JRC contribution to SMRs and the back-end fuel cycle

IAEA Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors, 20-23 September 2022

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Our mission

As the science and knowledge service of the European Commission our mission is to support EU policies with independent evidence throughout the whole policy cycle.

European Commission

The JRC within the Commission

European Commission

Horizon EU - Euratom Programme 2021-2025

“ The general objective of the Euratom Programme is to pursue nuclear research and training activities, with an emphasis on the continuous improvement of nuclear safety, security and radiation protection, as well as to complement the achievement of Horizon Europe’s objectives inter alia in the context of the energy transition.”

Specific objectives

(a) improve and support nuclear safety, security, safeguards, radiation protection, safe spent fuel and radioactive waste management and decommissioning, including the safe and secure use of nuclear power and of non-power applications of ionizing radiation;

(b) maintain and further develop expertise and competence in the nuclear field within the Community;

(c) foster the development of fusion energy as a potential future energy source for electricity production and contribute to the implementation of the European fusion roadmap;

(d) support the policy of the Union and its Member States on continuous improvement of nuclear safety, safeguards and security.

JRC
direct actions (2021-2025)

Nuclear Safety and Security

€ 532 million (39%)

DG-RTD
indirect actions (2021-2025)

Nuclear Fission, Safety and Radiation Protection

€ 266 million (19%)

DG-RTD
indirect actions (2021-2025)

Fusion Energy

€ 583 million (42%)

http://data.europa.eu/eli/reg/2021/765/oj/

European Commission

SMRs in the European context

- SMRs could provide a strong contribution to realize several European Commission targets as set within: **Green Deal – Re-power EU – Taxonomy – SET Plan – Energy Security.**
- Several EU Member State have SMRs related initiatives: developing, planning for construction, start-ups, etc.
- Key actors in the European nuclear sector are elaborating on an *SMR pre-Partnership*.
- The European Commission supports R&D activities through its indirect actions (RTD) and direct actions (JRC).
- JRC activities focus on: safety-security-safeguards by design, technical maturity, non-electric applications, pre-licensing/licensing harmonisation, economy and waste management

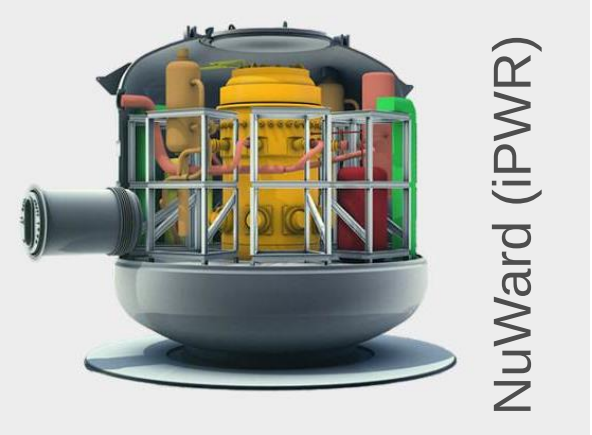
Expectations

- Lower fabrication costs and reduced construction time due to simplified design, serial factory fabrication of modules and self-financing scheme.
- Pre-Licensing/Licensing Harmonization (in EU and internationally)
- Greater flexibility of use and load-follow capability allowing for integration with intermittency of RES
- Significant safety advantages (relevant also for public acceptance)
- Offer electrical output at lower cost per kWh
- Could replace coal-fired power plants for heat generation and be coupled directly to industrial processes/factories.

Challenges

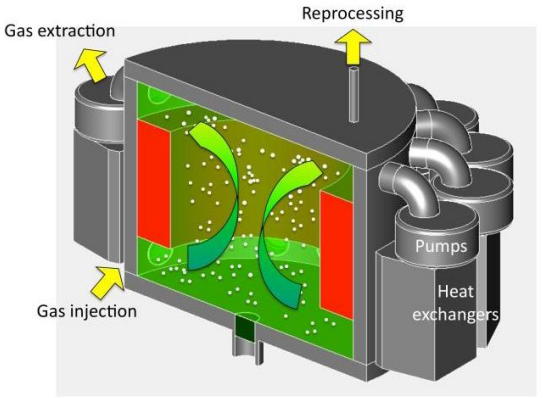
- **Safety, Security and Safeguards by Design:** proof of enhanced safety through validated codes; security considerations for new plants; safeguarding higher enriched fuel and reprocessing.
- **Emergency Planning /Siting**: Emergency response issues if SMR are close to industrial plants or urban areas.
- **International trade and supply chain**: Harmonisation of (pre)licensing requirements (close technical and regulator relationship e.g. to develop an international certification scheme for the design and in-factory fabrication).
- **New type of Fuels and Materials**: test data are required for codes and standards applied to safety case and demonstrate safety performance
- **Waste management**: integration with existing back-end processes and schemes; disposal solutions to be implemented

European SMR designs (Sample)



SEALER (LFR)

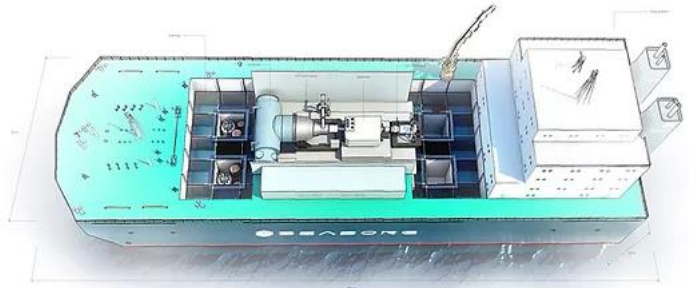
Source: LeadCold, Sweden



SAMOFAR (MSR)

Source: SAMOFAR [http://samofar.eu/concept/]

Compact MSR on barge



Source: Seaborg, Denmark

Spent fuel safety studies at JRC

assess SF/wasteform ability to fulfil its expected function over long-term

(Extended) Storage

radionuclides containment, rod retrievability *(≥100 y?)*

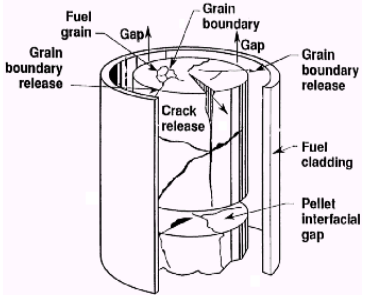
Spent fuel rod mechanical integrity degradation processes during storage

- cladding (hydrides);
- fuel: decay damage, He accumulation;

Accident conditions

pools, handling, transport, storage, retrieval:
corrosion, loss of cooling; damaged SF, debris properties.

- Mechanical load resistance: impact, bending;



Geologic Disposal

reduce uncertainties on release of long-lived radionuclides over an *open-ended disposal timescale*

radionuclides “Source Term”, “Instant Release”;
matrix corrosion: effects of environment and spent fuel properties

Convey experimental data into models and codes (predictions)

European Commission

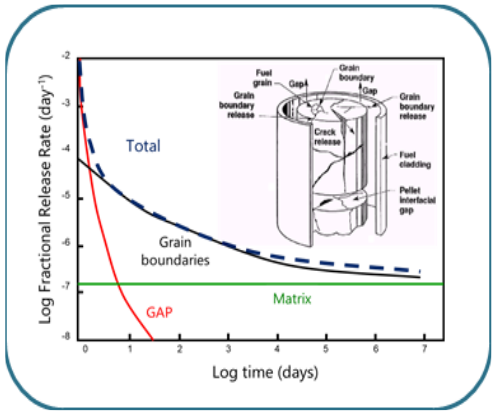
SMRs waste management

- Various fuel compounds and configurations proposed (oxides, nitrides, liquid fuel, TRISO particles, etc.)
- Different (higher) enrichment, burn-up
- Different clad materials (e.g. accident-tolerant).
- Which waste form (open or closed cycle)?

- Approach - Methods
  - No actual spent SMR fuel available. Preliminary studies using LWR SNF as analogue
  - Consider SNF/waste form stability associated to pre-disposal and disposal stages

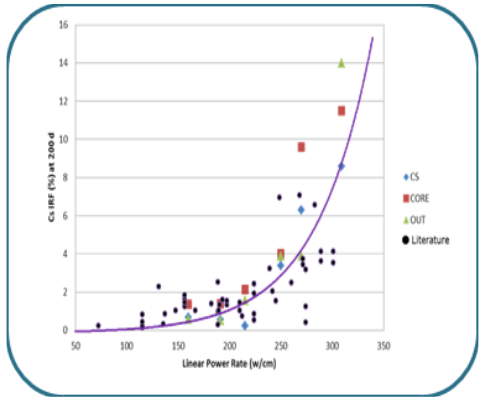
Examples of SNF experimental characterization for disposal

Leveraging experience and capabilities developed in LWR disposal studies



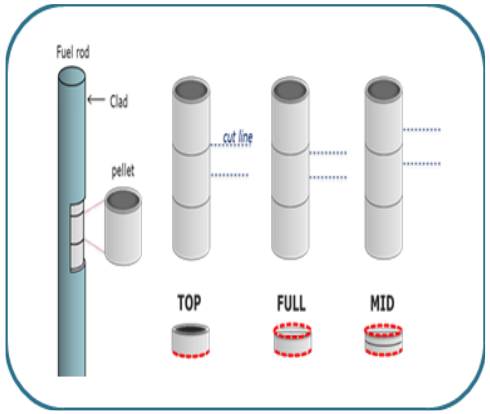
Safety assessment

- Reduce uncertainties
- Extend experimental database
- Improve Modelling



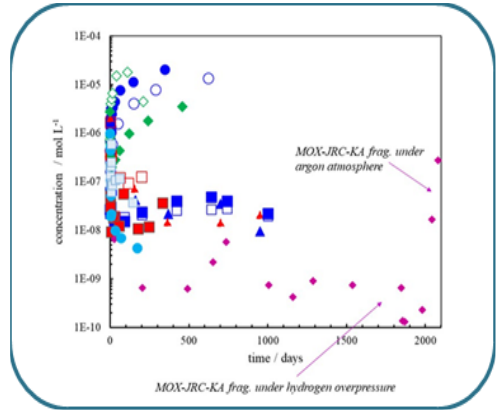
Correlation between Instant Release Fraction and irradiation history

- Linear Power Rating main factor affecting IRF
- Driving force for the relocation of some Rn to the void spaces



Addressing SNF heterogeneity

- Radial effect: HBS protective effect
- Positive dishing effect on IRF
- Axial effect: local irradiation differences



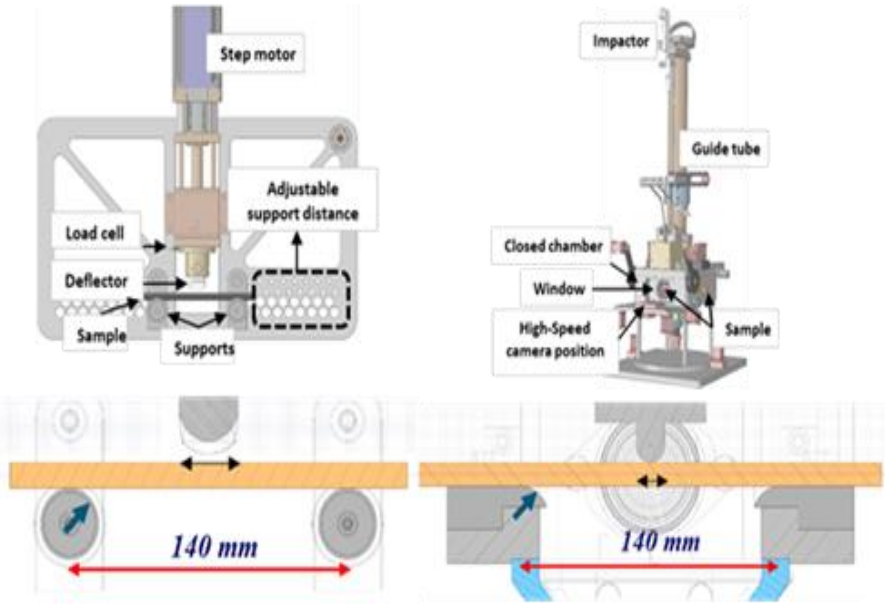
Long-term stability under repository conditions

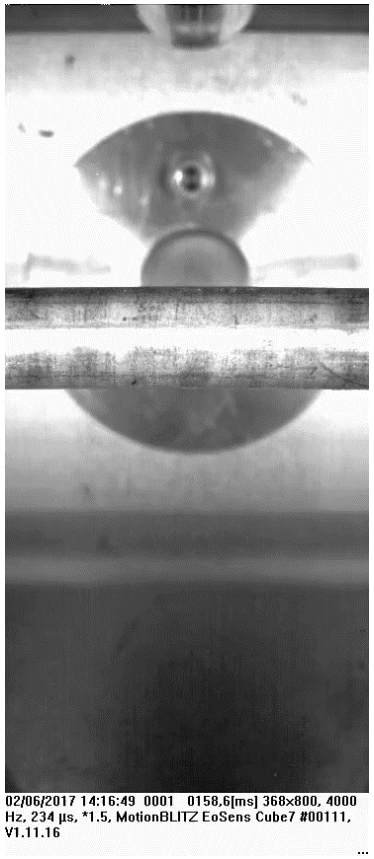
- Long-term matrix dissolution studies under reducing conditions
- High stability of SNF. Inhibition of matrix dissolution. Reduction to U(IV)

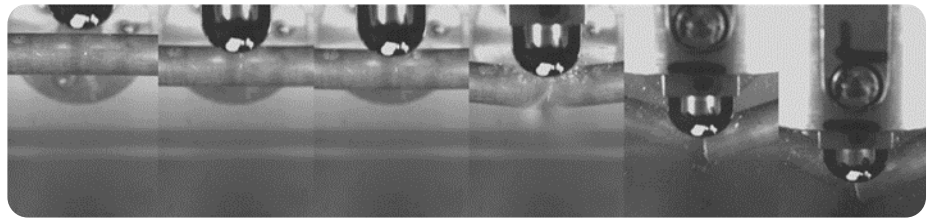
Examples of SNF studies related to pre-disposal stages

Leveraging experience and capabilities acquired from LWR SNF characterization in the frame of extended storage and retrievability studies, and response to mechanical loading conditions

Setup for bending, ring compression and impact tests







Main Results

- same order of magnitude of released fuel mass in bending or impact test
- relatively small fuel mass release, increasing with burnup
- ~ 0.5% mass as aerosol & fine particulates
- no significant differences for cladding type

Conclusion

- Interest for SMR is increasing in EU MS
- Several options considered: water cooled, Molten Salt, HTGC…
- Some more advanced than others
- Back-end of the fuel cycle to be considered (variety of potential waste forms)
  - Confirm compatibility with existing/planned waste management schemes
  - Lack of samples. Work with analogues; leverage expertise and capabilities acquired on LWR
  - Simulation tools, modelling
  - Increase available database
- Identify and focus onto specific aspects possibly affecting the back end of the SMR fuel cycle

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