Overview of Safety R&D in the Horizon-2020 ESFR-SMART project

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European Commission Joint Research Center

7th Joint IAEA-GIF Technical Meeting/Workshop on Safety of Sodium-Cooled Fast Reactors
IAEA Headquarters,
Vienna, Austria
27–29 March 2018

www.jrc.ec.europa.eu
European SFR R&D projects

2017 European SFR Safety Measures Assessment & Research Tools

2013 Preparing ESNII for Horizon 2020

2009 Collaborative project on European SFR

2007 Roadmap for ESFR
European SFR Safety Measures Assessment & Research Tools

Objectives:
- Selection and assessment of innovative safety measures for European SFR concept;
- Develop new research tools related to SFR safety:
  - Computational codes for each DiD level,
  - Experimental data (new & legacy) and,
  - Facilities
- Strengthen and link together new networks (European sodium facilities & European students working on the SFR technology)
- Test and qualify new instrumentations

Budget: 5 MEUR of Euratom contribution + ~5 MEUR of consortium’s own contribution

Duration: 01.09.2017 – 31.08.2021
ESFR-SMART Project

Experience from EU projects related to SFR safety

Past SFR safety-related tests

New SFR safety-related tests

Experience in SFR operation

Sodium facilities & instrumentation

SFR fuel measurements

ARDECo

Experience in SFR licensing

SFR safety-related education

Experience from EU projects related to SFR safety

Joint Research Centre

National Nuclear Laboratory

European Commission

Ciemat

AREVA

Lemta

EDF

RIA Consulting

PAUL SCHERRER INSTITUT PSI

KIT

HZDR

CHALMERS

UNIVERSITY OF CAMBRIDGE

IRSN

CRS

SFR fuel measurements

ARDECo

Sodium facilities & instrumentation

Experience from EU projects related to SFR safety

Past SFR safety-related tests

New SFR safety-related tests

Experience in SFR operation

SFR safety-related education

Experience in SFR licensing
ESFR-SMART Project

Coordinator:
K. Mikityuk (PSI)

Advisory Review Panel
ESNII
ARDECo
GIF
IAEA

Project Management Board

WP leaders
WP1.1 EDF
WP1.2 PSI
WP1.3 KIT
WP1.4 HZDR
WP1.5 KIT
WP2.1 IRSN
WP2.2 CEA
WP2.3 IPUL
WP2.4 HZDR
WP2.5 CEA
WP3.1 CEA
WP3.2 PSI

Partners

Governing Board
PSI
AFW
AREVA
CEA
CIEMAT
CHALMERS
EDF
ENEA
GRS
HZDR
IPUL
IRSN
JRC
KIT
LEMTA
LGI
NNL
UCAM
UPM

Project Management Office
LGI
# ESFR Plant Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor type</td>
<td>Pool</td>
</tr>
<tr>
<td>Reactor heat output</td>
<td>$3600\text{ MW}_{th}$</td>
</tr>
<tr>
<td>Net electrical output</td>
<td>$1500\text{ MW}_{e}$</td>
</tr>
<tr>
<td>Global Efficiency</td>
<td>42%</td>
</tr>
<tr>
<td>Plant lifetime</td>
<td>60 Years</td>
</tr>
<tr>
<td>Availability Objective</td>
<td>90%</td>
</tr>
<tr>
<td>Core inlet temperature ($^\circ\text{C}$)</td>
<td>395</td>
</tr>
<tr>
<td>Core outlet temperature ($^\circ\text{C}$)</td>
<td>545</td>
</tr>
<tr>
<td>Average core structure temperature ($^\circ\text{C}$)</td>
<td>470</td>
</tr>
<tr>
<td>Average fuel temperature ($^\circ\text{C}$)</td>
<td>1227</td>
</tr>
</tbody>
</table>
ESFR Primary System

<table>
<thead>
<tr>
<th>IHX / DHX</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary pumps</td>
<td>3</td>
</tr>
</tbody>
</table>
ESFR Secondary Loop
ESFR System Layout

<table>
<thead>
<tr>
<th>Secondary loops</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC loops</td>
<td>6</td>
</tr>
</tbody>
</table>
**ESFR Core Characteristics**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel residence time (EFPD)</td>
<td>2170</td>
</tr>
<tr>
<td>Fuel Burnup (GWd/t)</td>
<td>100</td>
</tr>
<tr>
<td>Fuel enrichment (%wt)</td>
<td>~ 17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner fuel</td>
<td>6 batches×36 = 216</td>
</tr>
<tr>
<td>Outer fuel</td>
<td>6 batches×48 = 288</td>
</tr>
<tr>
<td>CSD / DSD</td>
<td>24 / 12</td>
</tr>
<tr>
<td>1st / 2nd /3rd reflector ring</td>
<td>66 / 96 / 102</td>
</tr>
<tr>
<td>Spent Inner / Outer fuel storage</td>
<td>3 batches×36 = 108</td>
</tr>
<tr>
<td>Spent Inner / Outer fuel storage</td>
<td>3 batches×48 = 144</td>
</tr>
<tr>
<td>Corium discharge tubes</td>
<td>31</td>
</tr>
</tbody>
</table>
R&D on Safety Architecture

- **Determination of the provisions** (key structures, systems & components) performing the main safety functions;
- Definition of requirements for the safety provisions on the basis of their importance in the frame of the safety demonstration;
- Preliminary assessment of the adequacy of the safety provisions by OPT/LOP (Objective Provision Tree / Lines of Protection);
- **Demonstration of the adequacy of the safety provisions** by safety analysis of consequences of a set of events representative to families of risks: protected & unprotected TOP, LOF, LOHS and local disturbances;
- **Assessment of the impact of hazards on the prevention and mitigation provisions** considered in the design in order to meet the safety objectives;
- **Practical elimination** for situations for which it is deemed not reasonable to implement provisions to mitigate their consequences.
R&D on Reactivity Control

- Development of reactor cores with low void worth showing a better safety performance;
- Performance assessment of the redundant and diversified shutdown systems;
- Definition of requirements for passive devices for introduction of negative reactivity in case of abnormal situations (loss of coolant flow, increase of coolant temperature);
- Assessment of corium transfer tubes for partial relocation of molten fuel/structure from the core in order to prevent creation of a large molten fuel/structure pool in the core;
- Core surveillance.
R&D on Decay Heat Removal

- Practical elimination of situations with prolonged complete loss of DHR system;
- Improvement of diversification and redundancy: assessment of the performance of the DHR systems;
- Enhancement of natural convection capability: assessment of the transition from forced convection to natural convection;
- Consideration of provisions for decay heat removal in situations of core degradation.
R&D on Severe Accident

- **Measures to prevent severe accidents:**
  - Assessment of chugging boiling conditions;
  - Propagation of pressure waves through the core;
  - Dynamic reactivity effect of pressure waves.

- **Analysis of severe accidents:**
  - Transition phase and
  - Expansion phase.

  - Molten fuel ejection and molten pool behaviour;

  - **Performance assessment of in-vessel core catcher,**
    designed for the whole core meltdown;

  - Analysis of use of absorber materials to mitigate re-criticality inside the core catcher.
Other R&D topics

- **Codes calibration and validation:**
  - Core static neutronics & operational transients;
  - Sodium boiling & transitional convection flows;
  - Source term.

- **New experiments for safety:**
  - KASOLA test on transitional conditions;
  - Sodium boiling related tests;
  - Corium jet impingement study;
  - Tests on corium behaviour in core catcher;

- **New measurements of MOX fuel properties;**

- **Instrumentation for safety.**
European sodium facilities support

- Design guidelines for sodium loops;
- Procedures and standards for testing;
- Elements of sodium technology;
- Review of technologies worldwide;
- Support to students mobility program.
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