Overview of IAEA Activities on Fast Reactors

Vladimir Kriventsev, Mikhail Khoroshev, Chirayu Batra

Fast Reactor Technology Development Team
Nuclear Power technology Development Section
Division of Nuclear Power
Department of Nuclear Energy
International Atomic Energy Agency

https://www.iaea.org/topics/fast-reactors
Nuclear Power Technology Development
Section: Sub-Programme Structure

WCR

Technology Development for Advanced Reactor Lines

SMR

GCR + MSR

NEApp

Fast Reactors
IAEA Technical Working Group on Fast Reactors (TWG-FR)

“The Driving Force…”

Members of the IAEA Technical Working Group on Fast Reactors

**Full Members**
- Belarus
- Brazil
- China
- France
- Germany
- India
- Italy
- Japan
- Kazakhstan
- Korea, republic of
- Netherlands
- Russian Federation
- Slovakia
- Sweden
- Switzerland
- USA
- Ukraine
- UK
- OECD/NEA
- European Commission

**Observers**
- Argentina
- Belgium
- Czech Republic
- Mexico
- Romania
- Spain
- Generation-IV International Forum (GIF)

- Provide advice and guidance
- Forum for information exchange and knowledge sharing
- Link between IAEA activities and national communities
- Provide advice in planning and implementing of CRPs
- Develop and review selected documents
- Contribute to status report, technical meetings, topical conferences
- Identify important topics for SAGNE
- Encourage participation of young professionals in IAEA activities

**GIF Nominations?**

51st TWG-FR Meeting, Hefei, 21-25 May 2018

Vladimir Kriventsev, IAEA
12th GIF-IAEA Interface Meeting, Vienna, 26-27 March 2018
Fast Reactors: Key Activities

Modelling and Simulations
• Coordinated Research Projects (CRPs)
  • EBR-II (Shutdown Heat Removal Tests)
  • NAPRO (Sodium properties)
  • PSFR Source Term
  • CEFR Start-Up Tests: NEW
  • FFTF ULOF Test: NEW

Knowledge Preservation
• Fast reactor knowledge preservation portal (FRKP)
• Liquid metal cooled fast neutron system database (LMFNS)

Education and Training
• SFR Simulator for Educational Purposes
• ICTP-IAEA Workshop on the Physics and Technology of Innovative Nuclear Energy Systems

Safety
• Joint IAEA-GIF Technical Meeting on Safety of SFR
• Passive Shutdown Systems for Fast Neutron Systems – NES Publication

Technology Support
• NAPRO: CRP
• LMFNS Catalogue
IAEA Benchmarks / CRPs on FRs

• **Completed:**
  – **EBR-II** Shutdown Heat Removal Tests
    Completed and Published

• **Ongoing:**
  – **NAPRO** – Na Properties and Safe Operations of Exp. Facilities
  – **PSFR Source Term** – Radioactive Release Under Severe Accident Conditions

• **New Benchmarks:**
  Good Opportunity for Verification & Validation of Safety Analysis Codes
  – **CEFR Physics Start-Up** Experiments (19 proposals received):
    • **Most recent** data on Sodium-cooled Fast Reactor
    • **Neutronics** Codes Benchmarking
  – **FFTF ULOF** Test:
    • **Coupled** neutronics, thermal hydraulics, material behavior and system codes
    • **Essential Benchmark for Safety Analysis** (validation of models and assessment of simulation codes)
CRP on Benchmark Analysis of **EBR-II** Shutdown Heat Removal Test (2012-2016)

- **Participants**
  - China (CIAE, XJU, NCEPU)
  - France (IRSN)
  - Germany (KIT, HZDR)
  - Italy (ENEA, UNIPI, POLITO)
  - India (IGCAR)
  - Japan (JAEA, FU, KU)
  - Korea (KAERI, KINS)
  - Netherlands (NRG)
  - Russian Federation (IPPE)
  - Switzerland (PSI)
  - USA (ANL, TerraPower)

- **Timeline**
  - 1st RCM: Argonne, June 2012
  - 2nd RCM: Vienna, November 2013
  - 3rd RCM: Bologna, March 2015
  - 4th RCM: Vienna, April 2016
  - Publication of final TECDOC: June 2017
  - Presentation of final CRP results: Special session at FR17

- **Key Points**
  - A very productive verification and validation exercise
  - 20 Organizations from 12 Countries
  - Final TECDOC printed in 2017
CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions

Can be a Standard Benchmark for Verification of Safety Analysis Codes and Models

Reference design for the safety analysis:

500 MWe pool type PFBR

Numerical simulation of core bubble expansions during a CDA (100 MJ)

Still open for new participants

- Japan:
  - NRA applied (ASTERIA-FBR code)
  - JAEA expressed interest (SIMMER code)

Evaluation of:

- Transport of fission products (FP), Na and other radioactive materials from the melted core to the cover gas
- Ejection of FP, Na, fuel particles through the penetrations of the top shield reactor structure directly into the containment system and indirectly through the argon cover gas system
- Transport of fission products and other radioactive materials through the different containment compartments under various thermodynamics conditions

CRP on “Radioactive Release from the PFBR under Severe Accident Conditions”

Expressions of Interest

<table>
<thead>
<tr>
<th>Country</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada, UOIT</td>
<td>China, CIAE, NCEPU</td>
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<tr>
<td>France, IRSN &amp; CEA</td>
<td>Germany, KIT</td>
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<td>India, IGCAR</td>
<td>Korea, Republic of, KAERI</td>
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<tr>
<td>Russian Federation, IPPE</td>
<td>EC-JRC</td>
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</table>

First RCM: Vienna, May 2016

2nd RCM: IGCAR, November 2017

Vladimir Kriventsev, IAEA
12th GIF-IAEA Interface Meeting, Vienna, 26-27 March 2018
NAPRO CRP: Sodium properties and safe operation of experimental facilities in support of SFRs

- **WP1**: Collection and assessment of sodium properties: harmonization of international data and correlations
- **WP2**: Design rules and best practice for Na exp. facilities
- **WP3**: Guidelines for the safe operation of Na exp. facilities
- 4th RCM in Vienna, 12-14 June 2017
- Two TECDOCs and one NES to be published

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"Sodium properties and safe operation of experimental facilities in support of the development and deployment of SFR"

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<thead>
<tr>
<th>Country (Code)</th>
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<tr>
<td>Argentina (CNEA)</td>
<td>China (CIAE)</td>
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<td>France (CEA)</td>
<td>India (IGCAR)</td>
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<tr>
<td>Germany (KIT, HZDR)</td>
<td>Japan (JAEA)</td>
</tr>
<tr>
<td>Korea, Republic of (KAERI)</td>
<td>Netherlands (NRG)</td>
</tr>
<tr>
<td>Russian Federation (IPPE)</td>
<td>USA (ANL)</td>
</tr>
</tbody>
</table>

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Comparison of the data sets
New CRP on CEFR Start-Up

- **Title:**
  - Neutronics Benchmark of CEFR Start-Up Tests

- **Scientific Background:**
  - China Experimental Fast Reactor (CEFR), constructed and operated by CIAE, with a thermal power of 65MW and an electric power of 20MW.
  - During the physics start-up of CEFR, a series of experiments were carried out in four aspects, i.e., fuel loading and first criticality, control rod worth measurements, reactivity coefficient measurements, and foil activation measurements. A large amount of experiment data was obtained in the process.

- **Scientific Scope:**
  - to collect and evaluate experiment data obtained from CEFR physics start-up experiments
  - to establish a simplified model of the CEFR core and give the correction factors and associated method
  - to share the experiment data and the simplified core model with CRP participants for joint calculations and analysis;
  - to gather and analyze the calculation results, and
  - to publish a benchmark analysis report.
  - The overall objective is to establish a benchmark based on CEFR physics start-up experiments, which is helpful for the validation and verification of code and data of the participants.
New CRP on FFTF ULOF Test

- **Title:**
  - *Benchmark Analysis of FFTF Loss of Flow Without Scram Test*

- **Scientific Background:**
  - FFTF was a 400 MW-thermal loop-type oxide-fuelled sodium-cooled fast reactor operated at the U.S. Department of Energy's Hanford site as a test facility (1980-1992)
  - The principal missions of FFTF were to conduct a fuels irradiation campaign and to demonstrate the safe operation of a sodium-cooled fast reactor by performing a whole-plant testing program.
  - The passive safety tests demonstrated the potential of FFTF to survive severe accident initiators with no core damage.

- **Objectives:**
  - Validation of the state-of-the-art sodium-cooled fast reactor codes and methods used in neutronics, thermal hydraulics, and safety analyses
  - Training of the next generation of fast reactor analysts through international benchmark exercises

- **Specific Scientific Objectives**
  - A. Simulation of a specific FFTF ULOF test using different codes, methods, and models
    - Evaluation of the key parameters, including the reactor core flow rate and sodium coolant temperatures and IHX temperatures
    - Calculation and benchmark comparison of key reactivity effects
  - B. Evaluation of uncertainties for prediction of
    - Flow rates
    - Fuel, cladding, coolant, and structure temperatures along the length of a subassembly
    - Transition to natural circulation
New CRPs: Expression of Interest

**CEFR Start-Up Tests**

<table>
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<th>Country</th>
<th>Organization</th>
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<td>Belgium</td>
<td>SCK•CEN</td>
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<tr>
<td>China</td>
<td>CIAE, INEST</td>
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<tr>
<td>Russia</td>
<td>IPPE, IBRAE, SSL</td>
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<td>IGCAR</td>
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<td>Romania</td>
<td>ICN/NUCLEAR</td>
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<td>OECD</td>
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**FFTF ULOF Test**

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<th>Country</th>
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<td>&quot;Sapienza&quot; University of Rome</td>
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<td>Italy</td>
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<td>KAERI</td>
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<td>USA</td>
<td>MIT</td>
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Fast Reactors Safety: GIF-IAEA Workshops on Safety of SFR/LMFR

1st: June 2010  
2nd: Dec 2011  
3rd: Feb. 2013  
4th: June 2014  
5th: June 2015  
6th GIF-IAEA Workshop on Safety of SFR: 14-15 November 2016  
7th GIF-IAEA Workshop on LMFR Safety: 27-29 March 2018

Passive Shutdown Systems for Fast Neutron Reactors

• IAEA NES document submitted for publishing
• SharePoint site is used for collaboration and knowledge preservation
IAEA International Conferences on Fast Reactors and Related Fuel Cycles

560 Abstracts Submitted
460 Tech. Papers Accepted

FR09 >> FR13 >> FR17 Conferences

International Conference on Fast Reactors and Related Fuel Cycles: Challenges and Opportunities
7–11 December 2009
Kyoto, Japan

Organized by
IAEA

Supported by
Japan Atomic Energy Agency

FR13

International Conference on FAST REACTORS AND RELATED FUEL CYCLES:
Safe Technologies and Sustainable Scenarios
4–7 March 2013
Paris, France

BN-800

FR17

International Conference on FAST REACTORS AND RELATED FUEL CYCLES:
Next Generation Nuclear Systems for Sustainable Development
26–29 June 2017
Yekaterinburg, Russian Federation

Vladimir Kriventsev, IAEA
12th GIF-IAEA Interface Meeting, Vienna, 26-27 March 2018
FR17 Panel 1:
*Development and standardization of Safety Design Criteria (SDC) and Guidelines (SDG) for Sodium Cooled Fast Reactors*

<table>
<thead>
<tr>
<th>Country</th>
<th>Speaker</th>
<th>Title</th>
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<tbody>
<tr>
<td>India</td>
<td>S. C. Chetal</td>
<td>Safety criteria for future Indian SFRs</td>
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<tr>
<td>Japan</td>
<td>Ryodai NAKAI</td>
<td>The Safety Design Guideline Development for Generation-IV SFR Systems</td>
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<tr>
<td>France/GIF</td>
<td>Paul GAUTHE (GIF)</td>
<td>Considerations on GEN IV safety goals and how to implement them in future Sodium-cooled Fast Reactors</td>
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<tr>
<td>Korea</td>
<td>Jaewoon Yoo</td>
<td>Application of GIF SDC to PDC (Principal Design Criteria)</td>
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<tr>
<td>Russia</td>
<td>Yury ASHURKO</td>
<td>The Safety Design Criteria Development and Summary of Its Update for the Generation-IV SFR Systems</td>
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<tr>
<td>USA/GIF</td>
<td>Yasushi Okano Tanju SOFU</td>
<td>The Safety Design Criteria Development and Summary of Its Update for the Generation-IV SFR Systems</td>
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<tr>
<td>IAEA</td>
<td>Vladimir Kriventsev</td>
<td>(Moderator)</td>
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</table>
Training Courses and Workshops

- IAEA Workshops and Schools on Innovative Nuclear Energy Systems

- Recent Course: Joint ICTP-IAEA Workshop on the Physics and Technology of Innovative Nuclear Energy Systems for Sustainable Development, 29 Aug - 02 Sept 2016, Trieste, Italy
  - Imparted theoretical foundation of all aspects of innovative nuclear energy systems
  - Familiarized students with models and codes for design and safety analysis
  - Provided an active forum for sharing new ideas

- Next ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems
  20 – 24 August 2018, Trieste, Italy
  Open for Applications: indico.ictp.it/event/8324
Fast Reactors:
LMFNS Experimental Facilities Database

Experimental Facilities in support of Development and Deployment of Liquid Metal cooled Fast Neutron Systems

- A comprehensive Catalogue providing detailed information on experimental facilities currently designed, under construction or operating.
- Facilities Designed to support the development and deployment of innovative liquid metal-cooled (sodium, lead and lead-bismuth) fast neutron systems (LMFNS), both critical and subcritical.
- Identifies existing or future operational experimental facilities able to support innovative LMFNS.
- Expected to facilitate cooperation using existing and planned experimental facilities for LMFNS, and enhance their utilization by providing end-users with detailed information.
- Encourages international collaborations.

Freely Accessible at iaea.org: Search for “IAEA LMFNS”

19 institutions from 14 IAEA Member States contributed.
### 2017-2018: Meetings on FRs

<table>
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<tr>
<th>Date</th>
<th>Title</th>
<th>Major Output/Outcome</th>
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<tbody>
<tr>
<td>May 2017</td>
<td>50th Meeting of the Technical Working Group on Fast Reactors (TWG-FR)</td>
<td>Planning &amp; Actions</td>
</tr>
<tr>
<td>June 2017</td>
<td>4th RCM of CRP on Sodium Properties and Safe Operation of SFR (NAPRO)</td>
<td>Drafts of two TECDOCs</td>
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<tr>
<td>June 2017</td>
<td>International Conferences on Fast Reactors and Related Fuel Cycles in Yekaterinburg</td>
<td>~600 Participants from 29 MSs</td>
</tr>
<tr>
<td>Nov 2017</td>
<td>2\textsuperscript{nd} RCM on Radioactive Release (Source Term) from SFR under Severe Accident Conditions (IGCAR, Kalpakkam)</td>
<td>First Results of Benchmark Simulations</td>
</tr>
<tr>
<td>27-29 March</td>
<td>7\textsuperscript{th} IAEA-GIF Workshop on SFR/LFR Safety</td>
<td>Information Exchange on Safety</td>
</tr>
<tr>
<td>21-25 May</td>
<td>51\textsuperscript{st} Meeting of TWG-FR (Hefei, China, INEST)</td>
<td>Planning &amp; Actions</td>
</tr>
<tr>
<td>Feb 2018</td>
<td>5\textsuperscript{st} RCM of NAPRO-CRP</td>
<td>CRP-concluding</td>
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<tr>
<td>11-14 June</td>
<td>1\textsuperscript{st} RCM of CRP on CEFR Physics start-up Experiments</td>
<td>CRP kick-off</td>
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<tr>
<td>20-24 August</td>
<td>ICTP-IAEA Workshop on Innovative Nuclear Energy Systems (Trieste, Italy)</td>
<td>Education &amp; Training</td>
</tr>
<tr>
<td>23-25 Oct</td>
<td>1\textsuperscript{st} RCM of CRP on FFTF ULOF Test</td>
<td>CRP kick-off</td>
</tr>
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**GIF Nominations?**
Fast Reactors: 

**Publications**

**TECDOCs** and **NES** Reports:

- Analytical and Experimental Benchmark Analysis of ADS –
  - In Publishing
- Catalogue of Experimental Facilities for Liquid Metal Cooled FNSs –
  - In Publishing; Database is available online
- Benchmark Analyses of EBR-II Shutdown Heat Removal Tests
  - Published
- **NAPRO CRP**
  - WP1: Handbook on Sodium Physical and Chemical Properties
    - Under Review
  - WP1: Handbook on Thermal Hydraulics Correlations for Sodium-Cooled Reactors
    - Final Draft
- WP2/3: Design, Operation and Safety of Sodium Experimental Facilities - NES Report: end 2018
  - postponed

- **Passive Shutdown Systems** for Fast Neutron Reactors
  - IAEA NES submitted for publication

7 Publications in 2017/2018

3 NES documents

4 TECDOCs
Main Activities on Fast Reactor Technology

- FR17 Conference in Yekaterinburg
- CRPs/Benchmarks
  - 2 Ongoing: NAPRO and PSFR Source Term
  - 2 New: CEFR Start-Up and FFTF ULOF
  - Study on Passive Shutdown Systems for Fast Reactors
- Technical Working Group on Fast Reactors
  - 50th TWG-FR Meeting in Vienna, May 2017
  - 51st TWG-FR Meeting in Hefei, China, 21-25 May 2018
- GIF-IAEA Workshops on Safety of SFR/LMFR
  - 6th GIF-IAEA Workshop on SFR Safety: November 2016
    - Continuous in-depth discussions on the development of SFR SDC/SDG
  - 7th GIF-IAEA Workshop on LMFR Safety: 27-29 March 2018
- LMFNS Experimental Facilities Database
- Training Courses and Workshops
  - Joint ICTP-IAEA Workshop on the Physics and Technology of Innovative Nuclear Energy Systems for Sustainable Development (2016, Trieste, Italy)
  - Next Workshop: 20 – 24 August 2018, Trieste, Italy (open for Applications)
Thank You!