** (ATF) is meant to replace current fuel, to provide more margin of operation in case of off-normal situation, so as to avoid incidents and accidents. Both advanced-manufactured components and ATF are *de facto* new materials, from the application point of view, thus require full qualification and codification. The timely deployment of these technologies, therefore, pivots on the development of suitable AQP.

Smart Monitoring and Predictive Control

CONNECT-NM is also promoting the use of **Intelligent Materials Health Monitoring** systems that can track the condition of reactor components in real time. By integrating **sensor technologies** and **digital twins**, engineers are enabled to detect early signs of wear or degradation of materials and components, taking action *before* problems arise. This predictive approach could transform maintenance strategies, extending the lifespan of components and reducing operational costs. Artificial-intelligence models will help interpret the data, guiding better and faster decision-making.

Understanding Materials through Modelling and Characterization

At the heart of CONNECT-NM lies advanced **multiscale modelling, blended with modern data-driven (machine learning) approaches**, as a way to simulate how materials behave under the extreme conditions found in nuclear reactors. By combining in a smart way physics, chemistry, thermodynamics, materials science and artificial intelligence, researchers can anticipate problems that previously required years of testing. Close collaboration with experimental facilities, using ever more powerful **characterization and microstructure examination techniques**, and applying the concept of digital twins in an extended meaning, ensures that these models are constantly refined and validated, improving their predictive power.

Building a Shared Knowledge Base

Finally, a major ambition of CONNECT-NM is to create a **unified European framework for knowledge and data on nuclear materials**. By connecting existing databases and enforcing quality standards, using semantic-based technologies, the partnership will make reliable information easier to find and use. This approach is expected to cut testing time and costs by at least half, while encouraging a more collaborative, open-data culture in the field.

Collaboration and Open Project Calls

CONNECT-NM is a framework for collaboration amongst researchers. It works by launching **open calls for project proposals** that allow research teams to compete for funding while aligning their work with the partnership's overall strategy. More specifically, the partnership decides the research lines, as described in the previous paragraphs, while the consortia of researchers propose the specific ambits of application, selecting material and nuclear system of reference. **Most effort during the first year of the partnership was deployed to ensure** that all legal, administrative and logistic aspects of a **two-step open call for projects could see the light**, enabling the best projects to be launched at the beginning of 2026.

The first phase of the open call asked proposers to come up with project ideas (January-March 2025). These ideas were evaluated in a non-binding way by the research line leaders and advisors and presented in a brokerage event aimed at promoting collaboration and enlarging consortia. 65 project idea proposals were received and the brokerage event, where 40 of them were presented, was attended overall by more than 200 people, summing in-person and remote attendance. Then, full project proposals were prepared and submitted (April-July 2025): 51 were handed in and immediately entered the reviewing process. This was managed by an **independent international Evaluation Committee** that ensured that three reviewers would score each proposal and produced eventually a ranking, submitted to the approval of the general assembly, the decisional body of the partnership. These projects will start in 2026 and their progress will be reviewed by an independent **Scientific Advisory Board** of leading researchers.

Pre-selected Projects

The R&D activity of CONNECT-NM, however, is not limited to the work that will start in 2026. Preparatory, small-scale research projects were launched since the outset. Each research line included a so-called pre-selected project, each of which made solid progress towards the research line objectives, laying the foundations for faster innovation, safer operations, and smarter data use in nuclear materials research.

Concerning **accelerated materials discovery and manufacturing**, work started by looking at how to shorten the time needed to develop new nuclear materials. The involved team studied existing MAPs — most of them from non-nuclear fields — to gather best practices that could be adapted for nuclear applications. From there, they designed the architecture for a future nuclear MAP, defining how its different modules should interact. Particular attention went to advanced manufacturing for metallic alloys, concrete, and fuel components. A special focus was placed on irradiation testing, identifying the conditions and parameters that can help screen materials more efficiently. This early work sets the stage for faster and more predictive material development.

The objective of **speeding up the qualification of materials**, while ensuring their safety, was pursued by establishing in this first year guidelines for Quality Assurance in Test Beds, which are essential for producing reliable and consistent data. Testing procedures for materials exposed to heavy liquid metals were harmonised, as well, as a key step for future reactor designs. Efforts extended to innovative fuels, compiling a detailed inventory of neutron and ion irradiation facilities and defining experimental setups for pre- and post-irradiation testing. Research also revisited the behaviour of advanced concretes, studying how they can self-heal or resist ageing under extreme conditions. In parallel, new testing methods were explored for ATF, moving toward standardized testing procedures that will speed up qualification in the future.

CONNECT-NM is also **advancing on monitoring the lifetime of nuclear components**: a comprehensive classification of non-destructive testing methods was created, linking each technique to specific materials and degradation phenomena. Concerning **advanced predictive methodologies**, during the first year the relevant pre-selected project tested and compared different modelling approaches for key materials such as steels, concrete, and fuels. This work is helping to build confidence in simulation tools that can complement, and sometimes replace, lengthy experimental campaigns. Finally, CONNECT-NM is establishing the digital backbone for all this work: a unified system for collecting, storing, and using nuclear materials data. During the first year, the involved team produced a **Data Management Plan**, launched a pilot version of the **Nuclear Materials Knowledge System**, and integrated it with the existing ENTENTE database, through new ontology and virtualization tools. The full implementation of the knowledge base — including its ontology and virtual access layers — is expected to be completed soon, consolidating a shared European platform for nuclear materials data.

Education, Training and Communication

Education and training are central to CONNECT-NM's long-term vision. The partnership aims to become Europe's **main hub for learning and skills development in nuclear materials**. Through mobility programs, training schools, online courses, and workshops, it helps young scientists and engineers connect with the broader research community — including industries beyond the nuclear sector. A first training school, ESNMS 2024 (third European School on Nuclear Materials Science) was organised in October 2024 and a second one, jointly organised with the Jules Horowitz community, was scheduled for October 2025.

CONNECT-NM also takes communication seriously. A **network of young researchers** has also been created, with its kick-off workshop held in Bratislava, in concomitance with the first Plenary Meeting of the Partnership.

Plenty of communication actions were undertaken during this first year, including press releases, presentations to specific audiences, and digital communications of various kind. In addition, the partnership works closely with private companies, safety organizations, and regulators to ensure that research results reach those who can use them. For instance, an **Innovation and Exploitation Group** has been set in place to watch over the impact of projects' results, while a **Board of Regulators and** one of **Technical Safety and support Organisations**, have been created to maintain a dialogue with researchers and industries involved in the projects, ensuring that safety and licensability remain high in the agenda of the R&D activities. More in general, stakeholders have been mapped in view of keeping the dialogue open with the partnership's actors.

Towards a New Paradigm in Nuclear Materials Science

CONNECT-NM represents a **paradigm shift** in how Europe develops and uses nuclear materials. It promotes a move from merely observing and qualifying materials to **designing and controlling** them proactively. The project covers every step of the materials life cycle — from conception and manufacturing to operation, and eventually recycling and disposal.

The ability of the nuclear industry to embrace these innovations will play a decisive role in shaping its future. CONNECT-NM shows that with the right collaboration, digital tools, and scientific vision, Europe can lead the way towards a safer and more sustainable nuclear energy landscape.

The first year of CONNECT-NM has been about *building the foundations*: creating digital frameworks, aligning testing methods, and setting up the tools needed to speed up innovation. Together, these efforts mark the beginning of a new, faster, and more connected approach to nuclear materials science in Europe.

References

[1] Twidale S. Solar power overtook coal in EU's electricity mix in 2024, Ember says. Reuter Power Up (Jan. 2025). Available online: https://www.reuters.com/business/energy/solar-power-overtook-coal-eus-electricity-mix-2024-ember-says-2025-01-22/ (accessed 10 Nov 2025).
[2] IAEA Raises Nuclear Power Projections for Fifth Consecutive Year (15 September 2025). Available online : https://www.iaea.org/newscenter/pressreleases/iaea-raises-nuclear-power-projections-for-fifth-consecutive-year#:~:text=In%20the%20high%20case%20projection,pivotal%20role%20in%20this%20expansion (accessed 10 Nov 2025)
[3] At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero (1st December 2023). Available online: https://www.energy.gov/articles/cop28-countries-launch-declaration-triple-nuclear-energy-capacity-2050-recognizing-key#:~:text=Framework%20Convention%20on%20Climate%20Change,1.5%2Ddegree%20goal%20within%20reach (accessed 10 Nov 2025)

[4] L. Malerba, P. Agostini, M. Bertolus, F. Delage, A. Gallais-During, C. Grisolia, K. Liger, P.-F. Giroux, Advances on GenIV structural and fuel materials and cross-cutting activities between fission and fusion, EPJ Nucl. Sci. Technol. 6, 32 (2020).
[5] L. Malerba, A. Al Mazouzi, M. Bertolus, M. Cologna, P. Efsing, A. Jianu, P. Kinnunen, K.-F. Nilsson, M. Rabung, M. Tarantino. Materials for Sustainable Nuclear Energy: A European Strategic Research and Innovation Agenda for All Reactor Generations. Energies. 15, 1845 (2022). https://doi.org/10.3390/en15051845
[6] K. Mikityuk, L. Ammirabile, M. Forni, J. Jagielski, N. Girault, A. Horvath, J.-L. Kloosterman, M. Tarantino, A. Vasile, Review of Euratom projects on design, safety assessment, R&D and licensing for ESNII/Gen-IV fast neutron systems, EPJ Nuclear Sci. Technol. 6, 36 (2020).
[7] https://snetp.org

CONNECT IM

Co-funded by
the European Union