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NEWSLETTER

MIMOSA

MULTI-RECYCLING STRATEGIES OF LWR SNF FOCUSING ON MOLTEN SALT TECHNOLOGY

Orano reprocessing plant in La Hague (France)

A FEW WORDS FROM THE COORDINATION

Isabelle Morlaes - Sr. VP, MSR initiatives, Orano

It has been a great pleasure for me to coordinate the MIMOSA project on behalf of Orano for the past year. Through a multi-expertise consortium that develops chloride molten salt reactor key technologies as well as a multi-recycling strategy based on these reactors, we hope to contribute to the closure of the nuclear fuel cycle, and consequently, to even more sustainable waste management in Europe. Let me tell you a little bit more about the project rationale and approach.

I am convinced, like many in the industry, that fast chloride MSRs, although not mature today, are one of the most promising advanced fast reactor systems to convert plutonium isotopes and minor actinides into fission products with shorter half-lives.

(cont. on page 2)

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A few words from the coordination (cont.)

While the EU has the highest share of spent nuclear fuel reprocessing worldwide, most spent nuclear fuel is still declared waste.

The MIMOSA project, supported by the Euratom Research and Training Programme, has been the response of our 12-partner consortium to develop an accessible, cost/risk optimized and sustainable multi-recycling strategy of light-water reactor spent nuclear fuel, based primarily on multi-recycling of plutonium and reprocessed uranium in light-water reactors, combined with the chloride MSRs. The ambition is to provide a real option towards a closed nuclear fuel cycle in the EU while securing energy supply.

After more than a year of work, let me summarize how far we have come in the different areas of work:

- Spent nuclear fuel inventories, energy needs projections, nuclear fleet assumptions and potential evolutions have been assessed for all EU countries. A first simulation round of scenarios including MSRs is ongoing.
- Salt mixtures in $NaCl\text{-}MgCl_2\text{-}PuCl_3$ and $NaCl\text{-}ThCl_4\text{-}PuCl_3$ have been selected based on thermochemical properties and neutronics, and synthesis of selected salts is underway. At the same time, most of the salt properties measurement equipment has been set up and tested, and some measurements have started.
- The first assumptions on molten salt compositions of different MSR configurations have been assessed, as well as approaches to neutronic depletion simulations.
- In parallel, a special container has been prepared for the salt irradiation experiment to be performed in the LR-0 reactor in the Czech Republic.
- The test matrix for structural materials corrosion test has been completed, as well as the literature review on ceramics and corrosion mitigation methods. The ceramic testing methods and the corrosion set ups and loops are under development. In parallel, the molten salt neutron irradiation test is at the design and preparation phase.
- The study of used salt treatment in synergy with La Hague plant has been initiated with data collection and scenario preliminary assessment. The identification of the pyrochemical salt treatment alternative has also started, with literature review and preliminary thermodynamic calculations being carried out to define an experimental plan.
- A thermodynamic database on the platinoids chloride phases is under development, and some experiments are performed to validate the metallic state of the platinoids and noble metals. A device to extract by flotation the solid fission products from the molten salt is under construction. A year from now, we hope to have identified valuable isotopes and quantified their production in MSR. The applications for these isotopes and the associated market will be described in a specific deliverable.

I am pleased to report that the MIMOSA project is off to a great start. To keep up with project, follow us on LinkedIn / Twitter or visit the project website.

Multi-recycling scenario analysis and roadmapping

By Luc Van Den Durpel, Founding Partner - Nuclear-21

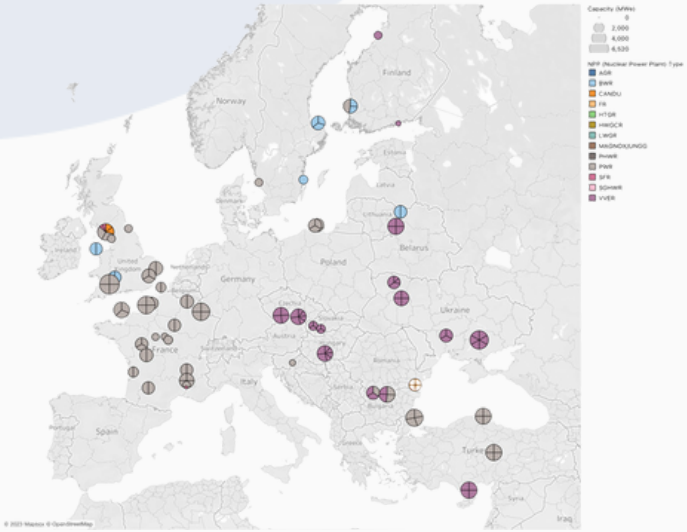
The role for MSRs in the EU-27's energy future is assessed within the Work Package 1 of MIMOSA's programme of work. The first year's activities involved the translation into scenarios of the EU-27's future energy demand covering both the electricity and process heat, particularly hydrogen production. Given the ongoing challenges regarding the EU's energy transition and the geo-political context, those energy demand scenarios are currently undergoing a new update reflecting the increasing role for nuclear energy and new momentum via the recent nuclear alliance formation. The nuclear energy demand scenarios and, subsequently, the nuclear energy park futures with various roles for MSRs are accordingly updated as well.

The scenario analysis within MIMOSA bases itself on a country-per-country analysis (see figure with projected NPP park in 2040 not yet including possible SMRs) ensuring that proper account is taken of past, present and projected spent nuclear fuel inventories as well as the uranium/plutonium and minor actinides inventories that would be amenable for use within MSRs. This is in view of as-accurately-as-possible simulation of which Pu and minor actinides compositions would enter such MSRs.

A first round of such scenario analysis will be reported by fall 2023 and will particularly seek to assess the most important parameters defining the MSRs performance in the EU.

Part of the developments required for such scenario analysis is a Reduced Order Model (ROM) representing the in-core burn-up evolutions for a variety of input compositions coming from such recycling scenarios. This ROM-model, developed by TU Delft, is currently being verified and integrated within the DANESS scenario analysis code by Nuclear-21.

A safety functional architecture has been documented within WP1 as input to the other work packages, providing a framework how the safety of such MSRs be assessed. The security and safeguarding of such MSR and their fuel cycle will be assessed from 2024 on, once the scenario analysis provided quantitative results from the scenario analysis.



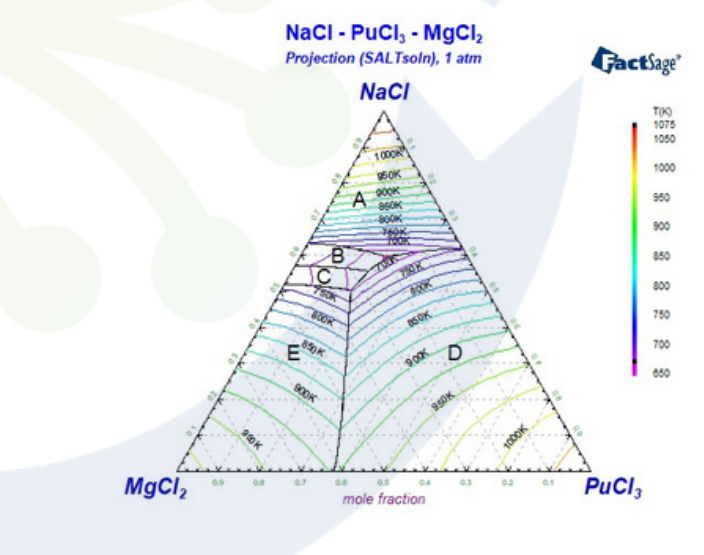
Molten salt properties

By Anna Smith, Associate Professor - TU Delft

The safe and optimal performance of a molten salt reactor design is directly related to the properties of the fuel salt mixture. WP2 aims to gain knowledge on some of the key properties for the reactor operation, namely melting temperature, heat capacity, vapour pressure, density, viscosity and thermal conductivity. Two fuel salt mixtures have been selected in the MIMOSA project in the NaCl-$MgCl_2$-$PuCl_3$ and NaCl-$ThCl_4$-$PuCl_3$ systems.

In the first year of the project, some specific compositions have been selected based on melting temperatures and neutronics. The synthesis procedure for $PuCl_3$ has been verified and reproducibility confirmed, leading to a product with high purity. The synthesis procedure for $ThCl_4$ has been developed in parallel and optimization and scaling-up of the process is ongoing.

Measurements of the thermochemical and thermophysical properties of salt mixtures will follow in the coming months. To this end, new experimental set-ups have also been developed, in particular for the measurement of density, viscosity and thermal conductivity. Density will be measured using Archimedes' method. The set-up has been optimized, tested and benchmarked on active salts already. The design optimization for viscosity and thermal conductivity is still on-going.



Molten salt composition evolution in reactor

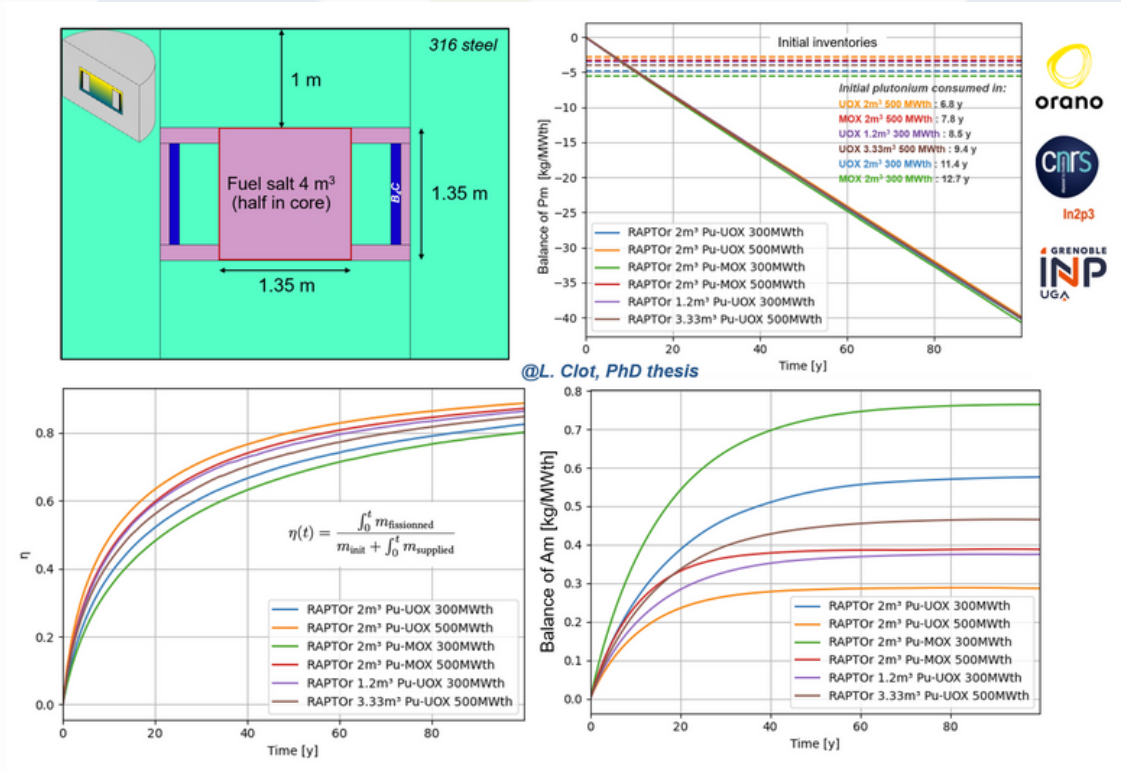
By Dirk Visser, Consultant in Fluid Dynamics - NRG

Within MIMOSA, experiments and advanced computer calculations will be developed and employed to simulate the evolution of the chloride molten salt composition in the reactor. These simulations will support fuel cycle calculations, safety evaluation and the analysis of valuable isotopes.

The MSR configurations and molten chloride salts for which depletion simulations will be performed to determine specific compositions of interest have been selected. The team has started the depletion calculations for some of the selected cases. In parallel, CV Rez has prepared a special container for the salt irradiation experiment to be performed in the LR-0 reactor in Czech Republic. Finally, a benchmark and parameter study is being prepared with the aim to assess delayed neutron effects in a simple loop system.

The figure below shows results of first depletion calculations performed with the CNRS REM code on some reactor configurations proposed by CNRS and ORANO. Interesting results can be identified on these images, such as the fact that converter configurations with a specific power of 250 MWth/m³ mobilise fissile material more quickly than 150 MWth/m³ versions, but also consume plutonium more quickly and produce less americium.

The next steps are to fine tune the processing scheme in collaboration with the partners working on molten salt recycling and back-end, and include these calculation results in the scenarios studies.



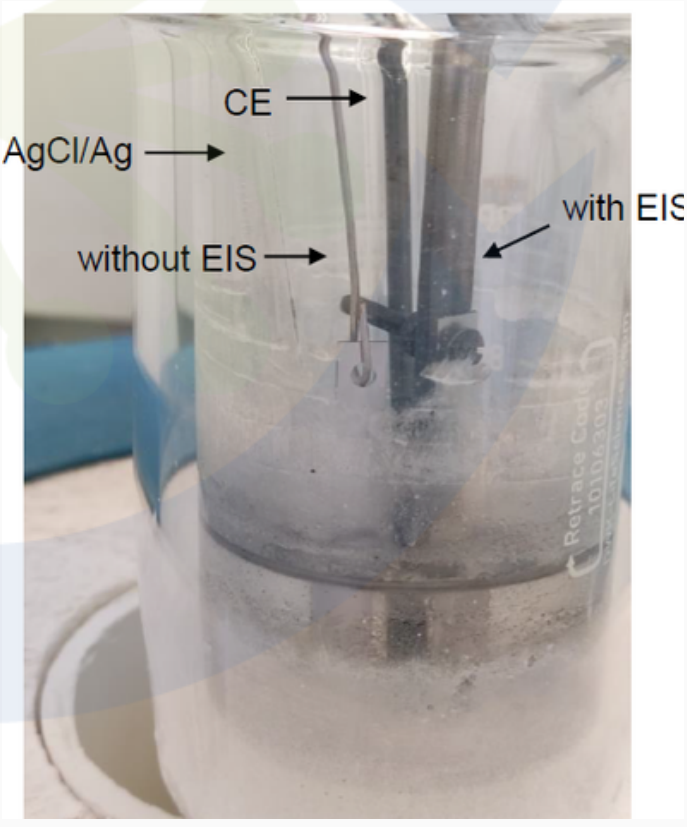
MSR key technologies

By Jaén Ocadiz, Chemical Lead - Thorizon

The recently completed test matrix for the studies on the corrosion of structural materials consists of three phases with increasing complexity of sample geometry and exposure duration. Both metallic and ceramic samples have been included. Additionally, crucible prototypes for the first phases have been manufactured and preliminary test runs have been carried out.

In parallel, corrosion control strategies have begun to be tested and monitored with electrochemical techniques.
Related to these developments is a survey of the literature on the interaction between fuel salt components with corrosion products, as well as calorimetric measurements to confirm and expand the findings in the literature when available, or else begin characterizing the phase diagrams for the first time.

Finally, the conceptual design of a capsule to irradiate actinide-bearing chloride salts in the High Flux Reactor in Petten, The Netherlands, is ongoing. The general scope of the irradiation test will be to assess fission product migration (fission gas release, fission product evaporation-condensation) and temperature gradient-driven corrosion. An additional goal is to collect irradiated salt for post-irradiation property measurements.



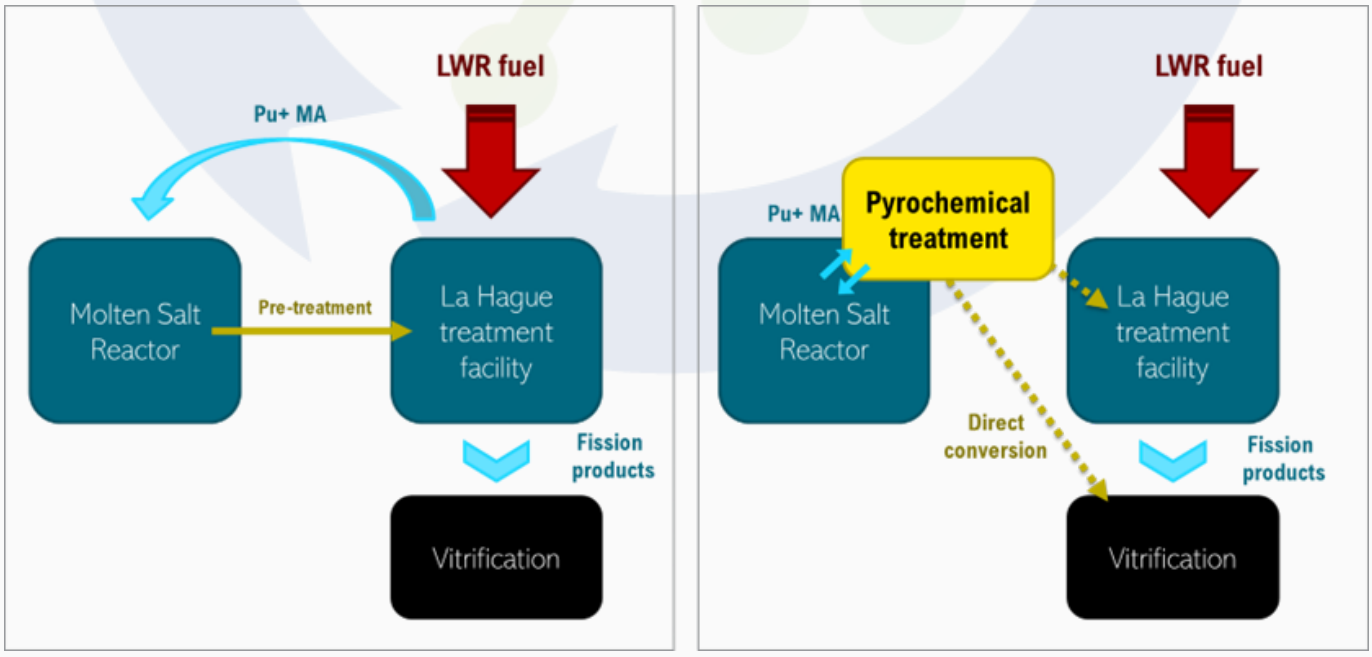
Experimental set up for the corrosion test

Molten salt recycling and back end

By Elisa Capelli, R&D Engineer - Orano

The cornerstone of any nuclear material recycling strategy is the reprocessing of Spent Nuclear Fuel (SNF) and the development of an efficient and selective separation of fission products and actinides in the fuel. The implementation of advanced nuclear systems, such as the chloride MSR studied within MIMOSA, requires the development of new technologies associated with the back-end of the fuel cycle and/or the adaptation of the existing technology. In this context, the main overall objective of Work Package 5 is to assess the back-end fuel strategies associated with the use of molten chloride salts fuel, relying on one hand on the existing technology at La Hague facility and assessing on the other hand alternative solutions for the fuel recycling which make use of pyrochemical separation as well as direct conversion of chloride salts into glass.

Within the first months of the project, the study of used salt treatment in synergy with La Hague has been initiated with data collection and scenario preliminary assessment. The key parameters for the interface with La Hague process were identified and will be studied for some defined reference SNF compositions (from WP3). The design of a dissolution experiment is on-going and aims to demonstrate the conversion of salt into a form typically treated at La Hague. This includes the development of a facility for purification of larger batch of salts. At the same time, the study of the pyrochemical salt treatment alternative has also started, with literature review and preliminary thermodynamic calculations done to define an experimental plan. The first experimental campaign to study the electrochemical behavior of salts in contact with Bi and Al metal has been recently started.



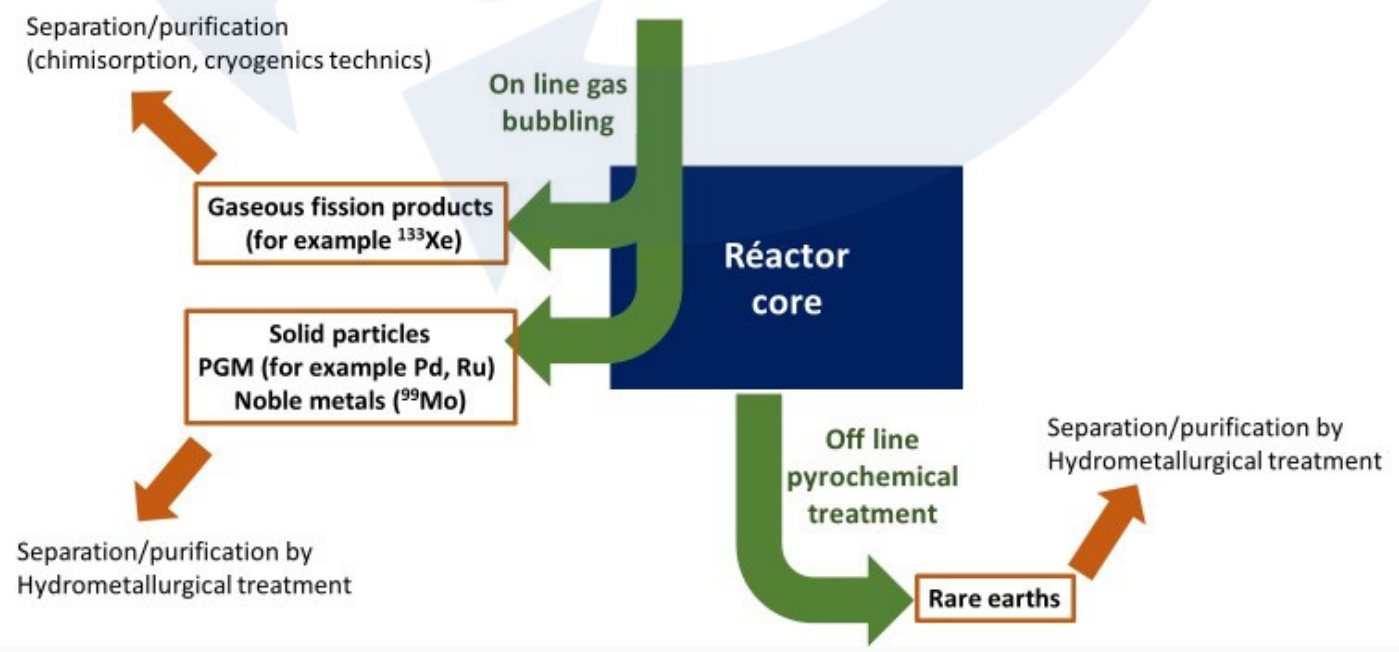
Main recycling scenarios considered for WP5. Some key technological solutions (depicted in yellow) are under study to assess and compare the fuel treatment options identified.

Production and recovery of valuable isotopes

By Sylvie Delpech, Research Director - Centre National de la Recherche Scientifique (CNRS)

In the molten salt reactor concept, the use of a liquid fuel leads to interact daily with the fuel through several processes such as introduction of fresh fuel or extraction of gaseous fission products and solid particles by on line gas bubbling. Contrary to other nuclear reactor concepts, it is possible to collect valuable isotopes immediately after their production and, mainly, before their decay. These isotopes are valuable for various applications depending (i) on their radioactive properties - that is the case of medical application which requires radioactive isotopes for therapy and nuclear imaging or (ii) depending on their natural properties - that is the case of the elements belonging to the Platinum Group Metal or to the rare earths group (or lanthanide group Ln) which are all in the heart of high-end and innovative technologies (notably fuel cells, air pollution devices - car catalyst, electronics, batteries).

Within the first months of the project, valuable isotopes have been identified. Thermodynamic and experimental studies were realized in order to study the chemical behaviour and the state of these isotopes, especially some of the Platinum Group Metal (Pd, Mo, Ru) in the chloride molten salt in order to plan the process required for their recovery. A device to test the on-line gas bubbling on the ability and the efficiency to extract solid particles is under construction and the results recently obtained are very encouraging. The process to separate and purify gaseous fission products will be studied later in the project.



MSR: political and regulatory landscape

By Elisabeth Guillaut, EU Affairs Manager - Orano

In the last couple of months, EU decision-makers have pursued significant actions with regards to the role of MSR - and, more globally, of nuclear - to achieve the EU objectives.

On 4 April 2023, the Commissioner Mariya Gabriel, together with EU nuclear stakeholders (nuclearеurope, Sustainable Nuclear Energy Technology Platform (SNETP), European Nuclear Society (ENS) and European Nuclear Education Network (ENEN)), signed a Declaration on 'EU Small Modular Reactors (SMRs) 2030: Research & Innovation, Education & Training'. It confirms the EC's commitment to promoting research in the field of SMR and advanced reactors.

On the same day, the European Commission opened the call for projects for the Euratom work programme 2023-2025. It includes calls for projects on the safety of advanced reactors, as well as one call for the partitioning and transmutation of minor actinides. The calls for projects are open until 8 November 2023. The EC also published a list of 28 ongoing SMR projects on its website, including MIMOSA.

On 16 May, 16 European countries met in Paris in the context of the Nuclear Alliance launched by France few months ago. This alliance aims to promote nuclear in EU policies. They signed a joint declaration and committed to prepare a roadmap to develop an integrated European nuclear industry reaching 150 GW of nuclear power capacity in the EU's electricity mix by 2050.

The declaration states that the 150 GW objective "represents the equivalent of up to 30 to 45 new build large reactors and Small Modular Reactors (SMR) in the EU and such new projects would also ensure that the current share of 25% electricity production be maintained in the EU for nuclear energy".

In parallel, SNETP organized its annual forum in Gothenburg. Several projects labelled by the association were presented in the exhibition area, including MIMOSA. Several sessions were organized in parallel, including one on SMR/AMR and advanced nuclear systems, waste management and recycling, fuels elements are core design.

Finally, the European Commission has drafted a regulatory proposal called the Net Zero Industry Act (NZIA), which aims at supporting industries that are key drivers of decarbonisation by speeding up administrative procedures, supporting investment in production capacity for low-carbon technologies and introducing regulatory sandboxes. Advanced technologies to produce energy from nuclear processes with minimal waste from the fuel cycle, SMRs, and related best-in-class fuels are classified in the Commission's proposal as net-zero technologies. The text is currently negotiated among the decision-makers and should be adopted by spring 2024.

Dissemination activities

Just a few months after its launch, the MIMOSA project was labelled by the Sustainable Nuclear Energy Technology Platform (SNETP).

SNETP was established in September 2007 as a R&D&I platform to support and promote the safe, reliable and efficient operation of Generation II, III and IV civil nuclear systems. It is recognised as a European Technology and Innovation Platform (ETIP) by the European Commission.

The platform provides dissemination support and opportunities for research projects included in its portfolio.

In the past year, we have presented our project at a number of nuclear research and industry events, including:

- the **CEA / CNRS Bootcamp on MSRs** (Avignon, October 2022);
- the **European Nuclear Education Network** (ENEN) event on training and education opportunities (Brussels, March 2023);
- the **SNETP Coordinators' Hub Day** (Brussels, March 2023);
- the **SNETP Forum** (Gothenburg, May 2023).

Project management

MIMOSA was officially launched in June 2023 with a consortium meeting at Orano's premises in the outskirts of Paris (*picture - top*). A year into the project, the partners met again in a General Assembly held at the Maison Irène et Frédéric Joliot-Curie in Brussels (*picture - bottom*).

An External Expert Advisory Board has been set up to provide independent guidance to the project partners.

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Abbreviations

LWR: light-water reactor
MSR: molten-salt reactor
SNF: spent nuclear fuel

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