

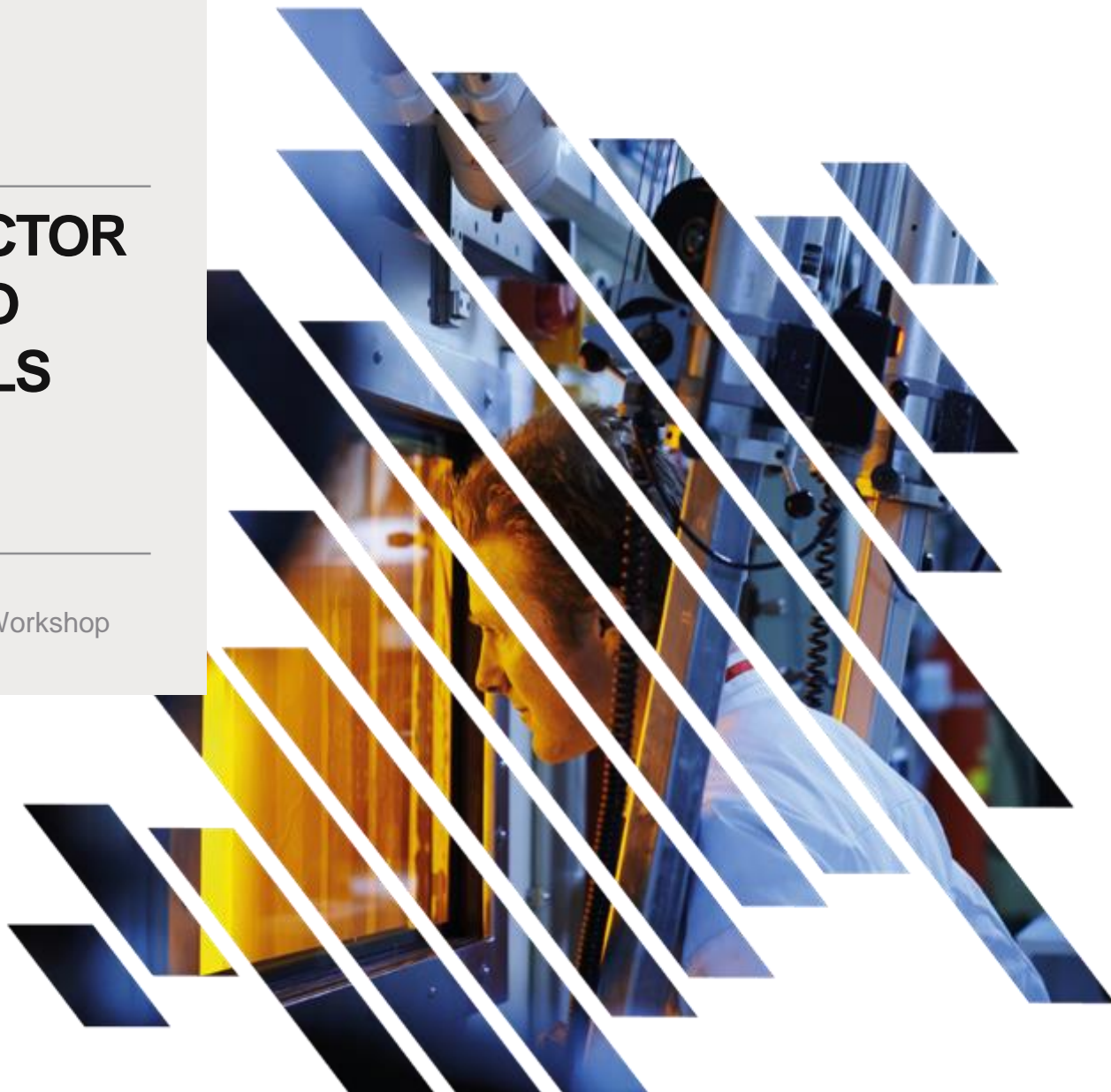


RESEARCH REACTOR EXPERIMENTS TO STUDY MATERIALS AND FUEL SALT PERFORMANCE

NRC Advanced Reactor Materials Workshop

Uazir Bezerra de Oliveira

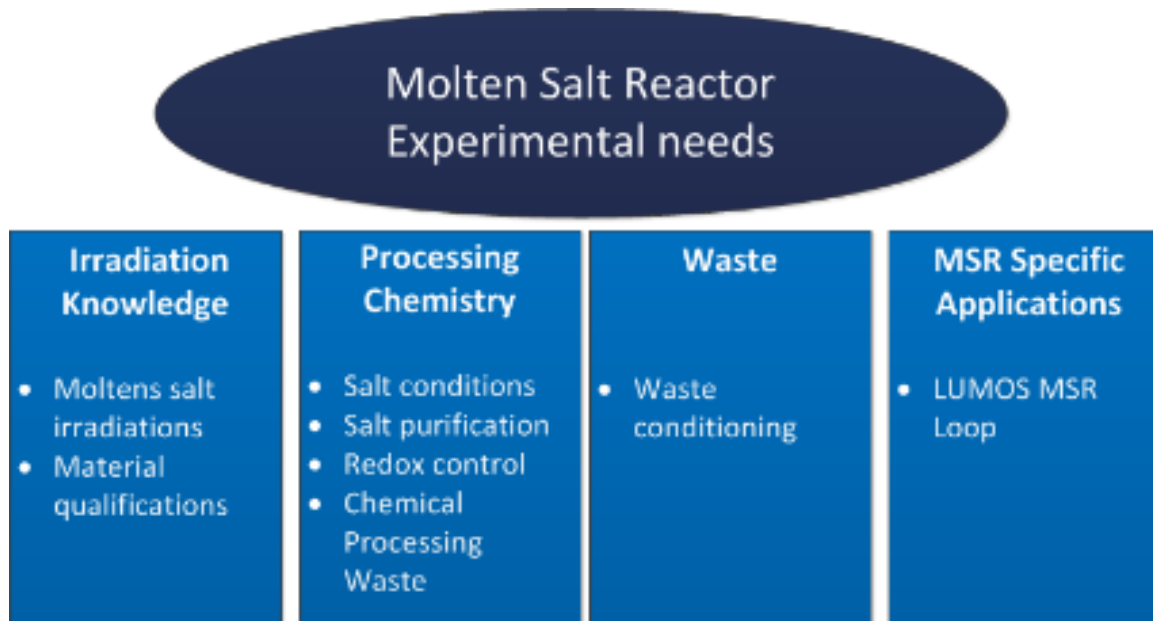
11 December 2019



OUTLINE

- The Dutch Molten Salt Program
- Projects of the MSR Program
- Roadmap - Molten Salt Reactor Program
- Projects in a nutshell →
 - Salient 1
 - Saga
 - Enickma
 - Salient 3
 - Waste
- Take away message
- Acknowledgements

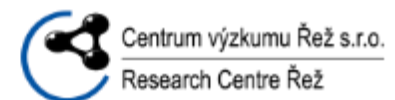
THE DUTCH MOLTEN SALT PROGRAM



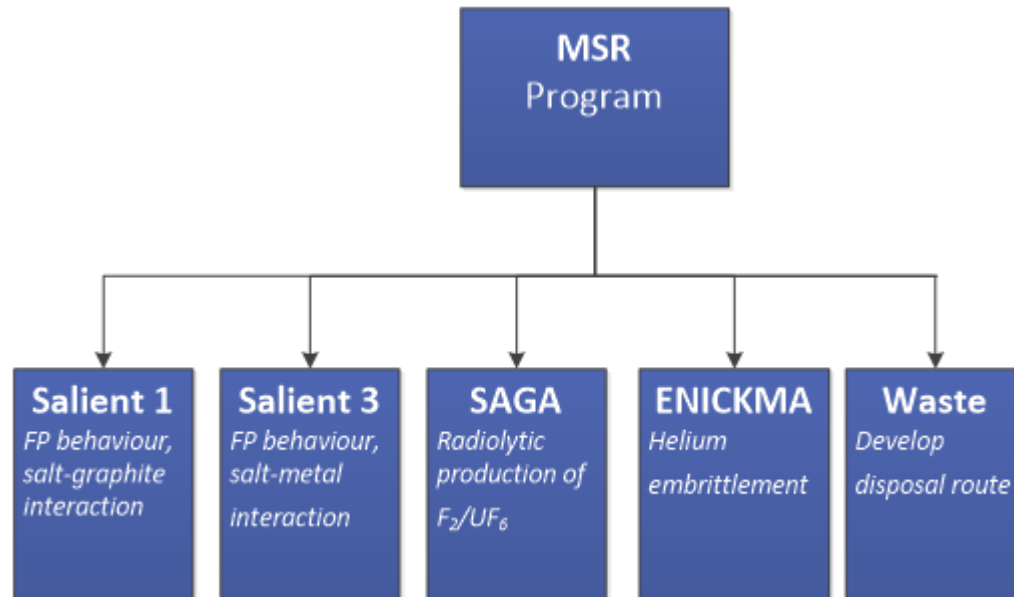
- **Molten Salt Technology fits with the Dutch energy R&D program:**
 - **Contribute to CO₂-free energy market**
 - **Reduce resource consumption / waste**
 - **Improve safety**

THE DUTCH MOLTEN SALT PROGRAM

- **NRG = Enabler of MSR Technology due to nuclear know-how, infrastructure, international network.**
- **Collaborations with competence centers:**
JRCs, TUDelft, FUBerlin and CV Rez.
- **Objectives:**
 1. **Obtain operational experience**
 2. **Safety**
 - Confirm Fission Products (FP) stability in the salt and FP migration
 - Investigate FP management methods
 3. **Material investigation:**
 - Material properties of irradiated containment materials
 - In-pile corrosion / deposition of metal alloys and SiC
 4. **Waste:**
 - Provide a waste route for spent molten salt fuel
 5. **Integral Demonstration:**
 - Feasibility of experimental Molten Salt loop for the HFR Petten



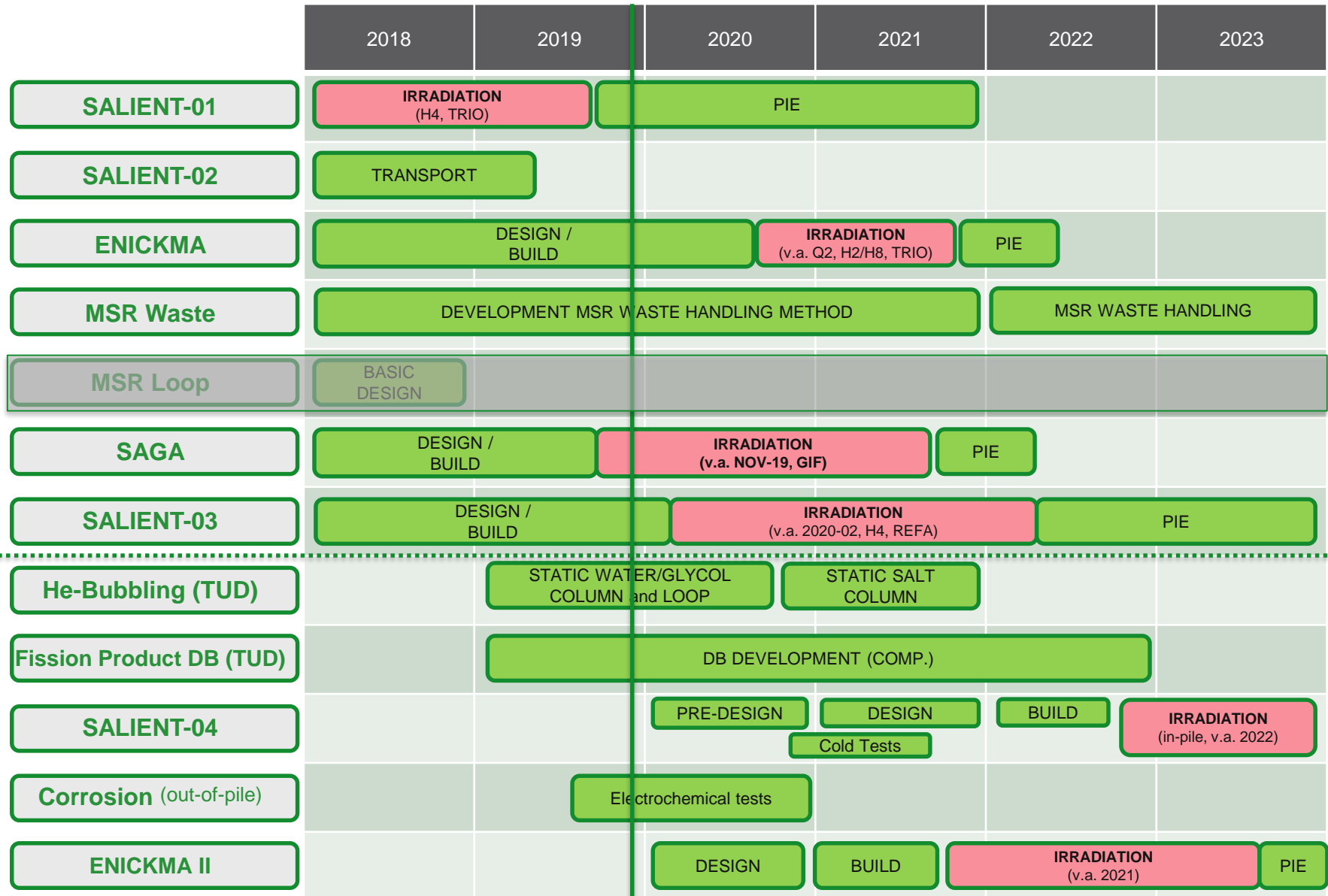
PROJECTS OF MOLTEN SALT PROGRAM



- Focus on irradiation technology for generation of reliable data.
- Focus on generic topics
- Ambitious R&D program open for partnering

Roadmap - Molten Salt Reactor Program

Under review



SALIENT-01

Idea: To build up experience with molten salt fuel irradiations.

Choices:

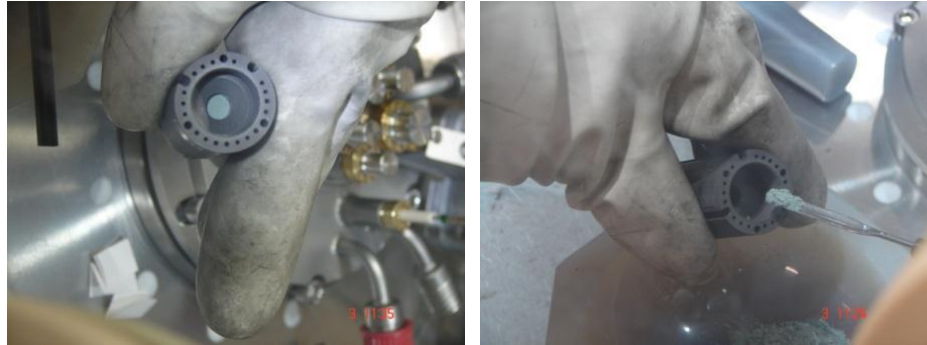
- Graphite was chosen for being corrosion free.
- Salt composition limited by JRC Karlsruhe capability at the time (no U nor Pu salts).

Scope:

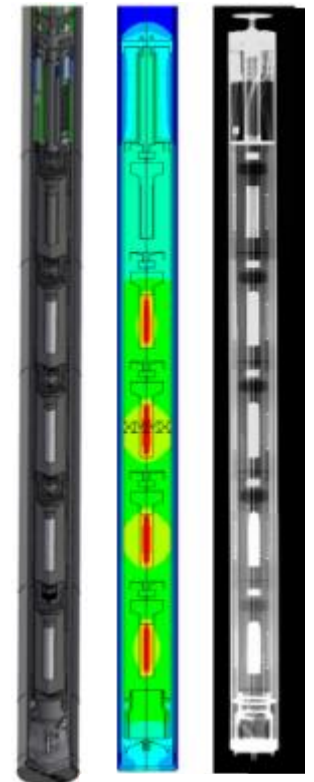
- Irradiation of 78LiF-22ThF₄ salt.
- In-pile temperature monitoring
- At JRC Karlsruhe: Knudsen cell effusion (determination of salt stability)
- Extensive PIE:
 1. Gamma scan (ongoing): qualitative view of fission product distribution
 2. Puncturing of 1st containment: fission gas characterization
 3. Calibrated burn-up analysis based on activation monitor set results
 4. Rinsing capsule + Analysing release of volatiles
 5. Microscopy (Salt and Fission product penetration, surface characterization, etc...)
 6. Salt impregnation test of irradiated graphite

SALIENT-01 ASSEMBLY

Synthesis and
crucible
loading at
JRC Karlsruhe



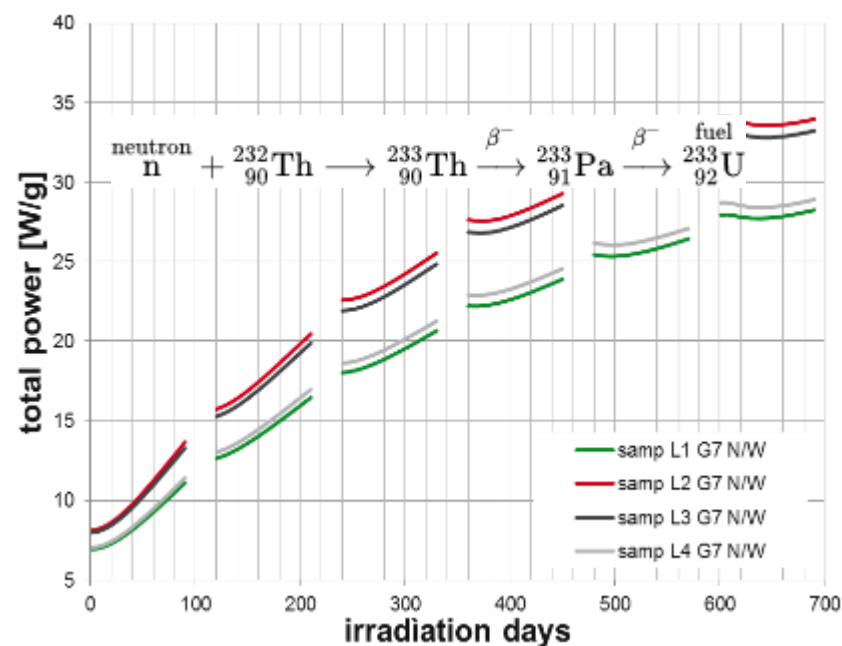
Assembly of
sample holder
at NRG



Design TMA X-ray

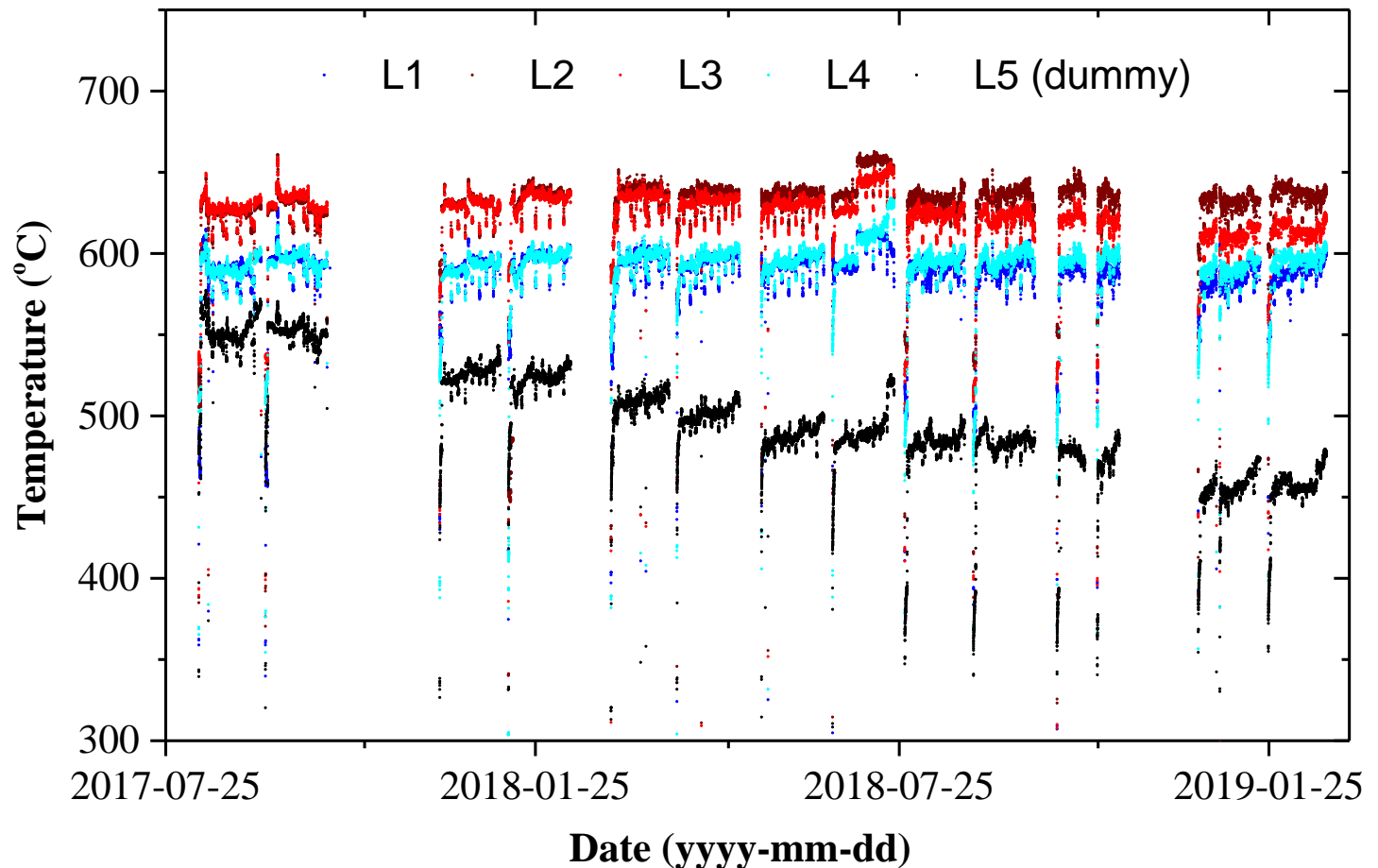
SALIENT-01 EXPERIMENT

- Open capsules fabricated from nuclear-grade graphite
- Fuel power rises during irradiation due to production of U-233
- Fixed crucible temperature (**~600 °C**) actively maintained



SALIENT 1: IN-PILE TEMPERATURE

Salt power, through thermal neutron flux, is relatively sensitive to changes in the core

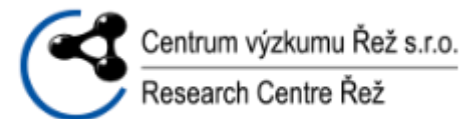


SAGA: GAMMA IRRADIATION OF FUEL SALT AT LOW TEMPERATURE

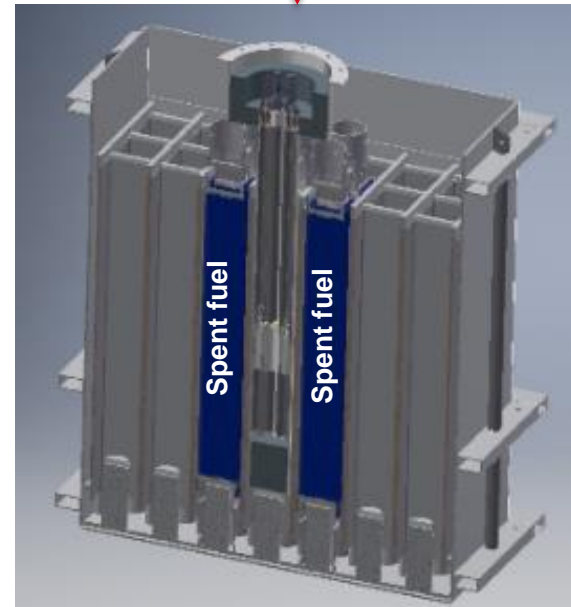
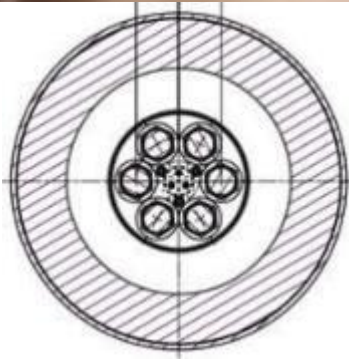
Idea: Simulate the formation of F_2 gas when the salt cools down (range 50-150 °C).

Scope:

- HFR Spent fuel used as the gamma source
- 40-45 °C base irradiation
- Monitoring of pressure, dose rate and temperature
- 5 salt samples provided by CV Řež & FUBerlin:
 - Powder: LiF , BeF_2 , ThF_4 , UF_4 , $LiF-BeF_2-UF_4$
 - Fused: 1 Empty reference capsule as reference



SAGA: EXPERIMENT



- 5 salt Capsules + 1 Empty
- Instrumentation (on-line measurement)

**Gamma Irradiation started
27 November 2019**

ENICKMA: EMBRITTLEMENT OF NICKEL-BASED ALLOYS IN HELIUM

Idea: Material transformations of Nickel based alloys during irradiation.

Scope:

Irradiation parameters:

- Temperature: 650 and 750 °C
- Up to $1\text{E}21$ n/cm² thermal, $3\text{E}21$ n/cm² fast (up to 50 appm helium, >1 dpa expected)

PIE:

- Microstructure analysis
- Tensile testing
- Low Cycle Fatigue
- Small Punch testing
- Oven anneal test at same temperatures as references

Grade	Supplier
3166 L(N)	CEA
Hastelloy N	Haynes
GH3535	SINAP
HN80MTY	COMTES FHT
MONICR	COMTES FHT
Hastelloy 242	Haynes

Start of irradiation foreseen Q2/3 2020

SALIENT-03: IN-PILE CORROSION OF NICKEL ALLOYS

Idea: Investigate in-pile corrosion of Nickel alloys by fluoride fuel salt. Heaters added to keep temp. > 150C.

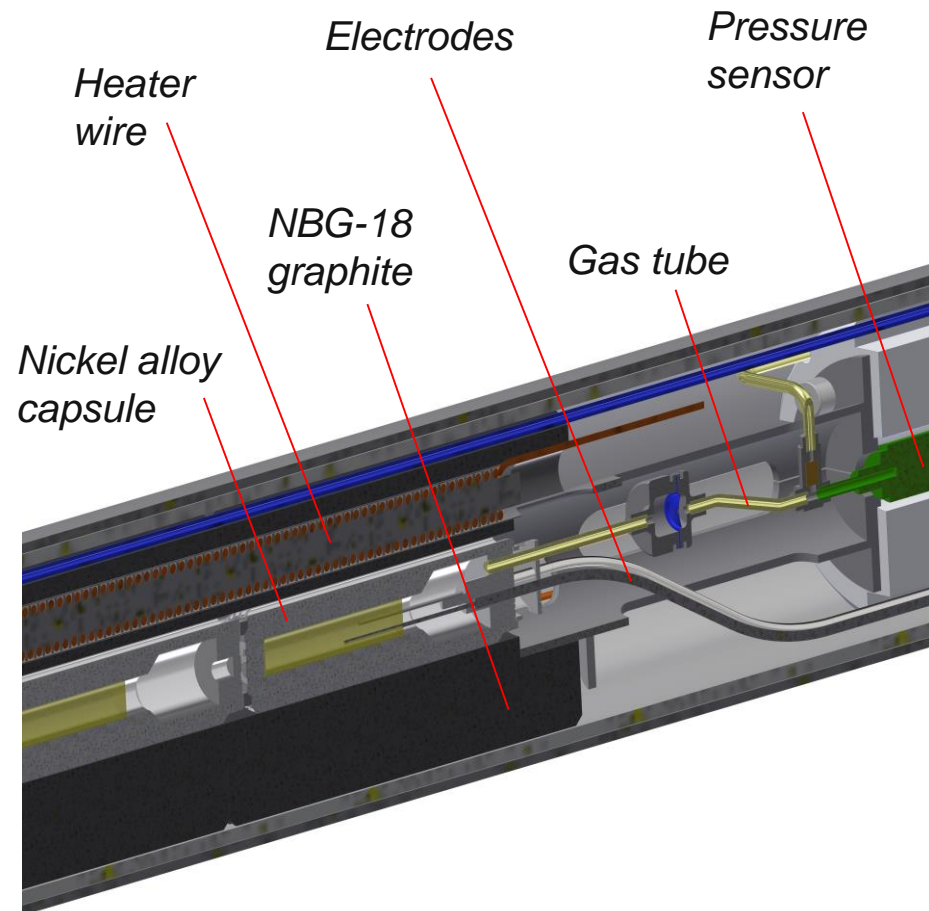
Scope:

- Corrosion assessment >13.000 hours in-pile
- Determine the influence of fission products and redox buffering on corrosion.
- Compare experimental mass transport in a non-isothermal salt column to CFD simulations.

(Fission product behavior)

- Determine in-pile fission gas release.
- Establish which fission products/species relocate to 'cold spots' during irradiation.
- Determine post-irradiation fission product release temperatures (Knudsen Cell Effusion test at JRC Karlsruhe).

Start of irradiation foreseen Q2 2020



WASTE STRATEGY AND R&D

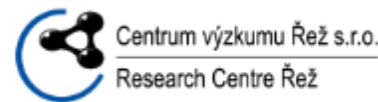
- **Idea:** Conversion of salt to recognizable, acceptable chemical forms, i.e.
 - Actinide-bearing oxide high level waste
 - Cemented intermediate level waste
 - Fluoride intermediate level waste (CaF_2 or fluorapatite)
- **Discussion with national repository**
- **Route: direct oxidation, aqueous processing**
 - Can be performed at NRG hot cells with relatively little infrastructure changes
 - No complicated gas streams
 - Limited spreading of dust



TAKE AWAY MESSAGE

- NRG is an enabler of Molten Salt Reactor Technology by developing testing irradiation capabilities to produce reliable data and knowledge.
- R&D Projects are tailored aiming to understand mechanisms, such as: corrosion (Salient 3), alloy embrittlement (Enickma), radiolytic production of F_2 gas (Saga), behavior of fission products (Sal. 1,3.)
- NRG is open for R&D collaborations with MSR community.
- Projects can be set to support specific needs of commercial clients.

ACKNOWLEDGEMENTS



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