Organisation of the European Research Community on Nuclear Materials

A Coordination and Support Action in Preparation of a Co-Funded European Partnership on Nuclear Materials

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# ORIENT-NM vision on nuclear materials research for all reactor generations

## April 2022

# Executive Summary


*ORIENT-NM is a Euratom-funded Coordination and Support Action (CSA) with the objective of exploring consensus on a* ***European partnership on nuclear materials****, establishing the relevant Strategic Research Agenda (SRA), governing structure and means for interaction with stake-holders, based on the SRA of SNETP and EERA-JPNM.*

*The ORIENT-NM analysis of the national energy and climate plans (NECP) suggests that,* ***from now to 2040, nuclear power will be maintained or even expanded in Europe through LTO, power uprates and new builds****. In addition, also in the light of recent geopolitical events, game-changers such as* ***small modular reactors and advanced designs*** *of interest throughout the continent may lead nuclear energy to be even more widespread in 2040 than currently foreseeable.*

***Research to understand and monitor materials behaviour in operation, and to improve materials performances, has always played a crucial role to continuously enhance the safety, efficiency and economy of nuclear energy.*** *The involved materials cover a wide spectrum: from metallic structural alloys, to polymers and concrete, and from nuclear fuel to substances for neutron control.*

*To timely meet the challenges posed by the clean energy transition,* ***this research needs to be boosted to accelerate the development, manufacturing and qualification of innovative nuclear materials, and so reduce their time to market****, by improving their performance by design. This implies a shift from the traditional "observe and qualify" to the modern "design and control" materials science approach, which is enabled by advanced digital techniques and suitable models.*

***With this goal in mind, an integrated nuclear materials research programme, i.e. a partnership, needs to be set up*** *to make coordinated use of assets that are spread across member states and associated countries, as well as to give continuity to the pursued research lines. With this, the paradigm shift in nuclear materials science is at reach for Europe. Such a partnership will "need and feed" available schemes and roadmaps for access to, and use of, infrastructures, such as those designed in the parallel JHOP2040 CSA for utilising Euratom access rights in the Jules Horowitz Reactor, or established in the starting OFFERR CSA, or in the framework of international organisations (e.g. OECD/NEA's FIDES initiative).*

***In order to produce fruitful results for all parties, including non-nuclear industries and countries, the partnership will pivot around five research lines that are transversal to all classes of nuclear materials****, consistently with the activities foreseen in the SET-plan implementation plan on nuclear safety and with the Advanced Materials 2030 Manifesto. Namely: (1) nuclear materials' test-beds, (2) nuclear materials' acceleration platforms, (3) advanced predictive methodologies, (4) Improved material and component health monitoring and (5) European nuclear materials' FAIR database.*

*Such a cross-cutting programme is expected to leverage substantial national and industrial support. Because of its* ***inherent multidisciplinary approach****, it will maintain and build competences, while its* ***cross-cutting nature*** *will equally serve all the various nuclear energy national strategies, supporting nuclear industry competitiveness and a robust supply chain, with benefits for fusion and non-nuclear energy, as well.*

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ORIENT NM

# 1. Introduction

ORIENT-NM (Organisation of the European Research Community on Nuclear Materials) is a Coordination and Support Action (CSA) partially funded by the Euratom research and training work-programme 2019-2020, which was set up, consistently with the call request, to explore the opportunity of establishing a European partnership on nuclear materials, following a procedure already adopted in the past for other partnerships. Accordingly, **this document presents the vision of the European research community on nuclear materials**, as represented in ORIENT-NM, which allies SNETP (snetp.eu) and EERA-JPNM (www.eera-jpnm.eu), **regarding**:

- **Sustainability**: Nuclear systems are crucial components, together with renewables, of a resilient and sustainable Energy Union, helping Europe to abate the use of fossil fuels, reduce European geopolitical dependence and become the first climate neutral continent by 2050 [1]. Their sustainability needs to be continuously improved and this document discusses how.
- **Innovation**: Materials research plays a crucial role to enhance the safety, efficiency and economy of nuclear energy, by supporting the existing fleet, the new builds and also enabling the deployment of advanced reactor concepts, including small and medium size modular reactors (SMRs), within the time horizon of 2040. This document discusses the relevant research needs.
- **Targeted collaboration**: The development and qualification of innovative materials solutions, and their monitoring in operation, needs to be accelerated, while also accounting for circularity and sustainability principles. This document advocates that the nuclear materials research community should work **towards five clearly identified Grand Goals**, along the corresponding research lines.

These five research lines, which are presented at the end of this document, stemmed from the analysis of the European member states' energy plans and of the short and long term needs of the nuclear industry. They correspond to a shift from an "observe and qualify" approach towards a more advanced "design and control" one, using advanced materials science practices combined with modern digital techniques. The corresponding Grand Goals are accordingly ambitious ones.

**Attaining these five Grand Goals calls intrinsically for Europe-wide collaboration.** These goals are therefore thought to serve equally well different national nuclear energy strategies and policies aimed at improving industrial competitiveness, and can thus be shared between all involved member states and associated countries, allowing their needs to be met, by valorising their research and industrial assets. **The European partnership is the tool** to enable the integration and coordination of a single nuclear materials research programme built around the shared Grand Goals. It will make optimal use of national competences, facilities and (present and future) infrastructures, to strengthen European leadership, and will guarantee continuity along the established research lines, differently from the present model based on scattered projects.

ORIENT NM

# 2. Nuclear energy's important role for a net zero Europe

## 2.1 Nuclear energy's assets

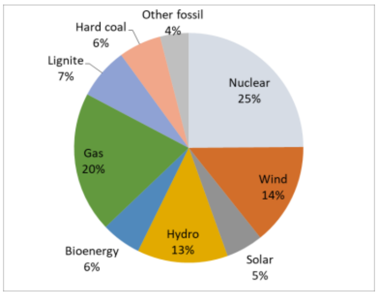
**Nuclear energy has predictable and relatively low prices, as reported in comparative studies** [2,3]**, and guarantees secure energy supply, creating little if any geopolitical dependence**. This is explicitly stated and explained in several National Energy and Climate Plans (NECPs) [4] that include nuclear energy in the secure energy supply section, recognising that the de-carbonisation targets could not be reached without the nuclear contribution during the transition. This is reflected in the European Commission revision of the taxonomy for sustainable financing [5]. Base-load is also a stabilizing factor for the grid operator in an energy mix with an increasing share of intermittent renewable sources. Finally, nuclear power has demonstrated ability and high potential to provide also low greenhouse gases (GHG) district heating and high temperature heat for various industrial applications, including hydrogen production and sea-water desalination, which need to be duly exploited.

**The alliance between renewables and nuclear energy has been shown to be the most effective response to the challenge of de-carbonisation of the energy sector** [6]. Consistently, the 2018 "1.5°C-report" of the International Panel on Climate Change (IPCC) [7] points to electricity from nuclear power as key to limit global warming to 1.5°C. Nuclear energy is therefore an asset for Europe with a view to honouring the engagement to reduce GHG emissions by 55% by 2030 and towards complete de-carbonisation in 2050.

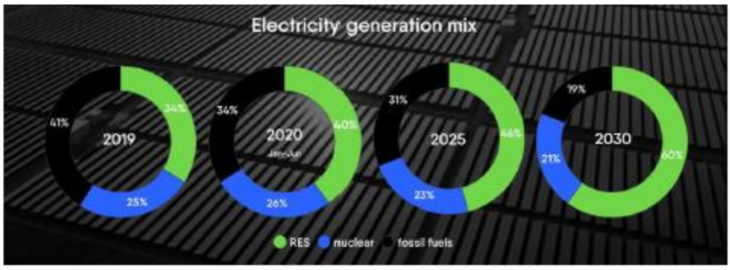
## 2.2 Nuclear energy contribution to decarbonisation in Europe

The transition from current fossil fuel based energy systems to low GHG emitting ones is the core of the European Green Deal [1] and a major global challenge to face the climate change emergency. Reducing the dependence on fossil fuels has currently also important geopolitical implications.

Figure 1 shows that, **despite varying national positions in Europe, different studies agree that nuclear energy remains the single largest low GHG emitting energy source for electricity production on the continent and will maintain this role in the foreseeable future**. The analysis of the NECP, prepared in 2019 and revised in 2020 by each EU country, consistently reveals that, up to at least 2040, and likely also beyond, nuclear will represent a significant fraction of the electricity production in Europe [8].




Source: Eurostat (2020)




Source: Eurelectric Power Barometer (2020)

***Figure 1*** *- Left: Electricity generation by fuel in the EU 27, in 2020 [9]. Right: Predicted evolution of the electricity generation by fuel [10].*

This role in electricity production is mainly realized through long-term operation (LTO) of current light water reactors (LWR), i.e. pro-active lifetime extension beyond original design lifetime, as well as power uprates. LTO is already an established reality in all nuclear countries, including some that are planning to phase out [8]. New-builds of evolutionary LWR designs, referred to as Generation III or III+, will also contribute to keep the nuclear electricity production stable. This will help enable the European Union to deliver on the commitments of the Paris Agreement and the 2030 Agenda for Sustainable Development [11,12].

In this context, small and medium sized modular reactors (SMR) are expected to be game-changers [13,14,15]. They will reduce significantly the initial capital costs and the time of construction, thanks to modularized production, while displaying enhanced safety performance through inherent and passive safety features. Interest for SMRs is accordingly widespread in Europe, including currently non-nuclear countries [8,10].

The attractiveness of SMRs and advanced designs, combined with the overall re-thinking of the role of nuclear energy in fighting climate change and especially in securing autonomous energy supply, may lead nuclear energy to be more widespread than currently foreseeable in 2040.

## 2.3 The journey towards increasing nuclear sustainability

Five issues still hamper the full-hearted adoption of nuclear as low carbon sustainable energy source in Europe: the worries concerning severe accident risk and safety of operation; the misperception and concern regarding management of long-lived radioactive nuclear waste; the perceived limited availability of fuel resources; the large initial investments, back-end costs and long construction times; and the fear of possible misuse of fissile materials.

**Integrated research programmes that pursue targeted research lines with the required continuity are crucial to tackle these issues,** stably enabling the preservation and expansion of competence and expertise and its transferral to young generations of researchers and operators. This is indeed key to ensure **continuous improvements in operational practices of current reactors, in the context of an increased flexibility of the network, exploiting margins to further increase current generation nuclear energy performance, efficiency and safety**. widespread adoption of SMRs, including high temperature systems that enable low-GHG heat production.

**through the commissioning and deployment of fast neutron reactors** [16] **combined with fuel recycling facilities**. These reactors produce more fissile material than they consume, thus they significantly improve the utilization of natural resources, reduce the need of mining, and guarantee stable and secure energy supply, reducing any geopolitical dependence. These systems also abate the long-term radiotoxic impact of irradiated nuclear fuel, by drastically decreasing the quantity of waste and its radiotoxicity duration, especially when minor actinides are burnt in reactors or dedicated facilities. Advanced design reactors will additionally enable higher safety standards by relying on passive systems, i.e., systems that are activated by physical laws, without any need for external intervention. Finally, they will improve plant economy through higher energy efficiency (higher operation temperature) and the adoption of advanced SMR concepts.

Fusion will finally represent a further step towards nuclear energy full sustainability, by eliminating high activity waste from fuel.

**In order for Europe to be able to profit of these options, a cohesive, targeted and properly supported European strategy including research, innovation and knowledge management on nuclear materials is needed**, as is demonstrated in the next section.

# 3. Materials' crucial role for both current and future nuclear reactor systems

Materials crosscut the entire technology portfolio, from energy generation and storage to delivery and end use. Materials discovery and development are the foundation of every energy innovation: advanced batteries and fuel cells, solar panels, thermal storage systems, capture and use of $CO_2$. **New or improved materials hence constitute one of the cornerstones for the global transition to a low-carbon future. This is also true for nuclear energy. As such, investment into research on innovative nuclear materials promises to pay good dividends.**

## 3.1 A large number and variety of nuclear materials

A nuclear reactor comprises a large number of materials [17], the properties of which are essential for its safe operation, efficiency and performance. The number of different nuclear materials is all the greater given the large variety of nuclear system designs, from current generation fission reactors to Gen-IV and fusion. The various classes of nuclear materials considered and targeted in this document and their inherent variety are illustrated in Figure 2.

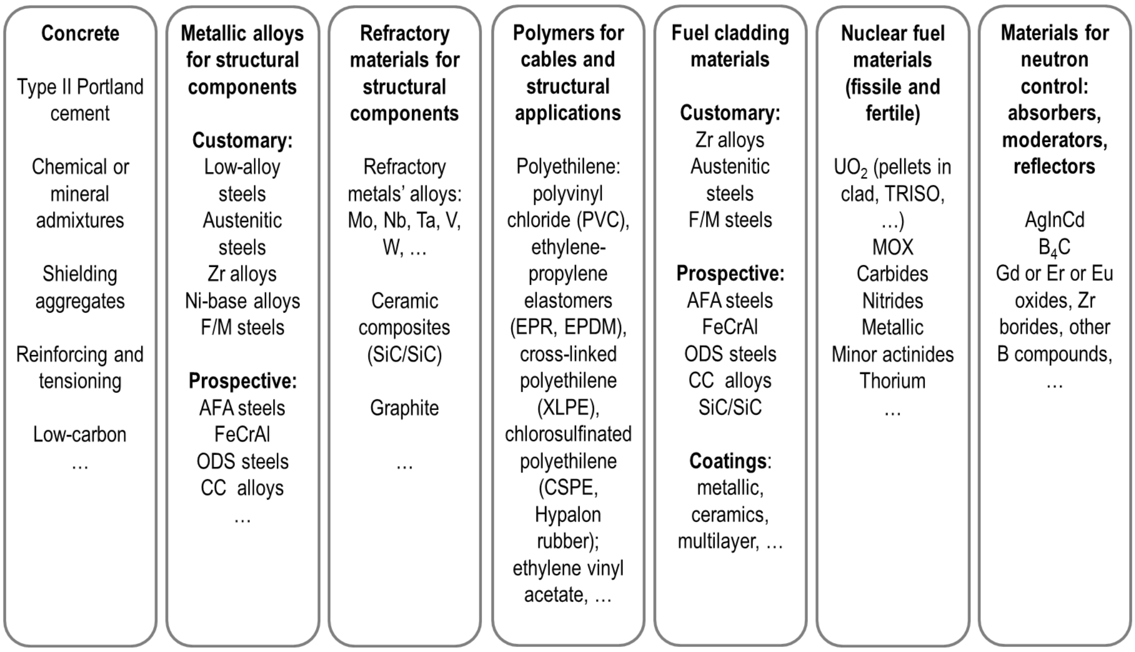



***Figure 2** – Classes of nuclear materials considered here and their variety.*

## 3.2 Nuclear materials' requirements

All components in a nuclear installation need to fulfil their structural and functional properties under both normal and off-normal conditions all along their design lifetime. They must in particular ensure a high degree of reliability according to specific nuclear standards and regulations, hence the importance of the involvement of standardization bodies and regulators in materials development. The materials of many of these components, especially those in the reactor core, are exposed to demanding environmental conditions in terms of neutron irradiation, temperature gradients, and corrosion under different forms, which all need to be harnessed. Materials need accordingly to be suitably selected by designers at early stages of reactor conception, based on the complete knowledge of the as-fabricated properties, the expected functionality and the operating requirements. Appropriate control, monitoring, maintenance, replacement and repair strategies are then used to control evolution and ageing mechanisms, to ensure that the equipment is able to perform its function reliably and safely throughout its time of use. **Research into these issues to improve the relevant practices has thus wide potential to increase the short and long-term safety, security, and stability of nuclear energy supply.**

***Initial Material Properties***

**For most materials currently in use in nuclear facilities**, design property data are available, within scatter and heterogeneities. However, **more efficient and less costly manufacturing and welding processes, and subsequent thermal and mechanical treatments, need to be studied** to guarantee safe and timely replacement, repair and robust supply chain, in compliance with regulatory requirements.

In turn, **gaps still remain concerning materials for the deployment of Gen IV reactors**, where not all relevant initial properties are available from established experience, and materials with improved initial properties are needed to achieve better resistance to severe degradation processes, which are due to exposure to higher irradiation dose and temperature than in current generation reactors, in contact with non-aqueous fluids.

***Ageing and Degradation Mechanisms***

All ageing and/or degradation mechanisms that could be active during the required lifetime of components need to be properly understood, modelled and adequately taken into account from design through integrity assessments under all operational conditions, this being true for reactors of any generation. Materials' property measurements and degradation analyses through health monitoring using non-destructive examination and testing (NDE&T), coupled with diagnostics, additionally enable accurate and continuous control of the performance of components, together with suitable preventive measures and on-site repair and replacement technologies and strategies. **All these materials' science related methodologies need to be suitably studied, improved and developed: combined with in-depth knowledge of materials behaviour, they clearly bring important advantages in terms of reduced maintenance costs and increased component lifetime, with obvious positive economic consequences**. Furthermore, new materials solutions need to include considerations of overall sustainability in terms of materials criticality, lifetime optimization and waste reduction. Finally, issues such as industrial production scalability, supply chain and standardisation are equally crucial to enable the deployment of a given materials solution on the path towards innovation. **Overall, in-depth knowledge of the properties of a large number and variety of materials, many still to be developed, and their evolution for their entire service life, while accounting for supply chain and sustainability issues, is strongly needed.**

## 3.3 Materials' needs for Gen III/III+ reactors

The above challenges need to be met in the short term for currently operating (Gen II/III) reactors and Gen III/III+ new builds.

Materials for Gen III/III+ are selected based on long-standing experience from the operation of Gen II reactors since the 1970s and 1980s. Designs have been optimised to take into account the properties of the materials under various operational conditions. Several issues, however, have been revealed recently in connection with obsolescence and repair needs. These issues affect not only core components that have been for long the focus of research for safety reasons, but also materials such as concrete and cable polymers, the degradation of which, in an LTO framework, is a point of attention. These issues need to be examined thoroughly to ensure the necessary reliability of the components concerned and their compliance with up-to-date codes and standards. **Increased efficiency of new builds and reduced costs of maintenance and availability of supply chain are expected from improved materials and new fabrication methods**, which also enable the modification of component design for better performance. **This approach will also benefit LTO of operating reactors**, allowing the introduction of new materials or new materials manufacturing processes. It may also facilitate the design of SMRs, particularly their modular construction in factories.

**On the fuel side, new materials solutions will further improve safety margins in operational conditions**, reducing reactivity and mechanical/chemical pellet-to-cladding interaction. Fuel elements with enhanced accident tolerance will also increase the time between departure from normal operation and the moment at which significant loss of geometry of the fuel assemblies occurs and the severe accident starts, and mitigate the consequence of an accident. Solutions to extend the recycling of used fuels in current reactors are also being investigated.

These aspects are extensively addressed in the Sustainable Nuclear Energy Technology Platform (SNETP) Strategic Research and Innovation Agenda 2021 [18].

## 3.4 Materials' needs for Gen IV reactors

In next generation reactors, structural and fuel materials will be exposed to significantly higher temperatures and temperature gradients, as well as increased levels of irradiation, compared to today's LWRs, as is illustrated in Figure 3 for cladding materials. Materials used in these reactors also need to be compatible with unconventional coolants, such as liquid metals, molten salts or gases, which have a high corrosive and erosive potential and for which in-service feedback experience is limited.

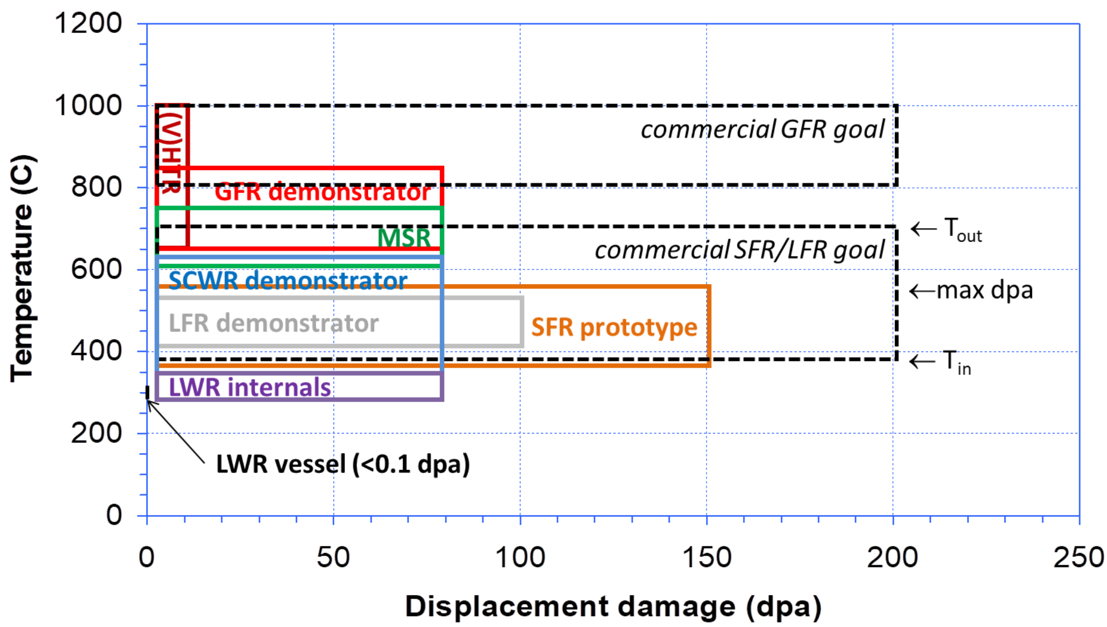



***Figure 3*** *– Ranges of temperature (inlet/outlet) and maximum neutron dose in the cladding in Gen IV reactor demonstrators and prototypes versus LWR, according to current EU designs. Indicative possible target regimes for commercial reactors are also indicated. From [19].*

**To date, no commercial materials enable the ambitious targets of Gen IV reactor operating conditions to be fully attained. There is therefore a clear need to develop and qualify materials with suitable properties.** The grand challenges for the development and qualification of materials for next generation reactors are:

- Elaboration of design rules, assessment and test procedures, for both operating and off-normal conditions, for all the materials of interest;
- Development of physical models coupled to advanced microstructural characterization to achieve high-level understanding and predictive capability, in combination with suitable data-driven modelling approaches;
- Development of advanced structural, fuel and other core materials solutions and application of advanced manufacturing techniques to achieve superior thermo-mechanical properties, better radiation-resistance and compatibility with fluids;
- Development of materials health monitoring through NDE&T methods applicable at all stages of product lifetime.

The first three challenges for metallic and ceramic structural and fuel materials are amply discussed in the Strategic Research Agenda of the Joint Programme on Nuclear Materials of the European Energy Research Alliance (EERA-JPNM) [20]. **Importantly, materials with superior properties in terms of radiation and thermal gradient resistance are also essential for fusion** [21].

# 4. Answering Europe’s materials’ needs for the development of nuclear systems

**The above considerations show unambiguously that materials are crucial both to further enhance safety and overall sustainability of current reactors and to enable the commissioning and deployment of next generation reactors, as well as fusion**, thereby directly addressing the above-mentioned issues that still hamper the full-hearted adoption of nuclear as low carbon sustainable energy source in Europe. The European nuclear materials science community is therefore called to provide the tools, knowledge and skills to enable each European country to maintain the wished and needed nuclear capacity and/or, depending on national policies and interests, to develop advanced nuclear systems, i.e., to:

- Ensure safe and affordable LTO of current generation reactors;
- Design, license and construct Gen III+ new builds;
- Deploy light water SMRs within the next decade;
- Facilitate and reduce the time and costs for design, licensing and construction of competitive next generation (GenIV) nuclear reactors, including advanced SMRs within the time horizon of 2040.

## 4.1 Five Grand Goals of the European nuclear materials' research

**Addressing the challenges described above, in such a way to have an impact on the clean energy transition, requires the application of modern materials science approaches to accelerate materials development and qualification pace**. This implies shifting from an "observe and qualify" approach towards a more advanced "design and control" one, combining applied research with more fundamental approaches. The knowledge of materials' behaviour in operation will be improved thanks to models that underpin empirical performance correlations, which will enable them to be extended reliably to yet unexplored operational regimes.

**Five materials science practices and relevant research lines underlie these endeavours and constitute the Grand Goals to be pursued within the next decade**, for full application also beyond this timeframe[1]:

a) **Nuclear materials' test-beds.** The goal here is to establish an efficient and integrated European networked system for the application of advanced and suitably standardized experimental procedures and methodologies for nuclear materials exposure, characterization and testing, be they destructive, non-destructive or microstructural. This network is eventually meant to be able to offer the nuclear industry a reference for any specific materials qualification need that may emerge. A connection with existing initiatives that coordinate the use of neutron irradiation facilities is clearly part of this endeavour.

b) **Nuclear materials acceleration platforms (nuclear MAPs).** MAPs are integrated, highly autonomous systems that combine advanced characterization and modelling with modern digital techniques for materials fitness and sustainability by design. Here the goal is therefore to apply, to the benefit of nuclear energy, methodologies that have been already applied in other technology frameworks, for the systematized, targeted and accelerated improvement, development, or even discovery, of materials, with the promise to drastically reduce time to market and therefore enhance innovation [22]. The inclusion in the loop of charged particle (ions, protons, electrons …) irradiation facilities is here clearly one of the specificities of a MAP applied to nuclear materials.

c) **Advanced predictive methodologies**. Here the focus in on suitably blending physical and data-driven (i.e. artificial intelligence-based) models, for the development of advanced predictive methodologies that, while being characterised by strong physical rooting, are also fast and efficient enough to be of direct application for industrial needs.

d) **Improved material and component health monitoring.** Here the goal is to develop the key technologies that enable the application of advanced monitoring methods through

[1] These Grand Goals are consistent with, and contribute to, the research and innovation activities 1, 2, 7, 8 and 9 of the SETplan implementation plan on nuclear safety (action nr. 10, https://setis.ec.europa.eu/implementing-actions/nuclear-safety_en) and support the key enabling condition 5.

non-destructive examination and testing. These, coupled with suitable diagnostics and simulation tools, including the above advanced predictive methodologies, enable the widespread implementation of digital twins, for optimised component and plant life management and increased safety.

e) **European nuclear materials' FAIR database**. Here the goal is to draw on already on-going work to establish an efficient platform, including all relevant ontologies, standards, regulations and procedures, for nuclear materials' data collection, storage, management and use, in accordance with FAIR (findability, accessibility, interoperability and reusability) principles.

**The above five research lines are transversal to all materials classes and varieties shown in Figure 2, irrespective of the specific nuclear generation application**, and profit of the opportunities offered by modern digital techniques, such as: artificial intelligence, blockchain, 3D visualisation, data analytics, high performance computing, robotics, etc. Together, these approaches and tools allow more efficient plant life and safety management, as well as better use of resources and thus improved competitiveness of the nuclear sector.

Nuclear materials test-beds and nuclear MAPs inherently require coordinated use of (present and future) European assets and facilities and exploitation of available schemes and roadmaps for access to, and use of, major infrastructures (essentially materials testing reactors and charged particle irradiation facilities). This includes those that are being designed in the parallel coordination and support action JHOP2040 [23], or established in the framework of either on-going projects (e.g., OFFERR), or international organisations (e.g. OECD/NEA's FIDES framework [24]), with an eye to the possibilities offered by research facilities that will become available in the next decade (JHR, MYRRHA, PALLAS, IFMIF-DONES). In turn, these European facilities and infrastructure plans require coordination with the materials research community, especially in identifying and prioritizing the future experimental needs for material studies.

## 4.2 Creating an organized European research community on nuclear materials

**The ambitious effort sketched in the previous section can only be achieved by promoting close, structured and continued collaboration between academia, research organizations and industrial partners all over Europe.** This will enable the European nuclear materials research community to maximize the effect of the assets and financial resources that are available in Europe, avoiding duplication and fragmentation and achieving European self-sufficiency Such structured collaboration is expected to provide orientation, prioritization and, especially, continuity to the five above R&D&I lines, leveraging significant national and industrial support. This is not fully achieved with the current EU financing model, which is based on smaller and fragmented communities and discontinuous projects. For example, in the Horizon 2020 framework programme, Euratom funded about 20 single nuclear materials' research related projects, overall worth about 120 M€, when the member states' contribution is included. The research community did benefit greatly from this support. However, this model did not enable the structured establishment and expansion of multidisciplinary, stable knowledge around clear targets.

**This coordinated use of resources by establishing a European partnership in the specific area of materials, will eventually serve equally well different nuclear energy strategies and policies, from current to next generation, from fission to fusion**. A large number of EU member states can share the above goals, as they will inherently allow each of them to valorise own research assets, in terms of knowledge and skills, as well as facilities and infrastructures, irrespective of their specific interests as to current and/or future nuclear systems. This is in fact the bottom-line of the identification of the transversal Grand Goals sketched in the previous section.

**Importantly, the methodology presented above is general, widely applicable to various nuclear systems, and goes even beyond nuclear use**. Even though the final application determines the specific requirements that the materials need to meet, the properties of interest, and the conditions under which these properties need to be tested, nuclear materials belong to the much wider class of materials operating under extreme conditions. **Therefore, even countries that do not adopt nuclear energy or are phasing out can find an interest in participating to develop materials science tools** dedicated to advanced materials discovery, development, screening, qualification and monitoring, of application to other high efficiency low carbon energy technologies, where materials are exposed to harsh operating environments, such as bioenergy, concentrated solar power, geothermal energy, and, to some extent, also fuel cells and hydrogen, or wind energy.

The whole framework and the steps to be taken to reach the Grand Goals of the partnership will be detailed in the SRA that is being worked on within the ORIENT-NM project [19], while the structure of the partnership, its way of working, its interaction with stake-holders and the opportunities offered by present and future large infrastructures in Europe will be analysed in separate dedicated documents. **What is beyond doubt, however, is that the instrument to realize the above purposes is a European partnership on nuclear materials built around the stated Grand Goals**.

## 4.3 Expected benefits of a partnership on nuclear materials

The aims of the proposed partnership have been drafted such as to advance all national nuclear energy strategies through optimised collaboration.

The research conducted by this partnership will further increase the safety, efficiency and economy of present nuclear energy. It is also a major step toward the introduction of SMRs and Gen IV reactors, which will reduce costs of capital investment for nuclear facilities, improve sustainability as well as provide economic opportunities for exporting nuclear energy and SMRs.

This partnership will enable the retention and expansion of multidisciplinary scientific knowledge and co-operation between stakeholders for continued technological innovation, being especially beneficial for nuclear energy, to which young researchers with varied background and competences will be attracted by the ambition and wide applicability of the pursued goals.

It will also produce fruitful results for all parties, including non-nuclear industries, such as renewables where operating conditions are extreme, as well as fusion, and thus interesting also for non-nuclear countries.

Because of the goals it is built around, this partnership can be a seed for collaboration on materials beyond, strictly, the nuclear sector, and act as starting point for a wider initiative on materials, e.g., as is put forward in the Advanced Materials 2030 Manifesto [25], with which the proposed partnership's goals are fully consistent.

On a wider horizon, advancing European nuclear materials research for current and future reactors plays directly into making Europe less reliant on oil and gas imports, and increases energy supply security while decreasing GHG.

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