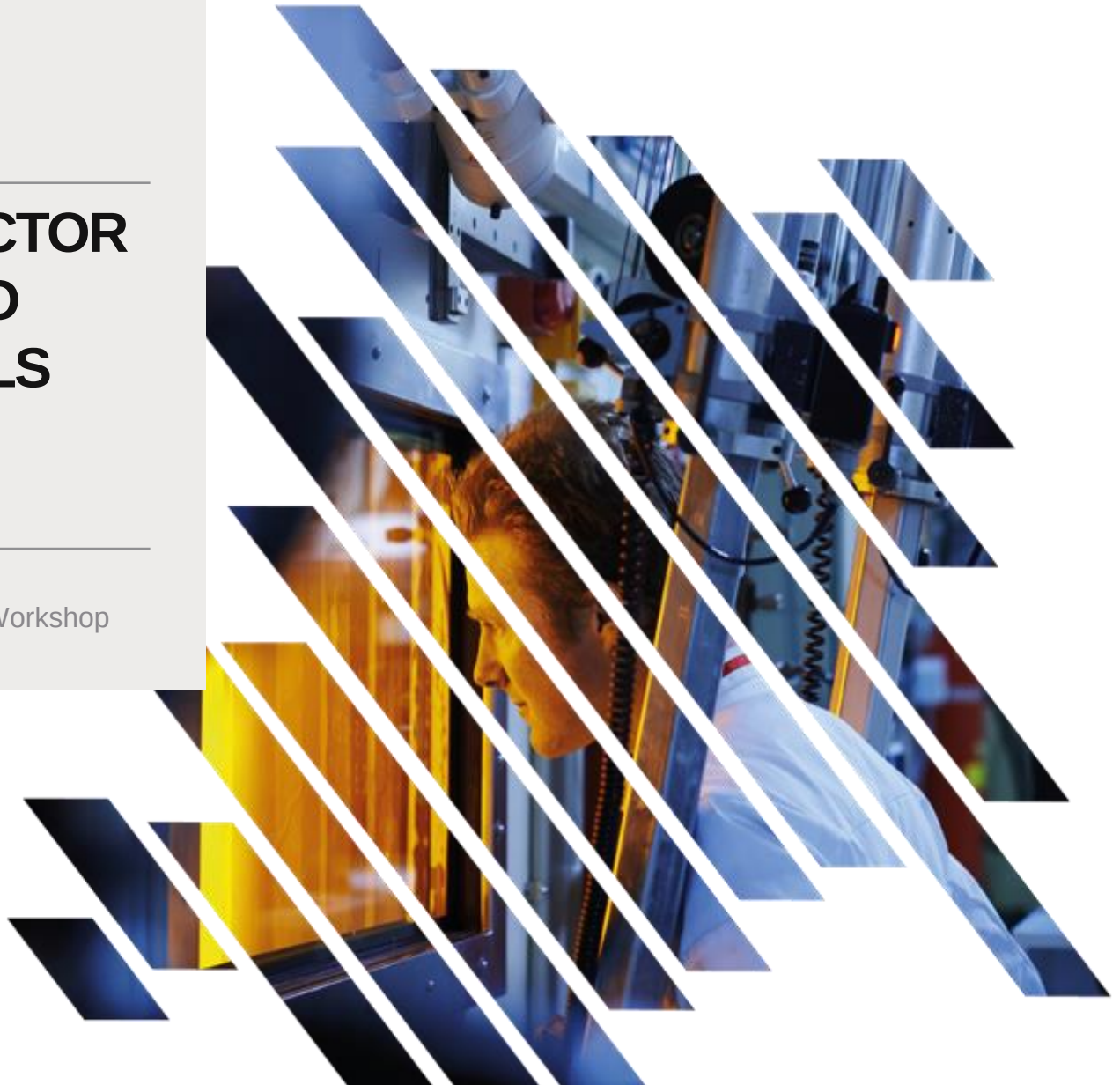
RESEARCH REACTOR EXPERIMENTS TO STUDY MATERIALS AND FUEL SALT PERFORMANCE

NRC Advanced Reactor Materials Workshop

Uazir Bezerra de Oliveira

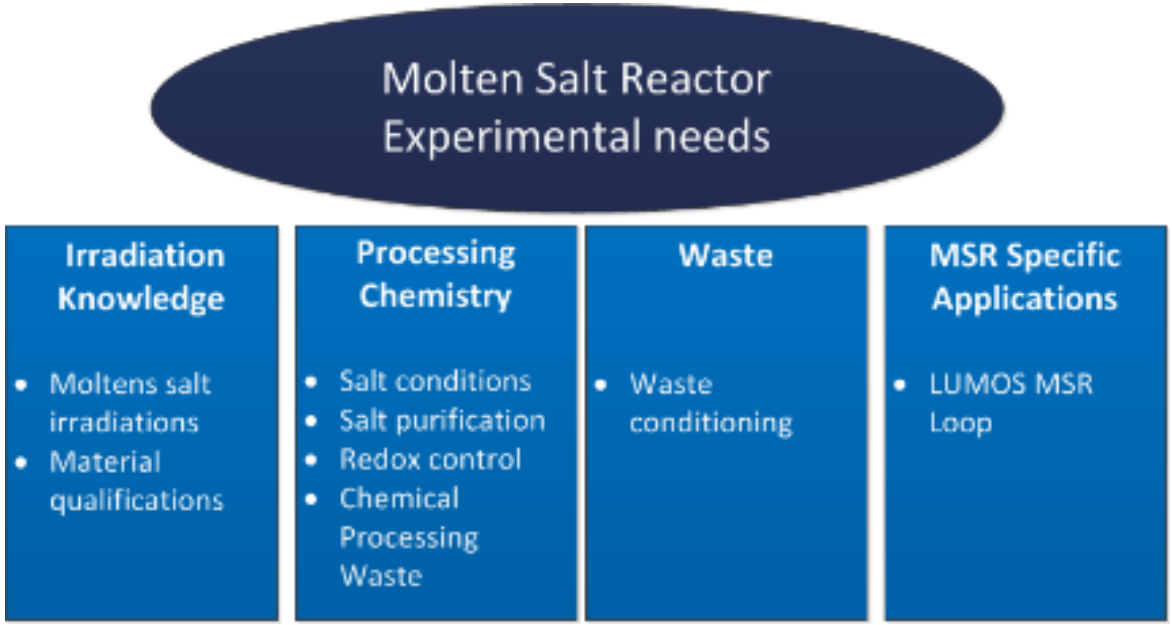
11 December 2019



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

Ministry of Economic Affairs of the Netherlands

JRC EUROPEAN COMMISSION

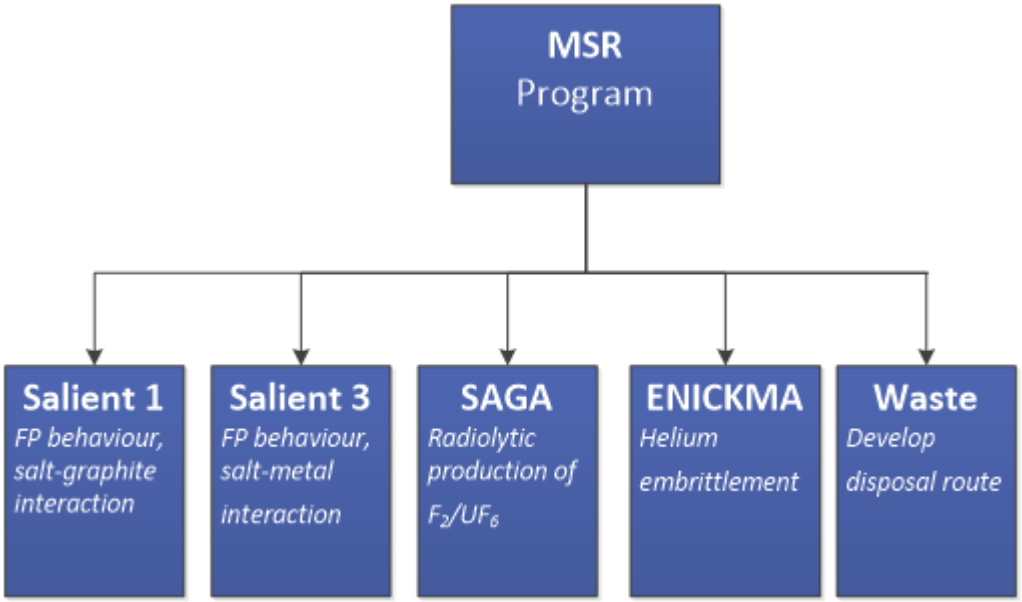
NRG

TU Delft Technische Universiteit Delft

Centrum výzkumu Řež s.r.o. Research Centre Řež

Freie Universität Berlin

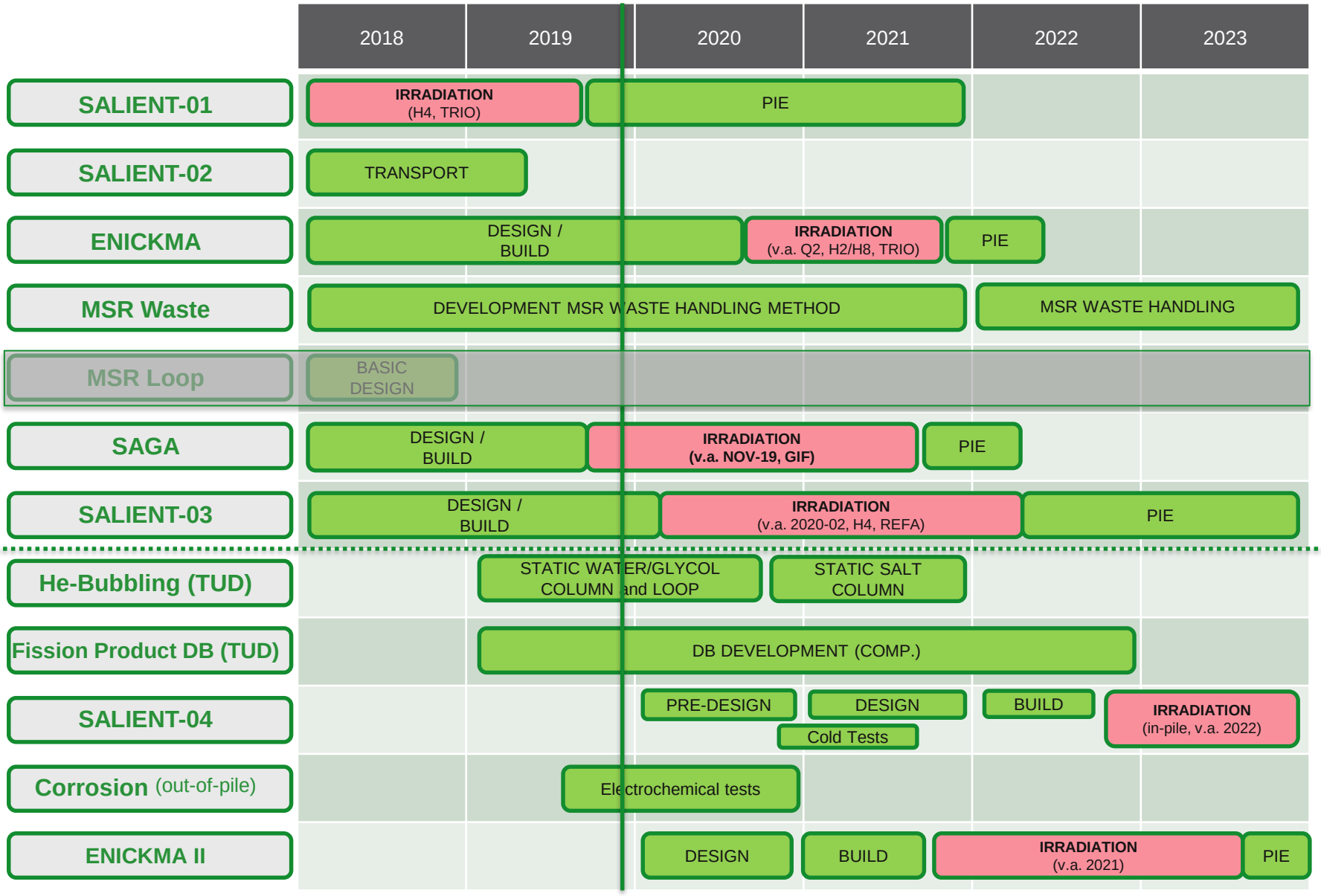
PROJECTS OF MOLTEN SALT PROGRAM



- **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).

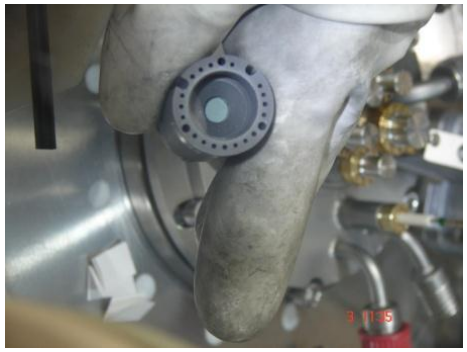
Scope:

- Irradiation of 78LiF-22ThF_4 salt.
- In-pile temperature monitoring
- At JRC Karlsruhe: Knudsen cell effusion (determination of salt stability)
- Extensive PIE:

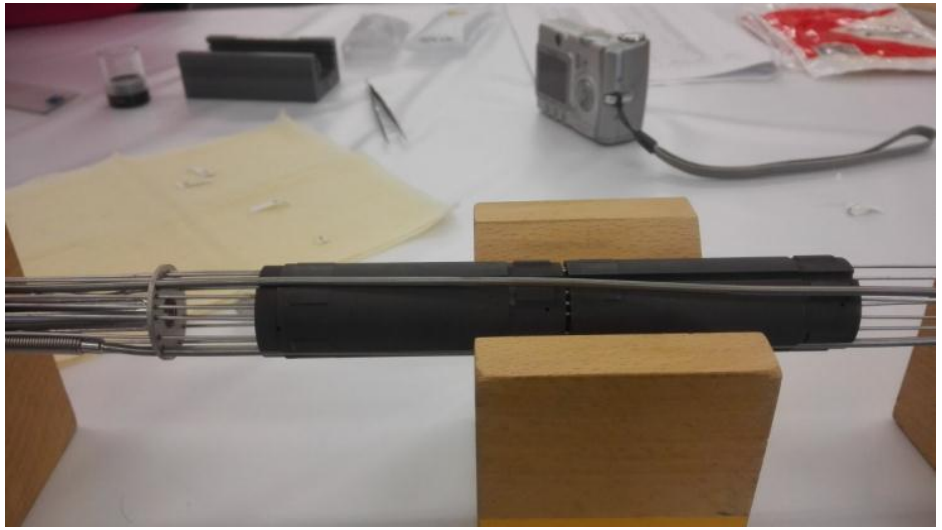
1. Gamma scan (ongoing): qualitative view of fission product distribution
2. Puncturing of 1st containment: fission gas characterization
3. Calibrated burn-up analysis based on activation monitor set results
4. Rinsing capsule + Analysing release of volatiles
5. Microscopy (Salt and Fission product penetration, surface characterization, etc…)
6. Salt impregnation test of irradiated graphite

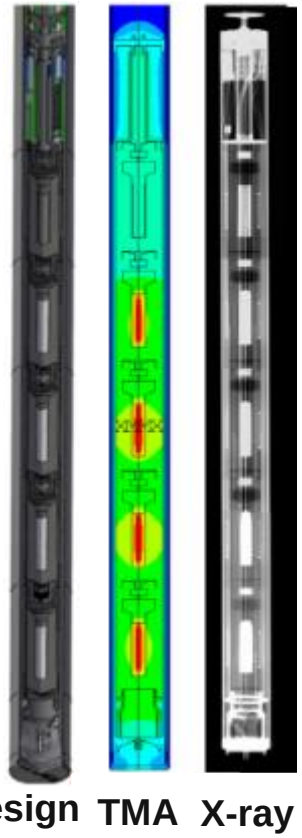
SALIENT-01 ASSEMBLY

Synthesis and crucible loading at JRC Karlsruhe



Assembly of sample holder at NRG

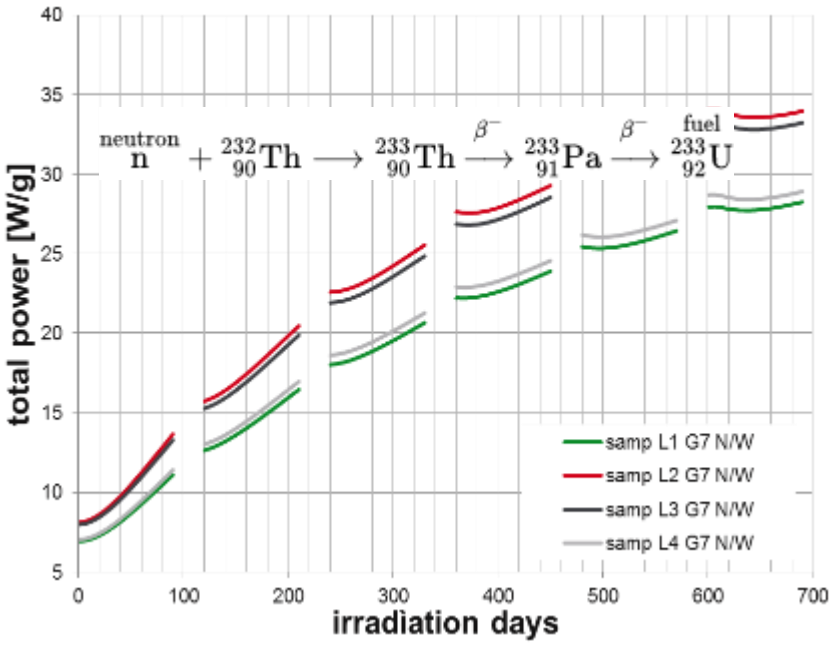




Design TMA X-ray

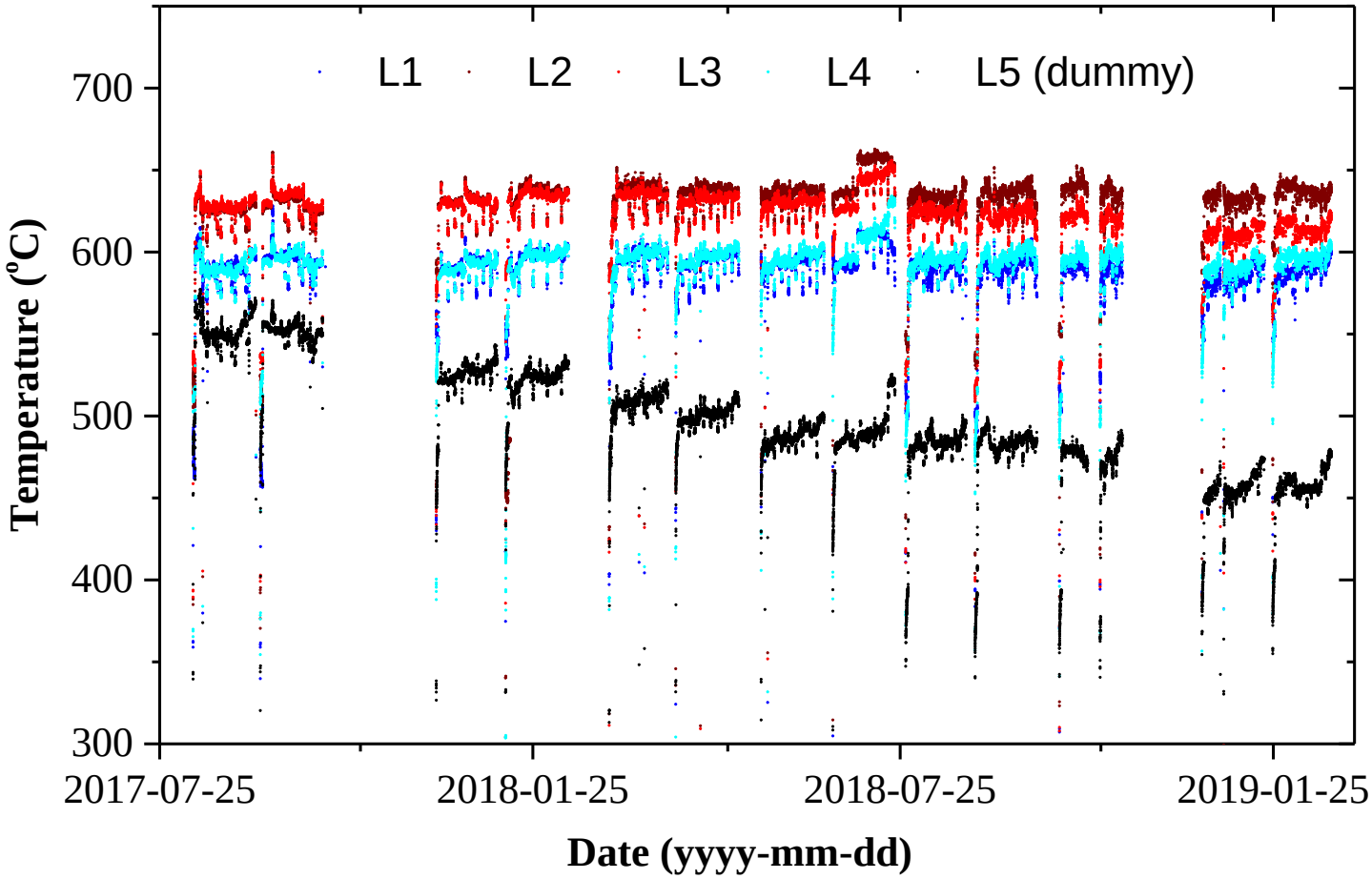
SALIENT-01 EXPERIMENT

- Open capsules fabricated from nuclear-grade graphite
- Fuel power rises during irradiation due to production of U-233
- Fixed crucible temperature **(~600 ºC)** 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 ^{o}C).

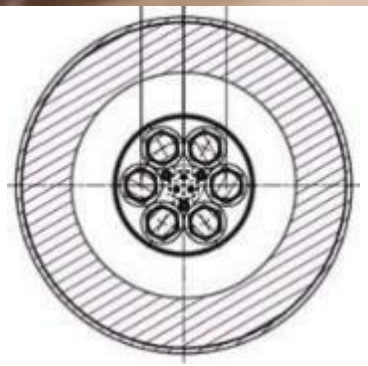
Scope:

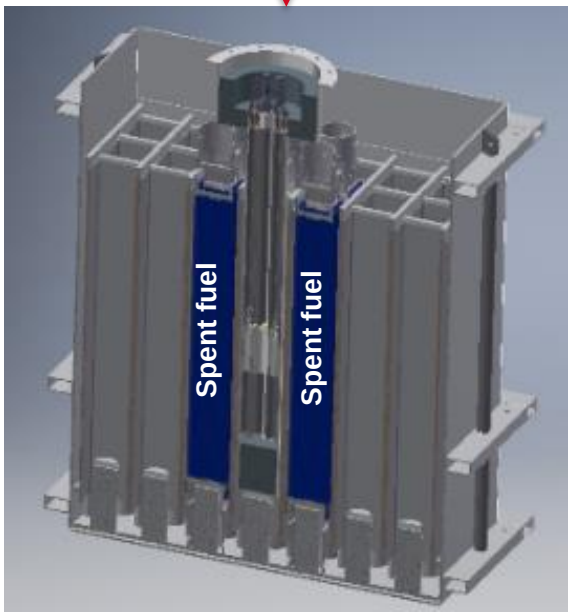
- HFR Spent fuel used as the gamma source
- 40-45 ^{o}C base irradiation
- Monitoring of pressure, dose rate and temperature
- 5 salt samples provided by CV Rez & FUBerlin:
  - Powder: LiF, BeF_2, ThF_4, UF_4, LiF-BeF_2-UF_4
  - Fused: 1 Empty reference capsule as reference

Centrum výzkumu Řež s.r.o.
Research Centre Řež

Freie Universität Berlin

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 ^{o}C
- Up to 1E21 n/cm^2 thermal, 3E21 n/cm^2 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.

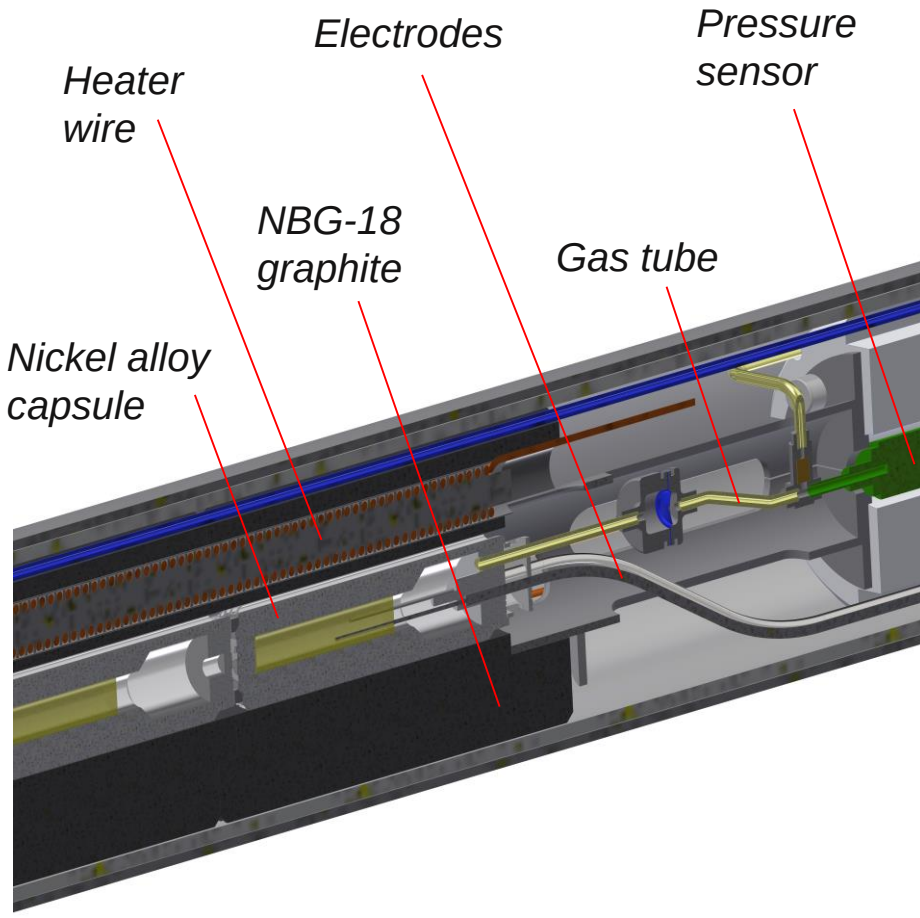
Scope:

- 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), radyolitic production of F_2 gas (Saga), behavior of fission products (Sal. 1,3.)

- NRG is open for R&D collaboratons with MSR community.

- Projects can be set to support specific needs of commercial clients.

ACKNOWLEDGEMENTS

Ministry of Economic Affairs of the Netherlands

JRC EUROPEAN COMMISSION

TU Delft Technische Universiteit Delft

Centrum výzkumu Řež s.r.o. Research Centre Řež

Freie Universität Berlin

EU DuC = N
Goods labeled with an EU DuC (European Dual-use Codification) not equal to 'N' are subject to European and national export authorization when exported from the EU and may be subject to national export authorization when exported to another EU country as well. Even without an EU DuC, or with EU DuC 'N', authorization may be required due to the final destination and purpose for which the goods are to be used. No rights may be derived from the specified EU DuC or absence of an EU DuC.