A paradigm shift in nuclear reactor safety with the Molten Salt Reactor

19-10-2015

Coordinated by Jan Leen Kloosterman, TU–Delft
Presented by Jiri Krepel, PSI
## SAMOFAR: Partners

<table>
<thead>
<tr>
<th>Number</th>
<th>Organisation</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Technische Universiteit Delft (TU Delft)</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>2</td>
<td>Centre National de la Recherche Scientifique (CNRS)</td>
<td>France</td>
</tr>
<tr>
<td>3</td>
<td>JRC – Joint Research Centre– European Commission (JRC)</td>
<td>Germany</td>
</tr>
<tr>
<td>4</td>
<td>Consorzio Interuniversitario Nazionale per la Ricerca Tecnologica Nucleare (CIR TEN)</td>
<td>Italy</td>
</tr>
<tr>
<td>5</td>
<td>Institut de Radioprotection et de Sûreté Nucléaire (IRSN)</td>
<td>France</td>
</tr>
<tr>
<td>6</td>
<td>Centro de Investigaciony de Estudios Avanzados del Instituto Politecnico Nacional (CINVESTAV)</td>
<td>Mexico</td>
</tr>
<tr>
<td>7</td>
<td>AREVA NP SAS (AREVA)</td>
<td>France</td>
</tr>
<tr>
<td>8</td>
<td>Commissariat a l’Energie Atomique et aux Energies Alternatives (CEA)</td>
<td>France</td>
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<tr>
<td>9</td>
<td>Electricité de France S.A. (EDF)</td>
<td>France</td>
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<tr>
<td>10</td>
<td>Paul Scherrer Institute (PSI)</td>
<td>Switzerland</td>
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<tr>
<td>11</td>
<td>Karlsruher Institut für Technologie (KIT)</td>
<td>Germany</td>
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</tbody>
</table>
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
  - safety assessment of the MSFR
  - update of the conceptual design of the MSFR
  - roadmap and momentum among stakeholders
SAMOFAR Project management

- **Project Coordinator:** Coordination of the progress
  *Who:* Jan Leen Kloosterman  *(J.L.Kloosterman@tudelft.nl)*

- **Project manager:** Project management aspects of the project
  *Who:* Karin van der Graaf  *(SAMOFAR@tudelft.nl)*

- **Legal and Financial support:**
  *Who:* Rogier van Loghem *(legal officer, R.W.vanLoghem@tudelft.nl)*,
  Ada Ruiterman *(financial officer, A.M.A.E.Ruiterman@tudelft.nl)*

- **Governing Council:** Decision-making body
  *Who:* One representative from each partner
  *Chaired by Project Coordinator, assisted by Project Manager*

- **Project Management Board:** responsible for WP progress & reporting
  *Who:* Jan Leen + WP leaders
  *Chaired by Project Coordinator, assisted by Project Manager*
Project Management Board

Work package leaders:

WP1  Elsa Merle-Lucotte (CNRS)
WP2  Ondrej Benes (JRC)
WP3  Marco Ricotti (CIRTEN)
WP4  Danny Lathouwers (TU Delft)
WP5  Sylvie Delpech (CNRS)
WP6  Jan Leen Kloosterman (TU Delft)
WP7  Karin van der Graaf (TU Delft)
Non–EU Projects

- Shanghai Institute of Applied Physics (SINAP). Executing a large project in the field of FHR and MSR (2nd stage)
- Kurchatov Institute applying for a research grant on SMART–MSFR
- University of New Mexico executing a large project on FHR together with MIT/UCB/Wisconsin
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WP1: Integral safety assessment

- Development of a power plant simulator
- Dynamic behaviour 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: Reference design**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>3000 MWth</td>
</tr>
<tr>
<td>Mean fuel salt temperature</td>
<td>700 °C (to be fixed)</td>
</tr>
<tr>
<td>Fuel salt temperature rise in the core</td>
<td>100 °C (to be fixed)</td>
</tr>
<tr>
<td>Fuel molten salt - Initial composition</td>
<td>LiF-ThF₄-UF₄-(TRU)F₃ with (77.7-6.7-12.3-3.3 mol%) and U enriched at 13%</td>
</tr>
<tr>
<td>Fuel salt melting point</td>
<td>565 °C</td>
</tr>
<tr>
<td>Fuel salt density</td>
<td>4.1 g/cm³</td>
</tr>
<tr>
<td>Fuel salt dilation coefficient</td>
<td>8.82 x 10⁻⁴ / °C</td>
</tr>
<tr>
<td>Fertile blanket salt - Initial composition</td>
<td>LiF-ThF₄ (77.5%-22.5%)</td>
</tr>
<tr>
<td>Breeding ratio (steady-state)</td>
<td>1.1</td>
</tr>
<tr>
<td>Total feedback coefficient</td>
<td>-5 to -8 pcm/K</td>
</tr>
<tr>
<td>Core dimensions</td>
<td>Diameter: 2.26 m</td>
</tr>
<tr>
<td></td>
<td>Height: 2.26 m</td>
</tr>
<tr>
<td>Fuel salt volume</td>
<td>18 m³ (¼ in the core + ¼ in the external circuits)</td>
</tr>
<tr>
<td>Blanket salt volume</td>
<td>7.3 m³</td>
</tr>
<tr>
<td>Total fuel salt cycle</td>
<td>3.9 s</td>
</tr>
</tbody>
</table>
WP1: Reference design

3 circuits:
- Fuel circuit
- Intermediate circuit
- Energy conversion system
+ Draining tanks

Fuel circuit = core + 16 external recirculation loops:
- Pipes (cold and hot region)
- Bubble Separator
- Pump
- Heat Exchanger
- Bubble Injection
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WP2: Safety related data

- Synthesis salts containing PuF3 and UF4
- 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: Safety related data example

Retention properties of elements in the fuel salt

JRC–ITU:
- Knudsen Effusion Mass Spectrometry of the simfuel samples containing Cs and I in their likely chemical form:
  - CsI dissolved in Flinak
  - CsI dissolved in the LiF–ThF4 eutectic
  - 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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WP3: Experimental validation

- Natural circulation dynamics of fuel salts with internal heating
- 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
- …
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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
- …
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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, etc.
- Evaluation of liners to the reactor vessel
- ...

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THE REPROCESSING SCHEME

**Helium bubbling**
Xe, Kr (+ brothers)
Noble metals

**Step 1**
Fluorination
(Extraction U, Np, l, Tc, Te, Nb, Mo, Se,...)

**Step 2.A**
Reductive extraction An
(Bi-Li₁)

**Step 2.B**
Reductive extraction Ln
(Bi-Li₂)

**Step 2.C**
Back extraction An
in LiF-ThF₄

**Step 3**
Back extraction Ln
in LiCl-LiF
and precipitation Ln₂O₃

**Step 5**
Redox potentiel
control and U amount

Reductive extraction: \( x\text{Li}_{Bi} + MF_x \rightarrow x\text{LiF} + M_{Bi} \)
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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
- …