IAEA Activities on Fast Reactor Technology Development

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Division of Nuclear Power
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International Atomic Energy Agency

https://www.iaea.org/topics/fast-reactors

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## IAEA Member State Activities on Fast Reactors

<table>
<thead>
<tr>
<th>Country</th>
<th>Recent Milestone</th>
</tr>
</thead>
</table>
| **Russia**    | SFRs in operation: BOR-60 (experimental), BN-600 (prototype), BN-800 (industrial)  
Under Construction: MBIR (experimental SFR); BREST-OD-300 (prototype LFR) |
| **China**     | SFRs in operation: CEFR (2011, 20MWe)  
Design/development: SFRs: CFR-1000; LFR SMRs: CLEAR-M10D, CLFR-300  
Under Construction: CFCR-600 (2 units) |
| **India**     | SFRs in operation: FBTR (13MWe); under commissioning: PFBR (500MWe)                                                                                      |
| **EU**        | Design/development: ESFR (EU), LFR ALFRED (Romania, Italy), GFR ALLEGRO (Czech Rep., Hungary, Poland, Slovakia), MSR SAMOSAFER (EU)                    |
| **Belgium**   | Design/development: MYRRHA – LBE cooled ADS                                                                                                             |
| **France**    | Design/development of Sodium-cooled Fast Reactors (ASTRID suspended), MSFR                                                                             |
| **Japan**     | SFRs: Experimental Joyo (experimental, suspended); MONJU (under decommissioning)                                                                     |
| **R. of Korea** | Design/development: SFRs: KALIMER-600, PGSFR (suspended)                                                                                         |
| **UK/Sweden** | Design/development: SEALER-UK                                                                                                                        |
| **USA**       | Design/development: SFRs: PRISM, Natrium, LLC ARC-100; Westinghouse LFR; GA GFR; MSFRs: KP-FHR, MCFR; VTR (research SFR, under development) |
# Fast Reactors in Operation, and under Construction and Decommissioning

<table>
<thead>
<tr>
<th>Country</th>
<th>Type</th>
<th>Coolant</th>
<th>Purpose</th>
<th>Power (th/e) MW</th>
<th>Year (Op.)</th>
<th>Status</th>
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<td>BREST-OD-300</td>
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<td>700/300</td>
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<td>China</td>
<td>CEFR</td>
<td>SFR</td>
<td>sodium</td>
<td>80/20</td>
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<td>CFR600 x2</td>
<td>SFR</td>
<td>sodium</td>
<td>1500/600</td>
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<td>India</td>
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<td>PFBR</td>
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<td>1250/500</td>
<td>?2022</td>
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<td>MONJU</td>
<td>SFR</td>
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## Fast Reactors under Developing and Design

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<td>LBE</td>
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<td>MOSART</td>
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<td>molten salt</td>
<td>prototype</td>
<td>2400/</td>
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<td>Gen-IV, industrial</td>
<td>2512/1000</td>
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<td>LBE</td>
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<td>LBE/lead</td>
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<td>CLEAR-M10d</td>
<td>LFR</td>
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<td>CLEAR-I</td>
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<td>demonstrator</td>
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<td>R. of Korea</td>
<td>KALIMER-600</td>
<td>SFR</td>
<td>sodium</td>
<td>GEN-IV, prototype</td>
<td>1523/600</td>
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<td>LFR</td>
<td>lead</td>
<td>demonstrator</td>
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<td>Westinghouse LFR</td>
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Main IAEA Activities on Fast Reactor Technology

Knowledge Sharing
- Publications
- Conferences
- TMs

Technology Development
- Coordinated Research Projects (CRPs)

Capacity Building
- Training Courses
- Workshops
- TECDOCs
IAEA Technical Working Group on Fast Reactors (TWG-FR)
New Term: 2022 - 2025

Members of the IAEA Technical Working Group on Fast Reactors

**Members**

- Argentina
- China
- France
- India
- Japan
- Korea, republic of
- Netherlands
- Russian Federation
- Switzerland
- Ukraine
- Belgium
- Czech Republic
- Germany
- Italy
- Kazakhstan
- Mexico
- Romania
- Sweden
- UK
- USA

**Observers**

- European Commission/JRC
- OECD/NEA

**Generation-IV International Forum (GIF)**

- From 2022: MSs as members; IOs as observers

- 53rd TWG-FR Meeting: 17-20 Nov 2020 (virtual)
- 54th TWG-FR Meeting: 22-25 June 2021 (virtual)
- 55th TWG-FR Meeting: 23-27 May 2022 (Hybrid)

- 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
Main IAEA Activities on Fast Reactor Technology in 2021 - 2022

- CRPs/Benchmarks/Studies
  - Completed
    • NAPRO (2013 – 2018, in publishing)
    • PSFR Source Term (2016 – 2020, just published)
  - 3 Ongoing CRPs:
    • CEFR Start-Up Tests (2018 - 2022)
    • FFTF ULOF Test (2018 - 2022)
    • NACIE (2022-2026): Benchmark of Transition from Forced to Natural Circulation Experiment with Heavy Liquid Metal Loop
  - New CRPs proposals (to start in 2023+):
    • PLANLTL: PLANt Dynamics Test Loop Decay Heat Removal Thermal Hydraulics Tests
    • Modelling of Total Instantaneous Blockage of SFR F/A (Delayed)
    • Benchmarking LOF transient test in CLEAR-S HML Pool Facility (Delayed)
    • Benchmark Analysis of STELLA-2 LOHS/LOF Tests
    • Thermal-hydraulic simulations of a high temperature helium facility S Allegro
  - Benefits and Challenges of Fast SMRs (published in 2021)
  - Structural Materials for HLM Reactors (published in 2021)
  - TM on Development and Application of Open-Source Modelling and Simulation Tools for nuclear Reactors (June 2022)
  - TM on State-of-the-art Thermal Hydraulics of Fast Reactors: ENEA Brasimone in September 2022

- Technical Working Group on Fast Reactors
  - 54th TWG-FR Meeting (Virtual), June 2021
  - 55th TWG-FR Meeting (Hybrid), May 2022

- Joint IAEA-GIF Workshops on LMFR Safety
  - 9th GIF-IAEA Workshop on LMFR Safety (2021)
  - 10th GIF-IAEA Workshop on LMFR Safety (2022)

- Basic Principles SFR Simulator
  - Factory Acceptance Test: 2021
  - Site Factory Acceptance Test: Jan 2022
  - Distribution to Member States: 2022
  - Training Course: 2022

- Training Courses and Workshops
  - Joint ICTP-IAEA Workshops on the Physics and Technology of Innovative Nuclear Energy Systems Trieste; December 2022
  - Regional Workshop on Advances in Modelling & Simulation of Thermal Hydraulics in LMFRs, India, November 2022

- Webinars
  - Repurposing sites of retired fossil plants with advanced nuclear reactors for clean energy transition; May 2022, available online
  - Multi-physics modelling and simulation of nuclear reactors using OpenFOAM (12 Lectures), Aug-Oct 2022, available online
Track 1. Innovative fast reactor designs
Track 2. Fast reactor safety
Track 3. Fuels, fuel cycles and waste management
Track 4. Fast reactor coolants, structures, and components
Track 5. Test facilities and experiments
Track 6. Modelling, simulations and digitalization
Track 7. Sustainability: Economics, environment and proliferation
Track 8. Commissioning, Operation and Decommissioning
Track 9. Education, professional development and knowledge management

and Special Session on IAEA ongoing CRPs

FR22: 365 Contributions
680 Registered participants
~120 in-person

FR22 Proceedings in preparation, expected Q1 2023
The IAEA encourages and assists research on and development and practical use of atomic energy and its applications for peaceful purposes throughout the world. It brings together research institutions from its developing and developed Member States to collaborate on research projects of common interest, so-called **Coordinated Research Projects (CRPs)**.

**IAEA Coordinated Research Projects on FRs**

**Completed CRPs**
- **PHENIX** – EOL Tests
- **MONJU** – Na Natural Convection
- Analytical and Experimental Benchmark Analysis of ADS
- **PSFR Source Term** – Radioactive Release Under Severe Accident Conditions

**On-going CRPs**
- **NAPRO** – Na Properties and Safe Operations of Exp. Facilities
  Ended in Sept 2018
  2 TECDOCs in Publishing
- Neutronics Benchmark of CEFR Start-Up Tests
- Benchmark Analysis of FFTF Loss of Flow Without Scram Test
- Natural Circulation in LBE Sub/Assembly: **NACIE** Tests

**New Proposals**
- Total Instantaneous Blockage of SFR Fuel Assembly
- Simulation of **CLEAR-S** Loss-of-Flow Experiment
- Benchmark Analysis of STELLA-2 LOHS/LOF Tests
- **PLANDTL** – Decay Heat Removal Thermal Hydraulics Tests
CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions (2016-2020): Summary

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

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<th>China (CIAE, NCEPU, XJTU)</th>
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<td>Japan (NRA, JAEA)</td>
<td>US (TerraPower)</td>
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Reference design for the safety analysis:
500 MW(e) pool type PFBR

- CRP is completed
- TECDOC is published:

CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions (2016-2020)

**CDA development and propagation in pool type SFR**

**I. Expansion Phase**
- Core bubble expands in sub-cooled sodium

**Initiation** (neutronics), and **Transition** (fuel relocation)

**Phases**
- Incipient melting and early relocation
- Extended relocation and core compaction
- Rapid fuel vapor bubble expansion

**Reference design for the safety analysis:**
*500 MWe pool type PFBR*

Very complicated multi-physics phenomenon
Can be a Standard Benchmark for Verification of Safety Analysis Codes and Models

**II. Quasi-static Phase**
Release of sodium to the Reactor Containment Building (RCB)

**III. Containment Source Term**
- Evaluation of multi-component aerosol evolution is required
- Two typical sodium fire accidents:
  - sodium pool fire accident
  - sodium spray fire accident
CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions (2016-2020): Expansion Phase

Click to play SIMMER-IV Video

(provided by JAEA)

WP-1. Sodium Bubble Expansion Phase
CRP: Benchmark Analysis of FFTF Loss of Flow Without Scram Test

- FFTF (Fast Flux Test Facility) Reactor:
  - 400 MW$_{th}$ sodium cooled fast test reactor
  - Mixed UO$_2$-PuO$_2$ (MOX) fuel
  - Loop type plant, axial and radial reflectors
  - Prototypic size
    - \~1 m$^3$ core volume
    - \~91 cm high, \~120 cm diameter
  - Built to assist development and testing of advanced fuels and materials for fast breeder reactors
  - Series of Passive Safety Tests performed in 1986
    - Unprotected transients including 13 Loss of Flow without scram tests
    - Demonstrated passive safety of SFRs
    - Demonstrated efficacy of negative reactivity insertion safety devises (Gas expansion modules - GEMs)
  - This Benchmark analysis is based on the Test number 13, which was initiated at 50 % power and 100 % flow.
CRP: Benchmark Analysis of FFTF Loss of Flow Without Scram Test

Aim of the Benchmark:
  • Support collaborative efforts within international partnerships on the validation of simulation tools and models in the area of SFR safety.

Outcomes:
  • Improved understanding of loss of flow events in fast reactors and validation of the state-of-the-art fast reactor analysis computer codes against the experimental data;
  • Improved understanding of fast reactor neutronics, thermal-hydraulics, and system analysis;
  • Improved understanding of the methodology employed to simulate fast reactor transient behaviour;
  • Improved verification, validation, and qualification of the methodology;
  • Reduced uncertainty in SFR codes, which will contribute to reducing costs of building liquid metal cooled fast reactors;
  • Enhanced reliability of the behaviour predictions for new advanced reactor designs;
  • Facilitated training of the young generation of reactor physicists; and
  • Identified additional research and development work needed to resolve open issues.

24 Participating Organizations from 13 Countries

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<thead>
<tr>
<th>Country</th>
<th>Organization</th>
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CRP: Benchmark Analysis of FFTF Loss of Flow Without Scram Test

**Plant Data**

**Modelling**

**Simulations**

**Benchmark**

**Kick Off: 1st RCM:**
October 2018, Vienna

**Blind Phase Results Submissions, March 2020**

**Refined Simulation Submissions, November 2021**

**Final Simulation Results, June 2022**

**Benchmark Specifications**

**Individual Simulations**

**Sharing of results and comparison with Experimental Data**

**Publication**

**1st Virtual Informal OM:**
October 2019, Vienna

**2nd Virtual Informal OM:**
October 2020, Vienna

**2nd RCM: December 2021, (virtual)**

**3rd RCM: November 2022, Italy**

IAEA TECDOC Draft December 2022
CEFR (China Experimental Fast Reactor)

- Located in China Institute of Atomic Energy
- 65MWt (20MWe) sodium cooled fast reactor with a high neutron leakage core fuelled with uranium oxide and stainless-steel radial reflector.
- The primary system is a pool-type design, liquid sodium working fluid for the primary and secondary circuits.
- In 2010, CEFR went into first criticality.
- A series of start-up experiments were carried out to measure reactor physics and kinetics parameters.
- **6 experiments were selected for benchmark analysis**
  - evaluations of the criticality, control rod worth, sodium void worth, temperature effect reactivity, and various reaction rates.
- This CRP provides an excellent opportunity to the member states for validation of the physical models and neutronics simulation codes by comparing the calculated results to the recorded experimental data from the CEFR start-up tests.
CRP: Neutronics Benchmark of CEFR Start-Up Tests

WP1. Net criticality

$k_{eff}$ in fuel load steps with deterministic codes (blind phase)

WP2. Control Rod Worth

WP3. Temperature reactivity coefficient

WP4. Sodium void reactivity effect

WP5. Core S/A exchange reactivity effect

WP6. Reaction rate distribution

WP7. Reactivity coefficients and kinetic parameter

WP8. Analysis of Uncertainties

Separate TECDOC

30 Participating Organizations from 18 Countries

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CRP: Neutronics Benchmark of CEFR Start-Up Tests

Kick Off: 1st RCM: June 2018, Vienna
2nd RCM: 28 October - 1 November 2019, Beijing (Blind Phase Results)

Benchmark Specifications
Individual Simulations
Sharing of results and comparison with Experimental Data
Publication

1st Online Update Meeting: June 2019, Vienna
2nd Online Update Meeting: November 2020, Vienna
3rd RCM: 6-9 April 2021 (Virtual)
4th RCM: 7-11 November 2022, Vienna

Refined Simulation Results, April 2021
IAEA TECDOC Draft October 2022
CRP: Neutronics Benchmark of CEFR Start-Up Tests

Training Course Series Documents

- Comprehensive Guidance and how-to perform MC simulations
- with SERPENT-2 and Open-MC
- Freely available IAEA Series of documents for capacity building
- Template for future CRP adaptations

Performing Neutronics Benchmark Calculations

- Intended for students or early career nuclear engineers.
- Can easily be implemented and used in classrooms.
- Also provides a valuable template for continuing benchmarking opportunities.

Finalized, under review
Expected Publication: Q4 2022, Q1 2023
The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) proposed this CRP to TWG-FR 2020. ENEA operates the Natural Circulation Experiment Upgrade (NACIE-UP) facility:

- Rectangular LBE flow loop
- Containing a wire spaced 19 pin fuel pin simulator
- Operating up to 250 kW for qualification and instrumentation testing.

**Objective**: Validation of computational fluid dynamics (CFD), subchannel, and system analysis codes for heavy liquid metal systems.

- 22 proposals received
- **1st RCM 12-15 July 2022**
- **TECDOC publication – Mid 2025**
Technical Meetings on

State-of-the-art Thermal Hydraulics of Fast Reactors &
Development and Application of Open Source Modelling and Simulation Tools for Nuclear Reactors

26-30 September 2022
C.R. ENEA, Lago Brasimone, Italy

20-24 June 2022
Milano, Italy

Using open access data
Using open source tools
Technical Meeting on Development and Application of Open-Source Modelling and Simulation Tools for Nuclear Reactors (ONCORE)

• Creating a common platform in the area of advanced reactor experiments and high-fidelity multi-physics nuclear simulation techniques for open-source code development and validation

• Links to 35+ Open source tools
  – Neutronics
  – Thermal-hydraulics, system analysis, containment
  – Structural mechanics
  – Multi-physics applications and libraries
  – Data processing, optimization, UQ, pre-post processing
  – Application frameworks

• 2 tools hosted and distributed by ONCORE
  – VSOP99/11: HTR pebble-type design and safety analysis
  – STACY: V/HTR safety analyses for the quantification of fission product release from the fuel

• TM on ONCORE 20-24 June 2022 in Milano
  – ~100 participants (50% online)
Fast Reactors Safety: Joint GIF-IAEA Workshops on Safety of LMFRs

A decade of cooperation

1st : June 2010
2nd : Dec 2011
3rd : Feb. 2013
4th : June 2014
5th : June 2015
6th : Nov. 2016

7th Joint GIF-IAEA Workshop on LMFR Safety
March 2018

8th GIF-IAEA Workshop on LMFR Safety
20-22 March 2019

9th GIF-IAEA Workshop on LMFR Safety
30 March - 01 April 2021

  • Discussion of review comments

10th GIF-IAEA Workshop on LMFR Safety
28 June – 1 July 2022

• Organized by NSNI
Joint ICTP-IAEA Workshops on Innovative Nuclear Energy Systems

- In 2016 and in August 2018 Trieste, Italy
- Contributed by NPTDS, INPRO, GIF, and other external experts
- Next Workshop: 12-16 December 2022
SFR Educational Simulator

- Pool type sodium cooled fast reactor simulator for education and training
- February 2021: Factory Acceptance Tests
- January 2022: Site Acceptance Test
- 2022: Distribution to Member States
## Fast Reactors: Main Events and Activities in 2022

<table>
<thead>
<tr>
<th>Date</th>
<th>Title</th>
<th>Location</th>
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<tbody>
<tr>
<td>Apr 2022</td>
<td><strong>International Conference on Fast Reactors and Related Fuel Cycles (FR22)</strong></td>
<td>Vienna</td>
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<td>May 2022</td>
<td>55th Meeting of TWG-FR</td>
<td>Vienna</td>
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<td>Jun 2022</td>
<td>10th Joint IAEA–GIF Workshops on LMFR Safety (organized by NS)</td>
<td>Brasimone, IT</td>
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<td>Jun 2022</td>
<td>TM on ONCORE (Development and Application of Multi-Physics Modelling and Simulation on Nuclear Reactor Using Open Source Tools)</td>
<td>Milano, IT</td>
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<td>Jul 2022</td>
<td>1st RCM of CRP on Lead Flow Transient to Natural Circulation at NACIE Facility</td>
<td>Brasimone, IT</td>
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<td>Sep 2022</td>
<td>TM on State-of-the-art Fast Reactor Thermal Hydraulics: TM was planned in 2021</td>
<td>Brasimone, IT</td>
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<td>Nov-Dec 2022</td>
<td>Regional WS on Advances in Modelling &amp; Simulation of T-H in LMFRs</td>
<td>GNCEP, India</td>
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<td>Nov 2022</td>
<td>4th RCM of CRP on Neutronics Benchmark of CEFR Start-Up Tests</td>
<td>Vienna</td>
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<td>Nov 2022</td>
<td>3rd RCM of CRP on Benchmark Analysis of FFTF ULOF Test</td>
<td>Lucca, IT</td>
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<td>Dec 2022</td>
<td>Joint ICTP–IAEA Workshops on Physics and Technology of Innovative NESs</td>
<td>Trieste, Italy</td>
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<td>2022</td>
<td>Training Course on PC-based SFR Simulator for Educational Purposes</td>
<td>Vienna</td>
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Thank You!

Atoms for peace and Development...

email: FR@IAEA.ORG