International perspectives: SAMOSAFER and ENDURANCE EU Projects

2024 Molten Salt Reactor Workshop, November 6th 2024, Knoxville (TN), USA

Stefano Lorenzi (stefano.lorenzi@polimi.it), Politecnico di Milano

SAMOSAFER Grant Agreement n° 847527
ENDURANCE Grant Agreement n° 101165896

Funded by the European Union

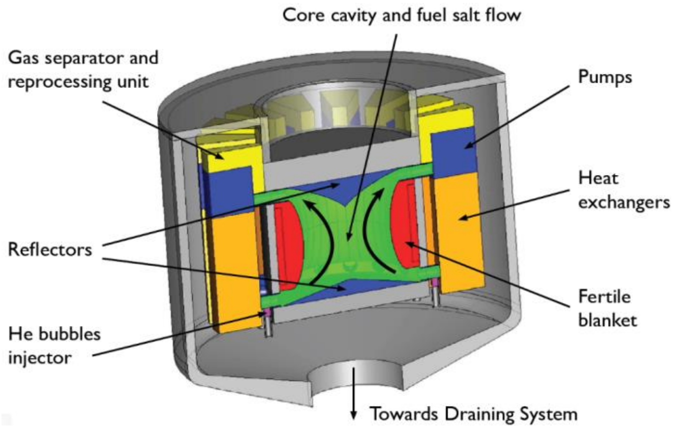
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Atomic Energy Community ('EC-Euratom'). Neither the European Union nor the granting authority can be held responsible for them.

SAMOSAFER Project (2020 – 2024)

Goal: ensure that the Molten Salt Reactor can comply with all expected regulation (safety, proliferation, licensing) in 30 years time

Activities:

- Translation and adaption of the current defence-in-depth safety approach to MSR
- Developing simulation codes for MSR safe design, safety assessment and severe accident analysis
  - Need for theoretical and empirical models for characteristic phenomena (natural circulation, solidification & melting, …) and their mutual interactions
  - Need for thermophysical & thermochemical properties
- Developing experimental setups for increasing the understanding of the phenomena and to generate validation database
- Design of advanced barriers for severe accidents
- Update of MSFR design



SAMOSAFER

Partners

TU Delft

POLITECNICO MILANO 1863

DE LA RECHERCHE À L'INDUSTRIE cea

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

KIT Karlsruhe Institute of Technology

cnrs

CVŘ Centrum výzkumu Řež

framatome

NRG

European Commission

eDF

Politecnico di Torino 1859

PAUL SCHERRER INSTITUT PSI

SAM SAFER

OntarioTech UNIVERSITY

DTU

Canadian Nuclear Laboratories

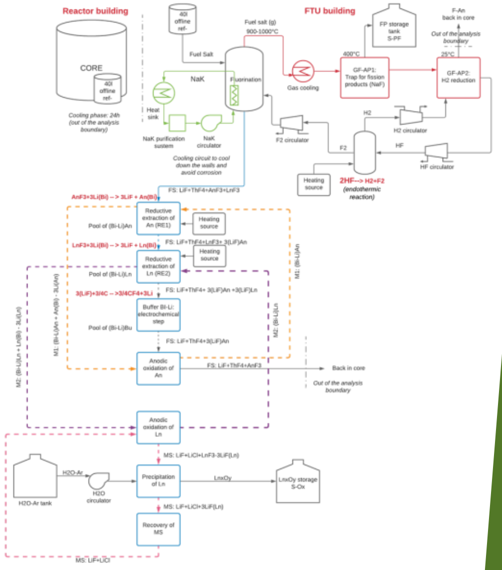
Third party observers

WP1: Safety requirements and risk identification

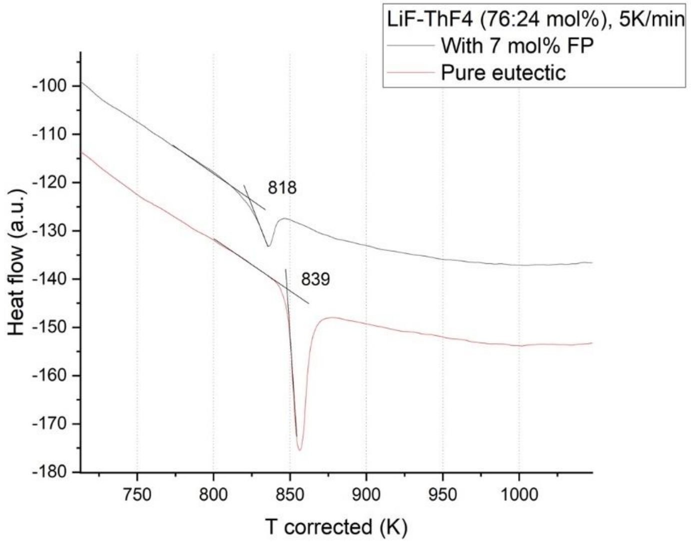
- **Application of DiD approach and definition of severe accident for MSR conditions** Importance of definition of Severe Accident to apply a proper DiD, implementing sufficient and independent provisions between the normal operation of the reactor and an unacceptable situation, i.e. the Severe Accident

- **Definition of a Severe Plant Condition:** high quantity of radiological elements involved + a loss in the retention of liquid or gaseous source term + a vector (energy), enabling the transportation of the radiological elements + a risk of simultaneous failure of containment barriers induced by the accident, until potential alteration of the last containment barrier

- **List of PIEs for RIA and FTU + key phenomena for RIA & functional analysis for FTU.** PIE and functional analysis needed to investigate the key phenomena, the physical components and events for accident category (RIA) or safety-related systems (FTU)

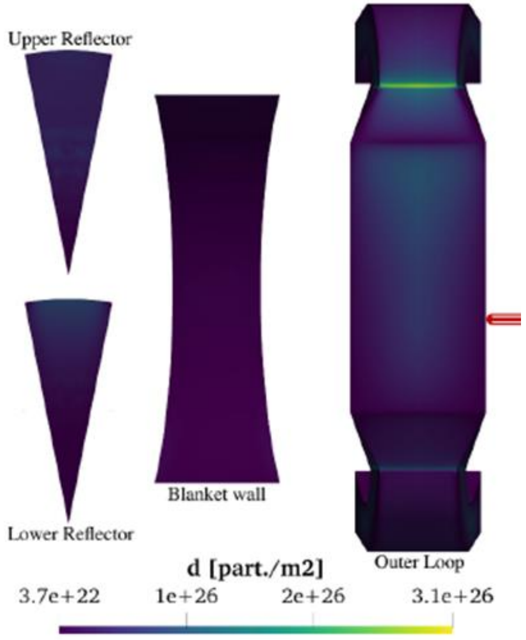


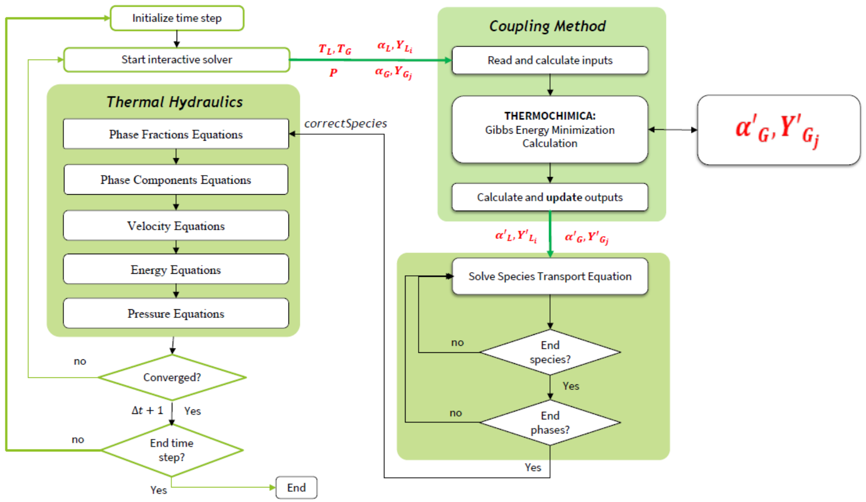
WP2: Fuel salt retention

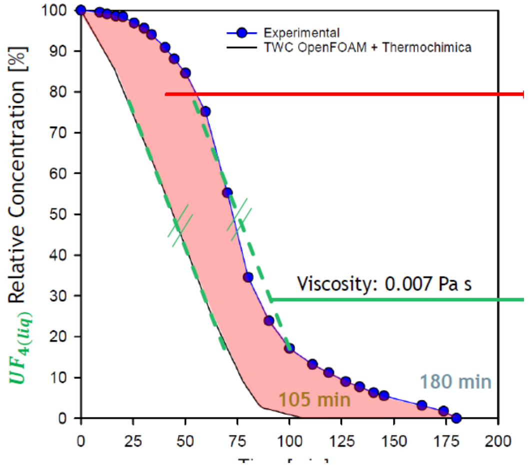


- **Novel Data on Fuel Properties and influence of FP-** Data on Meting points, vaportization, fusion enthalpy, vaporization /boilin point, phase diagrams measured for Fluorides (FUNaK) and chlorides (NaCL-PuCl3). Viscosity data.

- **Modelling and simulation of thermo-chemistry behaviour.** Implementation of JRCMSD into Thermochimica + Coupling of Thermodynamics with Multi-Physics simulation and validation with fluorination process ($UF_4 + F_2 \rightarrow UF_6$) + Multiphysics simulation for the transport, precipitation, deposition of metallic FP





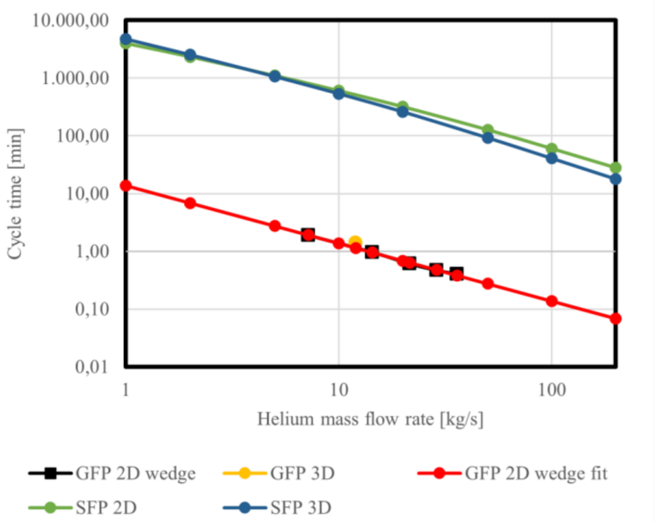


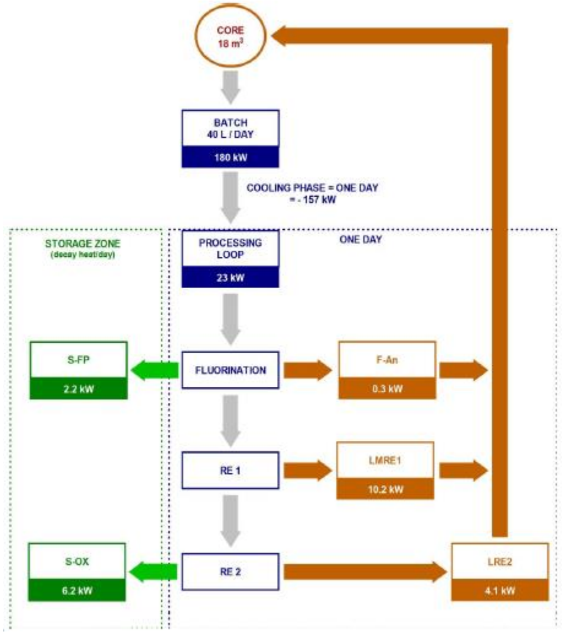
WP3: Source term distribution and mobility

- **Assessment of the efficiency of the He bubbling offgas system.** Relevant for the assessment of radioactive source in the nuclear plant. Different physics to be included: FP diffusivity (dependent on particle size), migration of GFP to helium (solubility), flotation. CFD-based M&S developed. SFP removal rate are 140x slower than GFP removal rate

- **Analysis of the material exchange with the reprocessing unit.** Determination of the isotopes in the reprocessing plant and need for testing the reprocessings steps (fluorination and chlorination, reductive extraction, precipitation)

- **Simulation of source term.** Capability of the burnup code to deal with the offgas system, fuel treatment unit and redox control. Needed for calculating the distribution of nuclides in all locations of the MSFR system, their radiotoxicity and decay heat. Benchmark created.



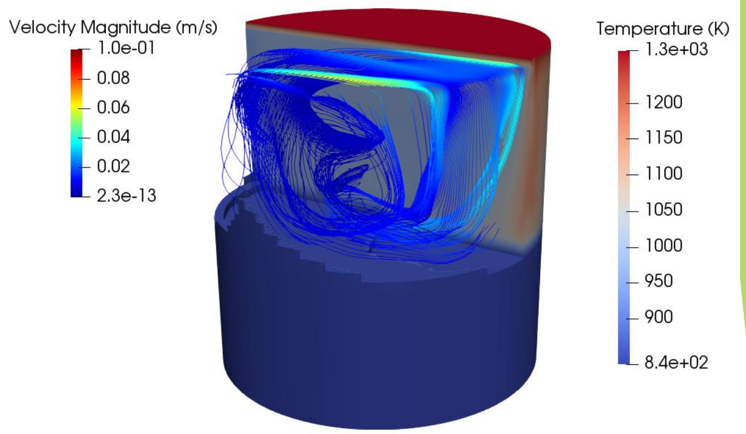


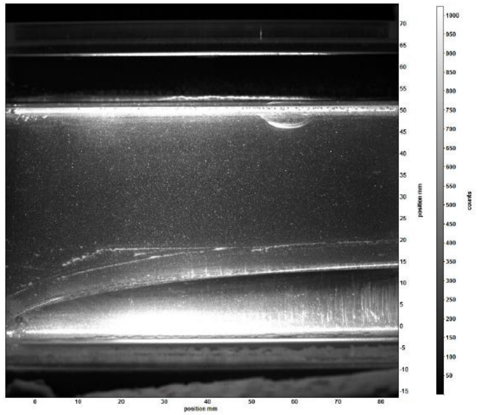
WP4: Fuel salt confinement

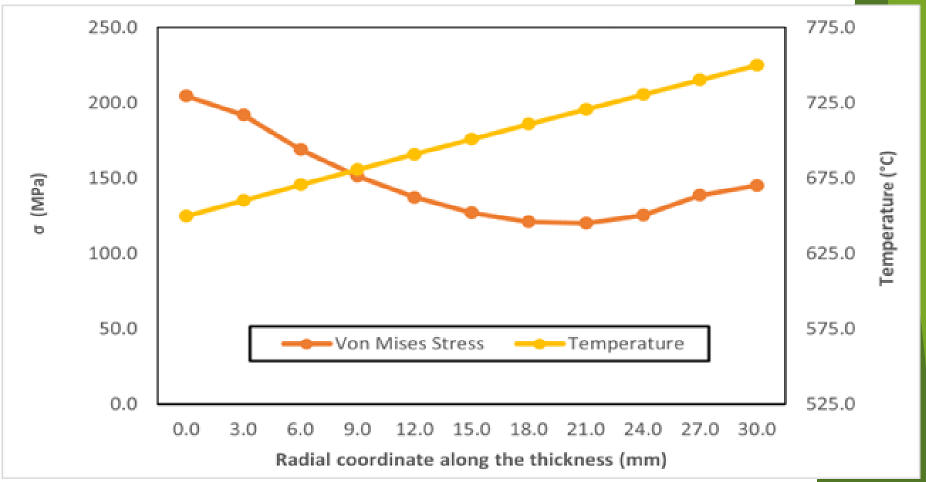
- **Code development for phase-change modeling including benchmark study.** An energy-conservative DG-FEM approach for solid-liquid phase change and an OpenFOAM solver has been developed for modelling melting and solidification

- **Verification & Validation.** Design and construction of ESPRESSO facility: experiments for transient ice-growth in forced internal flow + development of a numerical benchmark for modelling phase change in Molten Salt Reactors

- **Thermo-mechanical analysis of the confinement.** Map of thermal load, pressure and fluence on the reactor confinement (OF multiphysics solver) + Thermo-mechanical analysis: reducing thermal stress along the containment thickness to reduce thermal creep



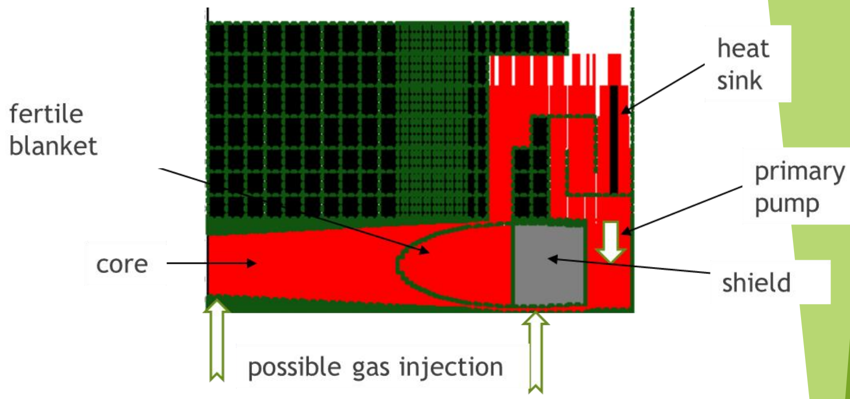




SAM SAFER

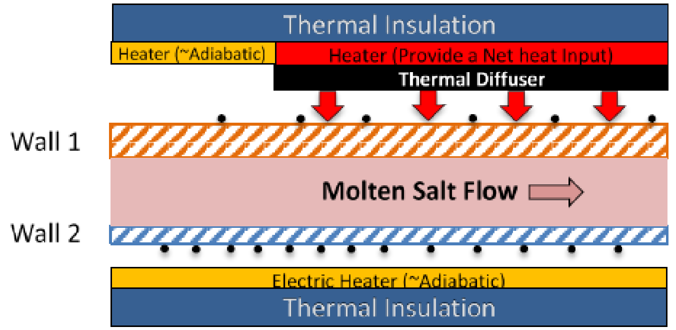
WP5: Heat removal and temperature control

- **Extension & Validation of SIMMER .** SIMMER extended to simulate gas injection. Good results with the comparison against Castillejos experiment



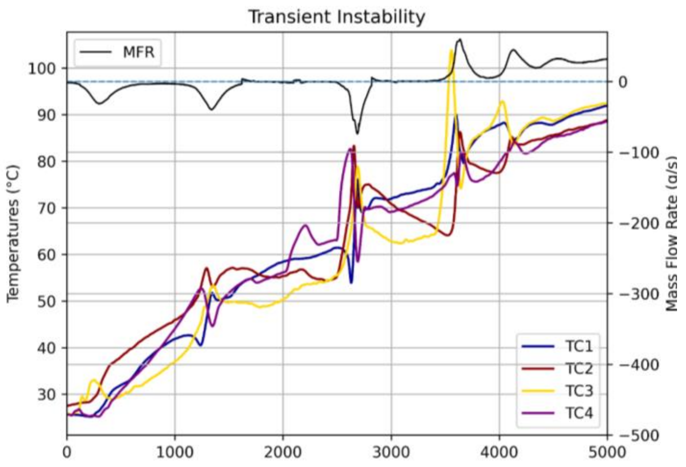
- **Radiative heat transfer experiments (SWATH) + modelling**

Radiative heat transfer experiments in SWATH-S with circulating salt in a flat section and in open channel (exchange with environment, surface tension and presence of solidification phenomena)



- **Natural circulation experiments (DYNASTY) + 2D cavity**

Studies on startup of natural circulation, transition from forced to natural circulation, passive heat removal during cool-down. Stability in 2D configuration has been also analyzed



SAM SAFER

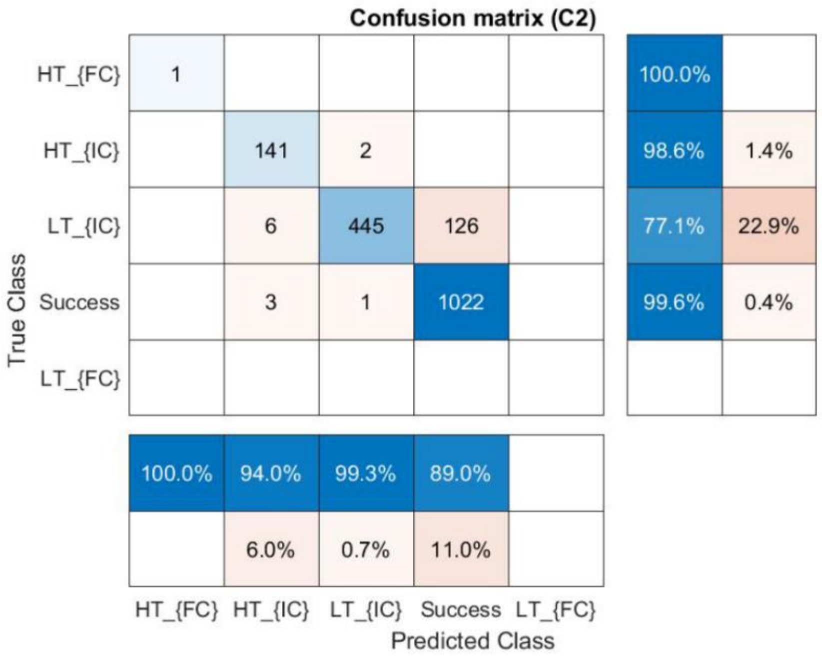
WP6: Reactor operation, control and safety

- **Definition of operational states, operational and safety margin.** Definition of safe and controlled states relevant for the accident prevention (monitoring, inspection and maintenance) and mitigation

- **Redox control for corrosion limitation.** he ratio U(IV)/U(III) directly related to the corrosion. For MSFR, addition of U metal can limit the corrosion

- **Development of incident detection methods, based on measureable plant parameters, to identify abnormal conditions.** Starting from a power plant simulator, a kNN classifer is trained to classify the monitoring signals of MSFR for fault detection

What happens to parameter in column A when the parameter in the other column increases? (considering other parameters constant)	Fuel salt temperature	Fuel salt flowrate	Reactor thermal power	Reactivity	Fuel salt level
Fuel salt temperature		Average T is stable (critical T) DT decreases as long as IHX is able to remove heat. Does fuel flow has an impact on heat production?	Average T is stable (critical T) DT increases	Average T increases and comes back to critical T DT increases	No impact (but reversely, if T increases, lvl increases)
Fuel salt flowrate (forced flow)			No impact	No impact	No impact
Reactor thermal power				Increases	No impact
Reactivity					Depends on reactor status: - during reactor filling: increase of reactivity - while reactor is full: no impact
Fuel salt level					



WP7: E&T, dissemination and exploitation

Education and training, dissemination and exploitation

- Online school available at YouTube channel of the SAMOSAFER project (https://www.youtube.com/@samosafer4017/videos)
- YMSR Conference (Lecco, June 6 – 8, 2022). Book of abstract and presentations available at https://samosafer.eu/2022/06/07/young-msr-conference-6-8-june-2022/
- 22 Journal Papers, 20 Conference papers disseminating the results of the project (up to now). Find the full list here https://samosafer.eu/publications-2/
- Zenodo community in which OA papers and dataset are published https://zenodo.org/communities/samosafer
- >45 Outreach events
- Exploitation event https://samosafer.eu/final-meeting-exploitation-workshop/

The ENDURANCE project

Eu kNowleDge hUb foR enAbling molteN salt reaCtor safety development and dEployment

Grand objective of the ENDURANCE: "to support the safe operation and the technological development of Molten Salt Reactor (MSR) technology in Europe, through the knowledge advancement in different fields of MSR research and safety assessment, connecting the needs of reactor designers and industry with the university and research centre capabilities and the regulator requirements."

Strength the European ENDURANCE on the MSR development

EU kNowleDge hUb = involvement of EU stakeholders & connections among research, lab & industry to maintain EU leadership in MSR technology

for enAbling MolteN Salt ReaCtor safety development and dEployment = bring the MSR technology safety development from research (TRL 1-3) to development (TRL 4-6) and deployment (TRL 7-9)

Four years project. Starting date: October 1st 2024, Budget: ~4 mln €

ENDURANCE

Partners

KIT
Karlsruher Institut für Technologie

cnrs

HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

Berkeley
UNIVERSITY OF CALIFORNIA

POLITECNICO
MILANO 1863

framatome

THORIZON

GRENOBLE
INP
UGA

JRC
EUROPEAN COMMISSION

naarea

NRG

TU Delft

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

PSI

STELLARIA

cea

Politecnico
di Torino
1859

IRSN

ETH zürich

CVŘ

SEABORG

High Level Objective - HLO1

HLO1 – "to create an environment for a constructive alignment aimed at the development of MSR among designers, university, research centers and TSO, maintaining the competence inside the Europe"

HLO2 – "enable the MSR safe development and deployment increasing the SRL and the TRL on key enabling phenomena, technologies and methodologies (Critical Technology Elements) and filling R&D gaps" → The focus is not on (a specific) design but it is rather on the scientific and technological challenges!

HLO3 – "Identify the future R&D needs required to enable the safe development of MSR in Europe and define the technology roadmap development to preserve research and industry leadership in Europe on MSR technology"

Critical Technology Elements

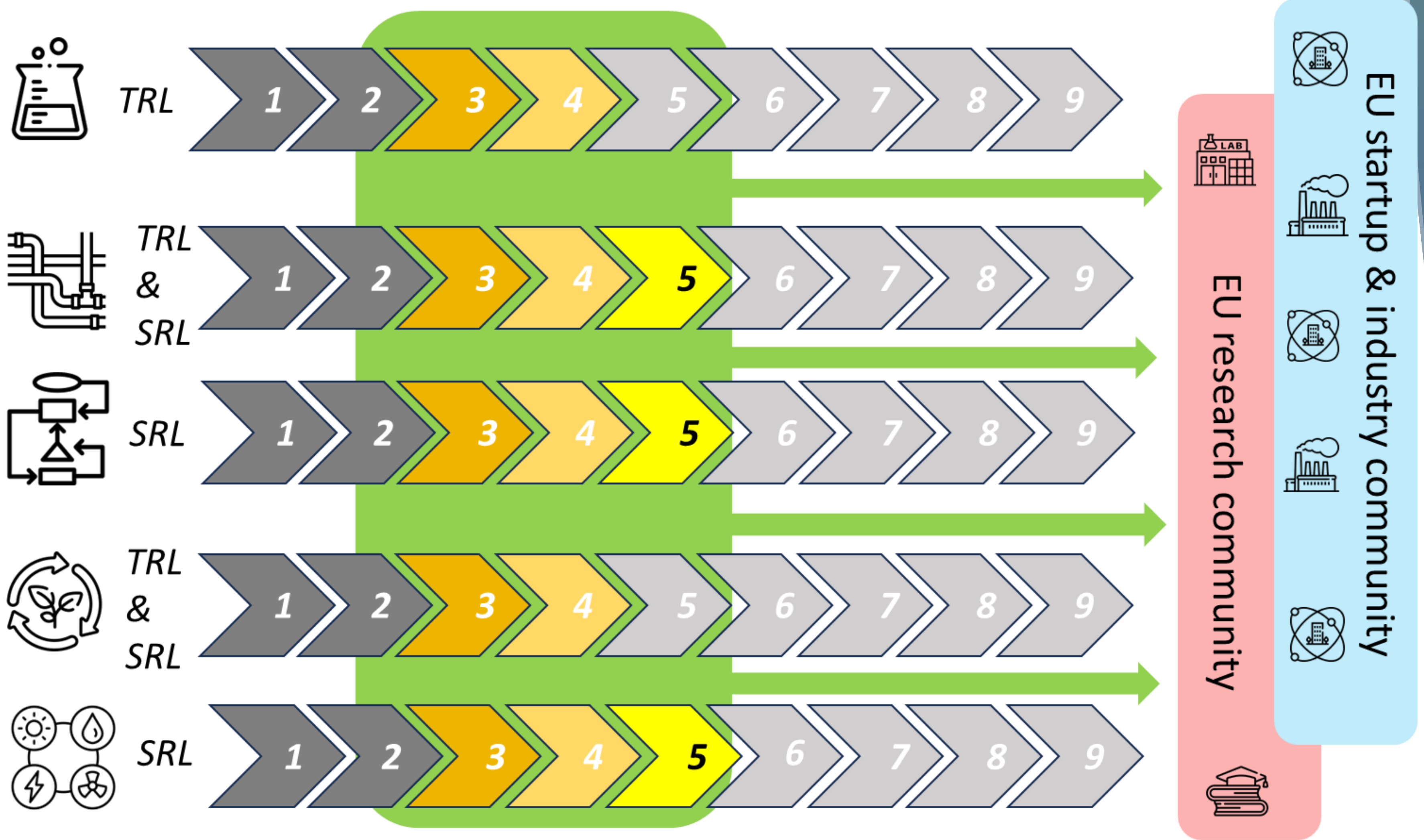
CTE1: Chemistry of fuel salt and structural materials in reactor environment

CTE2: Experimental evidence on safety related phenomena

CTE3: Modelling preparedness for safety and licensing

CTE4: Sustainability & safeguards compliance of MSR fuel cycle

CTE5: Demonstration of safe MSR adaptability in future decarbonized energy scenario



Chemistry of fuel salt and structural materials in reactor environment

Objectives:

- to provide experimental data and models on density, viscosity, and thermal conductivity of fission products systems, i.e., systems representative of irradiated fuel salt
- to address the combined effects of salt corrosion with respect to mechanical stress and irradiation.

Activities:

- Organize a round robin campaign on thermo-physical property measurements of salts;
- Define best practices for accurate measurements of thermochemical and thermophysical properties;
- Develop a density and viscosity database coupled to the JRCMSD;
- Perform sequential corrosion-mechanical stress and corrosion-creep tests
- Post-Irradiation Examinations (PIE) of SALIENT-03 campaign.

Experimental evidence on safety-related phenomena

Objectives

- To increase the knowledge of the phenomena that are relevant for safety-related components (e.g., passive safety systems, safety functions, …) by collecting new experimental data
- To improve the current understanding on safety-related phenomena and to provide recommendations for the MSR design.

Activities:

- Validate numerical models for the transport of the solid fission products, deposition on the structural components and interaction with bubbling system
- Assess the stability of natural convection in 3D geometry with molten salts;
- Evaluation of integral neutronics parameters in LR-0 reactor
- Define specification requirements for large experimental facilities for MSRs

Modelling preparedness for safety and licensing

Objectives

- to enable the compatibility of design studies and problem-oriented R&D with the European regulatory environment.
- to demonstrate the possibility to compensate the lack of practical experience involving modelling and simulation directly in the safety assessment of MSR

Activities:

- PIRT study to enhance the understanding of safety-related processes and factors that should be simulated + Target Accuracy Requirements
- develop computational chains combing well-elaborated system codes and high-fidelity to estimate uncertainties of such modeling;
- develop and perform relevant numerical and experiment-based benchmarks

Sustainability and safeguards compliance of MSR fuel cycle

Objective

- contributing to the evaluation of the sustainability, proliferation resistance and safeguardability of the fuel cycle options and reprocessing schemes for MSR

Activities:

- providing standardized methods to preliminary assess sustainability of fuel cycle performance of MSR concept
- simulating the detailed nuclides flow inside the MSR system
- analysis of possible salt clean-up and reprocessing techniques to assess their efficiency, pace and proliferation resistance;
- simulating the radionuclide releases from fuel salt during nominal condition and at elevated salt temperature
- evaluating the proliferation resistance and safeguardability of different reprocessing schemes and fuel cycle options;

Demonstration of safe MSR adaptability in future decarbonized energy scenario

Objective

- analysing the safety aspects of the MSR flexibility in terms of operation and cogeneration requirements to safely adopt the MSR in an energy mix with intermittent energy sources.

Activities:

- highlight the operation strategy, potential limitations and opportunities for flexible use of MSRs
- select cogeneration options for MSR systems and define energy conversion system configurations to cope with non-electrical end-usages;
- enhance and extend the numerical simulation tools to analyse the whole plant configuration arrangement and take into account the operating conditions and the plant dynamics situations to consider;
- identify specific safety issues coming from flexibility performance from a functional safety analysis perspective.

SAMOSAFER ENDURANCE

SAMOSAFER Grant Agreement n° 847527
ENDURANCE Grant Agreement n° 101165896

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Atomic Energy Community ('EC-Euratom'). Neither the European Union nor the granting authority can be held responsible for them.

Methodology

Phase 1 (M1 – M6)

Collection of design data + identification of R&D issues

- to align the analysis and research to the development requirements
- to provide a database on the EU MSR design

Fuel compositions

Design data

Safety systems

Phase 2 (M4 – M45)

CTE1: Chemistry of fuel salt and structural materials in reactor environment

CTE2: Experimental evidence on safety related phenomena

CTE3: Modelling preparedness for safety and licensing

CTE4: Sustainability & safeguards compliance of MSR fuel cycle

CTE5: Demonstration of safe MSR adaptability in future decarbonized energy scenario

Scientific and technology development (experiments, modelling development, critical evaluation, assessment study, qualification, ….)

- to improve the TRL and SRL of the selected CTEs

Scientific and technological results

Phase 3 (M44 – M48)

Critical analysis of the results and proposal for further technological development

Outcome & Impact creation for MSR technology