The EU SAMOFAR project goals and contents

SAMOFAR

SAMOFAR: Participants

Number	Organisation	Country
1 (Coordinator)	Technische Universiteit Delft (TU Delft)	The Netherlands
2	Centre National de la Recherche Scientifique (CNRS)	France
3	JRC – Joint Research Centre– European Commission (JRC)	Germany
4	Consorzio Interuniversitario Nazionale per la Ricerca Tecnologica Nucleare (CIRTEN)	Italy
5	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)	France
6	Centro de Investigaciony de Estudios Avanzados del Instituto Politecnico Nacional (CINVESTAV)	Mexico
7	AREVA NP SAS (AREVA)	France
8	Commissariat a l'Energie Atomique et aux Energies Alternatives (CEA)	France
9	Electricité de France S.A. (EDF)	France
10	Paul Scherrer Institute (PSI)	Switzerland
11	Karlsruher Institut für Technologie (KIT)	Germany

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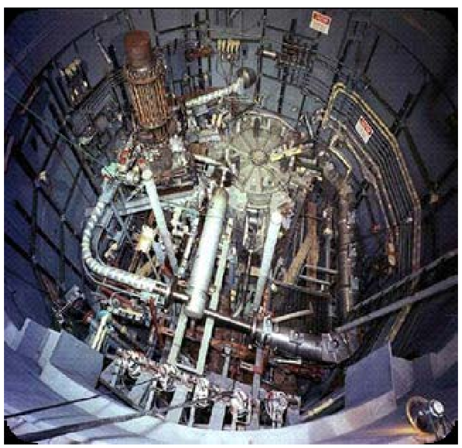
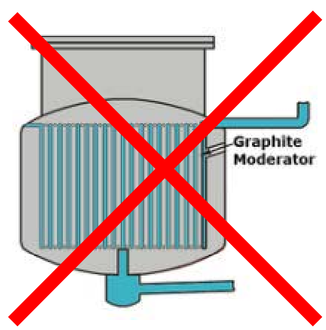
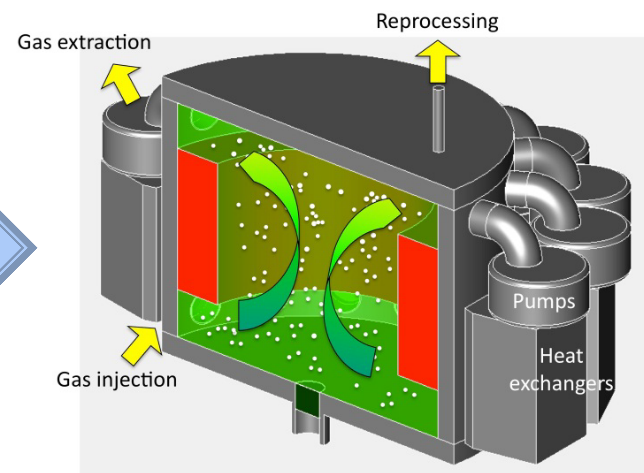
EU reference design

- From thermal to fast neutron spectrum.
- The first MSRs were thermal reactor designs, but since 2005 the EU R&D focuses on the Molten Salt Fast Reactor (MSFR).







General characteristics of MSR

- Molten fluorides as fuel fluid (homogeneous core)
- Wide range of fuel composition, *even* during operation
- Low-pressure and high boiling-point coolant
- Possibility to drain fuel passively in drain tanks with passive decay heat removal
- On-site fuel reprocessing (continuous or batch wise)
- Strong ionic bonding of all other fission products

Specific features of MSFR

- Strong negative reactivity feedback coefficients *everywhere* in the core (thermal and void)
- Fast reactor with its core in most reactive state
- Paradigm shift in reactor safety: let the fuel flow!
- Wide range of fuel composition: from *burner* to *breeder* in one reactor design
- Fuel cycle ideal for continuous recycling of actinides
- Ultimate goal: no control rods

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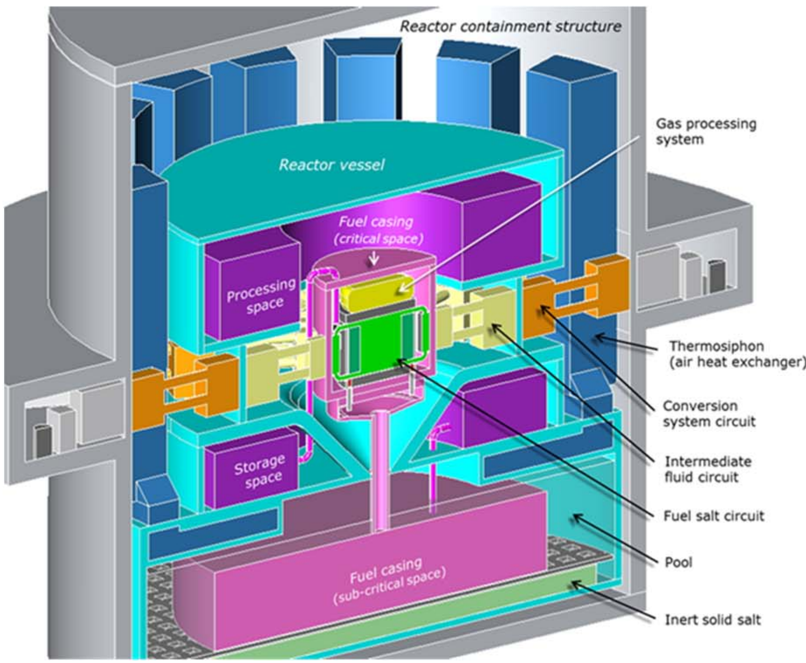
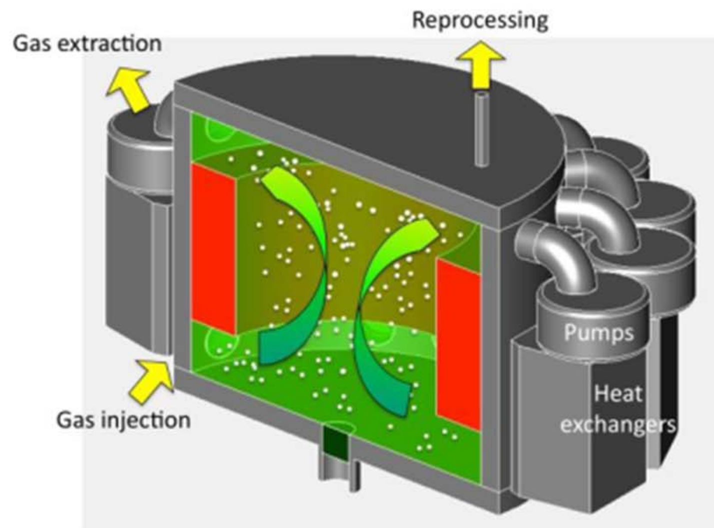
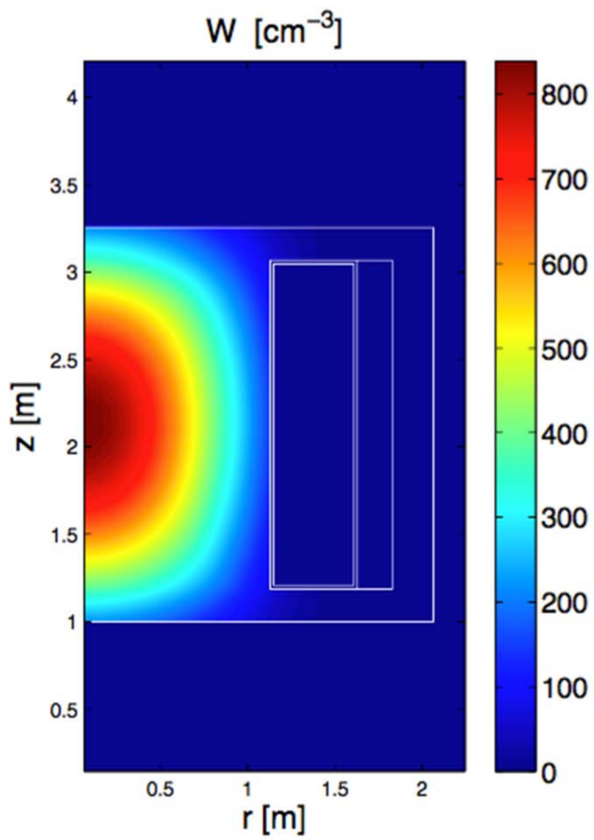
Molten Salt Fast Reactor

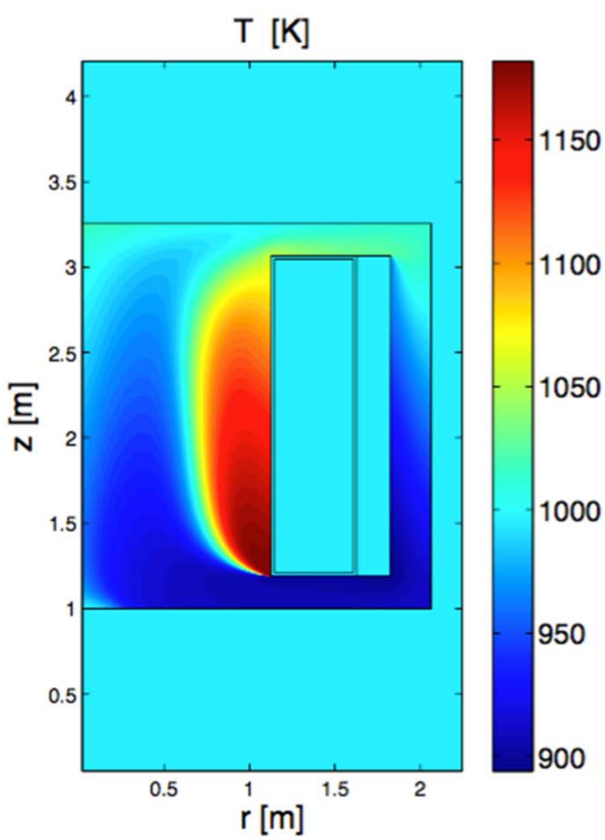


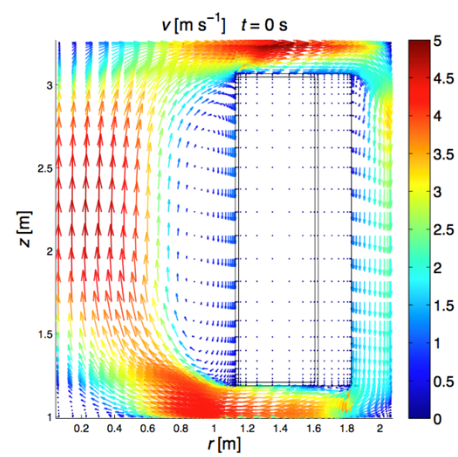


CNRS, Grenoble

Molten Salt Fast Reactor







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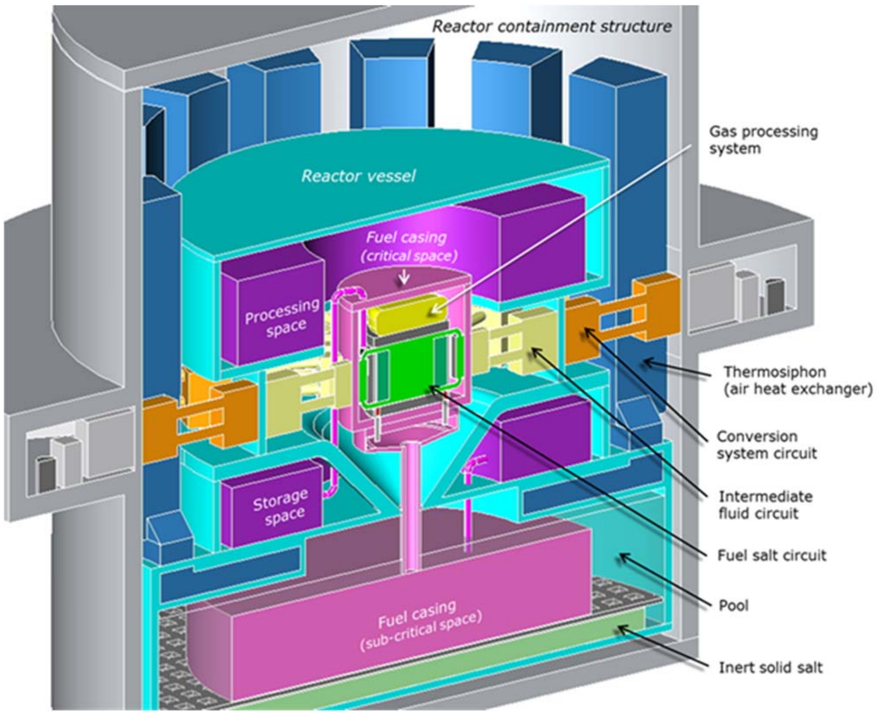
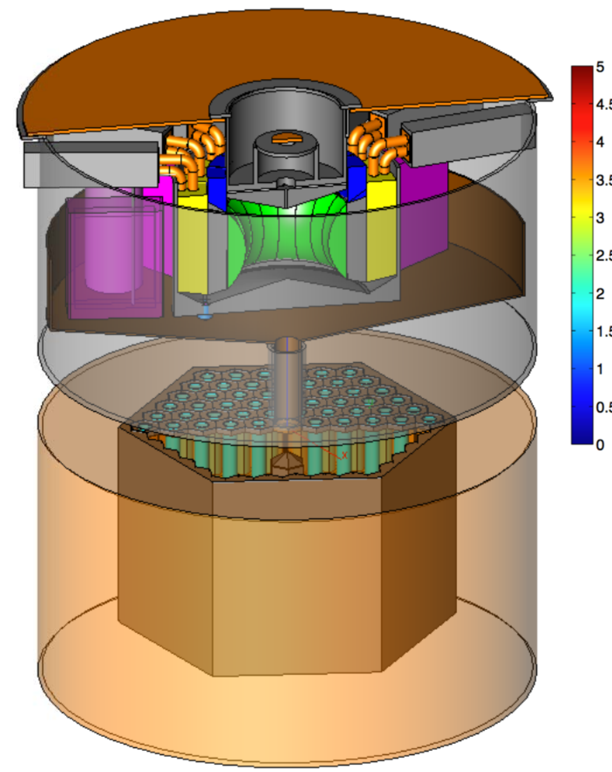
Molten Salt Fast Reactor

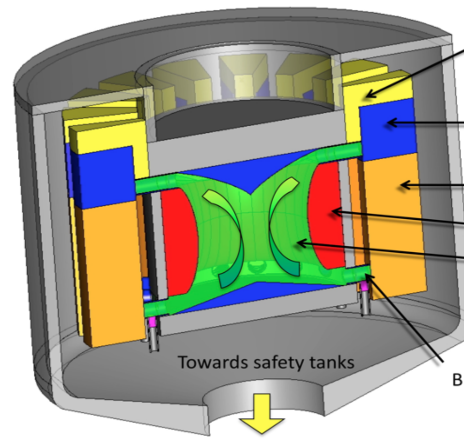


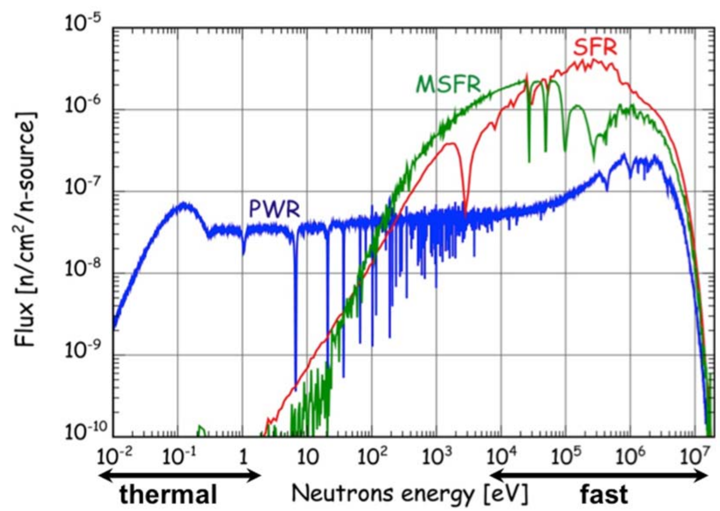


CNRS, Grenoble

Molten Salt Fast Reactor

Thermal power	3000 MWth
Mean fuel salt temperature	725 °C
Fuel salt temperature rise in the core	100 °C
Fuel molten salt - Initial composition	$LiF-ThF_4-UF_4-(TRU)F_3$ with (77.7-6.7-12.3-3.3 mol%) and U enriched at 13%
Fuel salt melting point	585 °C
Fuel salt density	4.1 g/cm^3
Fuel salt dilation coefficient	$8.82\ 10^{-4}$ / °C
Fertile blanket salt - Initial composition	$LiF-ThF_4$ (77.5%-22.5%)
Breeding ratio (steady-state)	1.1
Total feedback coefficient	-5 to -8 pcm/K
Core dimensions	Diameter: 2.26 m Height: 2.26 m
Fuel salt volume	18 m^3 (½ in the core + ½ in the external circuits)
Blanket salt volume	7.3 m^3
Total fuel salt cycle	3.9 s





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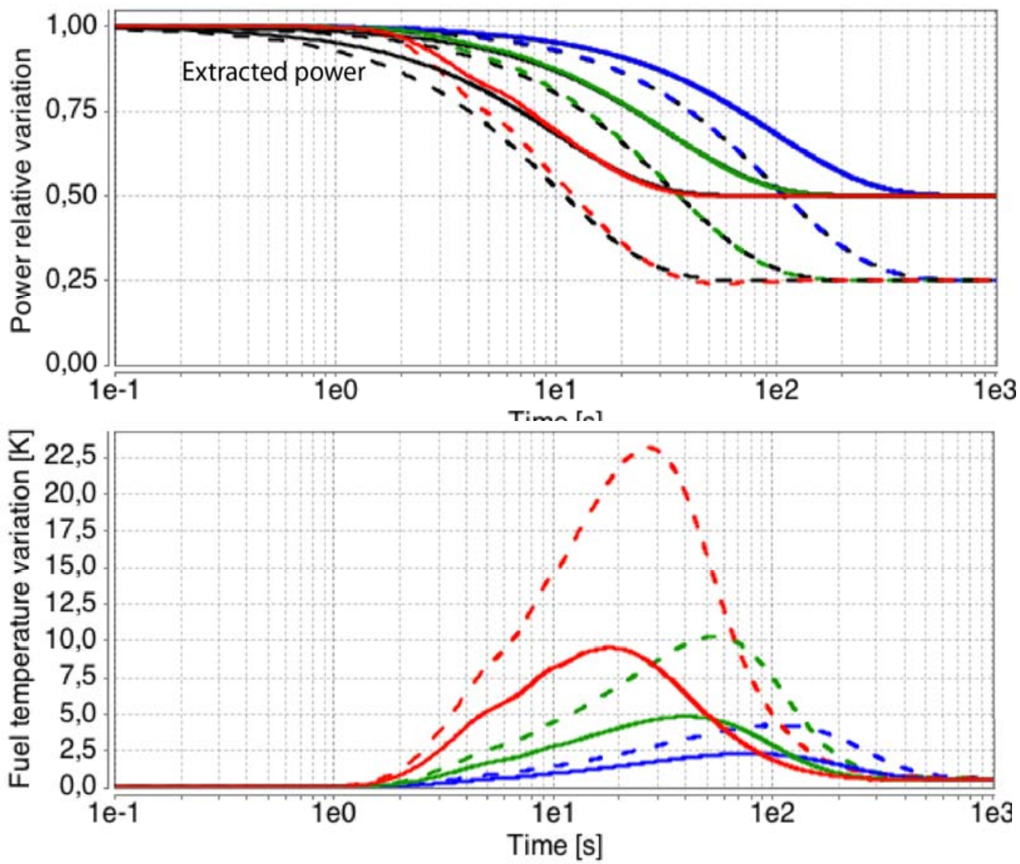
Molten Salt Fast Reactor



Colored lines: Fission power

Black lines: Extracted power

50% power change in just a few minutes!

Elsa Merle-Lucotte *et al*, ICAPP 2015, Nice, France

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SAMOFAR: Aim of the project

- The grand objective of SAMOFAR is to:
  - Prove the innovative safety concepts of the MSFR,
  - Deliver breakthrough in nuclear safety and waste management
  - Create a consortium of stakeholders to demonstrate the MSFR beyond SAMOFAR

- Main results are:
  - experimental proof of concept
  - (integral) safety assessment of the MSFR
  - update of the conceptual design of the MSFR
  - roadmap and momentum among stakeholders

SAMOFAR
WP1: Integral safety assessment

- Development of a power plant simulator
- Dynamic behavior of MSFR including startup, shut-down, control, load-follow operation
- Development of an integral safety assessment methodology
- Risk assessment based on integral safety method
- Proliferation aspects
- …

WP1: Accident categorization

Fuel circuit accidents

- LOHS - Loss Of Heat Sink
- LOFF - Loss Of Fuel Flow
- TLOP - Total Loss Of Power
- OVC - OVer-Cooling
- LOLF - Loss Of Liquid Fuel
- RAA - Reactivity Anomalies Accident

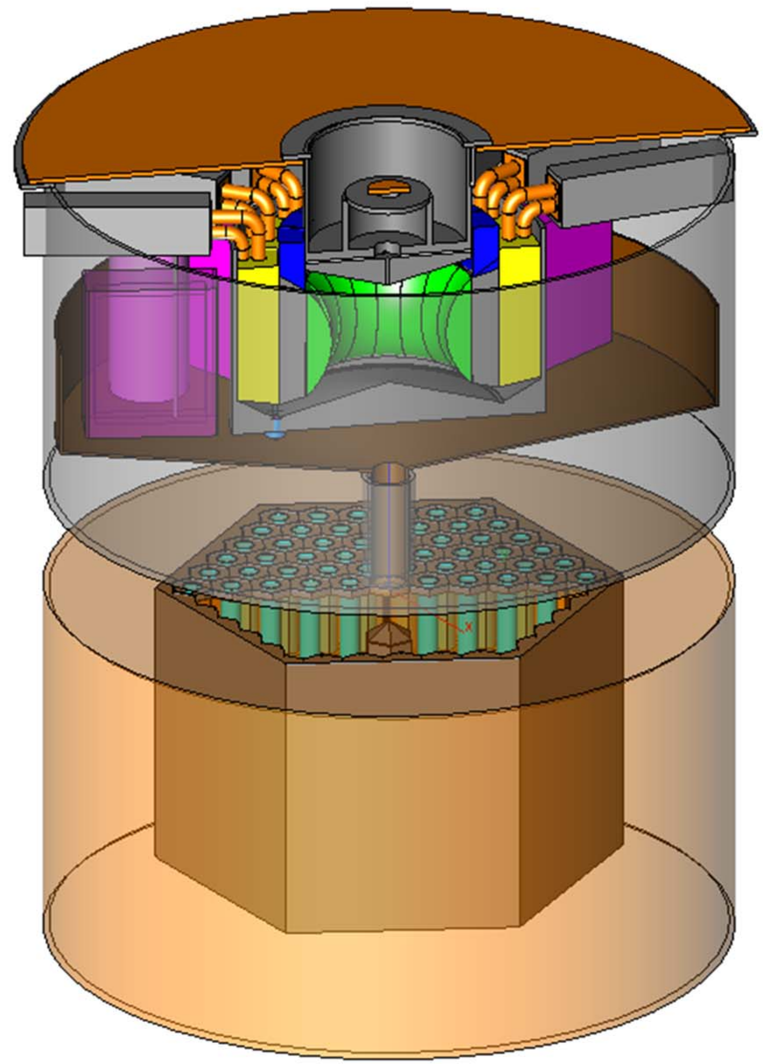
Draining system accidents

- LOHS - Loss Of Heat Sink
- LOLF - Loss Of Liquid Fuel
- DBA - Draining Blockage Accidents

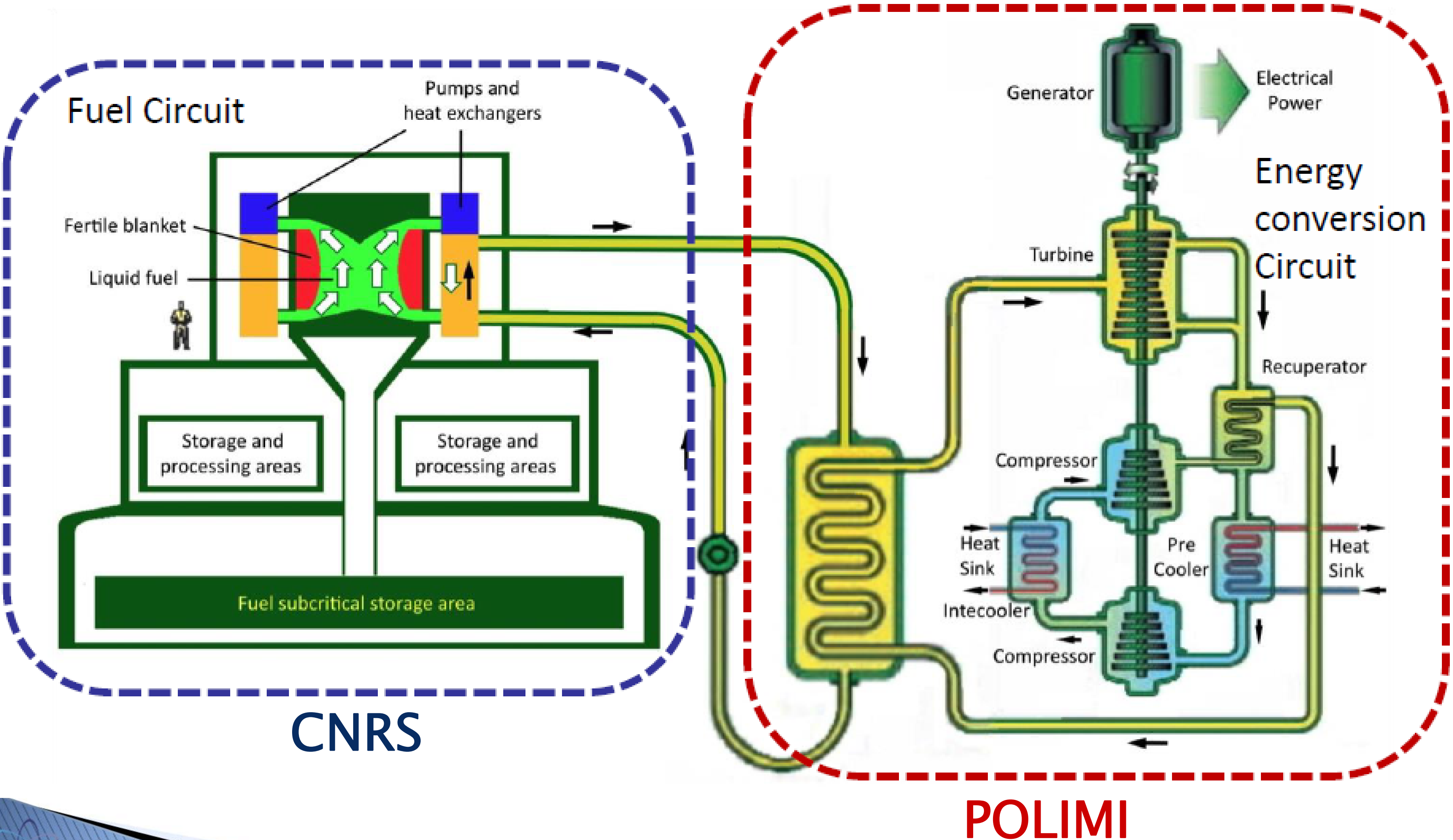
Beyond design basis accidents

- Steam pressurization accident
- Beyond design reactivity accident

Will be investigated in WP4



WP1: Simulator (CNRS+POLIMI)



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WP2: Safety related data

- Synthesis salts containing PuF_3 and UF_4
- Measurement of phase diagrams of fuel salts
- Development of experimental techniques and measurement of thermal properties of fuel salts
- Examining precipitates upon super-cooling
- Examining FP release upon super-heating (up to vaporization)
- Interaction of fuel salt with water under irradiation
- Measurement of retention properties Iodine and Cesium
- …

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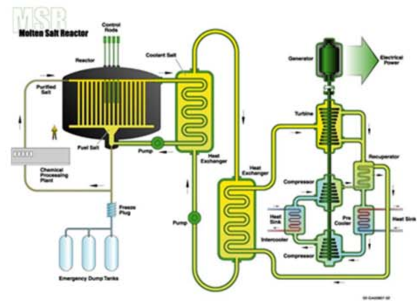
WP2: Modeling and experiments



- Neutronic properties
- Melting temperature
- Heat capacity
- Vapour pressure
- Actinide solubility
- Chemical stability to high T
- Density and Viscosity
- Thermal conductivity
- Stability to radiation

Thermochemistry

Thermodynamic modelling
(all properties linked to Gibbs energy)

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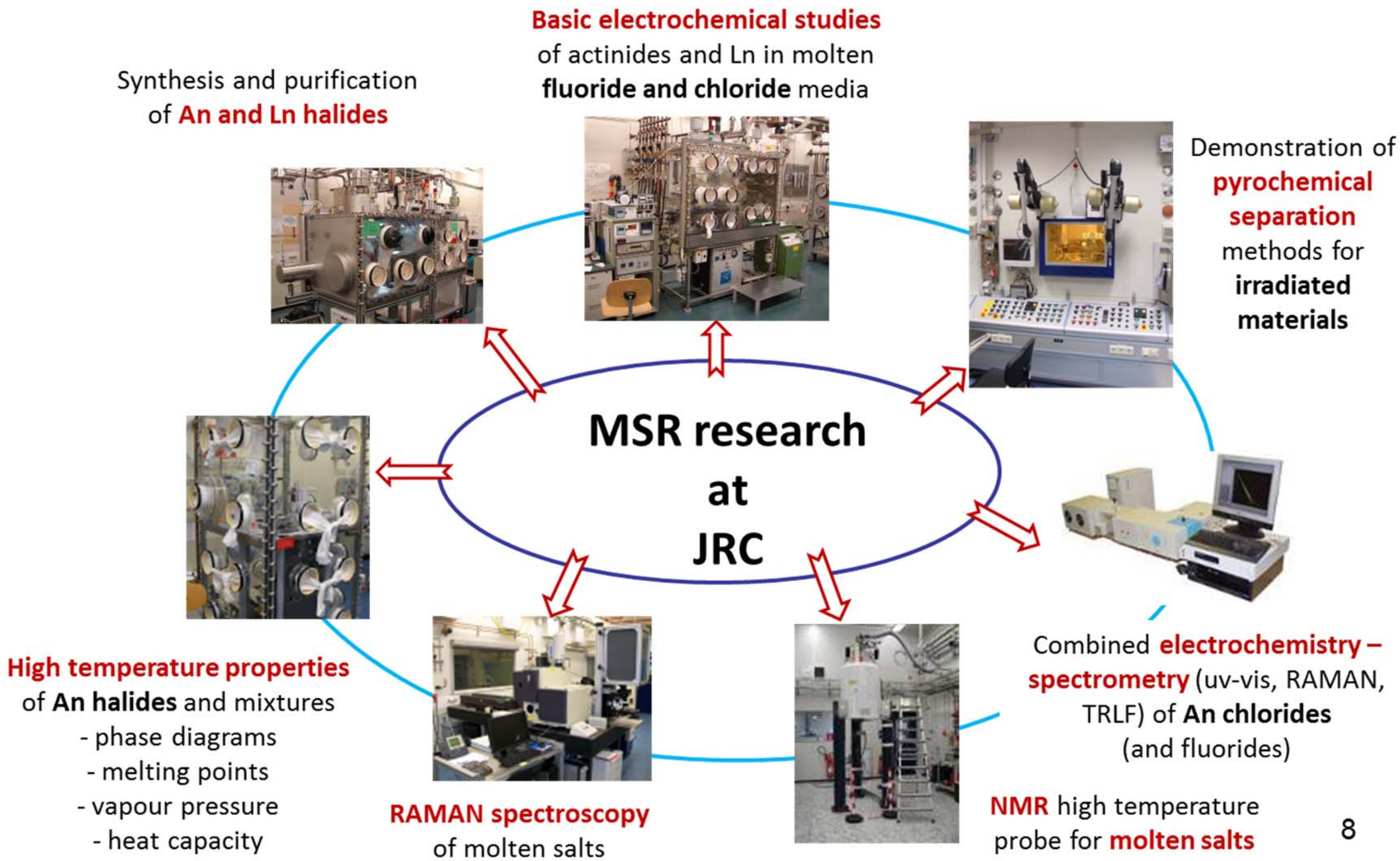
WP2: Experimental methods JRC

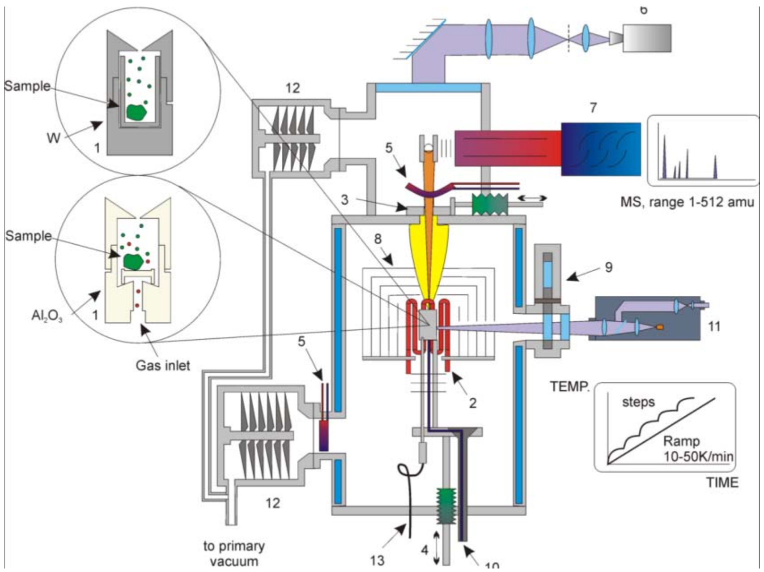


WP2: Retention properties (JRC+CNRS)

JRC-ITU: - Knudsen Effusion Mass Spectrometry of the simfuel samples containing Cs and I in their likely chemical form:

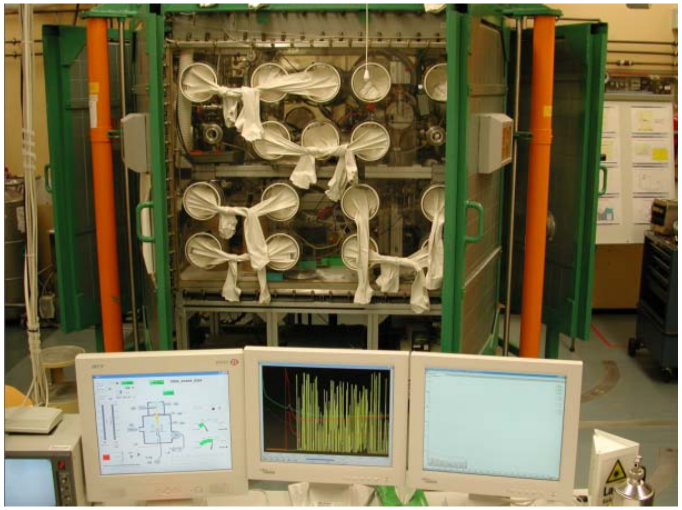
- o CsI dissolved in Flinak
- o CsI dissolved in the LiF-ThF4 eutectic
- o CsF dissolved in the LiF-ThF4 eutectic

- Comparison to irradiated oxide fuel will be made
- Identification of the frozen phase (extra)



CNRS (Toulouse):

- Te chemistry vs. redox potential (most likely in the LiF-CaF2 solvent)



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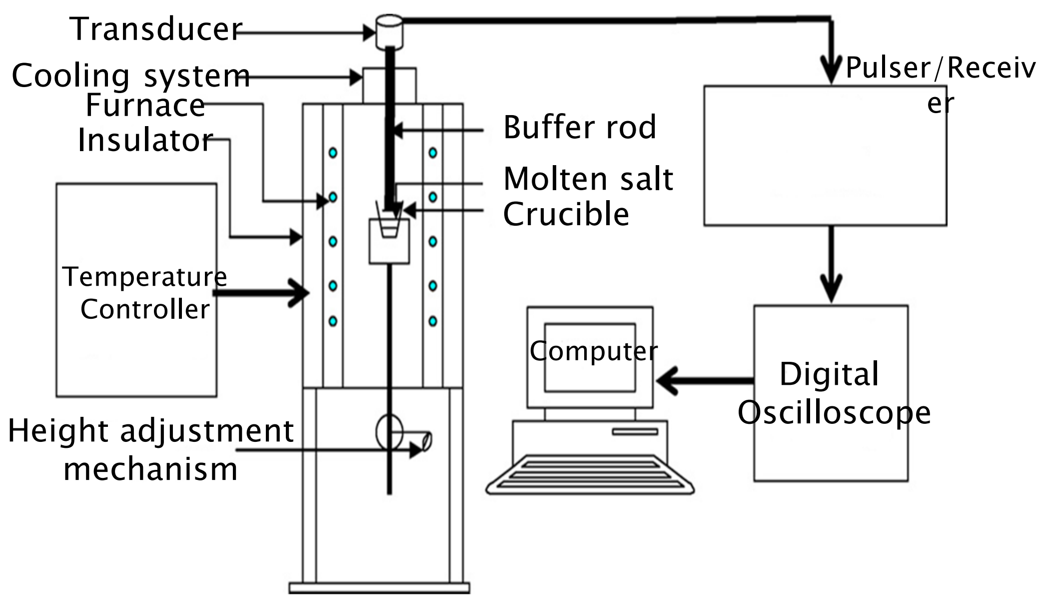
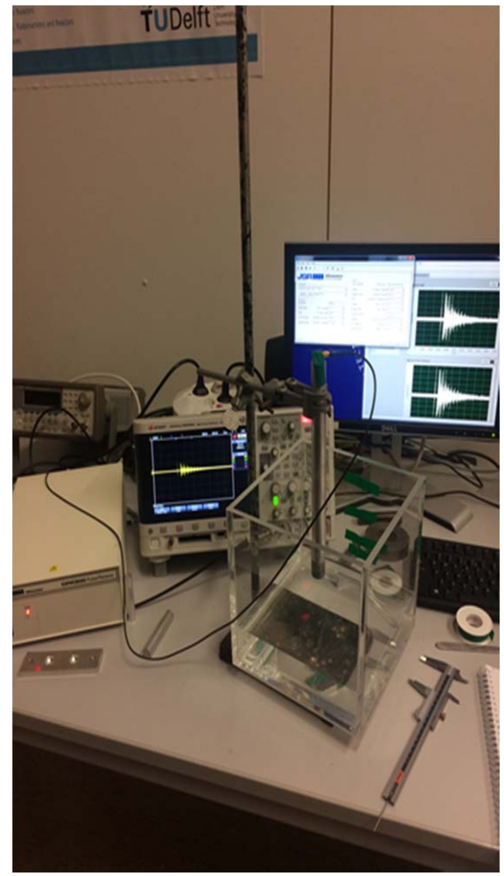
WP2: Viscosity measurements (TU Delft+JRC)

Ultra-sonic Viscometer

- Simultaneous measure of viscosity and density at high temperature
- Using a very small amount of sample with a non intrusive in line device



Prasad et al.; 2008; J. Mat. Proc. Tech. 207 315-320



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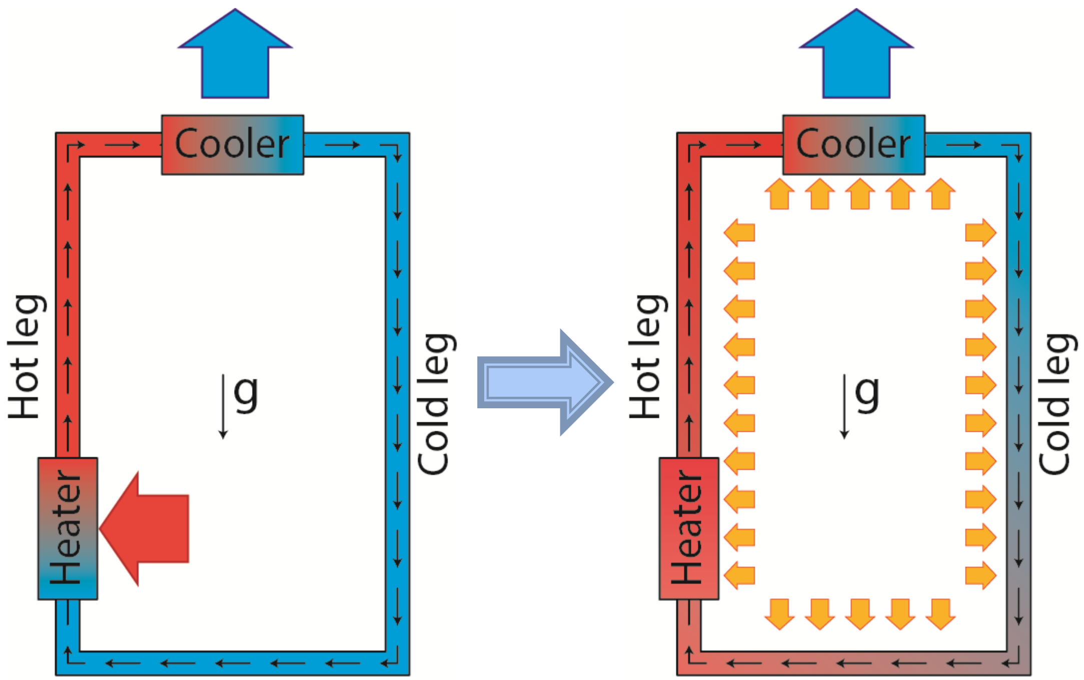
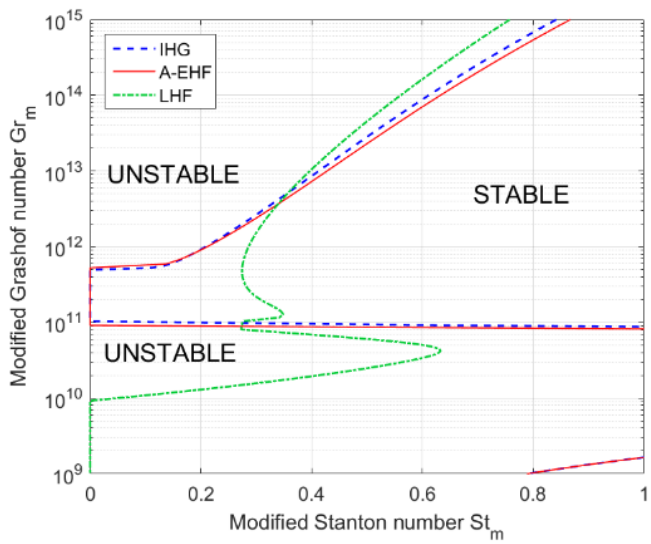
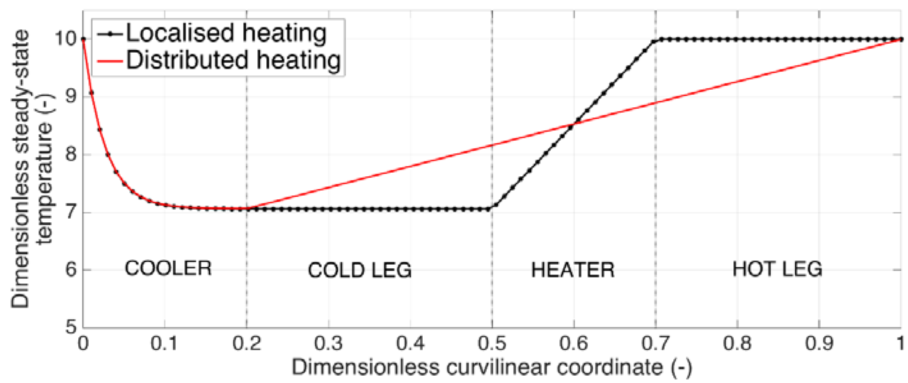
WP3: Experimental validation

- Natural circulation dynamics of fuel salts with internal heating
- Calculation and measurement of natural circulation stability maps
- Physical condition of fuel salt during draining
- Freeze plug design and salt draining dynamics
- Measurement of solidification phenomena along walls
- …

WP3: Dynasty facility (POLIMI)



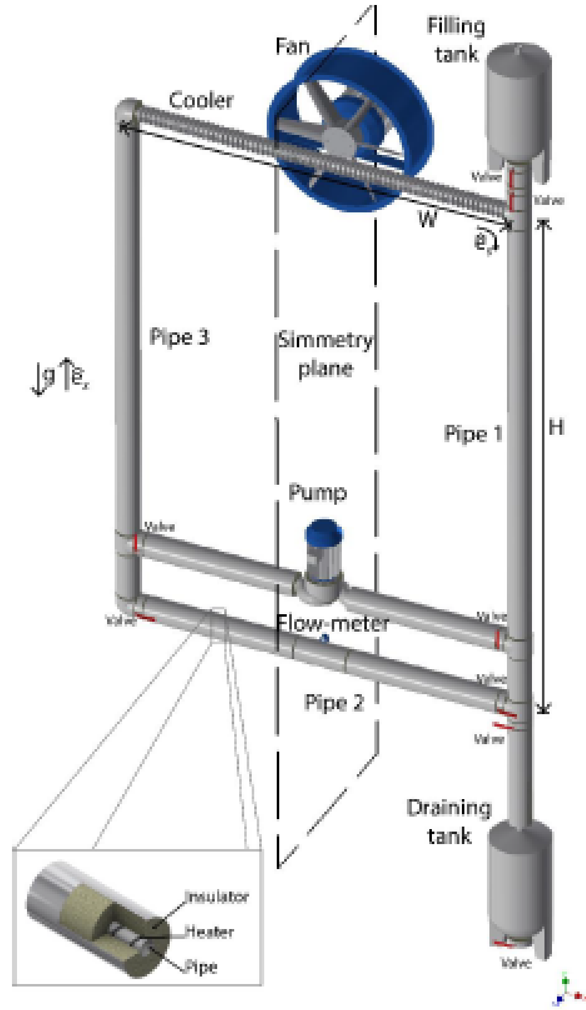




WP3 Dynasty

DYNASTY DESIGN

DIMENSIONS	Height (H): 3.2 m Width (W): 3.2 m Depth: 1.3 m Piping: ϕ 42.16 mm x t 2 mm
THERMAL CARRIER	Hitec® ($NaNO_3$-KNO_3-$NaNO_2$ 7-49-44 wt%)
MATERIAL	AISI 304/316 L
HEATING SYSTEM	UP TO 10 kW (electrical strips – fibreglass knitted and braided)
HEAT EXCHANGER	Molten salt /air finned tube (0:5 kW natural convection heat exchange, 5:10 kW forced heat exchange with FAN - 5000 m^3h^{-1})
TEMPERATURE RANGE	250 / 350 °C



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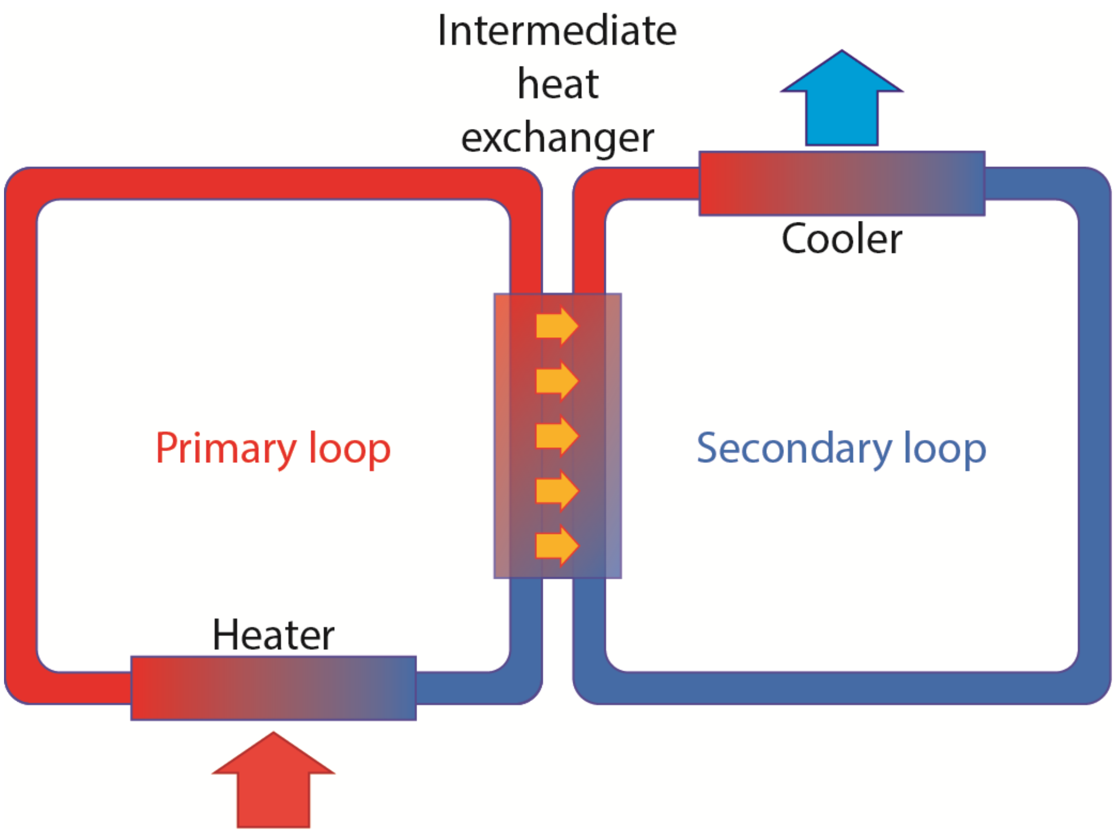
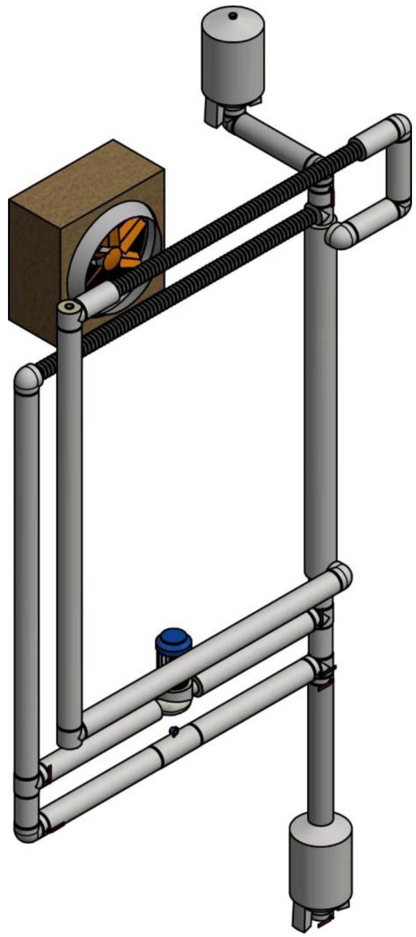
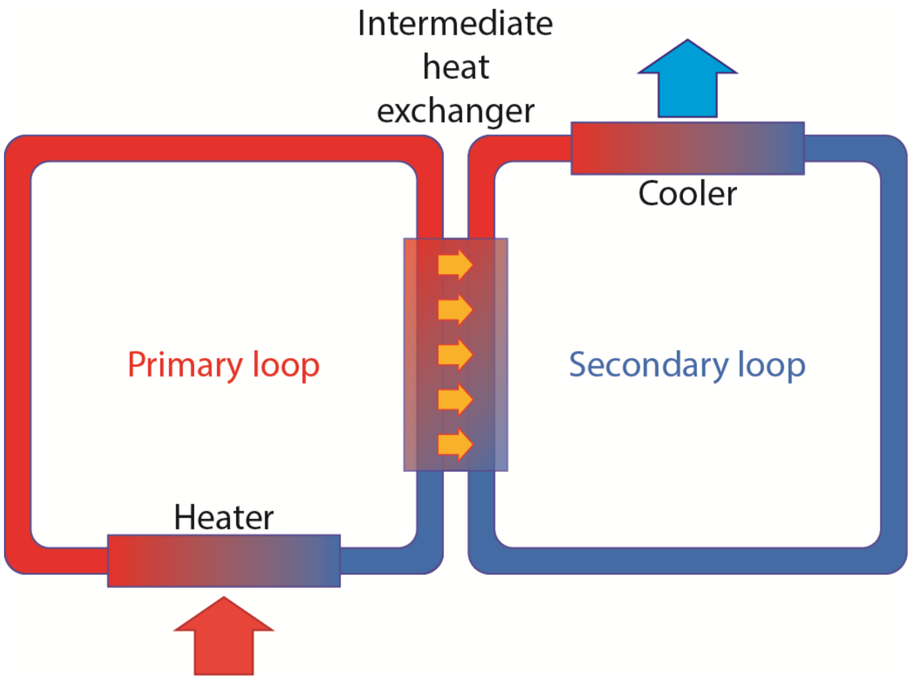
WP3: eDYNASTY coupled facility



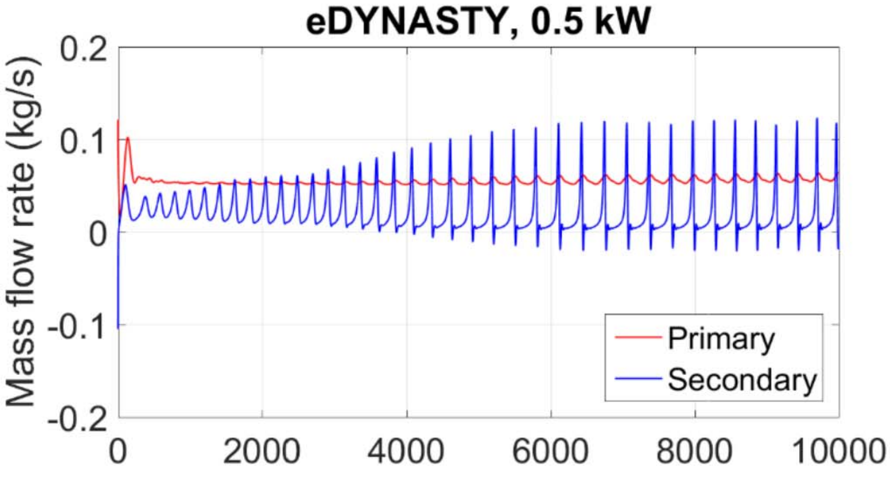


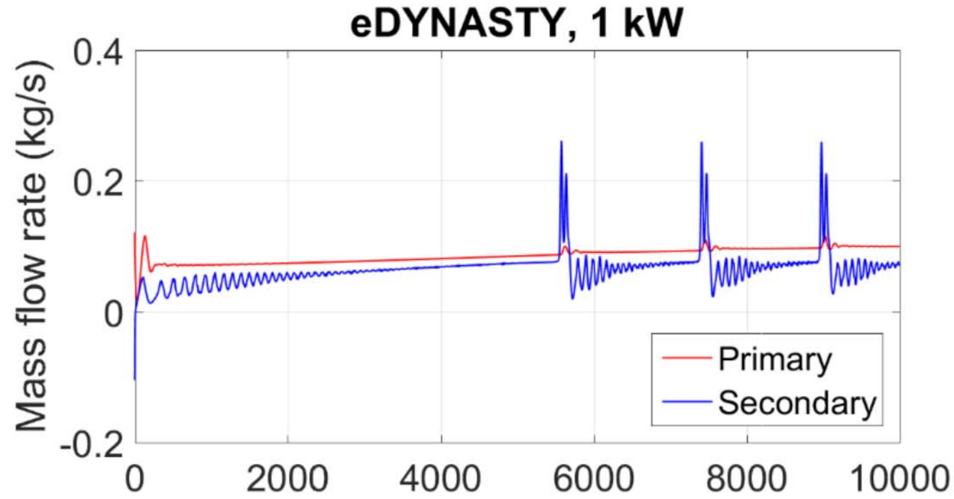
WP3: eDYNASTY coupled facility

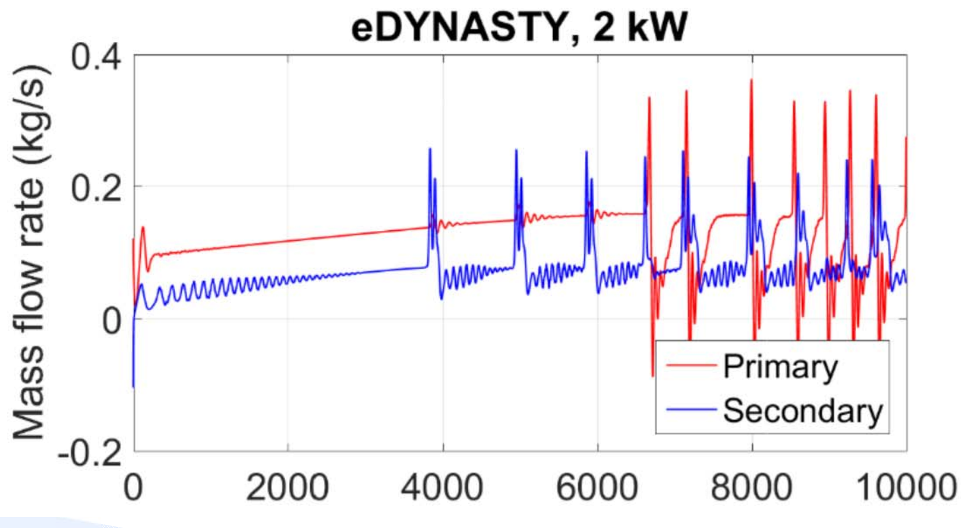


Coupled loops dynamics	
Loop 1 Loop 2	UNIDIRECTIONAL OSCILLATIONS UNIDIRECTIONAL OSCILLATIONS
Loop 1 Loop 2	UNIDIRECTIONAL OSCILLATIONS BIDIRECTIONAL OSCILLATIONS
Loop 1 Loop 2	BIDIRECTIONAL OSCILLATIONS UNIDIRECTIONAL OSCILLATIONS
Loop 1 Loop 2	MASS FLOW REVERSAL MASS FLOW REVERSAL
Loop 1 Loop 2	STABLE STABLE

WP3: eDYNASTY Modelica







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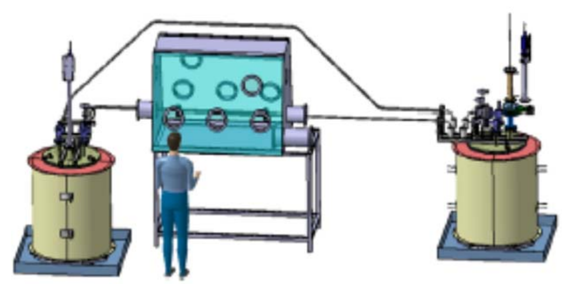
WP3: SWATH facility (CNRS)

Test section (1)	SWATH-W (Pump)	Steady Hydraulic conditions
(2)	SWATH-W (Pressure control)	SWATH hydraulic conditions
(3)	SWATH-S	HX + Phase change

Rows (1)–(2): PIV

Row (3): Q, P, T — 2017



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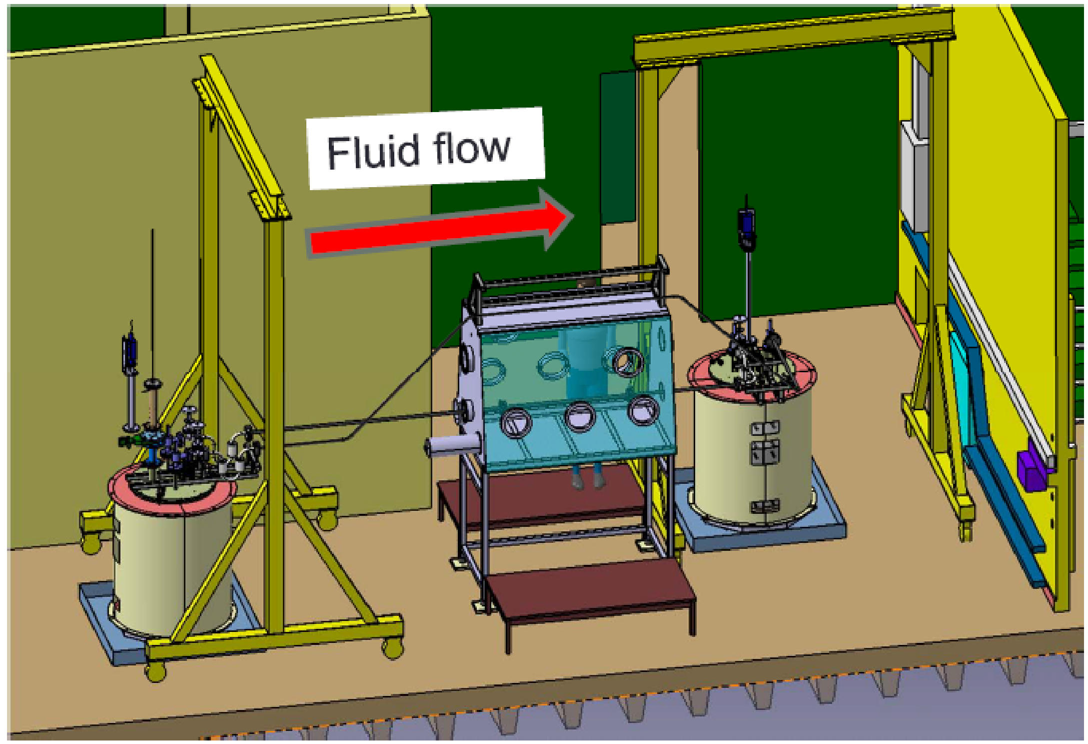
WP3: SWATH-S facility

Global performance :

- Salt : FLiNaK
- Total volume : 50 l
- Service temperature range : 550°c => 700°c

Velocity (m/s) 20 mm inner pipe diameter	Flow rate (l/min)	Time (minutes)
0.1	1.88	26.5
0.3	5.65	8.8
0.5	9.42	5.3



June 2016

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WP3: Phenomena investigated

(1) Heat transfer in very simple geometries

(2) Evolution of the salt solidification interface with and without forced convection

(3) Solidification along a cold wall after successive molten salt flows (lava flow like)

(4) Flow characteristics in an open channel

(5) Turbulence effects on the flow velocity and temperature profiles near a wall and

(6) Radiative heat transfer in the salt.

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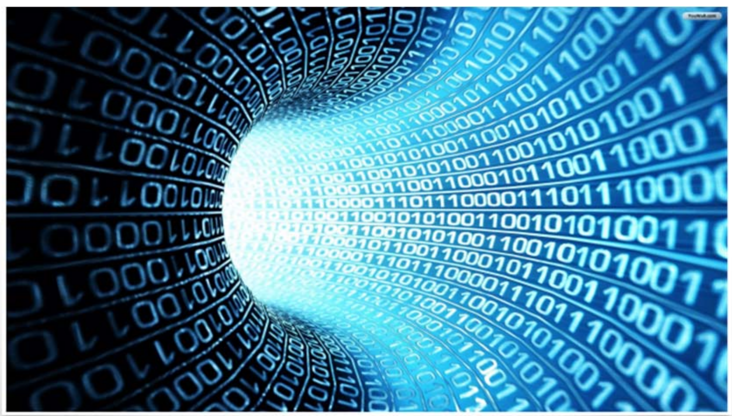
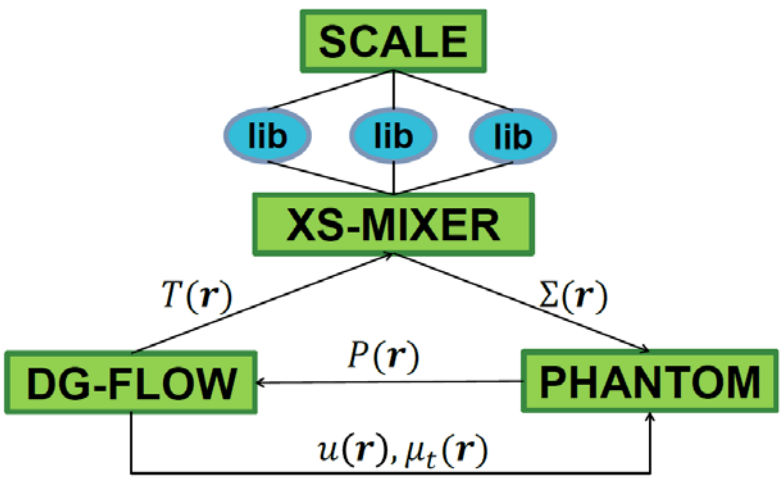
WP4: Numerical assessment

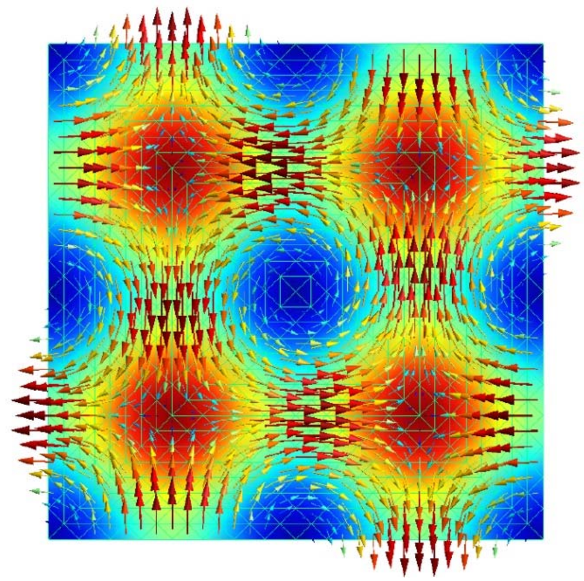
- Multi-physics simulation tools based on leading edge neutron transport and CFD methods including uncertainty propagation
- Transient analysis as identified in WP1 (normal operation and off-normal operation)
- Decay heat removal via natural circulation
- Thermal expansion reactor vessel
- Salt draining simulations
- …



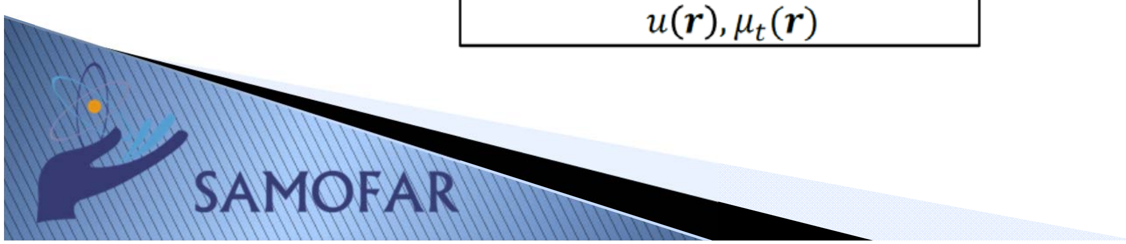
WP4: Coupled CFD-Neutronics (TU Delft)

- CFD and neutronics code based on DG
- RANS turbulence models (k-ω, k-ε) included
- Energy state and equations of state
- Benchmarking on Dynasty and others
- Coupled code benchmarking and transients 2017

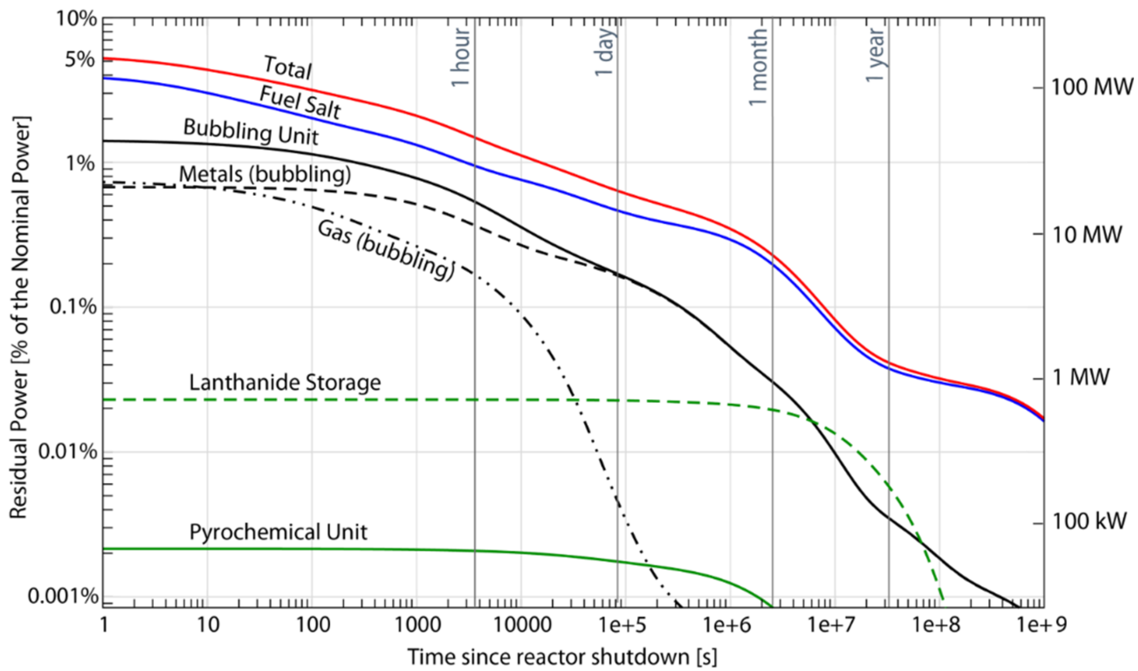




2D Taylor vortex benchmarking



WP4: Decay Heat Removal



1. Reactor nominal Power: 3000MWth; 18m^3 molten salt.
2. At beginning: ~ 4% DH in fuel salt = 120MW.

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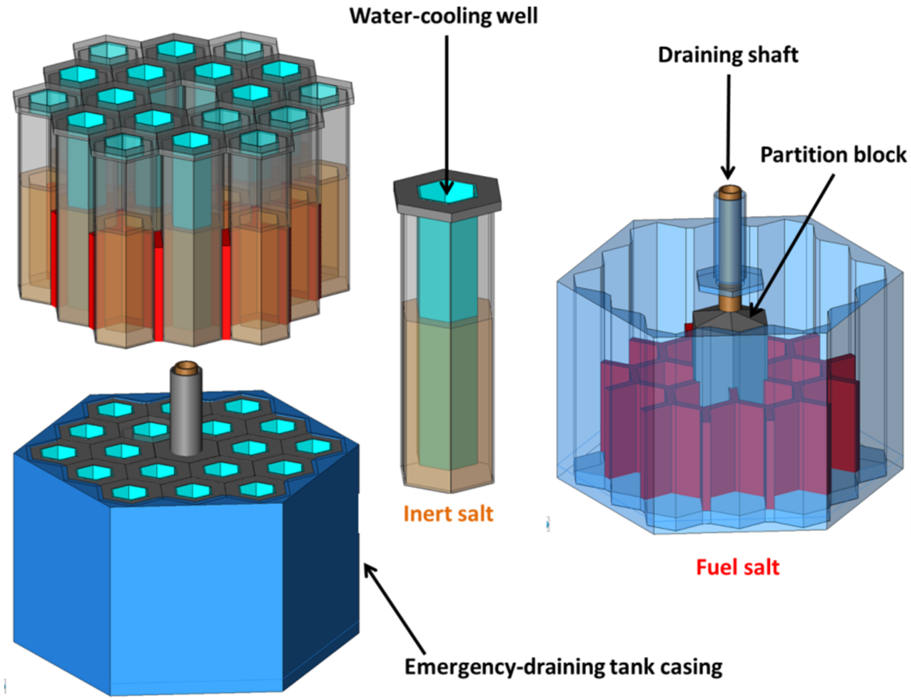
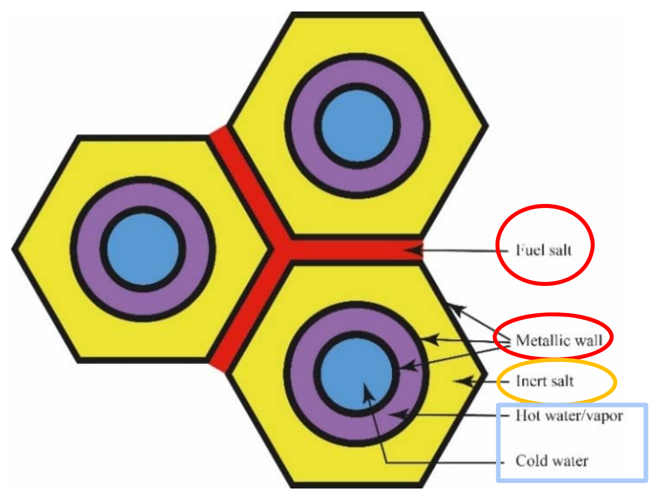
WP4: Draining tank (KIT)



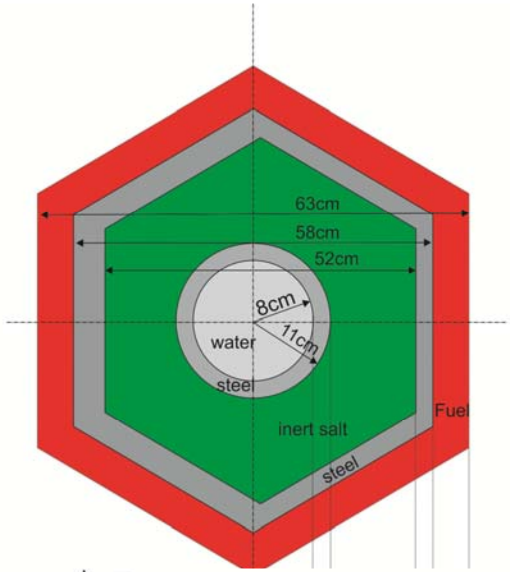
Hexagonal Design (D1.1):

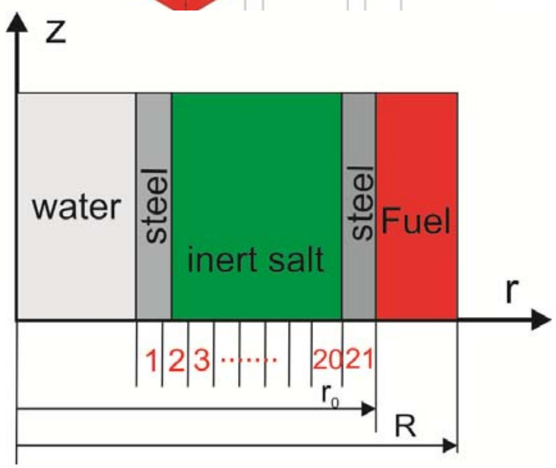
- a thick metallic casing (blue)
- cooling rods (center)
- Inert salt
- fuel salt (red) .

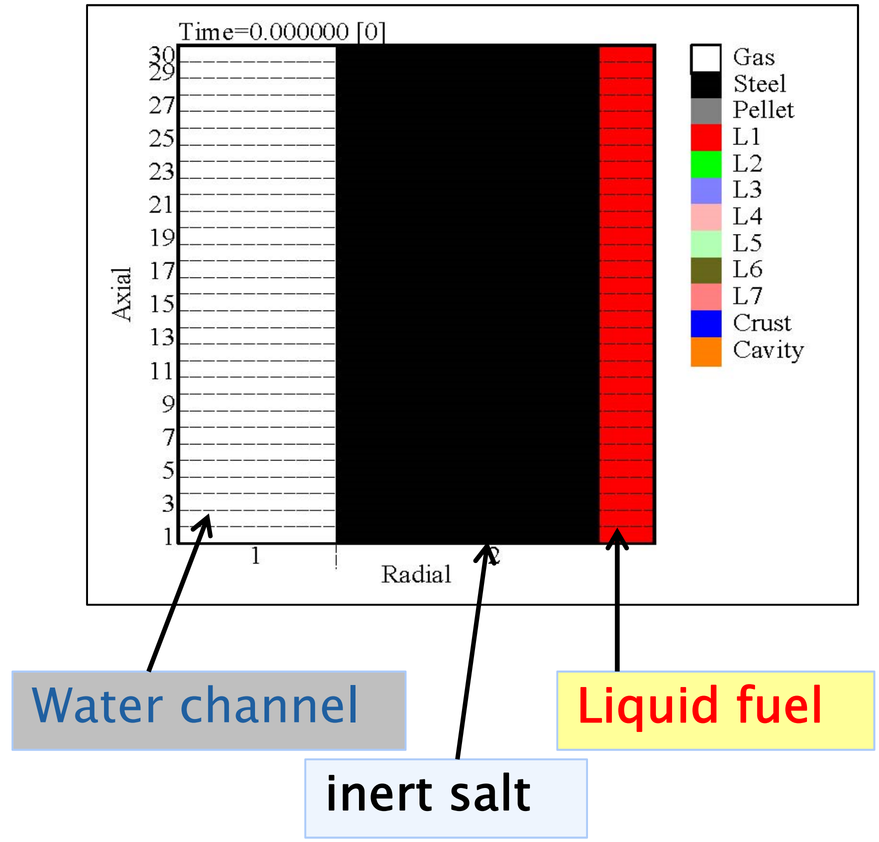


Status: Preliminary results available
More design iterations needed to assure inherently safe DHR
Extension of SIMMER

WP4 Decay Heat Removal







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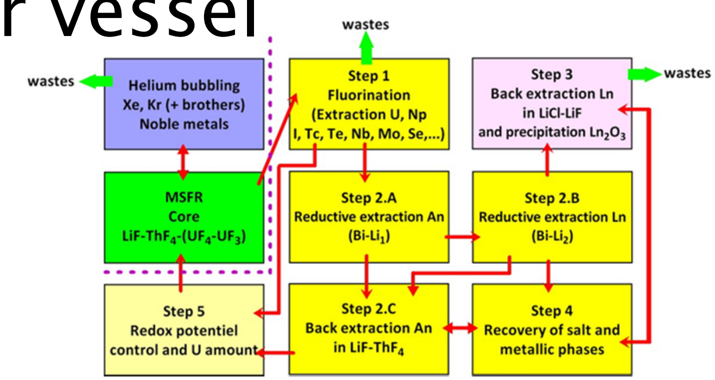
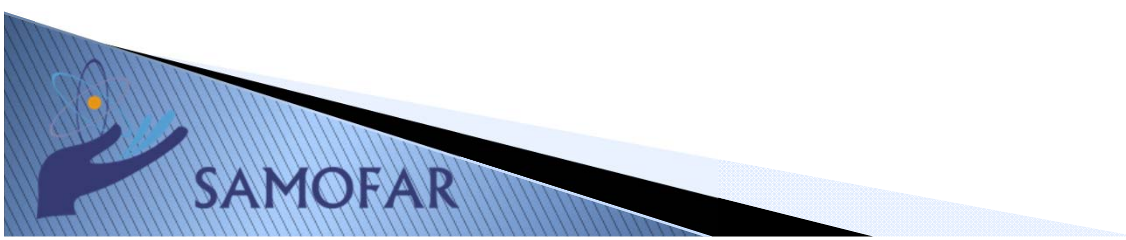
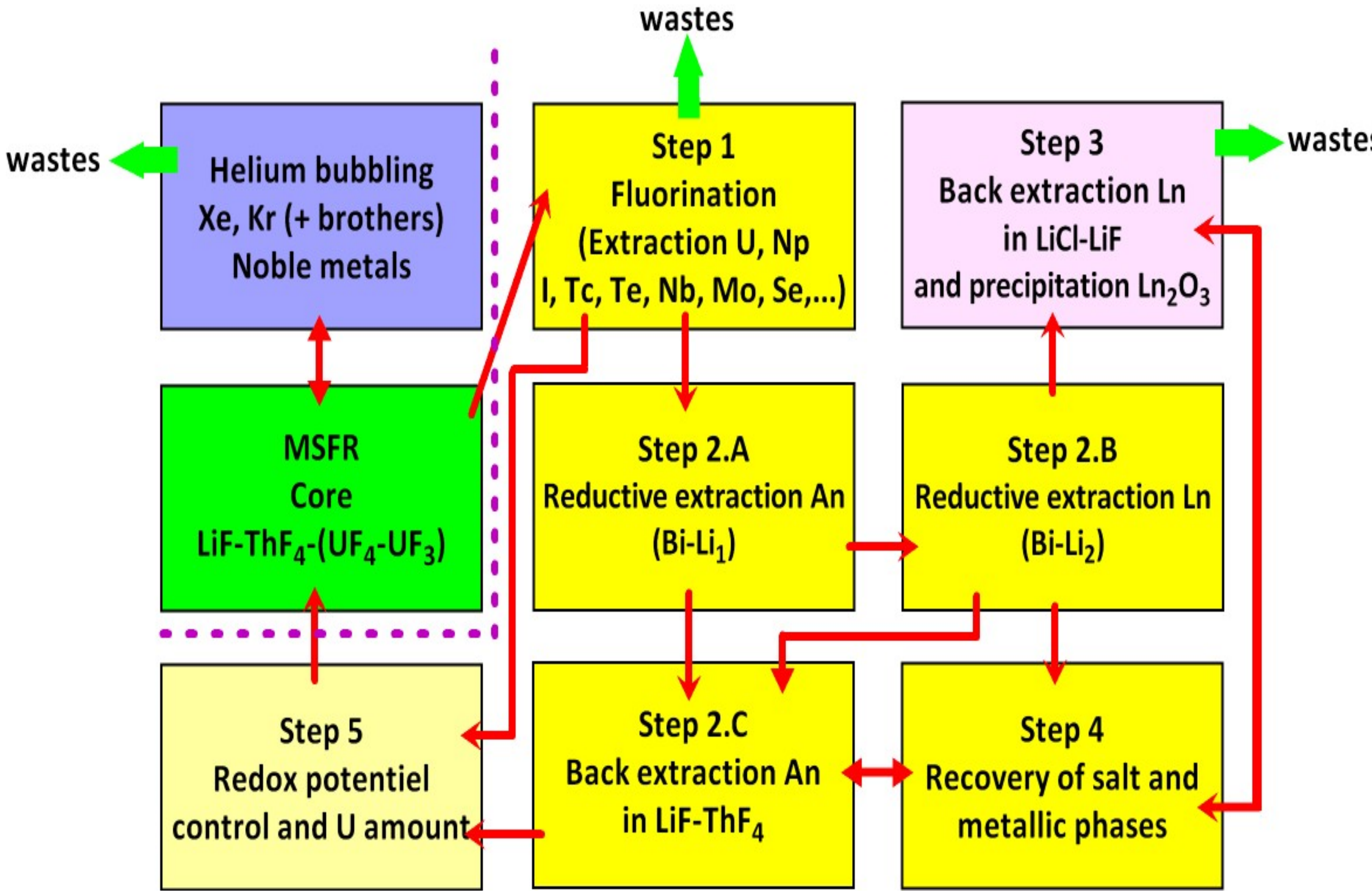
WP5: Chemical processing

- Safety assessment reprocessing facility
- Interaction chemical plant and nuclear reactor
- Proof of reductive extraction processes
- Evaluation of radioactive and chemical toxic gas streams
- Evaluation of solid and fluid product streams
- Shielding evaluation, hold-up tanks sizing,..
- Evaluation of liners to reactor vessel
- …





WP5: Reprocessing scheme (CNRS)



Reductive extraction: $xLi_{Bi} + MF_x \rightarrow xLiF + M_{Bi}$

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WP5 Reprocessing activities

- Determination of fundamental data such as activity coefficients both in metallic and salt phases (CNRS, JRC), the calculation of the separation/extraction efficiencies (based on experimental ONRL data) the elemental inventory and residual heat etc.
- The experimental validation of the reductive extraction between LiF-ThF4/Bi-Li will be done and the extraction kinetic will be studied for actinides (JRC) and lanthanides (CNRS).

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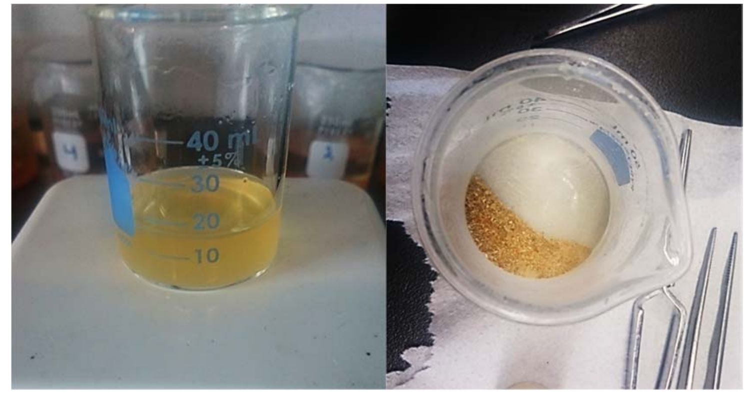
WP5: ZrO_2 coating (Cinvestav, CNRS)

Production of ZrO_2 via Sol-gel process



Coatings are being deposited through a direct gel route or through the resolution of powders.

Preliminary results show that spray-coating provide thicker coatings than dip-coating.

Ni-based alloys with ZrO2 coatings will be studied to evaluate their compatibility with non-active fluoride salts (CINVESTAV) and active salts (CNRS).

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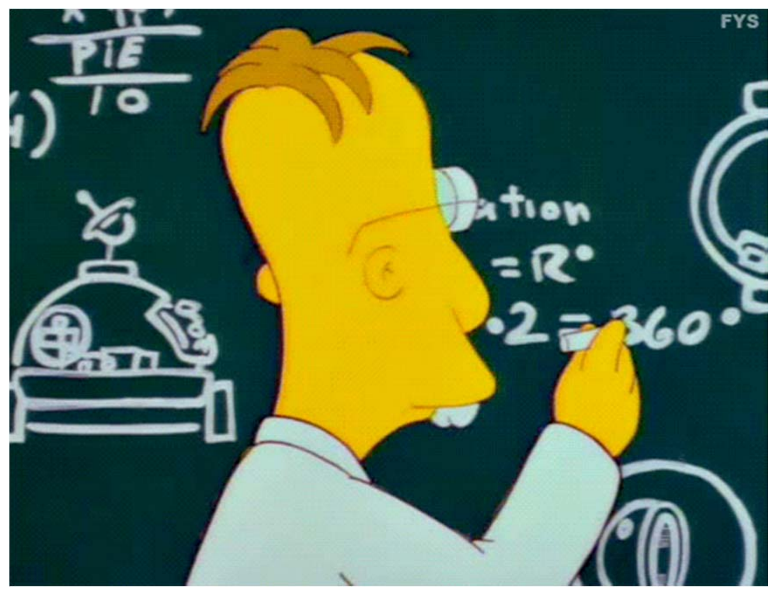
WP6: Dissemination/exploitation

- Education and training of students
- Exchange of students
- Compilation of strategic stakeholders
- School for students
- Workshop for stakeholders
- …



WP6: MSR school

- Audience: Students (BSc, MSc, PhD)
- Others interested in MSR
- Date: 2-4 July 2017
- Venue: POLIMI site @ Como lake

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WP6: program July 2

When	Title	Professor
	Sunday, July 2, 2017	
15:30–16:00	Registration	
16:00–16:15	Welcome by Politecnico di Milano	Marco Ricotti or Vice Rector for Lecco
16:15–16:45	MSR in framework of Gen-IV	Jerome Serp
16:45–17:30	Lessons from the past: MSR in the fifties and sixties	ORNL expert
17:30–19:00	Poster sessions and welcome cocktail	

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WP6: program July 3

When	Title	Professor
	Monday, July 3, 2017	
09:00-9:45	MSR Concepts	Dave Holcomb
9:45-10:30	Neutronics of MSR	Sandra Dulla
10:30-11:00	Coffee break	
11:00-12:30	Integral Safety Analysis (incl reactor design MSFR)	Elsa Merle-Lucotte
12:30-14:00	Lunch break	
14:00-14:45	Fuel cycle aspects of MSR	Jiri Krepel
14:45-15:30	Thermal-hydraulics and CFD	Pablo Rubiolo
15:30-16:00	Coffee break	
16:00-16:45	Multiphysics simulation of MSR	Danny Lathouwers
16:45-17:30	Startup and Control Strategies of MSR	Stefano Lorenzi
19:30	Social Dinner	TBC

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WP6: program July 4

When	Title	Professor
	Tuesday, July 4, 2017	
09:00-10:30	Kinetics and dynamics (incl noise analysis) of MSR	Imre Pazsit
10:30-11:00	Coffee break	
11:00-12:30	Thermodynamics analysis of salts Physico-Chemical properties of salts Control of salt properties during operation	Ondrej Benes
12:30-14:00	Lunch break	
14:00-15:30	Materials and metals in MSR	Victor Ignatiev
15:30-16:00	Coffee break	
16:00-16:45	Reprocessing of salt	Sylvie Delpech
16:45-17:30	Licensing and regulation	IRSN ?

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