# Shaping MSR Standardization for

# Europe's Energy Future through science

Advancing Nuclear Innovation: The Joint Research Centre's Contribution to Facilitate the Deployment of Sustainable Solutions

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**Abstract**

The Joint Research Centre (JRC), as the European Commission's science and knowledge service, plays a pivotal role in integrating scientific research with practical regulation through the Putting Science Into Standards (PSIS) initiative. In partnership with CEN-CENELEC, the JRC leverages its pre-normative research capabilities to forecast and address the standardization needs of emerging technologies. The 2024 PSIS workshop, focused on Molten Salt Reactor (MSR) technologies, exemplifies this foresight approach, uniting stakeholders across research, industry, policy-making, and standardization to align on the path forward for MSR standardization. The paper, arising from the PSIS workshop, details the collaborative effort to identify and prioritize standardization areas crucial for the safe, secure, and efficient deployment of MSRs, a technology increasingly recognized for its potential in contributing to the EU's energy transition and climate goals. It underscores the urgency for harmonized safety assessments, validated data on thermo-physical properties, fuel qualification processes, and material and component standards, all of which are instrumental in enabling MSR innovation. The workshop's outcomes signal a commitment to developing a comprehensive standardization roadmap, aiming to catalyze MSR deployment in alignment with the Net Zero Industry Act and to reinforce Europe's leadership in clean and sustainable energy technologies. It must be noted that this paper reflects the conclusions of the workshop and does not intend to present or convey the official position of the European Commission or the JRC.

## INTRODUCTION

In an era where technology permeates every facet of our lives, the silent orchestrators behind the seamless integration and safety of these innovations are the standards that underpin them. Standards ensure our daily interactions with technology are reliable, efficient, and harmonious. They provide the guidelines that inform the design, usage, and interoperability of products and systems, shaping our technological experience while ensuring our safety and the protection of the environment. From the construction codes that ensure the stability of the buildings we inhabit to the cybersecurity measures that guard our digital data, standards are foundational to technological trust and advancement.

Amidst the landscape of standardization, the Joint Research Centre (JRC) of the European Commission is tasked with the mission of providing independent scientific advice and support to EU policy. The JRC bridges the gap between cutting-edge scientific research and practical implementation in policy and standards. By engaging in fundamental and pre-normative research—ranging from defining new terms to establishing laboratory procedures—the JRC translates complex scientific findings into tangible, actionable regulations that uphold safety, security, and innovation across Europe and beyond.

The JRC's involvement in standardization extends beyond passive observation; its researchers actively participate in committees and working groups of European and international standards organizations. Here, in collaboration with industry experts, policymakers, and standard setters, JRC scientists contribute to the development of state-of-the-art standards that reflect the latest scientific understanding and technological capabilities. The JRC's dual role as a research entity and a participant in the standardization process uniquely positions it to influence the direction of standards development, ensuring they are grounded in robust scientific evidence and address real-world challenges.

Recognizing the dynamic nature of technology and the need to stay ahead of the curve, the JRC, in partnership with CEN-CENELEC, initiated the Putting Science Into Standards (PSIS) workshops. These workshops serve as a foresight tool, selecting fields of technology ripe for the support of standards. PSIS is more than a mere gathering; it is a strategic convergence of the research, industrial, policy-making, and standardization communities. The initiative aims to review current research and standardization initiatives, pinpoint gaps, and chart a course to meet future standardization requirements. Through these collaborative efforts, PSIS has addressed topics as diverse as hydrogen technologies, data quality for artificial intelligence, organ-on-chip systems, and quantum technologies, each time aligning the standards landscape with the horizon of scientific and technological progress.

The focus of the 2024 PSIS workshop on Molten Salt Reactors (MSRs) is a testament to the initiative's commitment to advancing sustainable energy solutions. MSRs hold the promise of safe, efficient, clean and flexible energy production, qualities essential for meeting the EU's ambitious energy and climate goals. The workshop's objectives—to identify standardization needs for MSR technology and to foster international collaboration—demonstrate the proactive approach the JRC and PSIS take in shaping the future of energy.

The transformative potential of MSRs aligns with the EU's strategic vision of a carbon-neutral economy, positioning this technology as a cornerstone of future power generation. The JRC's foresight in steering the discourse towards MSR standardization underscores its catalytic role in driving innovation that echoes the EU's broader energy and environmental aspirations. By harmonizing the scientific insights with practical regulatory frameworks, the JRC contributes to crafting an energy landscape that is not only technologically advanced but also sustainable and resilient. It is this synergy between scientific inquiry and pragmatic regulation that the JRC fosters—a synergy that will light the path towards a greener, more sustainable Europe, powered by the ingenuity of its scientists and the rigor of its standards.

As we stand on the cusp of a new energy paradigm, the PSIS workshop's deliberations on MSRs promise to lay the groundwork for a joint approach to nuclear safety, efficiency, and innovation.

## The Role of the JRC in MSR Development

The Joint Research Centre (JRC) of the European Commission participates in the enhancement of safety, safeguards and security of MSR technology, marrying rigorous scientific research with impactful policy support. Being the Euratom implementing agent in the Generation IV International Forum, the JRC stands as a pivotal entity, contributing to the research projects, representing Euratom in the forum and ensuring that the EU's low carbon energy policy goals are part of the discussion.

Central to JRC's scientific endeavours is its work in establishing a thorough thermodynamic database providing critical insights into the behavior of complex molten salt mixtures under various conditions, a resource indispensable for accurate safety assessments.

The JRC's Task Force on Molten Salt Reactors (MSRTF) further underscores the organization's dedication to enabling the advancement of the MSR safety. The MSRTF's mission to align MSR safety approaches across the EU serves as a testament to the JRC's dedication to optimizing the use of resources, sharing expertise, and upholding the highest safety standards. Acting as an EU nexus for MSR safety, the MSRTF ensures that R&D efforts within the MSR domain are synergistic and adhere to a stringent, unified safety protocol.

The JRC's pre-normative research initiatives provide a crucial foundation for MSR technology standardization. From defining pivotal new terms to devising robust laboratory procedures, these initiatives foster a collaborative spirit throughout the MSR community, ensuring a smooth transition from theoretical research to practical application.

The JRC's role extends beyond foundational research into the realm of policy enactment and industry guidance. By participating in European and international standardization bodies, the JRC actively contributes to the creation of standards that directly impact MSR technology's safety and operability. This proactive stance ensures that the evolving needs of the MSR sector are anticipated and addressed.

Moreover, the JRC's extensive network and partnerships facilitate a collaborative environment where knowledge is shared across borders. This European-wide collaborative approach not only accelerates MSR development but also ensures that the broader implications for energy security, climate change, and economic growth are considered.

## The PSIS Initiative and Its Impact on MSR Standardization

The Putting Science Into Standards (PSIS) initiative, spearheaded by the Joint Research Centre (JRC), is a strategic program designed to proactively engage with the emergent needs of technological standardization. In partnership with the European standardization organization CEN-CENELEC, the PSIS initiative systematically identifies technological fields where standardization could play a transformative role and orchestrates a convergence of interdisciplinary stakeholders to collaboratively address these needs.

One of the workshop's core objectives was to streamline the standardization process for MSRs by immersing stakeholders in a collaborative environment. This approach not only facilitated the identification of current gaps in MSR research and development but also bolstered the collective pursuit of standardization activities directly related to MSRs. By galvanizing researchers, innovators, and industrial partners into a cohesive unit, the PSIS workshop fostered an ecosystem ripe for innovation and practical application.

The MSR-focused workshop employed a rigorous methodology to ascertain the precise areas requiring standardization. By soliciting comprehensive input from across the research and industrial spectrum, the PSIS workshop undertook a meticulous gap analysis, ensuring that the future trajectory of MSR standardization is fully informed by actual industry needs and priorities. This meticulous approach was crucial in delineating future directives in critical areas like thermo-physical property measurements, development of new codes, and the creation of materials suitable for MSR applications.

The impact of the PSIS initiative extends far beyond the confines of a traditional workshop. As a catalyst for change, PSIS represents a paradigm shift in how technological standardization is approached, embracing a more inclusive and anticipatory strategy. This initiative is not only about setting today's standards but also about sculpting the regulatory landscape of tomorrow, ensuring that it is conducive to innovation while maintaining the highest echelons of safety, security, and efficiency.

In essence, the PSIS workshops are a microcosm of collaborative foresight, a place where the collective intelligence of diverse experts is harnessed to pave the way for technological advancements like MSRs. The initiative underscores the JRC's commitment to fostering a proactive, inclusive, and evidence-based standardization process that is responsive to the rapid pace of technological innovation. As MSRs edge closer to becoming a mainstay in Europe's energy portfolio, the PSIS initiative's role in their standardization will be recognized as a cornerstone in their successful deployment, ensuring that they are not only technically viable and economically competitive but also aligned with the EU's long-term sustainability goals.

## Key Discussions and Findings from the 2024 PSIS Workshop

The 2024 PSIS workshop served as a pivotal forum for addressing the multifaceted challenges and opportunities in the standardization of Molten Salt Reactors (MSRs). One of the focal points of the discussions was the safety assessment of MSRs, reflecting a shared recognition of the gravity of harmonizing safety evaluation methodologies. A core outcome was the consensus on the imperative for a unified safety framework tailored to MSR demonstration reactors, which are crucial in amassing data required for the substantiation of safety assessment models.

The workshop participants delved into the intricacies of measuring thermo-physical properties of MSR fuel and coolant systems, acknowledging the crucial role that precise measurements play in licensing processes and MSR design optimization. A concerted agreement emerged on the necessity to standardize measurement methodologies, with an emphasis on bridging data gaps through concerted collaborative efforts and data sharing initiatives.

Fuel and fuel cycle qualification discussions underscored the urgency for standards that articulate the purity specifications of fresh MSR fuel. This includes monitoring fuel composition and its interactions within the reactor environment, recognizing the importance of standardizing the entire MSR fuel cycle lexicon to avoid ambiguities and ensure clarity across the industry.

Material and component considerations also took centre stage, with a clear consensus on the absence of code-qualified materials for MSRs. Establishing test protocols for molten salt environments, particularly with controlled impurity content, was identified as a critical prerequisite for material development. Such standards would pave the way for innovative materials to meet the demanding conditions of MSR operation.

The workshop's discourse illuminated the path for collaborative development of standards and design codes that can underpin MSR technology, emphasizing the power of data sharing, benchmarking, and collective utilization of experimental facilities. Participants concurred that a harmonized licensing framework, both at European and international levels, could catalyse MSR deployment by streamlining licensing procedures, reducing costs, and fostering an efficient and competitive market.

The deliberations at the workshop are set to lay the foundation for the establishment of dedicated working groups within CEN TC430 / ISO TC85 and other pertinent platforms. These groups are tasked with the development of the inaugural set of standards and codes specifically tailored to Molten Salt Reactors. This collaborative venture is anticipated to mark a significant stride toward the standardization required to drive the MSR technology from the conceptual to the commercialization phase, thereby reinforcing its role in Europe's sustainable energy future.

## Toward a Harmonized Framework

The pursuit of a harmonized regulatory framework for Molten Salt Reactors (MSRs) within the European Union promises to yield numerous advantages. Central among these is the potential to significantly streamline the licensing process across member states, thereby catalysing investment and fostering a climate of innovation. By adopting a common set of standards, the EU can ensure that safety and environmental protocols are uniformly implemented, bolstering public trust in nuclear energy as a viable, secure alternative to conventional fossil fuels in those Member States that so decide.

A harmonised approach would also serve to alleviate the difficulties of regulatory fragmentation, that pose barriers to entry for emerging entities in the nuclear industry, and complicate wide deployment of this technology in the continent. The establishment of an EU-wide licensing paradigm is poised to eliminate such inconsistencies, providing a clear, unified pathway for MSR deployment. This streamlined regulatory environment would not only accelerate the adoption of MSRs but also guarantee that these advanced reactors meet rigorous safety and sustainability criteria.

The implications of a harmonized framework extend beyond the simplification of bureaucratic procedures. It embodies a commitment to fostering a robust, interconnected European market that is receptive to collaborative efforts in nuclear technology development. Uniform standards across the EU would ensure that MSRs and related innovations are seamlessly integrated into the energy infrastructure of all member states, promoting economic cohesion and strengthening the internal market.

Moreover, the EU's concerted efforts in standardization are likely to set a precedent on the global stage, influencing international regulatory practices and promoting Europe as a beacon of nuclear safety and responsibility. The EU's leadership in this domain is crucial not only for advancing clean energy objectives but also for setting the tone for global nuclear governance. As such, the harmonization of regulatory frameworks for MSRs is not merely a regional endeavour but a critical step towards shaping the international discourse on nuclear energy deployment.

In summary, moving toward a harmonized regulatory framework for MSRs within the EU presents a strategic opportunity to enhance economic integration, stimulate market competition, and elevate Europe's role as a standard-bearer in nuclear technology. It is an endeavour that requires the collective will and concerted action of policymakers, industry stakeholders, and regulatory bodies, united by the vision of a sustainable, energy-secure future. As the EU navigates the complexities of MSR standardization and harmonization, it stands to reinforce its commitment to innovation, safety, and environmental stewardship, setting the stage for a new era of nuclear energy within Europe and beyond.

## Developing a Roadmap for MSR Standardization

The development of a roadmap for MSR standardization is a strategic response to the complexities inherent in pioneering advanced nuclear technologies. Post-workshop initiatives are intensely focused on crystallizing priorities that will define the trajectory of MSR technology. These priorities encompass formulating robust testing protocols for materials exposed to molten salts, establishing stringent standards for fuel purity, and crafting comprehensive safety guidelines tailored for demonstration reactors. Such initiatives are indispensable in bridging the current knowledge gaps and setting a definitive course for the evolution of MSR research and development.

In the long-term vista, the roadmap envisages a dynamic standardization landscape, where standards are not static entities but living documents that are periodically revisited and revised. This adaptive approach ensures that the standards evolve in tandem with technological advancements and operational learnings from MSR deployments. The iterative review process will be designed to scrutinize the wealth of empirical data emerging from MSR operations, maintaining the standards' relevance and efficacy in the face of evolving challenges and opportunities.

Data stewardship, guided by the FAIR principles, underpins the roadmap's methodology. This commitment to data management enhances the discoverability, accessibility, interoperability, and reusability of MSR-related data, effectively democratizing the knowledge and facilitating cross-border, cross-sectoral collaboration within the EU. By championing the FAIR principles, the roadmap not only upholds transparency and accountability but also incubates a culture of collective intelligence, where innovation is a product of shared insights and endeavors.

The envisioned data repositories will serve as the nexus for a constellation of information, ranging from the minutiae of material properties and safety evaluation protocols to the granular details of MSR operational performance. The roadmap’s advocacy for FAIR-compliant data repositories is a testament to the EU's vision of an integrated and open research ecosystem, where data becomes the catalyst for breakthroughs and the scaffold for robust, reliable technologies.

Drafting MSR standards and codes is envisaged as a broad-based, inclusive process that harnesses the diverse expertise of stakeholders from across the spectrum of the nuclear industry. The roadmap underscores the necessity for an iterative, participatory process that actively solicits contributions from industry veterans, academic researchers, policy architects, and standardization authorities. This collaborative drafting process is not only about achieving scientific rigor but also about ensuring the pragmatic application of standards within the operational realities of MSR technologies.

To facilitate this collaborative ethos, the roadmap places significant emphasis on workshops and focus groups as pivotal forums for dialogue and consensus-building. These platforms will be leveraged to surface key standardization needs, draw on a diversity of expertise, and craft standards that are harmonious with the EU's regulatory fabric and industrial capabilities. Such interactive sessions will be integral to the roadmap's success, fostering a spirit of partnership and co-creation that is essential for the standardization of a technology as transformative as MSRs.

## Conclusion

The Putting Science Into Standards (PSIS) workshop, orchestrated by the Joint Research Centre (JRC), has served as a crucial congregation for experts dedicated to the standardization of Molten Salt Reactors (MSRs). Amid heightened interest from EU industrial entities, the JRC has adeptly demonstrated its capacity to synchronize the latest scientific research with pragmatic regulatory frameworks, thus contributing significantly to the development of standards across a spectrum of disciplines including physical sciences, health, ICT, life sciences, and nuclear safety and security.

The workshop has successfully pinpointed the urgent need for standardization across various facets of MSR technology, such as safety evaluation protocols, the precision of thermo-physical property measurements, the meticulous qualification of fuels and fuel cycles, and the establishment of codes and standards pertinent to materials and components. Participants collectively recognized the diversity of MSR designs under development, highlighting the necessity for a uniform safety methodology tailored to First-Of-A-Kind (FOAK) demonstration reactors. The consensus underlined the importance of collaborative endeavours to gather and share data on thermo-physical properties, which are foundational for fuel and coolant systems in MSR deployment.

A significant call to action from the workshop was the standardization of terminology within the MSR fuel cycle, alongside the development of standards for pyro-metallurgical processes should they be considered for the backend of the fuel cycle. The absence of code-qualified materials for MSRs within the current design codes was noted, emphasizing the need for the creation of molten salt test procedures, particularly those with controlled impurity content.

The workshop concluded with a strong endorsement of a harmonized licensing framework for MSRs, recognizing the potential it holds to streamline deployment across the EU and beyond. Such a framework would promise swifter licensing, cost reduction, supply chain efficiency, and market competitiveness. Yet, the acknowledgment that harmonized regulation is a prerequisite for this approach reflects the understanding of the complexities involved.

The proposal for a standardization roadmap and the formulation of a code-of-practice as part of the Annual Union Work Programme for standardization symbolizes a tangible leap towards EU-wide MSR deployment. This endeavour underscores the alignment with the EU Green Deal and the Net Zero Industrial Act, encapsulating the JRC’s commitment to a sustainable energy future.

As Europe contemplates the deployment of MSRs, the implications for the EU's energy landscape are profound. MSRs offer the prospect of diversifying energy sources, fortifying energy security, and making significant strides towards climate change mitigation. However, the inherent challenges presented by the corrosive nature of molten salts, the high operational temperatures, and the complex salt chemistry necessitate an innovative, research-driven approach bolstered by stringent standardization.

To initiate this transformative journey, a feasible first step at the European level could involve the implementation of a strategic standardization agenda. This would entail leveraging the Annual Union Work Programme for standardization to focus on pivotal areas requiring immediate attention. The 2024 PSIS workshop has marked the commencement of this strategic initiative, laying the foundation for the establishment of dedicated working groups within entities such as CEN TC430 and ISO TC85. These groups are tasked with the critical mission of developing the inaugural suite of standards and codes that will underpin the successful deployment of Molten Salt Reactors, thus propelling the EU into a new era of clean, reliable, and efficient energy.

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This paper and the promising directions it outlines for MSR deployment in Europe are a testament to the power of collaboration. Together, we have taken significant strides towards realizing a clean and sustainable energy future, and we eagerly anticipate the ongoing contributions of the JRC in contributing to these endeavors.

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