

Technical Meeting on  
Liquid Metal Reactor Concepts:  
Core Design and Structural Materials  
IAEA HQ, Vienna, 12–14 June 2013

***Recent IAEA Achievements in the Field of  
Fast Neutron Systems  
and  
Scope and Objectives of the Meeting***

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Department of Nuclear Energy  
Team Leader – Fast Reactors Technology Development

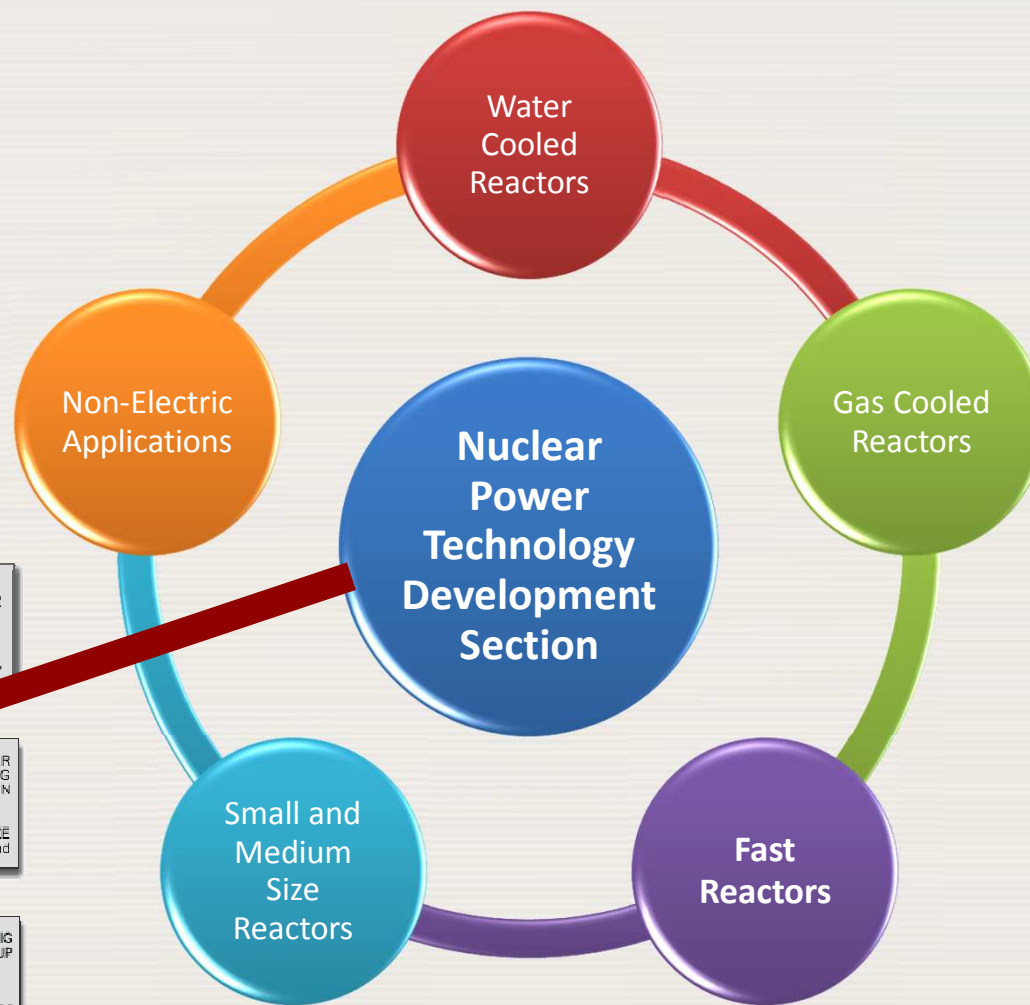
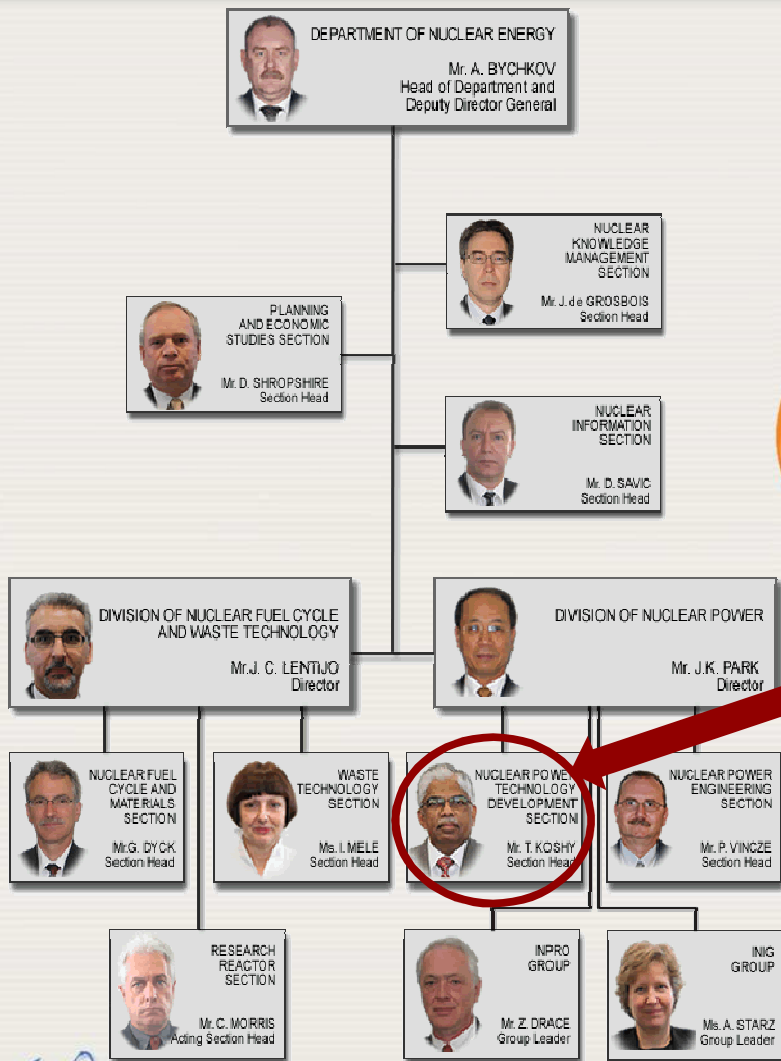


**IAEA**  
International Atomic Energy Agency

# Summary

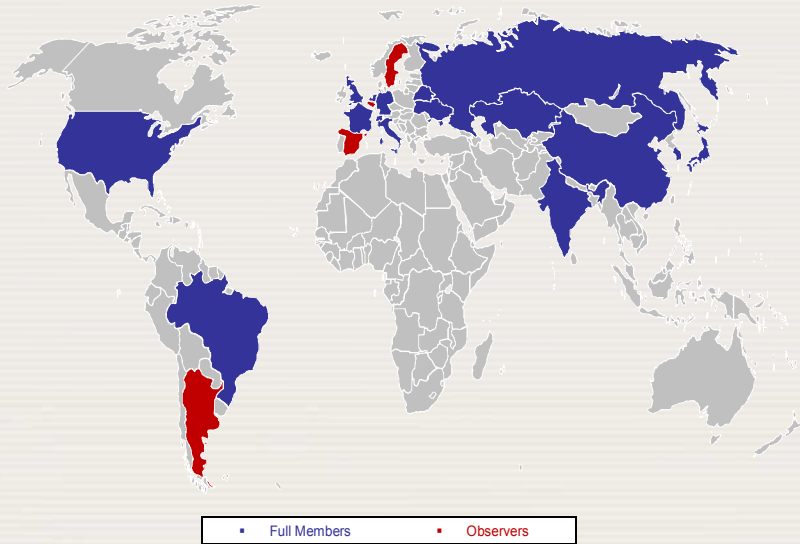
- ❑ Framework of the IAEA activities on FR and ADS technology
- ❑ IAEA Research coordinated research activities in the field of fast reactors
- ❑ Recent IAEA publications on FR technology
- ❑ FR13 Conference: statistics, highlights and main outcomes
- ❑ Scope and main objectives of this technical meeting

# IAEA Department of Nuclear Energy



# The IAEA Technical Working Group on Fast Reactors

Members of the IAEA Technical Working Group on Fast Reactors



Members of the IAEA Technical Working Group on Fast Reactors

## Full Members

Belarus  
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Ukraine  
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Brazil  
France  
India  
Japan  
Korea, republic of  
Russian Federation  
Switzerland  
UK  
*European Commission*

## Observers

Argentina  
Spain

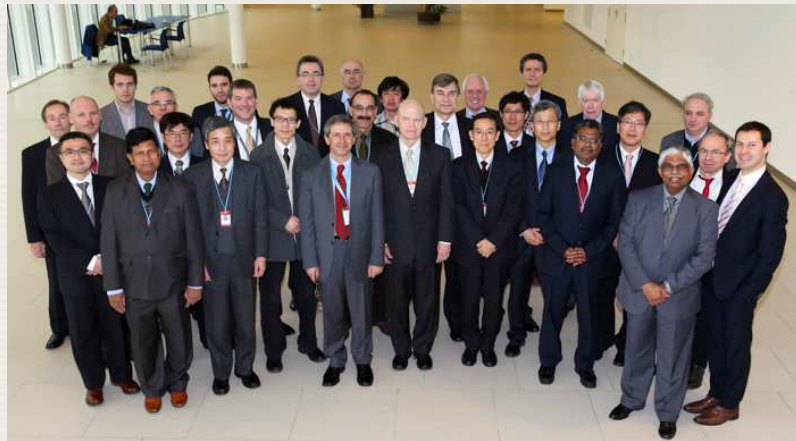
Belgium

**46<sup>th</sup> Annual Meeting  
IAEA - Vienna  
21 – 24 May 2013**



# Recent IAEA Conferences, technical meetings and workshops/seminar on FR - June 2012-May 2013 (3/3)

- *(Third) Workshop on Safety Design Criteria for Sodium-cooled Fast Reactors, held in Vienna on 26 – 27 February 2013*



The screenshot shows the IAEA website page for the workshop. The header includes the IAEA logo and navigation links. The main content area is titled "Nuclear Power Technology Development" and features a sub-heading "3rd Joint GIF-IAEA Workshop on Safety Design Criteria for Sodium-Cooled Fast Reactors". A date box indicates "26-27 Feb 2013" in "IAEA, Vienna, Austria". The text describes the collaboration between the Generation IV International Forum (GIF) and the IAEA, and lists the workshop's objectives. A "Working Documents" section lists "Terms of Reference", "Agenda", and "Summary Report". A "Presentations" section lists "Opening Remarks" by J.K. Park and Y. Sagayama.



All the presentations of the workshop, which represent a useful resource for education and training purposes, are downloadable on the related IAEA webpage <http://www.iaea.org/NuclearPower/Meetings/2013/2013-02-26-02-27-TM-SFR.html>



# IAEA Coordinated Research Activities on FR

## CRPs on Fast Reactors Technology

### CRP recently completed

*Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)*

*Analyses of, and Lessons Learned from the Operational Experience with Fast Reactor Equipment and Systems*

*Control Rod Withdrawal and Sodium Natural Circulation Tests Performed During the PHENIX End-of-Life Tests*

*Benchmark analyses of Sodium natural convection in the upper plenum of the MONJU reactor vessel*

### CRP currently on-going

*Benchmark Analyses of an EBR-II Shutdown Heat Removal Test*

*Sodium properties and safe operation of experimental facilities in support of the development and deployment of Sodium-cooled Fast Reactors (SFR) - NAPRO*

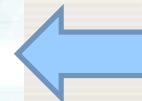
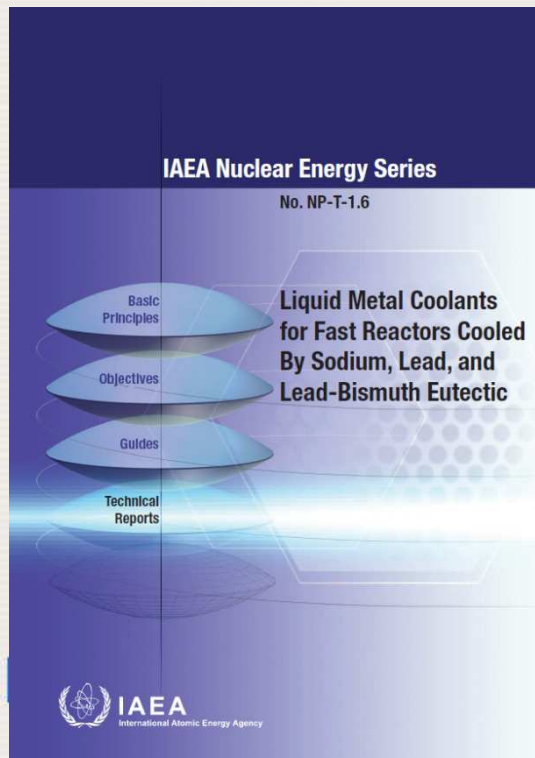
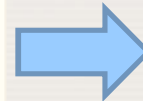
### CRP planned

*Source Term for Radioactivity Release Under Fast Reactor Core Disruptive Accident (CDA) Situations*

*Benchmark exercise on neutronic calculations for a mixed-oxide fuelled core of an industrial size Sodium-cooled Fast Reactor*

# Recent IAEA Technical Publications on Fast Reactors Technology

- ✓ Background and overview
- ✓ Operating experience with SFR
- ✓ Sodium-cooled FR Designs
- ✓ HLM-cooled FR Designs
- ✓ Gas-cooled FR Designs
- ✓ Status of FR core R&D
- ✓ Reactor plant engineering technology development
- ✓ Reactor safety design and analysis
- ✓ National strategies, international initiatives, public acceptance and final remarks



Summary of the status of liquid coolants technology for fast reactors with regard to basic data, main technological challenges and the various fast reactor concepts and designs that are being investigated, with a special emphasis on the choice of coolant



## Coming IAEA Technical Publications on Fast Reactors (already approved by NE-Dept. and Publication Committees)

- ❑ Design features and operating experiences of experimental fast reactors
  
- ❑ Final reports of the completed CRPs
  - ✓ *“BN-600 hybrid core benchmark analyses”, final report of the second part of the CRP on “Results from a coordinated research project on updated codes and methods to reduce the calculational uncertainties of the LMFR reactivity effects”*
  
  - ✓ *“Benchmark analyses on the natural circulation test performed during the PHENIX end-of-life experiment”, final report of the first part of the CPR on “Benchmark analyses of sodium natural convection in the upper plenum of the MONJU reactor vessel”*



# IAEA Technical Publications on Fast Reactors Technology under preparation

- ❑ Proceedings of the FR13 Conference
- ❑ *Status of Accelerator Driven Systems Research and Technology Development*
- ❑ Final reports of the completed CRPs
  - ✓ *“Control rod withdrawal tests performed during the PHENIX end-of-life experiments”;*
  - ✓ *“Benchmark Analyses of Sodium Natural Convection in the Upper Plenum of the MONJU Reactor Vessel”*
  - ✓ *“Analyses of and lessons learned from the operational experience with fast reactor equipment and systems”*
  - ✓ *“Analytical and Experimental Benchmark Analyses on Accelerator Driven Systems”*

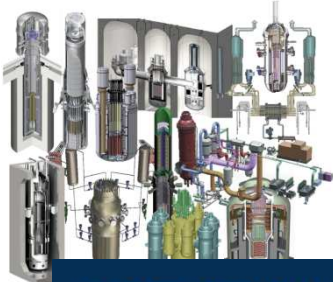
# Status of Innovative FR Designs



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*Atoms for Peace*

Status of Small and Medium Sized Reactor Designs

A Supplement to the IAEA Advanced Reactors Information System (ARIS)  
<http://aris.iaea.org>



## STATUS OF SMALL AND MEDIUM SIZED REACTOR DESIGNS

A Supplement to the IAEA Advanced Reactors  
Information System (ARIS)

<http://aris.iaea.org>



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September 2012



**IAEA**

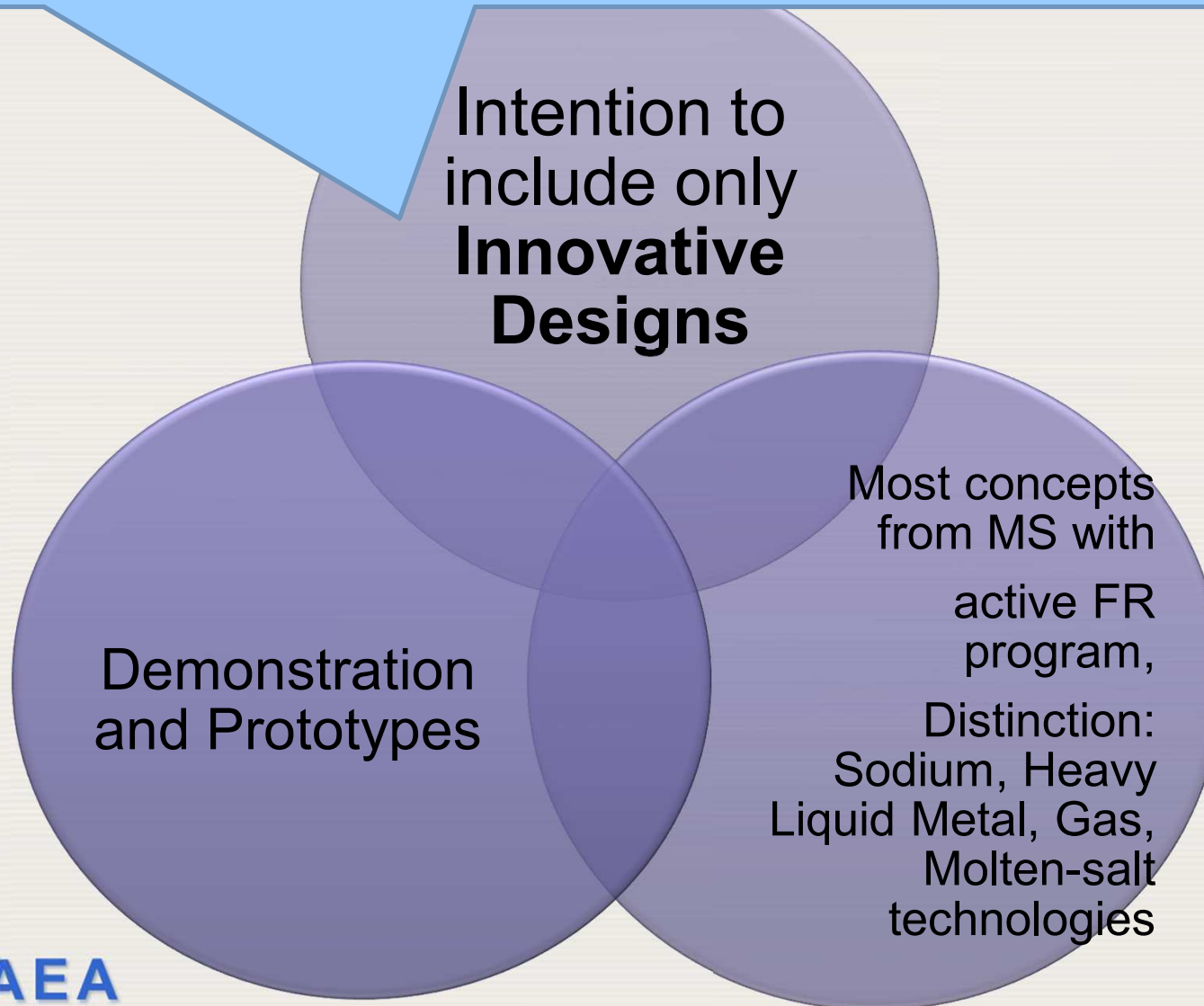
**IAEA's Activities on FR:** International Conference on Fast Reactors and Related Fuel Cycles, Status Report, TWG → information about innovative FR technologies, opportunities to interact with Developers

**Advanced Reactor Information System (ARIS): Booklet as a supplement to ARIS for providing** Members States with balanced, comprehensive and up-to-date information about advanced nuclear plant designs and concepts

**Experience from “Booklet on the Status of SMRs”:** 2011 and 2012 editions, providing a brief overview of SMR designs

***Niche for developing a Booklet on the “Status of Innovative Fast Reactor Designs”***

**Innovative designs** - advanced designs which incorporate radical conceptual changes in design approaches or configuration in comparison with existing practice. Substantial research and development efforts, feasibility tests, and a prototype or demonstration plant are probably required prior to the commercial deployment.



# Contents & Structure of the Publication

Previous Experience and Current Status Fast Reactors

Foreword, Introduction

Innovative Fast Reactor Designs

Sodium-cooled Fast Reactor Designs

Heavy Liquid Metal-cooled Fast Reactor Designs

Gas-cooled Fast Reactor Designs

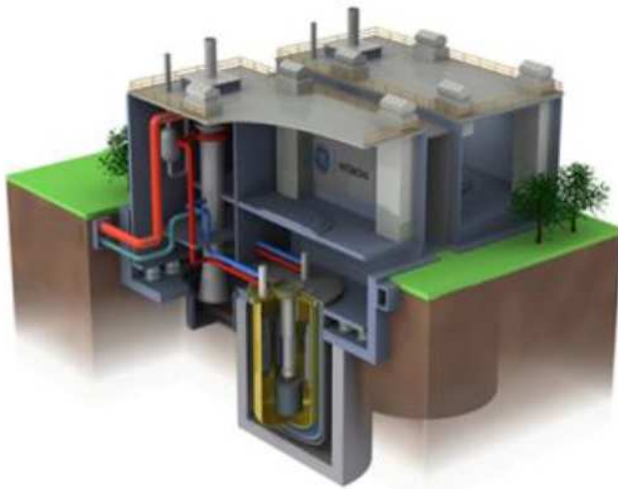
Molten-salt Fast Reactor Designs

Additional Material

- List of Acronyms
- Glossary
- Appendix: Tables presenting synoptically the status of the designs



# Approach for design descriptions



Reactor type:	<i>Liquid metal cooled fast breeder</i>
Electrical capacity:	<i>311 MWe</i>
Thermal capacity:	<i>840 MWt</i>
Coolant:	<i>Sodium</i>
Primary Circulation:	<i>Forced circulation</i>
System Pressure:	<i>Low pressure operation</i>
Core Outlet Temperature:	<i>485°C</i>
Thermal Efficiency:	<i>33%</i>

Two pages per design:

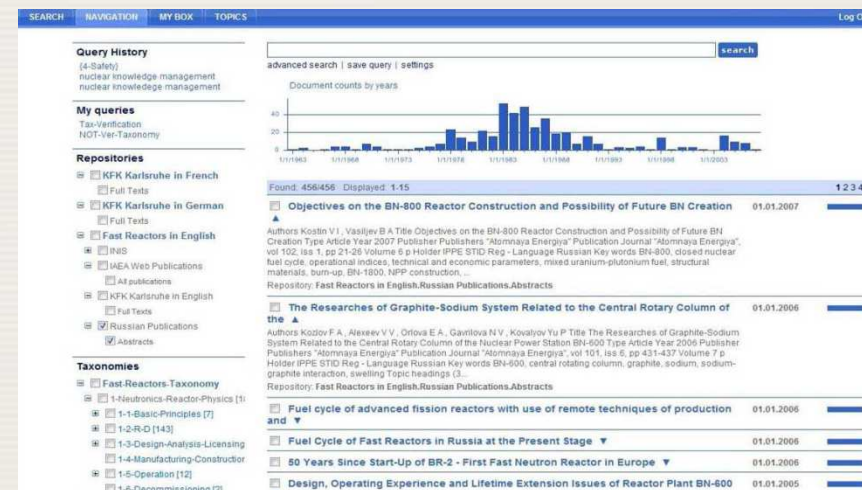
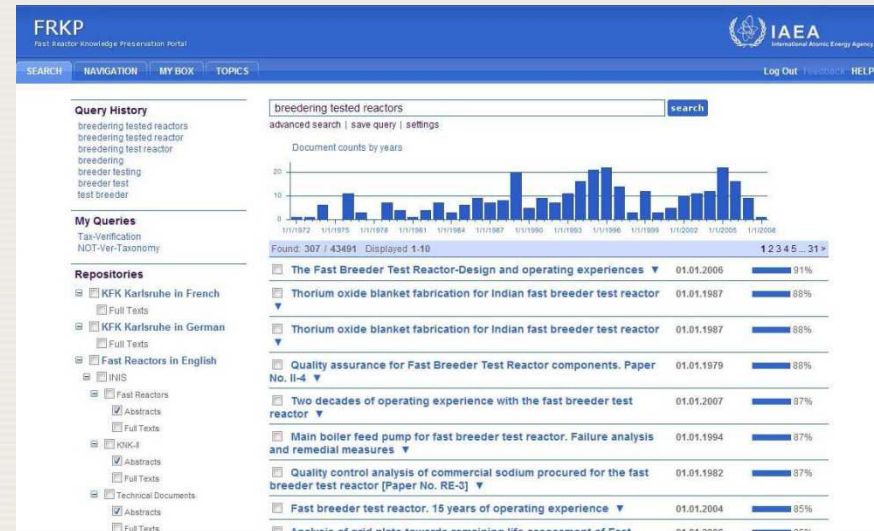
- 1<sup>st</sup> page: picture, table of main technical parameters
- 2<sup>nd</sup> page:
  - Introduction
  - Description of Nuclear Systems
  - Description of the Safety Concept
  - Non-electric Applications (if applicable)
  - Development Status and Planned Schedule



# FRs Knowledge Preservation Portal: FR-KOS System

<https://nkm.iaea.org/nkm1/>

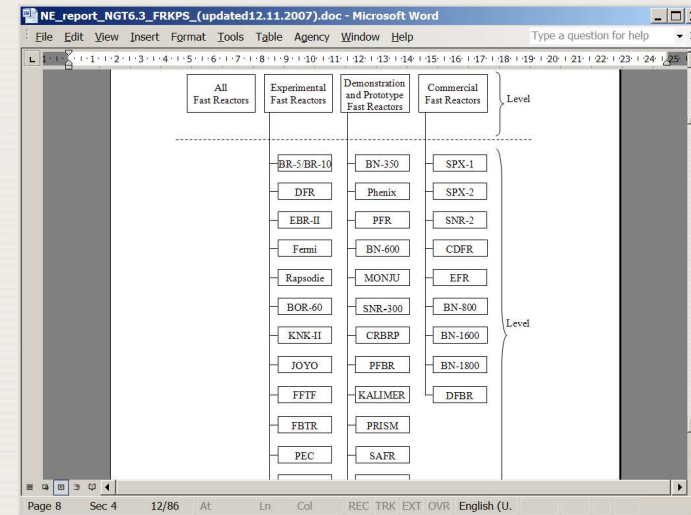
- NKM Section developed a **Fast Reactor Knowledge Organization System (FR-KOS)**: IT system to retrieve information stored in an international data base
- The NPTDS/FR Project collaborates with the NKM Unit to update the system and collect data and info to be uploaded into the system
- First version released to MSs for testing and stimulating contributions to FR-KOS
- Next TM on FR-KP: Vienna, 3-5 December 2013



# FR-KOS System: Fast Reactor Taxonomy

## ➤ Covers

- ✓ all possible types of fast reactors
- ✓ all aspects of fast reactors
- ✓ all stages of implementation of fast reactor technology



## ➤ Based on 2 dimensional matrix (2 top levels):

- ✓ stages of implementation
- ✓ technology elements

Basic principles	R&D	Design, analysis, licensing	Manufacturing & construction	Fuel cycle	Operation	Decommissioning
Fast fission	Reactor physics	General system criteria	Site development	Waste management	Cold startup	Planning
Basic design and variations	Fuel and materials	Codes and standards	Components manufacturing	Transport	Low power commissioning	Experience
Safety principles and philosophy	Heat transfer and transport systems	Core design	Plant assembly		Full power operation	
	Pipe integrity	Dynamic analysis	Balance of plant		Environmental impact	
	Seismic analysis	Environmental impact	Inspection		Maintenance	
	Accident analysis	System design description	Codes & standards		Off-normal & emergency operation	
	Sodium fire	Demonstration of safety			Failed fuel detection	
	BDB events	Project cost analysis(economics)			Fuel handling	
	Control materials	Control systems				
	Shielding	Failed fuel detection				
		Shielding				

FIG. 1. Structure of the two top levels of the LAEA FRKP system proposed at the Consultancy Meeting in Vienna [9]. |

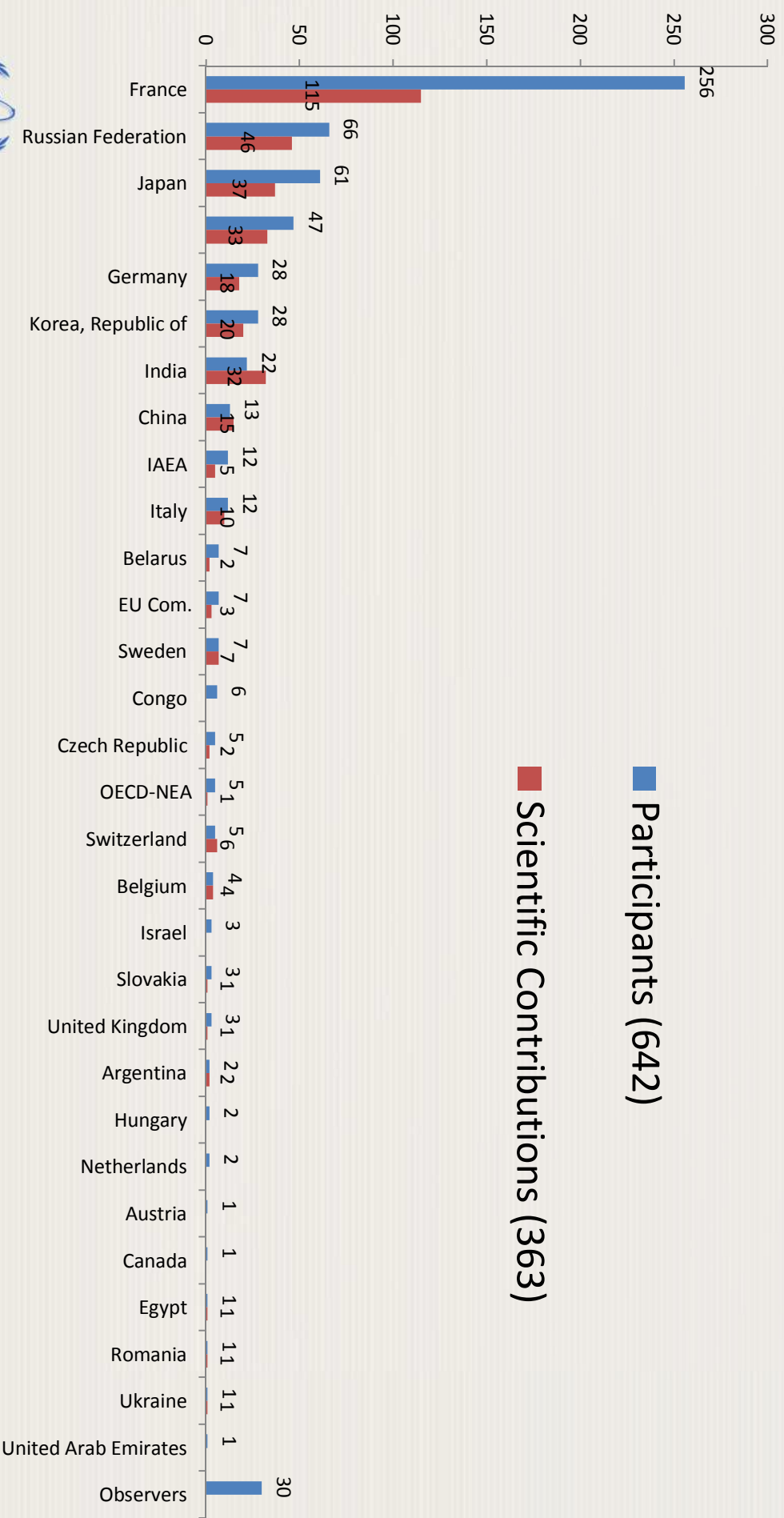
# IAEA International Conference on *Fast Reactors and Related Fuel Cycles – FR13*



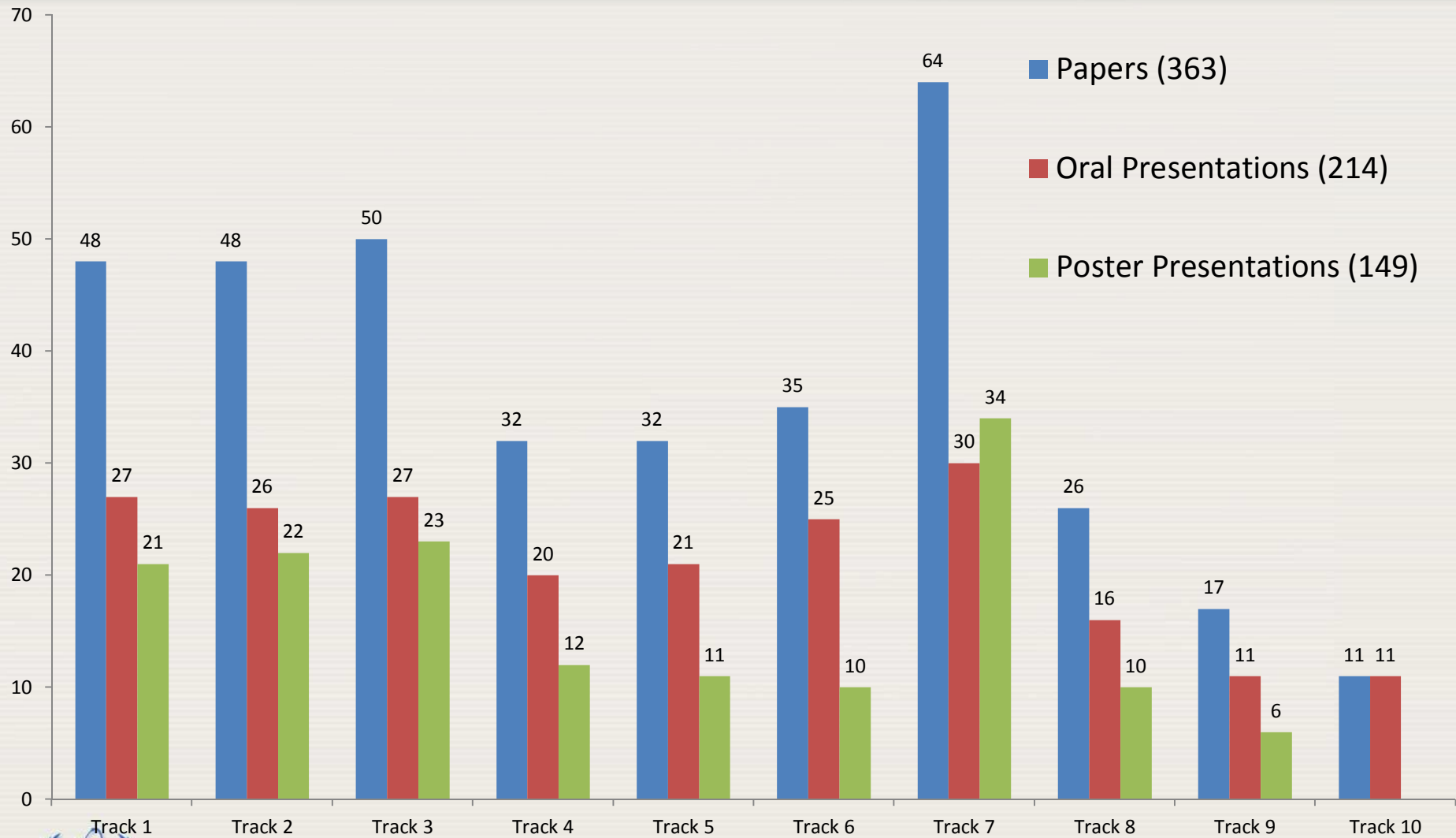
- Total number of participants: 642
- Participating countries: 27
- International Organizations: 4
- Plenary sessions 4
  - ✓ *Opening session* 5
  - ✓ *National and International Programmes* 9
  - ✓ *Safety Design Criteria* 7
  - ✓ *Sustainability of Advanced Fuel Cycles* 8
  - ✓ *Young Generation Event* 7
  - ✓ *Closing Session* 7
- Topical Tracks: 10
  - ✓ *Technical Sessions* 41
  - ✓ *Poster Sessions* 2
- Scientific Contributions: 371
  - ✓ *Oral presentations:* 214
  - ✓ *Poster presentations:* 157



# FR13 Participants and Scientific Contributions by Country



# FR13 Scientific Contributions per Track





# IAEA International Conference on Fast Reactors and Related Fuel Cycles – FR13

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Nuclear Power (NENP) Nuclear Energy Nuclear Safety & Security Nuclear Applications Safeguards Technical Coop.

Division of Nuclear Power

- Nuclear Power Engineering
- Nuclear Power Technology Development
- INPRO
- Infrastructure
- Meetings
- Publications
- Information Systems & Databases

International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13) 4-7 Mar 2013 Paris, France

The conference, which was held last week from 4 to 7 of March 2013 in Paris, provided a forum to exchange information on national and international programmes, and more generally new developments and experience, in the field of fast reactors and related fuel cycle technologies. A first goal was to identify and discuss strategic and technical options that have been proposed by individual countries or companies. Another goal was to promote the development of fast reactors and related fuel cycle technologies in a safe, proliferation resistant and economic way. A third goal was to identify gaps and key issues that need to be addressed in relation to the industrial deployment of fast reactors with a closed fuel cycle. A fourth goal was to engage young scientists and engineers in this field, in particular with sustainability, innovation, simulation, safety, economics and public acceptance.

This page contains the most up-to-date information and materials regarding the event. Please visit this page regularly, as new and revised materials will be uploaded here as they become available.

Working Documents

- Programme
- Announcement

Presentations

Opening Session

- Opening Address  
L. Michel, Ministry of Ecology, Sustainable Development and Energy, FRA
- Opening Address  
Y. Amano, IAEA, Director General
- Opening Address - Text  
B. Bigot, Chairman, CEA, France
- Fast Reactor Development and World-wide Cooperation in Generation IV International Forum  
Y. Sagayama, Former GIF Chairman, Japan

Plenary Session: National and international fast reactor programmes

- Fast Reactor Development Strategy in China  
D. Zhang, CIAE, China
- French R&D program on SFR and the ASTRID prototype  
C. Behar, CEA, France
- A perspective on the Indian programme on Fast Reactors and associated fuel cycles  
P.R. Vasudeva Rao, IGCAR, India
- Deliberation of Post 3.11 Fast Reactor R&D Strategy in Japan

*All the presentations given at FR13 Conference including opening addresses, closing remarks, panels' and YGE contributions are available at the following website:*

*<http://www.iaea.org/NuclearPower/Meetings/2013/2013-03-04-03-07-CF-NPTD.html>*

*Book of Abstracts and not-reviewed / not-edited full papers were distributed in an USB stick memory at the conference*

# FR13 Highlights and Main Outcomes

## *FR projects worldwide*

### □ Research & Projects on Fast Neutron Reactors & related Fuel Cycles remain at sustained level worldwide

#### ➤ Near term projects of SFRs:

- ✓ *India: PFBR (500 MWe) (2014, Kalpakkam) + 2 CFBR units (500 MWe)*
- ✓ *Russia: BN-800 (800 MWe) (2014, Beloyarsk-4) -> BN-1200, MBIR (150 MWth) (~2019)*
- ✓ *China: CFR-600 (600 MWe) (2023)*

#### ➤ Near term projects of LFRs:

- ✓ *Russia: SVBR-100 (100 MWe) (2017)*
- ✓ *Russia: BREST-300 (300 MWe) (~2020, Tomsk) -> BREST-1200*

#### ➤ SFR Demonstrations & Research

- ✓ *Japan: Restart of MONJU, Safety tests & Continuing research (JSFR)*
- ✓ *USA et al.: Continuing research on reactor, fuel & fuel cycle*

#### ➤ Gen-IV Systems Technology Demonstrators & Prototypes

- ✓ *France: ASTRID (~ 600 MWe SFR) (2020s) -> ESFR (1500 MWe)*
- ✓ *Europe: MYRRHA (~50-80 MWth LBE-FR) (~2020, Mol Belgium)*
- ✓ *Europe: ALFRED (~300 MWth LFR) -> ELFR*
- ✓ *Europe: ALLEGRO (~70 MWth GFR) (> 2025, CZ, SK, HR + PL)*
- ✓ *USA: SMFR (50 MWe)*
- ✓ *Rep. of Korea: PGSFR (150 MWe)*

# FR13 Highlights and Main Outcomes

## *Track 4 - fast reactors materials: achievements and challenges*

### ❑ Structural materials with improved resistance (high temperatures, high neutron flux, corrosion, 60y lifetime, etc.)

- ✓ Advanced Austenitic steels
  - ✓ Advanced ferritic/martensitic steels
- } Improvement of ageing (creep, fatigue, creep-fatigue) mechanisms understanding

### ❑ Low swelling steels for fuel cladding

- ✓ Advanced Austenitic Steels
- ✓ Advanced Ferritic and Ferritic/Martensitic Steels
- ✓ Oxide Dispersed Strengthened Steels (ODS)
- ✓ SiC-SiC

### ❑ Large components (steam generators, pumps, etc.) materials

- ✓ Research on codes for mechanical design

### ❑ Materials specific issues

- ✓ SFR: alternative coatings for stellite replacement
- ✓ LFR: control of steel corrosion in lead-alloys
- ✓ GFR: SiC-SiC as fuel cladding, 9 Cr F/M steel for the vessel, Ni-alloys for HX

# FR13 Highlights and Main Outcomes

## *Final Conclusions*

- FR13 Conference confirmed that, in spite of the recent Fukushima accident, nuclear energy remains a necessary resource to meet the expected significant increase in the world energy demand
- Fast reactors and the corresponding closed fuel cycles will play a key role to guarantee a long term sustainable energy supply
- FR13 represented an effective framework to share updates on national programs of fast reactor developments, projects of new builds and plans for the future
- The importance of international collaborations was firmly remarked. In this regards, FR13 represented a catalyst for further collaborations and alliances
- The conferences effectively provided a forum to review new developments arising from R&D programmes in the key areas of fast reactors technology
- **Next conference FR17 was announced to be held in Russian Federation in 2017**

# Scope of this technical meeting

- ❑ Within FR development programmes, significant research and development (R&D) efforts are devoted to the design of innovative reactor cores
  - intrinsic safety features (enhanced negative reactivity feedbacks, reduced coolant void reactivity effects, etc.),
  - high performance (in terms of cycle length, high fuel burnup, breeding gain, etc.)
  - Minor Actinide transmutation capability
- ❑ The development of high performance in-core structural materials represents one of the most challenging aspects
  - high neutron flux
  - liquid metal coolant
  - high temperatures



# Objectives and expected outcomes

- ❑ Present and discuss results of studies and on-going R&D and design activities in the field of innovative reactor core concepts
- ❑ Present and discuss results of studies and on-going R&D activities in the field of advanced reactor core structural materials
- ❑ Identification of research and technology gaps to be covered through new R&D initiatives to be carried out under the aegis of the IAEA.

# FR Project WEB-site: http://www.iaea.org/NuclearPower/FR/

The screenshot shows the IAEA website's 'Nuclear Power (NENP)' section. On the left is a navigation menu with categories like 'Nuclear Power Engineering', 'Nuclear Power Technology Development', 'Advanced Reactors Support', and 'INPRO'. The main content area features an article titled 'Support for Innovative Fast Reactor Technology Development and Deployment'. The article includes three images of reactors: the Prototype Fast Breeder Reactor (PFBR) in India, the China Experimental Fast Reactor (CEFR) in China, and the Russian sodium-cooled fast reactor BN-800. The text discusses the need for fast reactor technology to increase energy yield and improve nuclear waste management, and mentions the operational experience of sodium-cooled fast reactors like the FFTF in the USA and the Phenix in France.

**Navigation Menu:**

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  - Gas Cooled Reactors
  - Fast Reactors**
    - Small and Medium Sized Reactors
    - Near Term Deployment
    - Non-Electric Applications
    - Technology Training
- INPRO
  - Infrastructure
  - Meetings
  - Publications
  - Information Systems & Databases

**Article Content:**

### Support for Innovative Fast Reactor Technology Development and Deployment

It is generally recognized that long term development of nuclear power as a part of the world's future energy mix will require fast reactor technology with closed fuel cycle. The fast neutron spectrum allows fast reactors to increase the energy yield from natural uranium by a factor of sixty to seventy compared to thermal reactors, granting therefore realization of nuclear power programmes for thousands of years, as well as a significant improvement of nuclear waste management. It is for these reasons that fast reactors have been under development for decades in several countries, primarily as breeders and, in recent years, also as High-Level Waste burners.

The necessary condition for successful deployment in the near and mid-term is the understanding and assessment of technological and design options, based on both past knowledge and experience, as well as on scientific and technological research efforts.

With regard to the first, the design and operation of several sodium-cooled fast reactors, such as the Fast Flux Test Facility (FFTF) in USA, the small size Prototype Fast Reactor in the United Kingdom, the prototype Phenix in France, the BN-350 in Kazakhstan, the demonstration plant BN-600 in Russia, Monju in Japan, the commercial size Superphenix in France, etc. have provided an operational experience base of about 400 reactor-years. In addition, there is a considerable base of experience with lead-bismuth (eutectic) cooled propulsion (submarine) reactors operated in Russia.

Examples of current sodium-cooled fast reactors are the China Experimental Fast Reactor (CEFR), which has been connected to the grid in July 2011, the Russian BN-800 and the Prototype Fast Breeder Reactor (PFBR) in India, both under construction.

>Besides current fast reactors construction projects, several countries are engaged in intense research and development programmes for the development of fast reactors innovative (GENIV) concepts. In order to establish multilateral international cooperative frameworks to carry out R&D in support to the next generation nuclear reactors, the following initiatives have been launched:

# TWG-FR WEB-site

<http://www.iaea.org/NuclearPower/Technology/TWG/TWG-FR/>

**IAEA.org**  
International Atomic Energy Agency

Search IAEA.org

**Nuclear Power (NENP)**

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

For almost 45 years, the IAEA has been serving interested Member States as a major fulcrum for fast reactors information exchange and collaborative research and technology development. Since 1967, the keystone of the Agency's activities in this field is the Technical Working Group on Fast Reactors (TWG-FR).

The TWG-FR consists in a group of experts to provide advice and support programme implementation, reflecting a global network of excellence and expertise in the area of advanced technologies and R&D for fast reactors and sub-critical hybrid (e.g., accelerator driven systems, and fusion/fission) systems for energy production and for utilization/transmutation of long-lived nuclides.

The TWG-FR assists in formulating an international vision applicable, on the one hand side, to current and advanced fast reactors, and, on the other hand side, to sub-critical hybrid systems. Improved economics, sustainable development and enhanced safety and security represent the inspirer elements of the vision.

In this framework, the TWG-FR assists in defining and carrying out the Agency's activities in the field of nuclear power technology development for fast reactors in accordance with its Statute. It promotes the exchange of information on national and multi-national programmes and new developments and experience, with the goal to identify and review problems of importance and to stimulate and facilitate cooperation, development and practical application of fast reactors and sub-critical hybrid systems.

Finally, the TWG-FR provides Member States with information about the current status and development trends of advanced technologies for fast neutron systems.

*Participants at the last annual technical meeting of the TWG-FR, ANL, Chicago, USA, 20 - 22 June 2012*





<http://www.iaea.org/NuclearPower/FR/>

***Thanks for Your Attention !***



***...Atoms for Peace***

