IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Workshop on Molten Salt Reactors Fuels: Recent Development and Future Challenges

IAEA Headquarters, Vienna, Austria
and virtual participation via Cisco Webex

21 July – 25 July 2025

Ref. No.: EVT2501798

Information Sheet

Introduction

Molten Salt Reactors (MSRs), which use fuel dissolved in a liquid salt, represent an advanced technology of GEN-IV and Small Modular Reactors (SMRs). They are one of the promising high-temperature nuclear reactor types for future electricity generation and heat production for hydrogen. MSRs also have potential as transmuters, capable of burning plutonium and other transuranium (TRU) elements. Fuels used in MSRs include enriched uranium, plutonium and TRU elements from reprocessed PWRs' spent nuclear fuel, and ^{233}U produced from fertile thorium. The typical fuel in a MSR is a mixture of fission material halides (fluorides or chlorides) dissolved in a carrier salt. Numerous countries worldwide are studying this reactor technology, including Canada, China, France, India, Korea, Japan, the Russian Federation, the UK, the USA, and the European Commission (JRC).

In 2023, the IAEA published the Technical Report Series No. 489 on the Status of Molten Salt Reactor Technology, which provides a comprehensive overview of the current developments in MSR technology. This report covers key advancements in MSR designs, technological challenges, and areas such as fuel cycle options, reactor physics, thermal hydraulics, materials compatibility, and safety concerns. It also highlights research and development (R&D) efforts in various countries and serves as a resource for research organizations, policymakers, and industry stakeholders to better understand MSR technology needs.

Currently, MSRs progress from conceptual stages to design and pilot-scale demonstrations. Recent examples of this shift include the 2MWt Li,Be,Th,U/F MSR-LF1 in China, the 1MWt

Li,Be,U/F Natura MSR1 at Abilene Christian University, the 1MWt Na,Mg,U,Pu/Cl TerraPower's Molten Chloride Reactor Experiment (MCRE) project in the USA, and the 10MWt Li,Be,An/F test MSR in the Russian Federation, as well as Copenhagen Atomics Waste Burner (Copenhagen Atomics, Denmark), CMSR (Seaborg Technologies, Denmark), the IMSR by Terrestrial Energy, the Stable Salt Reactor-Wasteburner (SSR-W300) by Moltex Energy (Canada and UK), Thorcon (USA and Indonesia). As this transition continues, there is an increasing need to establish a supply chain for MSR fuels and to support the MSR fuel qualification process, and in understanding the in-reactor behaviour under both normal and accidental operational conditions.

For commercial MSRs to be deployed, several technological gaps need to be addressed, particularly regarding fuel salt supply and maintenance. However, sources for MSR fuel salts have not been fully identified, and scalable technologies for chlorinating and fluorinating metallic and oxide fuel sources to produce fuel salt are still under development. Currently, small amounts of pure MSR fuel salts are produced at the laboratory scale for property measurements or feasibility tests, but there is no commercial capacity to produce large quantities. Each MSR using liquid fuel will require a fuel salt specification for procurement. Contamination of molten salts by corrosion of containment or exposure to atmospheric oxygen or water during synthesis can impact reactor performance. Technologies for removing oxygen, water, and trace metal impurities from chloride and fluoride salts are still in the experimental phase and require scaling up. Once synthesized and purified, fuel salts must be properly packaged to avoid contamination and to be compatible with reactor equipment. Chloride salts for fast-spectrum reactors may require the use of ^{37}Cl to avoid generating ^{36}Cl, which is a strong neutron absorber and would reduce fuel efficiency. Similarly, fuel compositions containing LiCl or LiF may require the use of stable isotope ^{7}Li, instead of the neutron-absorbing ^{6}Li, to mitigate the generation of tritium. Scalable methods for producing mass quantities of salts with the desired isotopes are needed to support MSR operations.

Before MSR fuel can be used in reactors, it must meet qualification requirements for licensing. This includes addressing fuel salt preparation, transportation, and storage processes, as well as acceptable contamination levels and fuel qualification criteria. Acceptable levels of contamination and qualification requirements remain to be determined. Current methods for characterizing molten salt focus on identifying and understanding the fuel life-limiting failure mechanisms and fuel salt property degradation that occur due to irradiation during MSR operation. Key salt properties that support the achievement of fundamental safety functions under normal operations and design basis events include elemental and isotopic composition, liquidus and boiling temperatures, density, thermal conductivity, heat capacity, viscosity, redox potential, vapour pressure, phase stability, bubble content and aerosol formation. Currently, methods for characterizing molten salt for nuclear material accountancy and fuel qualification are experimental and need to be standardized.

Liquid and solid fuels have significantly different chemical and mechanical properties, which impact fuel qualification. In conventional solid fuel reactors, the safe operation under normal and accidental conditions is ensured by maintaining the structural integrity of the Nuclear Fuel Assembly (NFA). Nuclear safety is ensured by controlling reactivity, efficiently removing heat, and confining radioactive materials. The NFA includes physical barriers, such as the fuel matrix and cladding, which prevent fission products from entering the coolant.

In contrast, MSRs use a liquid fuel that serves as both the fuel and the coolant. MSRs lack external radionuclide retention layers like solid fuels, which could result in significant liquid and gaseous radionuclides being released in case of containment failure. The chemical composition of the fuel

salt changes over time due to fission products and transmutation accumulation. This changes the chemical composition of the fuel salt, and in turn changes the thermophysical properties of the fuel/coolant. The changing of the salt composition can affect properties such as melting point, boiling point, density, and viscosity. These properties must be monitored and adjusted during operation to maintain the reactor safety. Understanding the impact of changes in the thermophysical properties of the fuel/coolant resulting from the addition of fission products and possible corrosion product impurities will be essential to the analyses of the ability to remove heat from the fuel during normal and off-normal conditions and after shutdown.

The modelling of complex interactions in liquid fuel requires new simulation tools, including neutronics depletion calculations, computational fluid dynamics (CFD), and thermodynamics simulations to model fission product retention and release in MSRs. Developing codes that can simulate molten salt heat and mass transfer with high-fidelity chemical reactions and phase transformations is essential for analysing salt properties, material corrosion, source term evolution, and material safeguards in MSRs.

To support its Member States in advancing the development of MSR fuels and fuels' qualification process, the IAEA is organizing a Workshop focused on synthesis processes for producing molten salts, scaling up fuel synthesis and packaging, characterization and qualification of MSR fuel salts, and developing modelling and simulation tools for fuel salt mixtures and their in-reactor behaviour.

Objectives

The purpose of the event is to exchange information on the latest cutting-edge research and perspectives in the area of molten salt fuel development, aimed at supporting Member States in the development of advanced reactors utilizing this reactor technology.

Target Audience

The event is intended for participants from research organizations, nuclear fuel design organizations, regulatory bodies, technical support organizations, universities, and other organizations engaged in MSRs and related fuel development, and in the simulation of fuel behaviour and MSR cores, as appropriate.

Working Language(s)

English

Expected Outputs

The outputs of the workshop will be:

- Establishment and/or strengthening collaborations among Member States to accelerate R&D activities relevant to MSR fuels development.

- Recommendations for future IAEA activities in molten salt fuel development.

Structure and topics.

Participants are expected to provide presentations on one or more of the topics identified below:

- *MSR fuels salt synthesis processes, Scaling Up Fuel Synthesis and Packaging*
    - Synthesis processes for producing MSR fuel salts from a variety of materials (uranium, thorium, or plutonium and minor actinides in metal or oxide forms), efforts to scale-up salt synthesis and packaging requirements will be discussed.

- *Purification Technologies for MSR Fresh Fuel Salt*
    - Technologies for removing oxygen, water, and trace metal impurities from molten chloride and fluoride fuels will be discussed.

- *Characterization and Qualification of MSR Fuel Salt*
    - Methods for characterizing molten salts for the purposes of material accountancy and fuel qualification will be discussed with focus on identification and understanding of fuel life-limiting failure and fuel salt property degradation mechanisms that occur as a result of irradiation during MSR operation.

- *Modelling and Simulation tools for fuel salt mixtures in-reactor behaviour.*
    - Modelling and simulation tools for fuel salt mixtures and their in-reactor behaviour will be discussed.

      NOTE: technologies for MSRs spent fuel salt reprocessing, waste forms for disposal and safeguard issues are considered outside the scope of this workshop.

Each session will feature presentations by experts on the current state of technology in each area, followed by a Questions and Answers session and an extended open discussion. During these discussions, participants will identify key research needs and opportunities for further development.

Participation and Registration

In order to be designated by an IAEA Member State or invited organization, participants are requested to submit their application via the InTouch+ platform (https://intouchplus.iaea.org) to the competent national authority (Ministry of Foreign Affairs, Permanent Mission to the IAEA or National Atomic Energy Authority) or organization for onward transmission to the IAEA by **9 May 2025**, following the registration procedure in InTouch+:

1. Access the InTouch+ platform (https://intouchplus.iaea.org):
   - Persons with an existing NUCLEUS account can sign in to the platform with their username and password;
   - Persons without an existing NUCLEUS account can register here.

2. Once signed in, prospective participants can use the InTouch+ platform to:
   - Complete or update their personal details under 'Complete Profile' and upload the relevant supporting documents;
   - Search for the relevant event under the 'My Eligible Events' tab;
   - Select the Member State or invited organization they want to represent from the drop-down menu entitled 'Designating Authority' (if an invited organization is not listed, please contact InTouchPlus.Contact-Point@iaea.org);
   - If applicable, indicate whether financial support is requested and complete the relevant information (this is not applicable to participants from invited organizations);
   - Based on the data input, the InTouch+ platform will automatically generate the Participation Form (Form A) and/or the Grant Application Form (Form C);
   - Submit their application.

Once submitted through the InTouch+ platform, the application, together with the auto-generated form(s), will be transmitted automatically to the required authority for approval. If approved, the application, together with the applicable form(s), will automatically be sent to the IAEA through the online platform.

NOTE: The application for financial support should be made, together with the submission of the application, by **9 May 2025.**

For additional information on how to apply for an event, please refer to the InTouch+ Help page. Any other issues or queries related to InTouch+ can be sent to InTouchPlus.Contact-Point@iaea.org.

Papers and Presentations

The IAEA encourages participants to give presentations on the work of their respective institutions that falls under the topics listed above.
Participants who wish to give presentations are requested to submit an abstract of their work. The abstract will be reviewed as part of the selection process for presentations. The abstract should be in A4 page format, around 1 page (including figures and tables) and should not exceed 1000 words. It should be sent electronically to **Ms Anzhelika Khaperskaia**, the Scientific Secretary of the event (see contact details below), not later than **9 May 2025.** Authors will be notified of the acceptance of their proposed presentations by **31 May 2025**.

In addition to the registration already submitted through the InTouch+ platform, participants have to submit the abstract, together with the Form for Submission of a Paper (Form B), to the competent national

authority (e.g. Ministry of Foreign Affairs, Permanent Mission to the IAEA or National Atomic Energy Authority) or organization for onward transmission to the IAEA not later than **9 May 2025**.

Important: Contributors of material to be included in the meeting proceedings are required to assign all copyrights or rights to publish to the IAEA. The authors should make sure that the files do not include copyrighted figures or other impediments for reproduction.

Expenditures and Grants

No registration fee is charged to participants.

The IAEA is generally not in a position to bear the travel and other costs of participants in the event. The IAEA has, however, limited funds at its disposal to help meet the cost of attendance of certain participants. Upon specific request, such assistance may be offered to normally one participant per country, provided that, in the IAEA's view, the participant will make an important contribution to the event.

The application for financial support should be made, together with the submission of the application, by 9 **May 2025**

Venue

The event will be held at the Vienna International Centre (VIC), where the IAEA's Headquarters are located. Participants must make their own travel and accommodation arrangements.

General information on the VIC and other practical details, such as a list of hotels offering a reduced rate for IAEA participants, are listed on the following IAEA web page: www.iaea.org/events.

Participants are advised to arrive at Checkpoint 1/Gate 1 of the VIC one hour before the start of the event on the first day in order to allow for timely registration. Participants will need to present an official photo identification document in order to be admitted to the VIC premises.

Visas

Participants who require a visa to enter Austria should submit the necessary application to the nearest diplomatic or consular representative of Austria at least four weeks before they travel to Austria. Since Austria is a Schengen State, persons requiring a visa will have to apply for a Schengen visa. In States where Austria has no diplomatic mission, visas can be obtained from the consular authority of a Schengen Partner State representing Austria in the country in question.

Additional Information

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Subsequent correspondence on scientific matters should be sent to the Scientific Secretary/Secretaries and correspondence on other matters related to the event to the Administrative Secretary.

Event Web Page

Please visit the following IAEA web page regularly for new information regarding this event:

https://www.iaea.org/events/EVT2501798