

## Molten Salt Reactors

24 November 2023

### **Nuclear Innovation Conference Topical Webinar**

- Tjark van Staveren (Programme manager materials, NRG)
- Isabelle Morlaes (Sr. VP MSR Initiatives, ORANO)
- Sander de Groot (CTO and co-founder, Thorizon)

## Objectives

- To present current initiatives, strategies and R&D efforts for Molten Salt Reactors
- To discuss key issues and perspectives with regards to the development of Molten Salt Reactors

## Nuclear Innovation Conference 2024

- Nuclear Innovation Conference will be held in Amsterdam on 5 and 6 June 2024, hosted by NRG in collaboration with IAEA
- Webinar is part of a series in preparation of the conference, covering topics on LTO, New Build and Advanced Reactors
  - Workshop on “LTO Beyond 60 Years” in Petten on 27-28 February 2024, subscribe via <https://www.nuclearinnovationconference.eu/workshops/workshop-registration> before 30 November

- Isabelle Morlaes
  - Senior Vice President, MSR Project Manager in Orano
  - 30 years of experience in the nuclear business, in both reactor design & maintenance field and fuel cycle field
  - She held several management and strategy positions in different business units of AREVA and Framatome, then Orano
- Sander de Groot
  - CTO and co-founder at Thorizon
  - 24 years of experience in nuclear industry, in computational engineering, materials and fuels irradiations, business and medical isotope development
- Tjark van Staveren
  - Programme manager materials irradiations at NRG
  - 13 years of experience in R&D projects for nuclear materials to support LTO, operation and new reactors



Isabelle Morlaes



Sander de Groot



Tjark van Staveren

Time	Subject
14:30 – 14:35	Opening - Tjark van Staveren, moderator
14:35 – 15:00	NRG Molten Salt Reactor R&D activities Tjark van Staveren, Program Manager Materials Irradiations, NRG, the Netherlands
15:00 – 15:30	ORANO perspective and activities on Molten Salt Reactor developments Isabelle Morlaes, Sr. VP MSR Initiatives, ORANO, France
15:00 – 16:00	Thorizon Molten Salt Reactor development Sander de Groot, CTO and co-founder, Thorizon, the Netherlands
16:00 – 16:25	Additional questions and discussion – all
16:25 – 16:30	Summary and wrap-up – Tjark van Staveren

## NRG Molten Salt Reactor R&D

24 November 2023

### **Nuclear Innovation Conference Topical Webinar**

- NRG introduction
- Molten Salt Reactors introduction
- NRG R&D for Molten Salt Reactors

## VISION

Nuclear technology provides solutions  
for health and energy.

---

## MISSION

We develop and deliver nuclear medicine  
products  
and contribute to energy solutions.

## CONSULTANCY & SERVICES



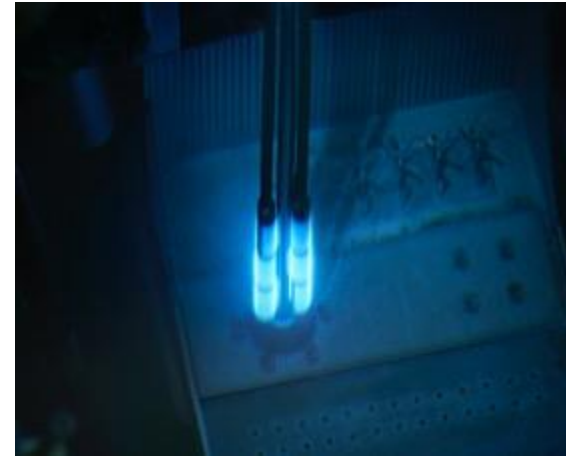
We provide services for safe and reliable operation of reactors and nuclear facilities, radioactive waste handling, and radiation protection.

## ACADEMY



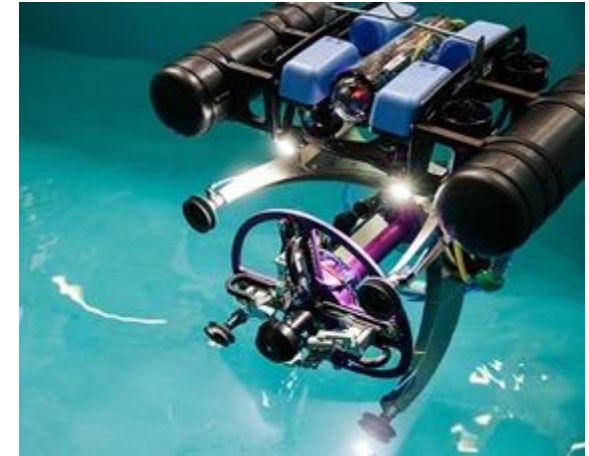
Our Academy offers a wide range of courses on radiation protection and nuclear technology and is recognized by the ANVS (The Dutch regulator)

## MEDICAL AND INDUSTRIAL RADIOISOTOPES



The HFR is one of the few reactors in the world which can make medical isotopes. In addition, the reactor is used for the irradiation of industrial isotopes and research into new nuclear energy, such as Thorium reactors.

## RESEARCH & INNOVATION



Our 60 years of experience in nuclear technology is the solid foundation for our research programs and new innovations.

# ENERGY & HEALTH CAMPUS



# UNIQUE NUCLEAR INFRASTRUCTURE



Molybdenum Production Facility



Radiological laboratory



Radiological laboratory



High Flux Reactor



Waste management facilities



Hot Cell Laboratories

# HIGH FLUX REACTOR



HFR is a multipurpose reactor for medical isotope production and nuclear energy research.

It is in operation since 1961, and operates in 9 'cycles' per year with intermediate maintenance and fuel loading.

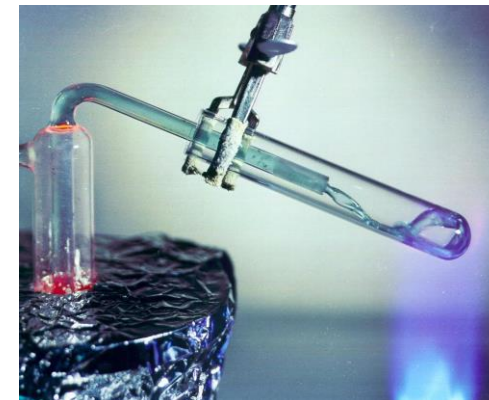
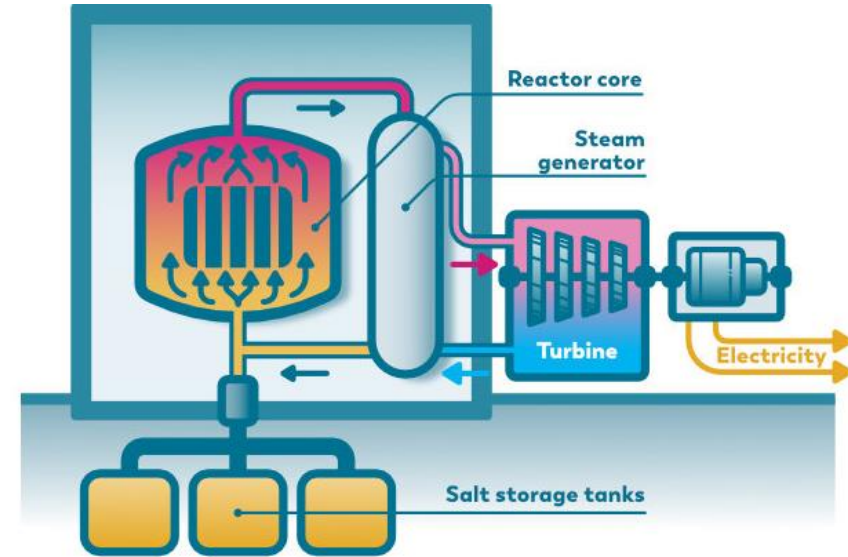
High flux in combination with instrumentation allows (accelerated) testing of materials and fuels under controlled conditions

# FUTURE PALLAS



# Molten salt reactors?

- Molten salt is the primary coolant, and can be the fuel (i.e. salt containing fissile material)
- Wide variety of MSR reactor designs
  - Power outputs range from tens to hundreds of MWth
  - Salt loaded with fissile materials (uranium / plutonium / thorium), or salt used as coolant of solid fuel types
  - Mixtures of salts (chloride / fluoride / lithium / beryllium)
  - 'Fast' vs. 'thermal' spectrum designs
  - With or without on-line refuelling
  - 'Monolithic' vs. modular designs



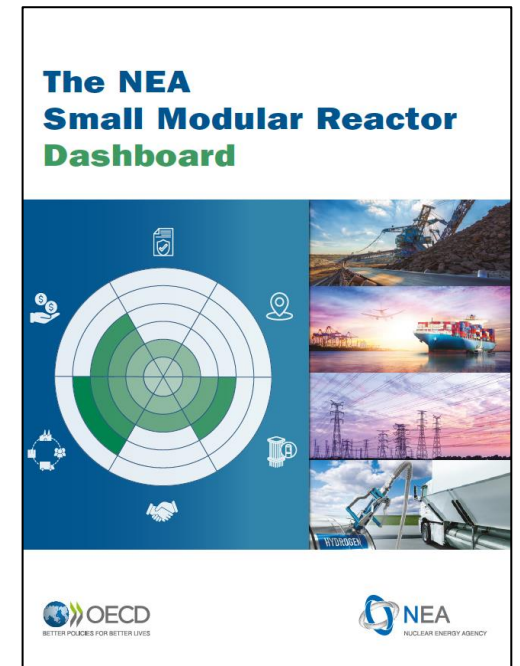
# Why Molten Salt Reactors?



- High temperature operating window (500-800°C) allows for higher efficiency electricity production and industrial heat applications
- Enhanced safety
  - High boiling point and excellent cooling properties of molten salt
  - Low pressure operation > reduces loading of containment
  - Passive safety features > prevent runaway reactions
- Reduction in long lived waste products
- Capable of response to load changes

# What is happening?

- World-wide R&D efforts by research organisations and universities
- Range of (mostly private) organisations around the world develop molten salt reactor designs, often in partnership with existing nuclear supply chain
- NEA SMR dashboards report progress on SMRs and advanced reactors (6 out of 42 reported are MSR-type) working on:
  - Licensing
  - Siting
  - Fuel
  - Engagement
  - Supply chain
  - Financing
- IAEA advanced reactor information system (ARIS) reports 8 MSR initiatives (out of 78 advanced reactor and SMR reactor designs)
- But there are quite a few more...



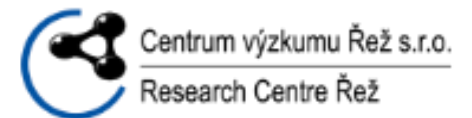
- Technical
  - Materials challenged by radiation damage, corrosion and other chemical interactions
  - Changing fuel chemistry during operation
  - Fuel cycle (from production to use, recycling and waste)
- Licensing
  - Existing licensing frameworks are designed for LWR reactors
  - Nuclear proliferation and safeguards
- Supply chain, finance, organization and siting



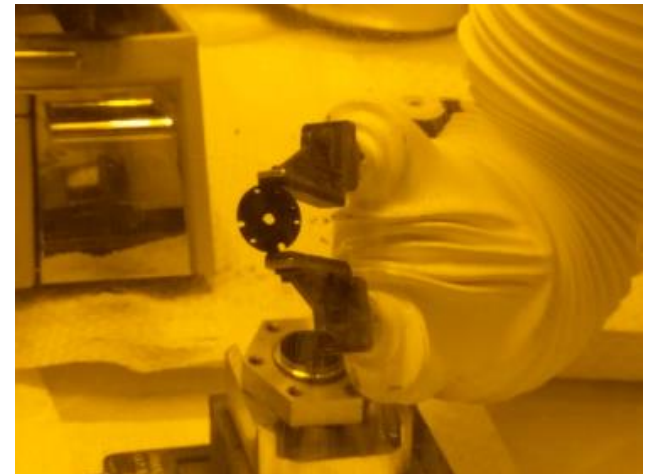
# Why MSR R&D activities at NRG?



- Decades of experience in R&D activities for LWR and advanced reactor concepts (incl. High Temperature Reactors, Lead cooled reactors, fusion etc.)
- ~2015 start of R&D activities sponsored by the Dutch Ministry of Economic Affairs as part of a broader Nuclear Energy R&D program
  - Program objective: contribute to MSR technology development and realisation
  - In collaborations with JRC, TU Delft and CV Rez
- Leveraging unique nuclear infrastructure and obtain operational experience
  - Salt handling, liquid fuel irradiation
  - Qualify materials and fuels
  - Temperature, Radiation, Corrosion
  - Study fission product behaviour (normal and accident conditions)
  - Tackle waste issues
  - Work towards Integral Demonstration
- Data and knowledge publicised

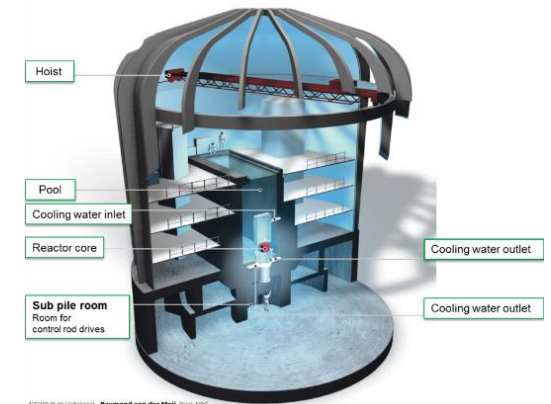
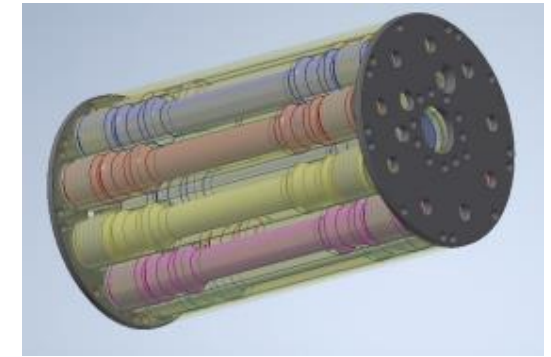


- Fuel for MSRs
  - Wide variety of options for salt composition and fissile material loading
  - With irradiation, composition of the salt changes (fission products, transmutation, interaction of salt with structural materials)
- Fuel testing objectives
  - Confirm claims of good fission product retention in the salt
  - Obtain size distributions for noble metal particles
  - Assess interactions between fuel salt and nuclear graphite, as well as possible uptake of fission products by the graphite
- Current status
  - Successful irradiation of fuel salts in graphite crucibles
  - First characterisation results after irradiation available give information on distribution and retention of fission elements
- More complex irradiations with e.g.: salt buffering, redox control, fission gas removal through helium bubbling, and salt flow are in design

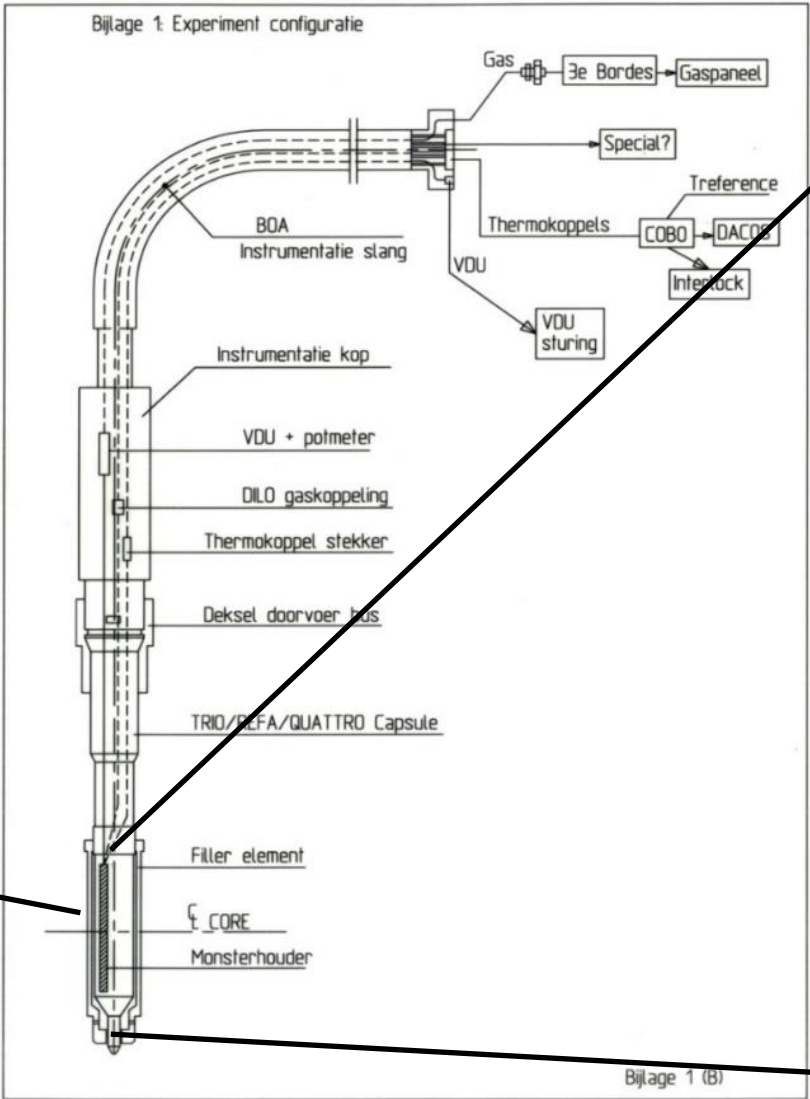
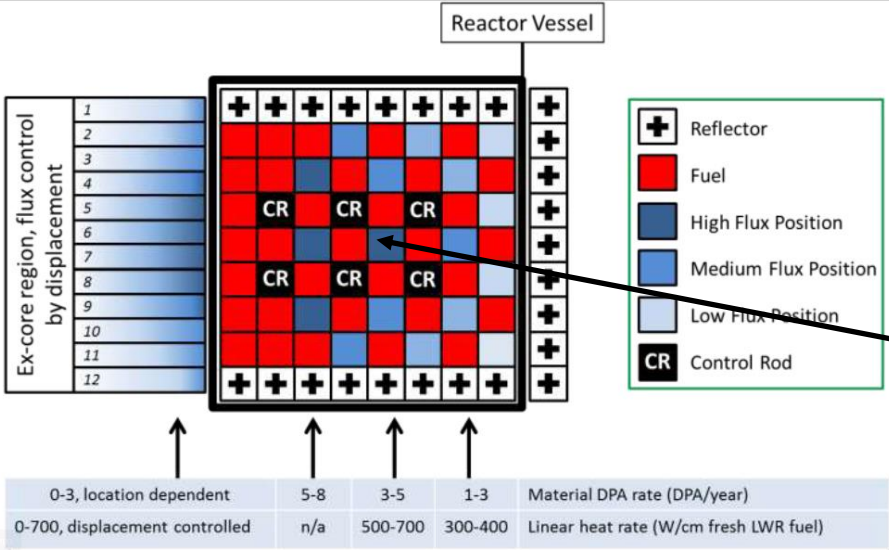
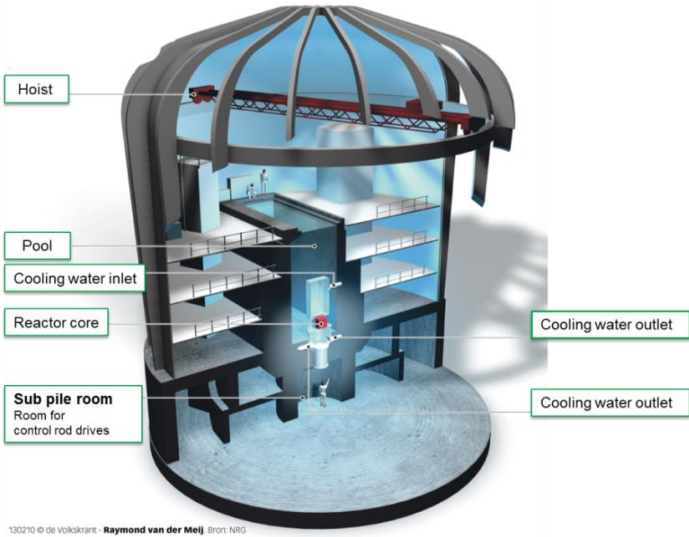


# MSR R&D: irradiation testing of materials

- Materials for MSR reactors
  - Steel and nickel alloys > structural components and containment
  - Graphite > neutron moderator and structural component in reactors with thermal spectrum
  - Novel materials: newly designed alloys and composites
- Materials properties change with irradiation at high temperature in molten salt environment
  - Embrittlement by neutrons and helium generation
  - Thermal ageing effects
  - Corrosion from salt interaction
  - Infiltration of molten salt into porous materials (e.g. graphite)
- Materials testing by irradiation High Flux Reactor (accelerated aging) and testing in Hot Cell Laboratories
  - Screening of materials
  - Materials optimisation
  - Qualification of materials



# MSR R&D: fuel and materials irradiations

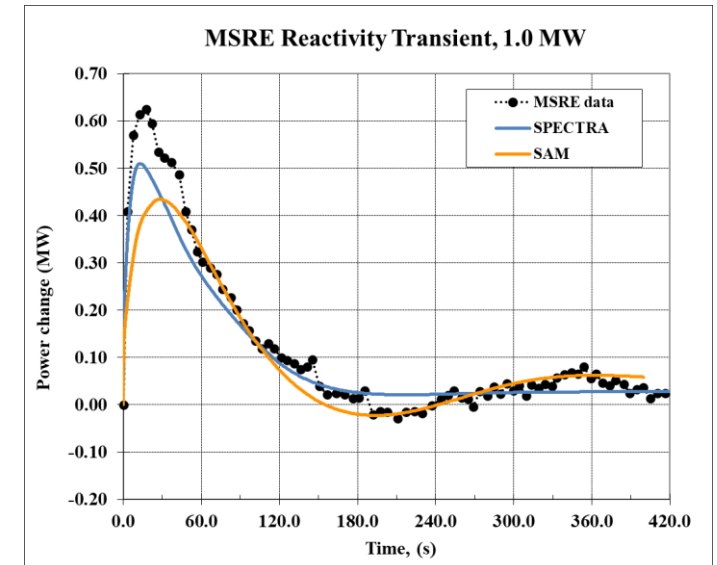


- Waste and reprocessing options need to be developed for future operation of MSRs (and R&D activities)
- Salts can be processed into glass form, e.g. borosilicate glass or iron phosphate glass
- Reactive components are added to the salt, and vitrification (process of forming glass) occurs after melting at  $\sim 1100^{\circ}\text{C}$
- Laboratory scale processing of salts into glass is demonstrated



# MSR R&D at NRG: modelling and simulation

- Modelling and simulation is required to understand MSR system functioning under normal and off-normal conditions
- SPECTRA: 1D fast running system code
  - Developed at NRG, originally designed for thermal-hydraulic analysis of LWR, has been applied to HTGR, SFRs, and MSRs
- Specific MSR features:
  - delayed neutron precursor drift
  - fission product transport in (fueled) molten salt reactors
  - noble gas and noble metal behavior
  - noble metal extraction
  - chromium leaching and deposition
- Benchmarking against experiments (e.g. irradiation experiments, MSRE at ORNL)



- MSR R&D activities are a key pillar in research program at NRG
- MSR R&D activities at NRG and partners contribute to understanding of MSR systems, fuels and materials
- Competences and technology are developed, which are leveraged to support reactor developers and the nuclear supply chain

# Nuclear Innovation Conference



- Nuclear Innovation Conference in Amsterdam on 5 and 6 June 2024
- Plenary sessions and parallel tracks for LTO, New Build and Advanced Reactors
- Registration is open!
- Visit [www.nuclearinnovationconference.eu](http://www.nuclearinnovationconference.eu)

**NUCLEAR  
INNOVATION<sup>24</sup>  
CONFERENCE**

**JUNE 5-6**

- In collaboration with the IAEA
- Showcase of the latest developments
- Live discussions with decisionmakers
- The ultimate networking event

**IAEA**  
International Atomic Energy Agency

The banner features a blue background with a stylized atomic symbol graphic on the left. The text 'NUCLEAR INNOVATION<sup>24</sup> CONFERENCE' is prominently displayed, followed by the dates 'JUNE 5-6'. A list of four bullet points highlights the conference's features: collaboration with the IAEA, showcasing latest developments, live discussions with decisionmakers, and being the ultimate networking event. The IAEA logo and full name are positioned on the right side of the banner.

- Visit NRG, ORANO, Thorizon and many other nuclear industry representatives at the World Nuclear Exhibition
- 28-30 November, Paris - Nord Villepinte - France

