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Summary

This reports provides the Vision for EERA JPNM in the timeframe 2015-2020

Approval

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Contents

Executive Summary

Nuclear energy has an important role in implementing the challenge of the Energy Union's forward-looking climate change policy, as it provides energy with very limited CO_2 footprint at stable and comparably low prices, as well as a secure and reliable supply of base-load electricity. Nuclear power today fulfils these requirements but two main issues remain, namely accident risk and long-lived nuclear waste. Sustainability is not adequate (less than 1% of the energy content of the fuel is actually used), but can be resolved completely by the deployment of Gen IV fast neutron reactors along with the necessary fuel cycle facilities (beyond the state of the art) to extract reusable components of the fuel from which new fresh fuel is generated. Thus, the energy utilization of the fuel is increased and the radiotoxicity of the waste is dramatically curtailed. In this framework, the performance of nuclear (structural and fuel) materials is essential for the development of sustainable nuclear energy. Materials in fast reactors will be exposed to higher temperatures and higher irradiation levels than today's light-water reactors. Fast reactors also use non-aqueous coolants, for which the full compatibility of materials needs to be demonstrated. The European Energy Research Alliance (EERA) Joint Programme on Nuclear Materials (JPNM) was launched in 2010 to provide the R&D for materials needed for the development and implementation of fast reactors in Europe, as defined by the European Sustainable Nuclear Industrial Initiative (ESNII).

This report describes the Vision of the EERA JPNM with respect to *Grand Challenges* that must be addressed and resolved to take full advantage of the nuclear GenIV technology, with respect to safety, performance and cost, and to ensure implementation towards 2040.

- Grand Challenge 1: Elaboration of design rules, assessment and test procedures for the expected operating conditions and the structural and fuel materials envisaged. This involves deployment of infrastructures for relevant ageing phenomena and for testing of materials, data and knowledge, which is currently limited.
- Grand Challenge 2: Development of physical models coupled to advanced microstructural characterization to achieve high-level understanding and predictive capability: an asset, given the scarcity of experimental data and the difficulty and cost of obtaining them.
- Grand Challenge 3: Development of innovative structural and fuel materials with superior thermo-mechanical properties and radiation-resistance or, in general, nuclear-relevance, in partnership with industry.

Addressing these Grand Challenges requires a concerted action at European level involving research community and industrial partners. The EERA JPNM addresses this by proposing a five-step process towards an integration of relevant nuclear material laboratories in the EU Member States by 2020 with the overall objective to ensure that nuclear GenIV technology can be implemented, as planned, in Europe from 2040. The integration of nuclear materials research is necessary to optimise the use of the available human and financial resources, as well as facilities and expertise, with the goal of solving the future energy needs, but it requires sufficient support and engagement of the European Commission and Member States.

1. Target of this document

This report presents the vision of the European Energy Research Alliance (EERA) Joint Programme on Nuclear Materials (JPNM) with respect to:

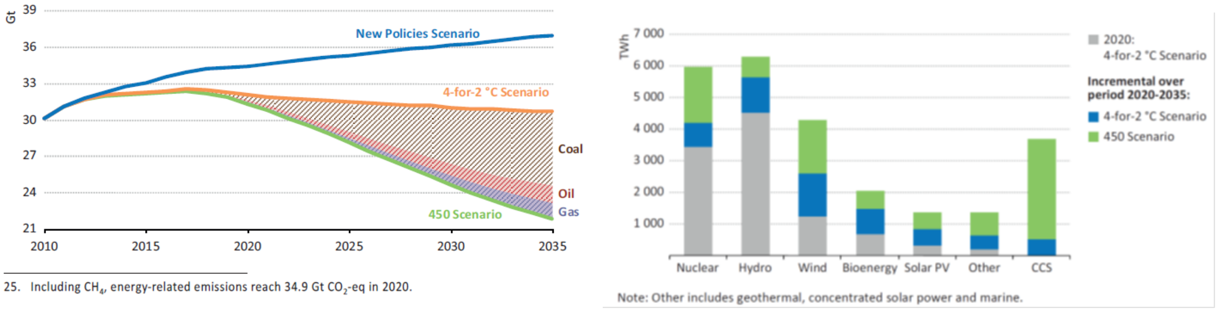
- the need for future nuclear energy as a component of a resilient Energy Union with a forward-looking climate change policy;
- the key role of structural and fuel materials for the development of sustainable nuclear reactor systems;
- the Grand Challenges for such materials that need to be addressed;
- the establishment of an integrated European nuclear (structural and fuel) materials research programme.

This report serves as a reference document for the Roadmap and more detailed Descriptions of Work of the EERA JPNM over the coming five-year period. It is aimed primarily at our stakeholders, such as members of the Strategic Energy Technology Plan (SET-Plan) Working Groups, nuclear and non-nuclear technology platforms representing both industry and research organizations, as well as managers and decision-makers, especially Member States representatives and Euratom officers.

2. Nuclear energy in future low-carbon energy systems

The transition from fossil fuel-based to low-carbon energy systems is a major global challenge as expressed by the Strategic Energy Technology Plan (SET-Plan) [1] and the "resilient Energy Union with a forward-looking climate change policy", now a key priority of the new Juncker Commission (http://ec.europa.eu/priorities/energy-union/index_en.htm). Two key instruments for the development and implementation of the SET-plan technologies are the European Industrial Initiatives for demonstration at industrial scale and the European Energy Research Alliance, led by Member State public research organisations, for the necessary supporting R&D.

In the last decades nuclear energy has been, together with hydropower, the major low-carbon energy source. Although the share of nuclear has somewhat declined, it was still the largest energy source for electricity in the EU in 2013, with a share of 27% [2]. Most future low-carbon energy scenarios include a significant share of nuclear energy. **Figure 1** shows that the ambitious scenario 450 of the International Energy Agency, which limits global warming to 2°C, requires a very large nuclear share of electricity generation by 2035 [3]. Another trend is that electricity will be an increasingly important vector in future energy systems, as stated in the Energy Technology Perspectives 2014 (ETP 2014) [4].



25. Including CH_4, energy-related emissions reach 34.9 Gt CO_2-eq in 2020.

Note: Other includes geothermal, concentrated solar power and marine.

Figure 1 - a) world energy related CO2 emissions by scenario b) world electricity generation from low-carbon technologies in different scenarios from [3].

In addition to reducing CO_2 emissions and having minimal environmental impact, future energy systems need also to provide energy at affordable prices and ensure security of supply, while optimizing the use of resources. Nuclear energy has predictable and relatively low prices, as reported in comparative studies, e.g. in [5]; nuclear base-load is also a stabilizing factor in an energy mix with an increasing share of intermittent renewable sources, although a large share of the latter will require that nuclear is operated in a more flexible manner to balance this increased intermittency in a future low-carbon energy mix.

Reliable supply is secured as stable countries provide uranium for nuclear fuel, which can be stored for long periods. Nuclear-generated electricity in the next 2-3 decades will mainly be provided by life-extension of today's Generation II light-water reactors and new-build of evolutionary designs referred to as Generation III or III+, but two issues remain open today, namely the accident risk and the long-lived nuclear waste. In addition, sustainability of Gen II and III reactors is limited. These issues can be faced and sustainability increased by the deployment of safely designed Gen IV fast neutron reactors along with fuel recycling facilities, for both of which extensive R&D is needed. Such reactors create more fissionable material than used (conversion ratio greater than 1) and should reach high fuel burn ups for greater efficiency, while the recycling facilities should extract reusable components from the fuel for the preparation of fresh fuel. Coupled together, the long term radiotoxic impact of irradiated nuclear fuel can be abated, especially when minor actinides are recycled. It is expected that the GenIV systems can be commercially deployed from 2040. Prototypes and demonstrators are being developed now in Europe within the European Sustainable Industrial Initiative (ESNII), with sodium fast reactors (SFR) as the most mature technology, and lead (LFR) and gas cooled fast reactors (GFR) as alternatives [6,7].

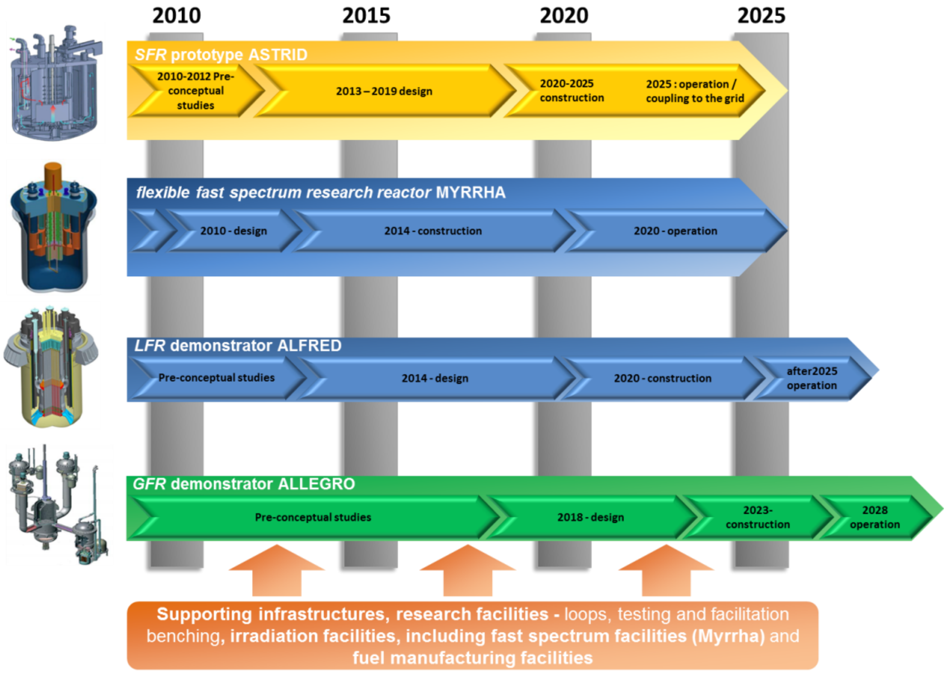


Figure 2 - The schedule for the design and construction of the four demonstrators and prototypes in ESNII.

Figure 2 shows the time line for the different stages towards construction of the SFR prototype ASTRID, the LFR (ALFRED) and GFR (ALLEGRO) prototypes, as well as MYRRHA, a flexible research facility for material testing and demonstration of accelerated driven systems (ADS) for waste minimization, which is strongly related with

LFR technology. The indicative cost in 2010 for the ESNII programme outlined in Figure 2, 10 810 M€ [6], is likely to be an underestimation. Given the technological challenges and the required financial and human resources, the implementation of the ESNII plan must be based on a concerted action between industrial partners and research organizations from different EU Member States. In this framework, concerted research actions on materials for GenIV reactors constitute an especially crucial need.

3. Materials for future nuclear reactor systems

Materials in nuclear reactor components include the structures of the reactor and the fuel assemblies formed by the fuel, cladding and neutron absorbent materials. All are exposed to very demanding conditions in combination with very high safety requirements. In particular it should be noted that:

- Structural and Fuel Materials for Gen IV reactors will generally be exposed to higher temperatures and higher levels of irradiation than in today's light-water reactors, as illustrated in **Figure 3**.
- These materials also need to be compatible with unconventional coolants, such as liquid metals or gas, for which experience is limited.
- Moreover, the design life should be at least 60 years, compared to the typical 40 years for today's reactors.
- Finally, the requirements to demonstrate safety in both normal and accidental conditions will be more stringent, while the overall costs for nuclear energy need to be competitive, i.e. similar to or lower than alternative low-carbon energy sources.

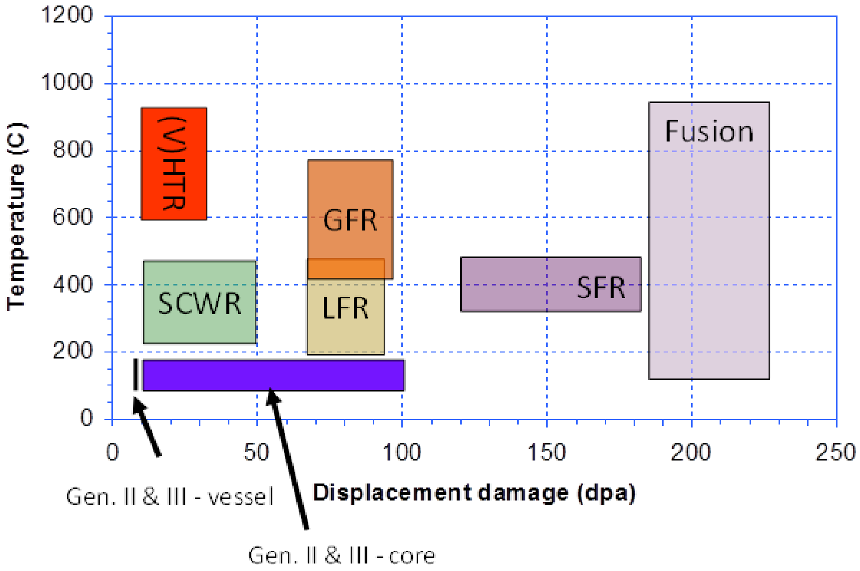


Figure 3 - Range of temperature and irradiation damage for different fission reactor concepts and fusion.

Consequently, materials research, qualification and development are crucial for the deployment of GenIV nuclear systems. Materials under extreme conditions, in which the nuclear sector traditionally has had a leading role, is also a cross-cutting area for different high-efficiency low-carbon energy technologies [8]. In this framework, the overall objective of the EERA JPNM is to provide the underpinning materials related research, in close collaboration with industrial partners, serving EU Member States and society, and in support of the development, design and construction of future safe and sustainable nuclear reactors. EERA JPNM is therefore an integrated part of ESNII [7].

The development of nuclear materials and components has always been driven by a close integration of research and feedback of experience from reactor designers and operators, as well as material and component manufacturers. The qualification of structural materials, components and fuel materials in nuclear reactors is a long process that typically has taken decades. To reduce time and costs, future reactors will use, initially and to a large extent, proven technology and available nuclear materials, but to further improve safety margins and reactor performance, innovative technologies and materials must be developed.

The EERA JPNM therefore follows three pillars, which combine modelling and experimental work, as illustrated in **Figure 4**:

1. Assessment of candidate structural and fuel materials and components in operational conditions with respect to: prediction of long-term behaviour: screening, selection and qualification, as well as development of design rules;
2. Development of advanced models to rationalise materials behaviour, support the elaboration of design rules and provide basis for the improvement of materials properties, by providing predictive capability;
3. Development of innovative structural and fuel materials for industrial use with superior capabilities in terms of resistance to irradiation, high-temperatures and aggressive environments.

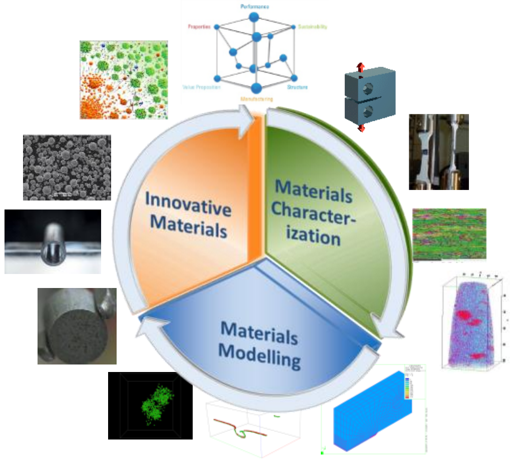


Figure 4 - The pillars of EERA JPNM

The work is organized in six sub-programmes (SPs) covering structural materials and fuel and addressing appropriate topics from basic research to industrial applications, as shown in **Figure 5**.

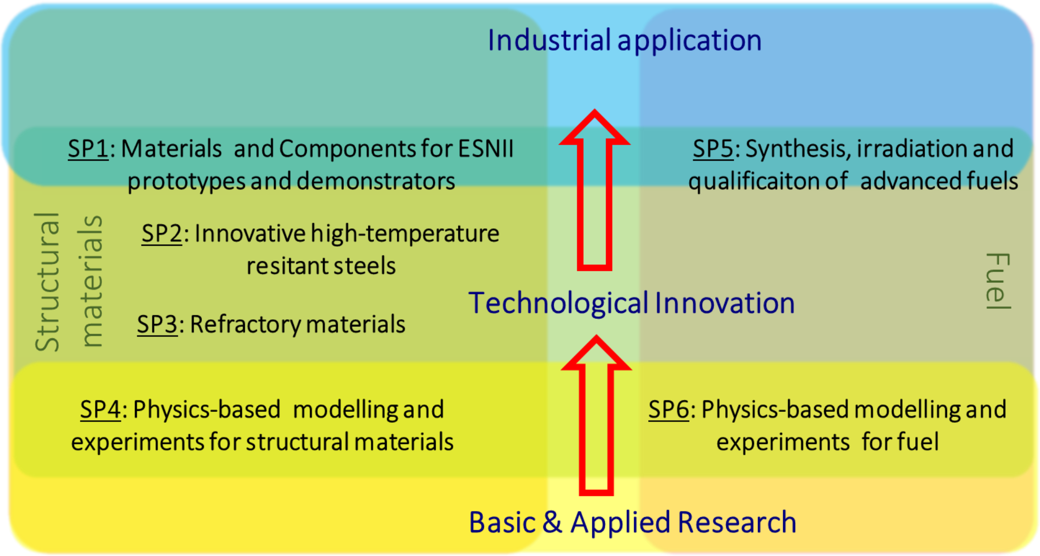


Figure 5 – Subprogramme structure of the EERA JPNM

4. Grand Challenges for structural and fuel materials for future nuclear reactors

The nuclear energy sector has always been required to deal with demanding material issues and has responded by finding new engineering solutions. These include nuclear-grade materials and standardized test procedures, design and construction codes and defect assessment codes. Furthermore, within nuclear research programmes, state-of-the-art models in fields such as elastic-plastic fracture mechanics and high-temperature degradation of materials, with and without irradiation, and, more recently, multi-scale models and physics based models have been developed.

The requirements on structural materials, fuel and components of the prototype and subsequently industrial scale GenIV nuclear systems present the nuclear community with a number of grand challenges. Some of these are common for all fast reactor concepts, whereas others are reactor-type specific. The problems to be addressed concern the degradation of properties of materials: this is a synergistic effect of radiation, high temperatures, mechanical stresses and aggressive environments, accumulated over a long exposure time. Moreover, under rare but abnormal conditions (e.g. accidents), the structural materials and the nuclear fuel will encounter even harsher conditions, which also need to be accounted for in an integrity analysis. These degradation modes may also interact, thereby further complicating their analysis. One problem that is more pronounced for nuclear than other sectors is the need to predict, with sufficient confidence, the long-term behaviour of materials and components under tough conditions, for which there is no or very little operational experience.

Structural material exposed to irradiation and high temperature become mechanically less performing (embrittlement, reduction of elongation, …) and change their dimensions (swelling, creep, …). Exposure to coolants produces general and localised corrosion and erosion and these effects are generally exacerbated by irradiation. The consequences of all these processes must be harnessed and mitigated via materials science knowledge and appropriate design.

With respect to novel fuels, important features to be addressed are increased burn-up, tolerance to possible accident scenarios (margin to melt), good compatibility with the coolant swelling, and cladding, capability to include minor actinide, neutronic performance, etc. The fuel chemical form and consolidation mode (pellet vs particle) need to be assessed.

One important objective of the GenIV nuclear systems initiative is the “safety and reliability” of the advanced reactors, while also considering the overall cost. In order to accomplish this goal, the scientists and engineers have to address three grand challenges related to structural materials and nuclear fuels:

Grand Challenge 1: Elaboration of design rules, assessment and test procedures suitable for the expected operating conditions and the materials envisaged. This involves deployment of infrastructures for relevant ageing phenomena and for testing of materials, data and knowledge, which is currently limited.

Design codes are crucial for ensuring that nuclear reactor components are designed on well-established safety procedures and with proven safety margins. Design codes are also central to reducing the costs of nuclear reactors, for instance facilitating licensing; e.g. the French design codes RCC-MRx will be used for GenIV ESNII reactors.

However, some rules of these codes may be overly conservative for GenIV, while others may have a quite limited conservatism. There are therefore strong arguments for improvements to: (i) revise and modernize rules, material design data and procedures for existing structural and fuel materials under currently known conditions; and (ii) develop new design rules, material design curves and assessment procedures to cover both existing and new materials, but for longer design lifetime and harsher conditions.

This approach will be based on extensive qualification of the structural and fuel materials of interest in the correct environment (pre-normative research) in order to obtain the necessary data for the development of robust engineering models. The key for the fulfilment of this goal is the availability and accessibility of research facilities that are suitable to expose the materials to conditions resembling as close as possible the expected operational conditions, especially in terms of prolonged irradiation and presence of flowing fluids. This involves large investments for the deployment of suitable infrastructures and corresponding testing capabilities, as well as testing expertise under conditions for which often standards do not exist yet.

All these activities are also necessary in order to plan adequate safety integrity assessments for key components of the reactors. The research activities concerning the ESNII advanced reactor prototypes are included in subprogramme 1 of EERA JPNM (Figure 5).

Together with extensive testing and characterization for qualification, physics-based models may be used to guide the elaboration of design criteria or the extrapolation of materials' property data curves to regions where experimental data are scarce. This approach applies in particular to new (or existing but not in the design code) materials, for which understanding of relevant phenomena is necessary to define adequate and reliable design criteria. The next Grand Challenge is therefore:

Grand Challenge 2: Development of physical models coupled to advanced microstructural characterization to achieve high-level understanding predictive capability: an asset, given the scarcity of experimental data and the difficulty and cost of obtaining them.

Simultaneous complex processes cause changes to the microstructure of materials, when exposed to the extreme conditions envisaged in fast nuclear reactors. These take place over different length and time scales and manifest themselves at the macroscopic scale as a change in material properties. For instance, neutron irradiation induces damage at the atomic level, which affects the dynamics of dislocations in structural alloys; in turn, this controls ductility and toughness at the materials' macro-level. A fundamental grand challenge is therefore to understand, model, predict and verify the degradation of materials properties that are induced by microstructural evolution, when operational experience is limited or does not exist at all. The approach combines advanced microstructural characterization of materials that are subjected to specific and

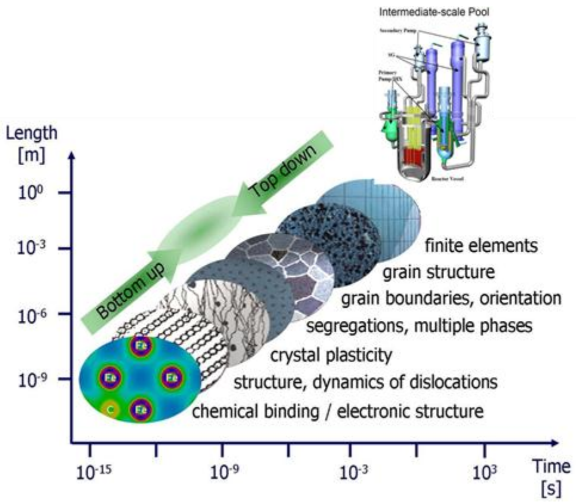


Figure 6 - Models and processes at different length scales

controlled conditions (i.e. 'separated effects') with physics-based models at the appropriate length and time scales: these include electronic structure calculations, molecular dynamics, kinetic Monte Carlo or cluster dynamics, dislocation dynamics and crystal plasticity. Dedicated experiments, targeting the identification of specific mechanisms and guided by models, must be used both for calibration and validation. For fuel materials there is a need for thermochemical models to understand the complex behaviour of the fission products in gaseous, volatile or solid form and their physical and chemical interaction with the fuels. The final step for prediction requires a multi-scale approach that bridges models at different scales, allowing appropriate extrapolation, as illustrated in **Figure 6**. Physics-based models that incorporate the relevant length scales are also necessary to correctly interpret data from miniature tests such as nano-indentation and to apply this understanding to structural components. Investigations along these lines have been initiated in EERA JPNM subprogrammes 4 and 6, for structural and fuel materials, respectively.

Grand Challenge 3: Development of new materials with superior thermo-mechanical properties and radiation-resistance or, in general, nuclear-relevance, in partnership with industry for a faster industrial upscaling.

Future advanced reactors will rely initially to a large extent on proven technology and commercially available structural and fuel materials, e.g. austenitic and ferritic-martensitic steels or nickel-based alloys, and MOX fuels, respectively. Their qualification and codification is already a challenge. However, to safely exploit the full potential of nuclear reactors by, for instance, achieving higher burn-ups or higher operating temperatures, or by using these reactors to burn minor actinides, new materials need to be developed. Promising structural materials, already used in other sectors, also need to be adapted for nuclear applications. Two classes of structural materials for fuel claddings are included in EERA JPNM: high-temperature resistant steels, mainly oxide-dispersion strengthened (ODS), but also improved by tuning composition and thermo-mechanical treatments, which are addressed in subprogramme 2, and silicon-carbide composites (SiC/SiC_f), which are considered in subprogramme 3. Exploratory work on MAX phases ceramic-metallic composites (cermets), which may have mechanical properties akin to metallic alloys, is also included in subprogramme 3. Besides these three classes, modified surface layers and coatings for the mitigation of structural material degradation are under evaluation in subprogramme 1 and have shown promising results. However, there is no overall or globally ideal material and there is always a trade-off between the material properties. Materials with tailored properties would be an ideal solution, which may come from functionally graded materials. The potential for future nuclear applications of the newly discovered high-entropy alloys that combine high ductility and toughness might for example also be considered.

To exploit the features of the fast reactor technology, the 'driver' fuels need to be designed through incremental innovations (geometry, enrichment, etc.) on mixed oxide fuel or more radical innovation based on carbides or nitrides. Advanced fuels to achieve minor actinide burning represent a high degree of innovation. These are investigated in the subprogrammes 5 and 6.

There is no established industrial production for the above mentioned structural materials that allows their manufacturing according to current nuclear specifications and therefore their widespread use; even less is there an established industrial production of nuclear components made with these materials. In general, to obtain materials with the desired properties, which are suitable for industrial up-scaling, there is a need for an advanced "Design and Control" approach. This implies pro-active interaction of the nuclear materials community, with material producers and the development of advanced models that can reach the required level of industrial usability and coupling with industrial procedures. For ceramics and composites there is an existing and large industrial market in the aerospace domain which can be exploited in this context.

In order to allow the introduction of new materials onto the engineering scene, to either reduce the cost or dramatically increase the performance of components, new and emerging technologies such as 3D-printing or hot isostatic pressing (HIP) and modification of component design, for instance to achieve minimal amounts of joining, should be considered. In general, the speed of up-scaling from laboratory to industrial production needs to be faster for all nuclear materials, both structural and fuel. This is primarily a task for industry, but a close collaboration between industrial partners and the research community is of mutual benefit where research could provide supporting models and design, and also perform and evaluate tests.

5. Towards an integrated European Nuclear Materials Programme

The development, design and construction of sustainable nuclear energy reactors, according to the GenIV paradigm, is a very challenging endeavour that requires large financial and human resources. However, it is a necessary undertaking due to the importance of sustainable nuclear energy in guaranteeing a constant, reliable, abundant and cost-effective production of low-carbon energy. Given the grand challenges described above, this also applies to materials and components. However materials research is also to a large extent a cross-cutting issue not only for the different reactor system concepts and generations of nuclear reactors themselves, but also other high-efficiency low-carbon energy technologies. This is the reason why the EERA JPNM was formed: to integrate the materials research that is conducted by the national research organizations, for nuclear energy but not only, into a truly European programme, to form a vital asset to be exploited. This implies making efficient, coordinated, optimized and wise use of the resources, human and financial, that the different Member States have and can offer and share. However, it is currently unlikely that the funding that Member States can provide for nuclear materials research will increase and a careful analysis of the current situation in terms of financial approaches and realistic opportunities [9] has made it evident that the JPNM funding for GenIV research and coordination unavoidably requires Euratom support as well. It is essential to secure the current level of funding and make the best use possible of it by the combination of two schemes:

1. a co-fund action with consistent Euratom participation, such as a European Joint Programme on nuclear materials, as a way to at least earmark, and possibly leverage, funds for the EERA JPNM also from the Member States;
2. a pro-active role on the EERA JPNM side in coordinating research activities and promoting the efficient use of human resources and facilities throughout Europe, by limiting duplication and enhancing integration, while remaining in constant dialogue with Member States and European Commission.

Since its official start in November 2010, the EERA JPNM has been very successful in terms of the alignment of national activities into a consistent joint programme; for the reasons above, further integration still remains one of the main items on its agenda.

As sketched in the EERA position paper [10], integration is a stepwise process (see **Figure 7**):

Figure 7 – Steps towards full research integration at European level

The first integration step has been taken. Several intermediate steps are being taken now, with the support of the Seventh Framework Programme's MatISSE integrated research project, namely the elaboration of common roadmaps for structural and fuel materials, the mapping of experimental facilities, the identification of common projects via monitoring of activities, the updating of sub-programme Descriptions of Work and the elaboration of joint pilot projects, to be internally as well as externally and transparently reviewed by a scientific advisory pool. The establishment of common work plans pivots around intense involvement of the researchers in the identification of the content of the work, by taking into account their actual capabilities and expertise and by identifying gaps and setting objectives together, within the framework given by the Grand Challenges to be faced. It is crucial that researchers know each other and each other's capabilities, developing mutual trust in order to learn to work together. The next steps will be in the direction of establishing criteria for priorities, via closer links with the industrial counterparts, by the creation of stake-holder groups that are to be used as consultants, while exploring and setting up training and mobility schemes as a first step to effective sharing of facilities and infrastructures. In terms of stake-holders, these obviously include designers and nuclear component manufacturers involved in ESNII, as well as other nuclear platforms, such as SNETP and NUGENIA. They also include other energy materials initiatives, ranging from other EERA JPs where materials under extreme conditions are an issue, to industrial energy materials platforms such as EMIRI; materials manufacturers need also to be included, either through platforms (e.g. ESTEP for steel manufacturers) or by the direct involvement of specific industries.

The ambition is to reach the final steps of integration by 2020. Steps 4 and 5 (Figure 7) are in fact closely linked and can be pursued in parallel. The "Thematic virtual research centre" refers here to a system where researchers working on similar subjects at different locations establish a very close collaboration in a specific area in terms of their coordination of work and sharing of data and computational resources, while utilising a delocalised set of accessible and integrated facilities. Necessarily, this occurs via promoting interaction between researchers to learn how to work together effectively, as outlined above. Moreover, an integrated approach to the collaborative use of facilities, with the support of the management of the different research organizations, is a very important step. Ultimately the goal would indeed be that experimental facilities should be shared in an optimal way, according to a scheme that ensures fair costs and distribution of intellectual property rights, protecting acquired know-how. Sharing of data respecting intellectual property rights and according to commonly accepted fair rules is another crucial and very difficult step towards integration. To start with, data generated in common projects can be shared through a common web-based database, but for a true integration, mechanisms need to be found to share data generated outside common projects, while ensuring that the data owner retains the full control of who can access these data. **These steps towards full integration are, however, totally impossible without a strong commitment from the management of the research organizations, and therefore Member States that actually own and fund the organizations, as well as from the European Commission**. There must be expressed willingness at Member State level to proceed along this integration, overcoming all potential legal and administrative difficulties. Crucially, there must also be a commitment to support the process financially and, even more importantly, the research that the virtual centre would perform. The latter requires, as anticipated, that the European Commission offers a suitable instrument that should not only promote coordination and integration involving actively the Member States, but also provide adequate funding for the research work.

6. Risks

The path towards integration sketched in the previous section constitute the goal of the EERA JPNM and is currently the only sensible means to address the Grand Challenges described above, that constitute the scientific objective of the JPNM. However, even with all the integration effort and after securing available funding, there remains risks that the Grand Challenges might not be appropriately addressed. First and foremost, there is a problem in connection with the costly facilities for the exposure of materials to conditions of relevance for the reactors that are crucial for their qualification of the materials. These facilities are scarce or do not exist, yet. Despite efforts to develop models and new paradigms that make laboratory data relevant for real conditions, their scarcity or the need for additional funding for their construction or upgrade may be a serious hindrance to addressing especially the first of the Grand Challenges. The political will to invest in nuclear energy and pursue the certainly costly, but equally certainly rewarding in the long-term, goal of Gen IV nuclear systems, is another unknown. It is clear that, if within the next 10-15 years no prototype reactors such as Myrrha or Astrid is commissioned, it is unlikely that the goal of GenIV nuclear systems will be reached on time with respect to current goals for counteracting climate change and ensuring more sustainable energy production.

Appendix: milestones and high-level deliverables

Milestones towards integration	Integration level	Tentative date
Roadmaps for structural materials and fuel	2	2015
EERA JPNM Description of Work for 2016 – 2020	2	2015
Establishment of Scientific Advisory Group and End-Users group	2	2015
Review of EERA JPNM 2011-2015	2	2016
EURATOM projects or co-fund actions based on EERA JPNM DoW 2016-2020	3	2016-2017
Deployment Plan EERA JPNM	3	2017
Collaboration Agreement with other materials networks	2	2017
Establishment of Virtual Centers	3	2018
Collaboration Agreement for sharing of facilities	3	2018
Management of Common projects with funding from Member States and EC.	4	2020

High level Deliverables
Qualification of structural and fuel materials suitable for the construction of efficient and safe Gen IV reactor systems, with focus on the ESNII demonstrators and prototypes, in particular Myrrha and Astrid.
Pre-normative research recommendations for component design rule modifications in support to ESNII's demonstrators and prototypes.
Standardized test procedures to codify and disseminate results of R&D&I activities on advanced materials.
Path towards industrial production scaling of innovative materials for continuously increased safety and efficiency of Gen IV reactor systems
Robust understanding of main physical mechanisms determining the response of materials to Gen IV reactor operating conditions and relevant models.

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