IAEA
International Atomic Energy Agency

"Atoms for Peace and Development"

Joint ICTP-IAEA Workshop on Open-Source Nuclear Codes for Reactor Analysis
7-11 August 2023, Trieste, Italy

Innovative Nuclear Energy Systems: Introduction of IAEA Activities

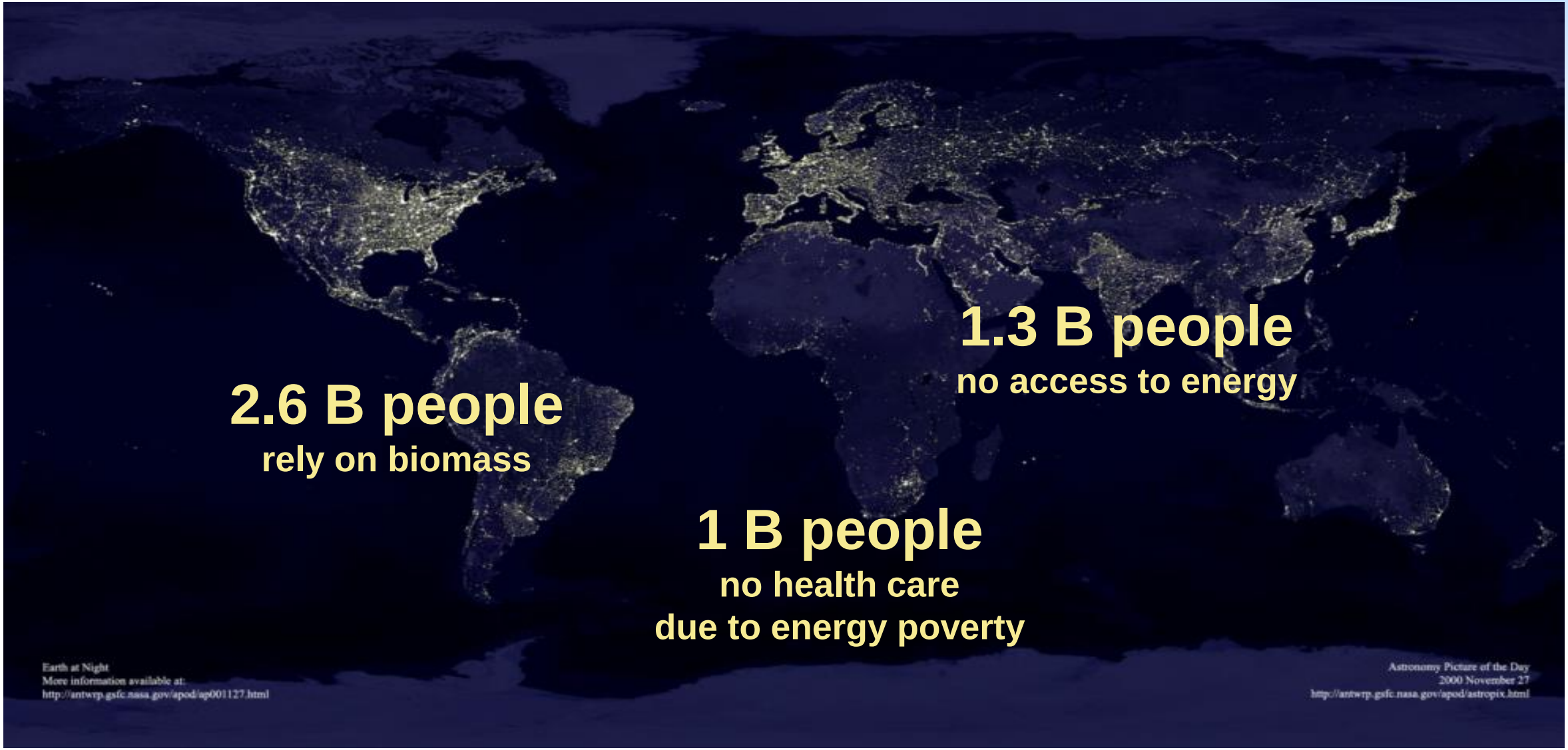
Vladimir Kriventsev, Nikoleta Morelová, Lingli Li

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

email: FR@IAEA.ORG

Energy


2.6 B people
rely on biomass
1.3 B people
no access to energy
1 B people
no health care
due to energy poverty
Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

Nuclear Power Reactors Today

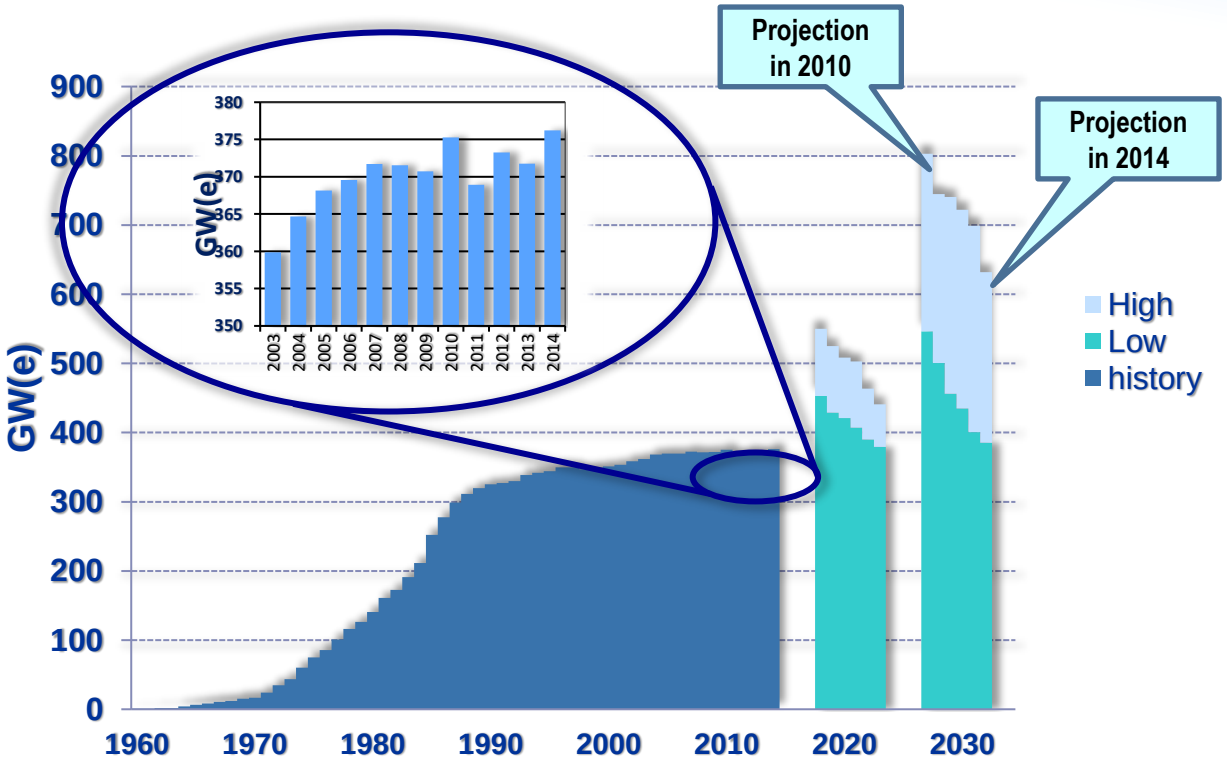
437 nuclear power reactors (~390 GWe)
in operation in 30 countries

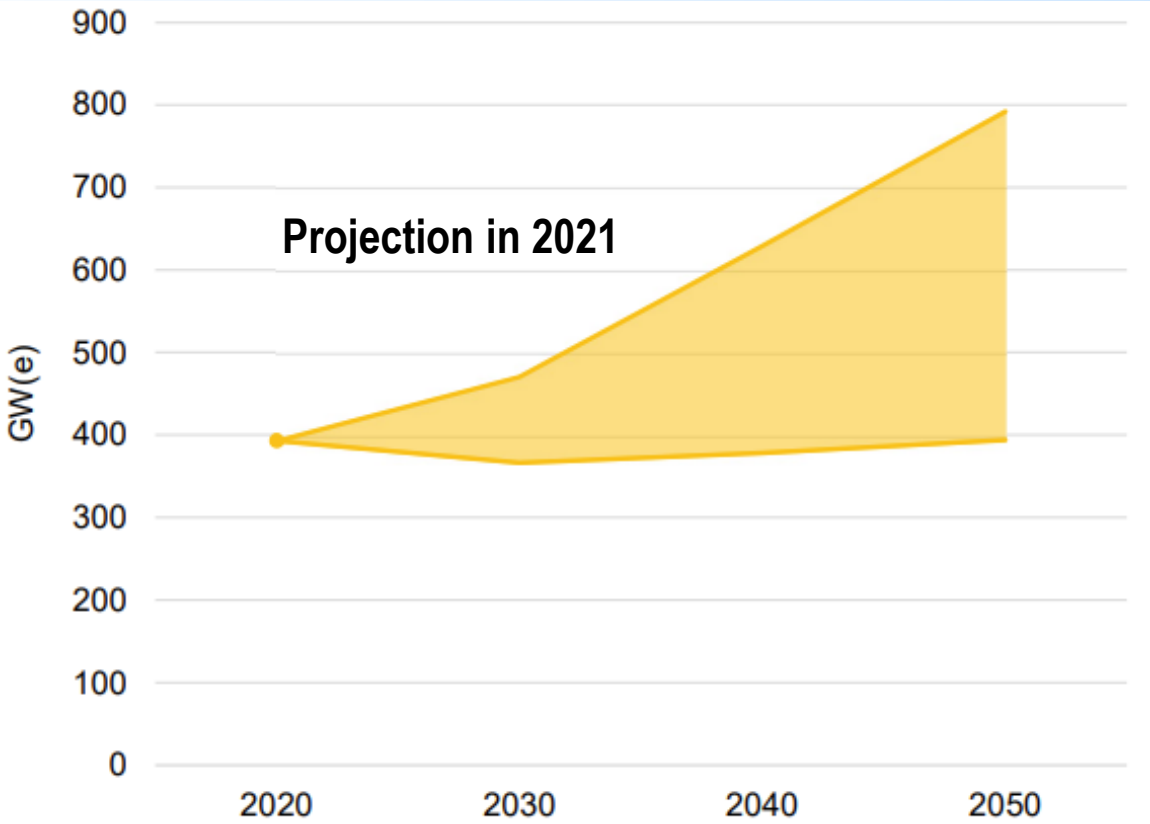
In 2022, nuclear power reactors generated 9.2%
of total electricity generated in the world:
2633.4 TWh

57 reactors under construction, 59 GW(e)
in 15 countries (2 newcomer countries)

IAEA Power Reactor Information System (PRIS) pris.iaea.org

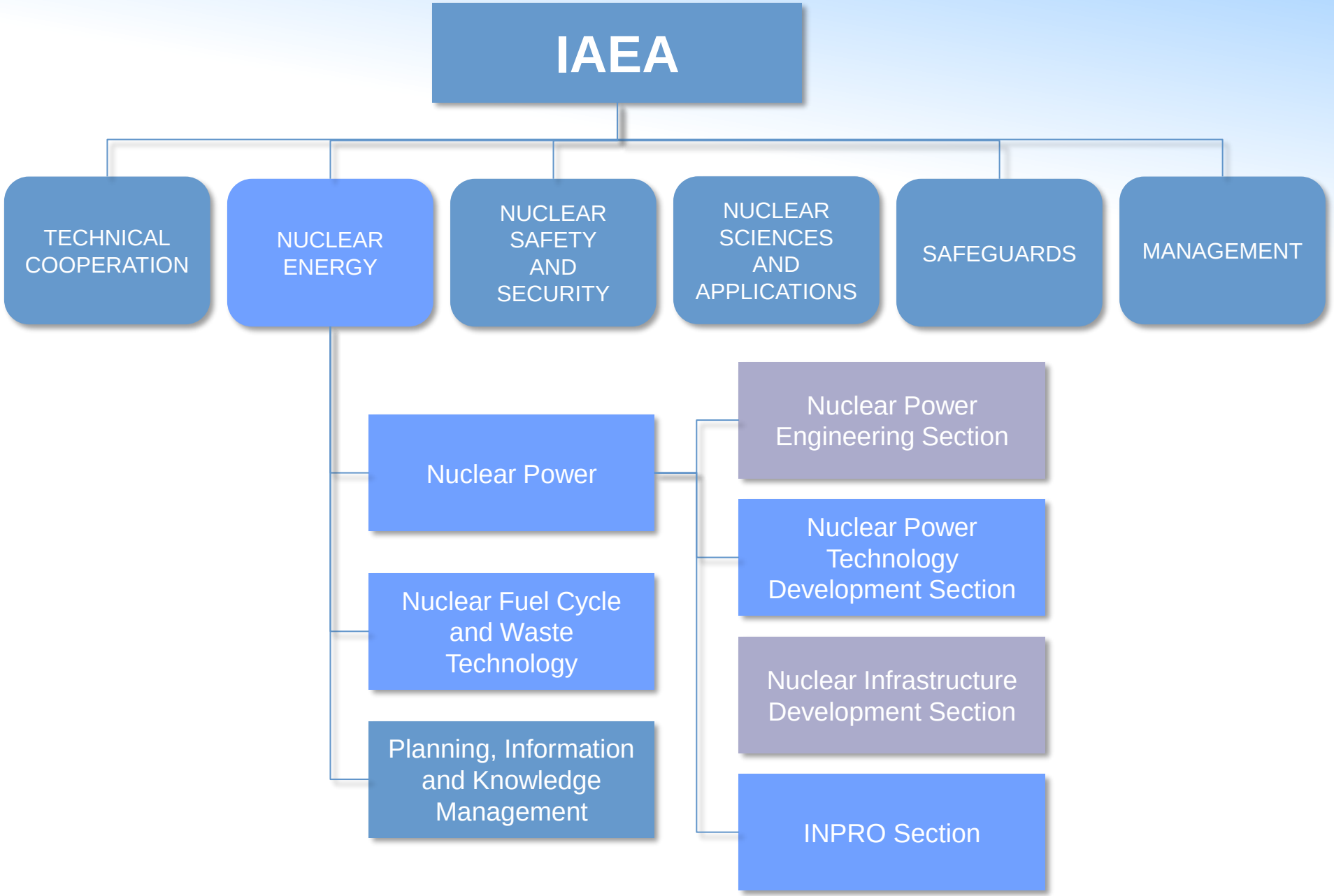
Nuclear Capacity 2020 – 2030: IAEA Projections





Ref.: Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, 2015 Edition, IAEA

This is the IAEA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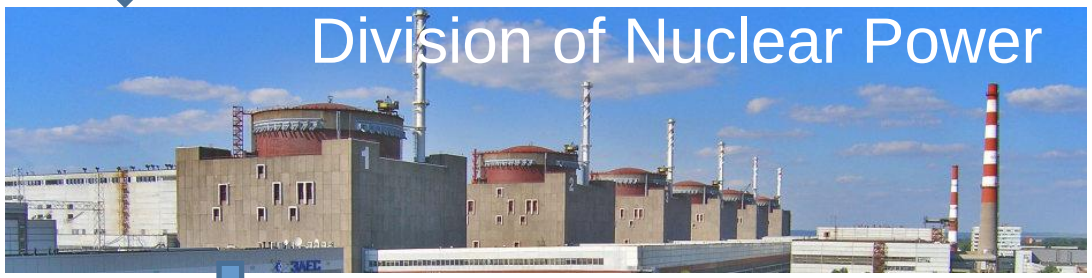
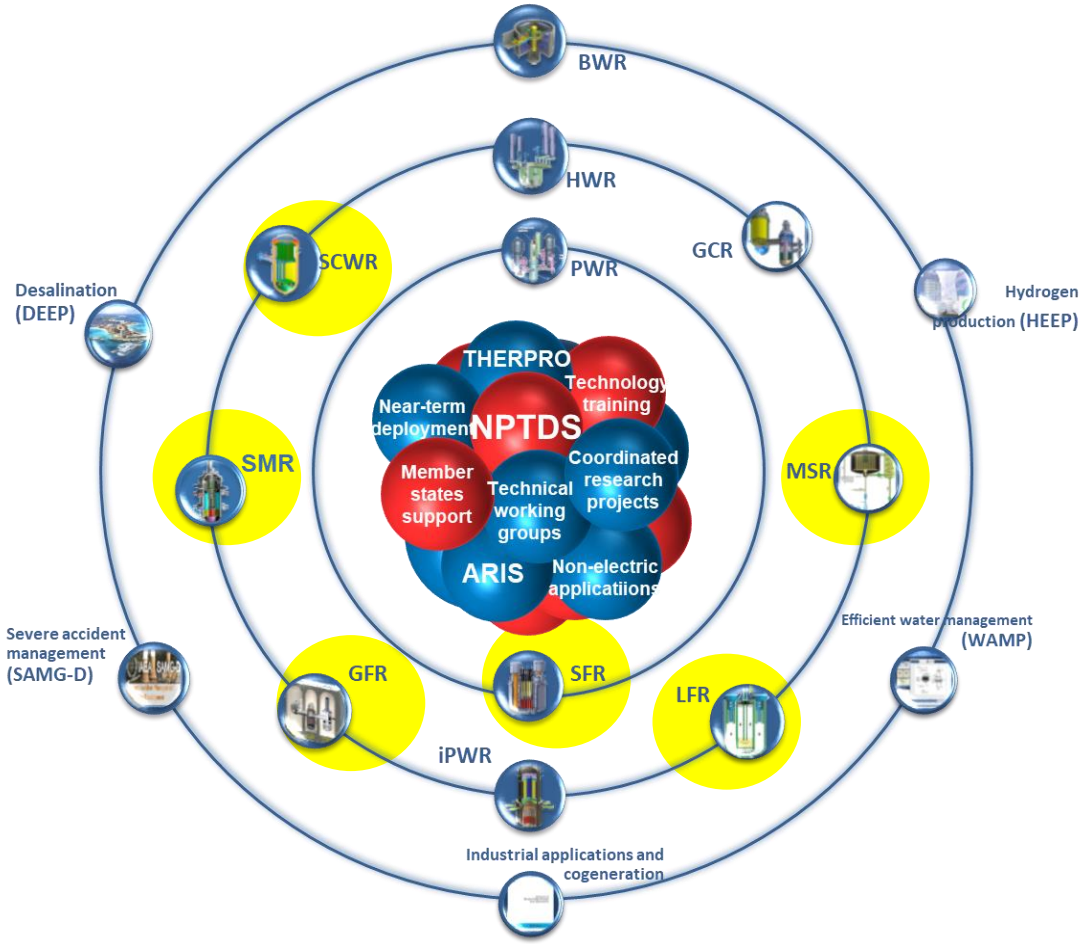
TECHNICAL COOPERATION
NUCLEAR ENERGY
NUCLEAR SAFETY AND SECURITY
NUCLEAR SCIENCES AND APPLICATIONS
SAFEGUARDS
MANAGEMENT
Nuclear Power
Nuclear Fuel Cycle and Waste Technology
Planning, Information and Knowledge Management
Nuclear Power Engineering Section
Nuclear Power Technology Development Section
Nuclear Infrastructure Development Section
INPRO Section

Fast Reactor Technology Development Team



NPTDS:
Nuclear Power Technology Development Section

- Advanced WCRs
- SMRs
- Non-Electrical Applications
- Fast Reactors



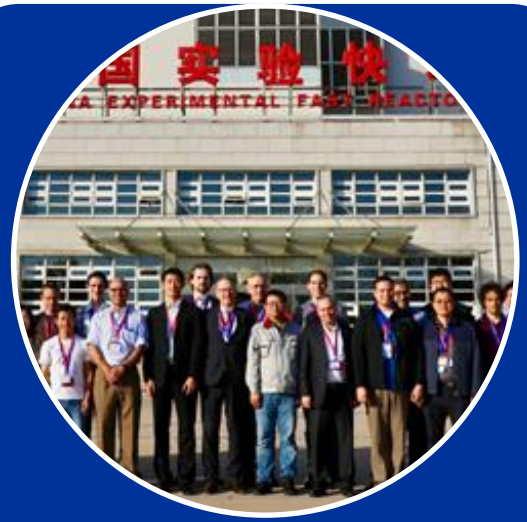
Main IAEA Activities on Advanced Reactors Technology

Knowledge Sharing

Publications

Conferences

TMs



Technology Development

Coordinated Research Projects (CRPs)

Capacity Building

Training Courses

Workshops

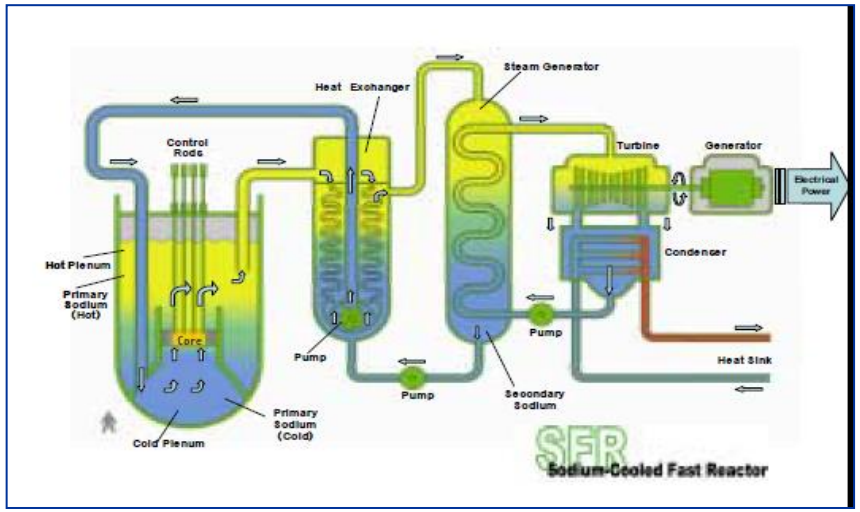
TECDOCs

Six Generation-IV Reactor systems

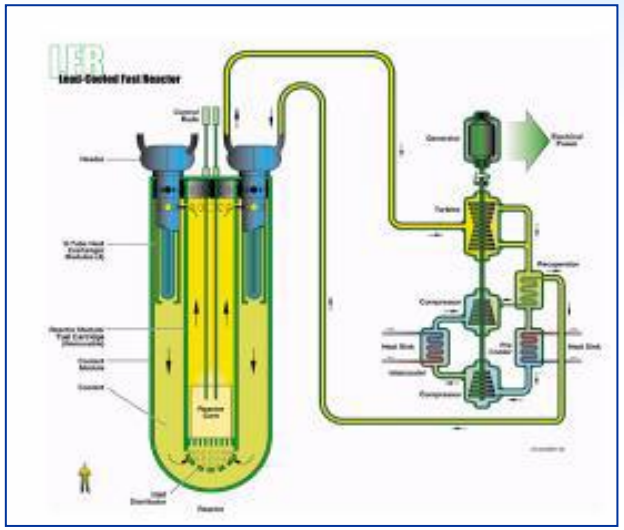
GIF website: www.gen-4.org

IAEA

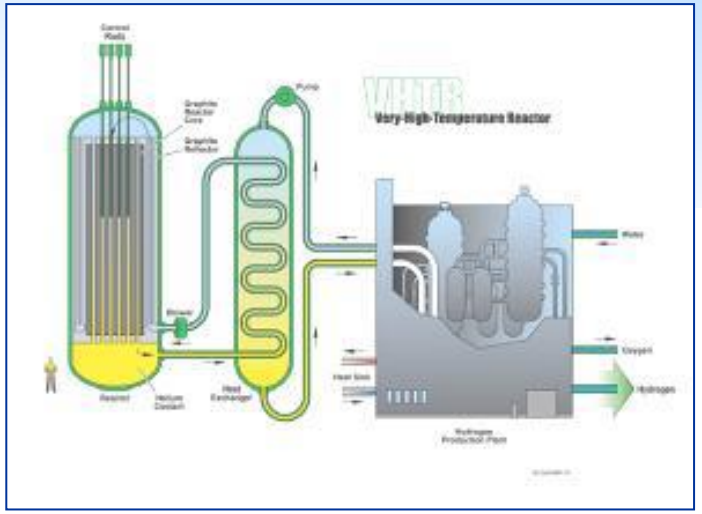
Sodium cooled Fast Reactor (SFR)

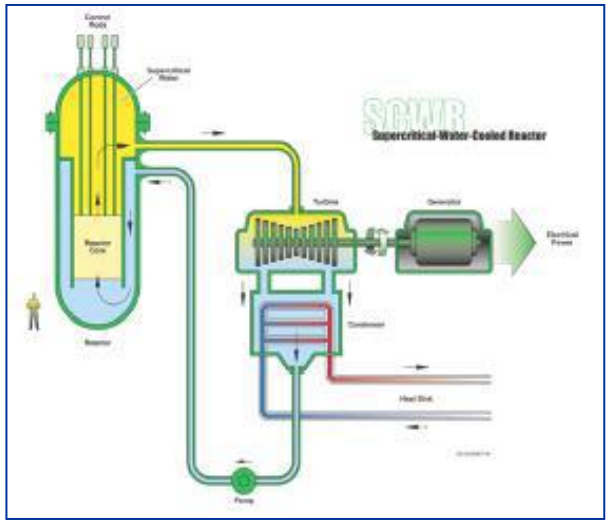


Lead cooled Fast Reactor (LFR)

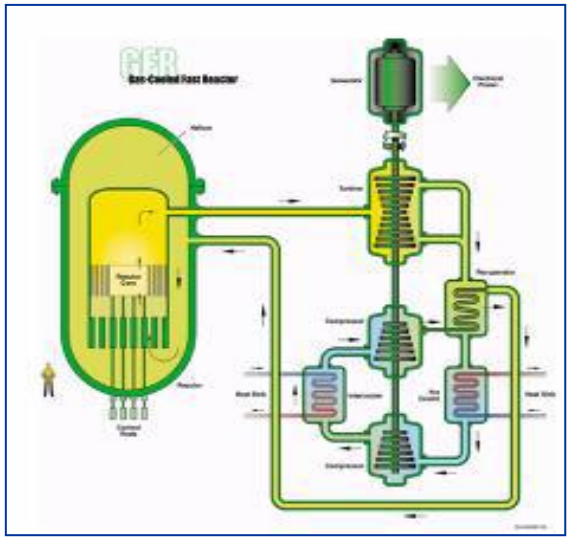


Very-High-Temperature Reactor (VHTR)

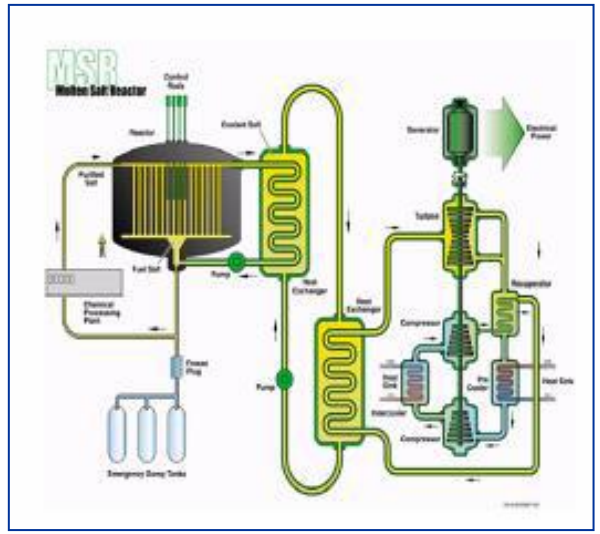




Supercritical Water cooled Reactor (SCWR)



Gas cooled Fast Reactor (GFR)



Molten Salt Reactor (MSR)

Fast Reactors in Operation & under Commissioning

Country	Name	Coolant	Purpose	Power (th/e) MW	Year (Op.)	Status
Russia	BOR-60	sodium	experimental	60/10	1969	operating
	BN-600	sodium	prototype	1470/600	1980	operating
	BN-800	sodium	commercial	2100/880	2015	operating
China	CEFR	sodium	prototype	65/20	2011	operating
India	FBTR	sodium	experimental	40/13	1985	operating
	PFBR	sodium	prototype	1250/500	(Est.) 2024	commissioning
Japan	JOYO	sodium	experimental	150/--	1978	license renew (2024?)

BN-600
Russia, 1980

BN-800
Russia, 2015

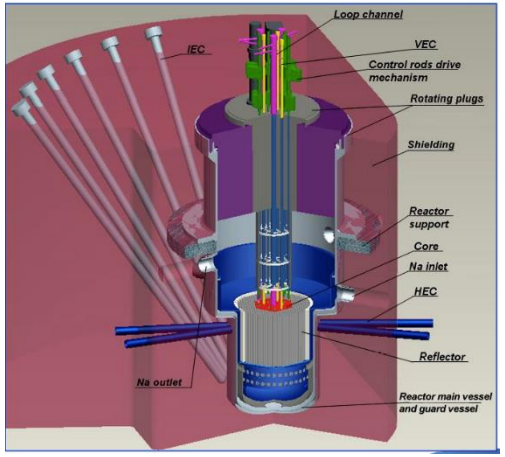
CEFR, 20 MW(e)
China, 2011

FBTR, 13 MW(e)
India, 1985

PFBR, 500 MW(e)
India, 2024

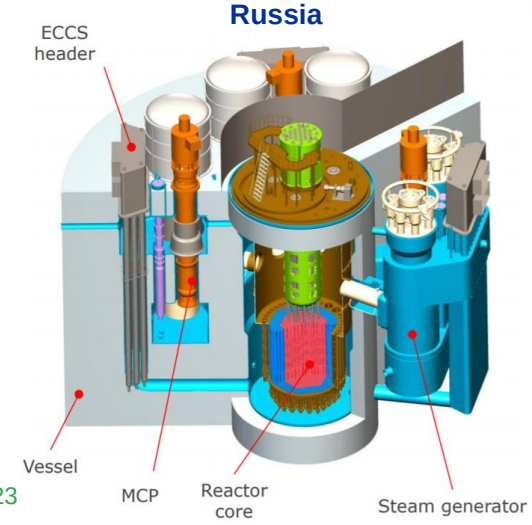
Fast Reactors under Construction and Decommissioning

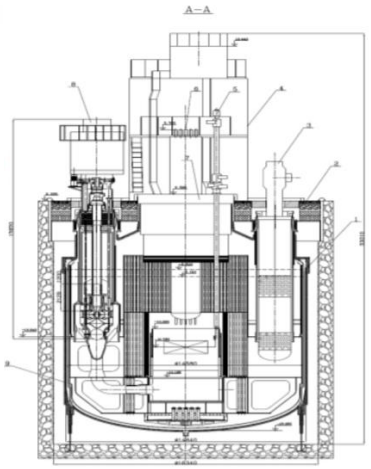
Country	Name	Coolant	Purpose	Power (th/e) MW	Year (Op.)	Status
Russia	MBIR	sodium	experimental	**150/50**	~2028	construction
	BREST-OD-300	lead	demonstrator	**700/300**	~2026	construction
China	CFR600 x2	sodium	prototype	**1500/600**	~2025	construction (2 units)
Japan	MONJU	sodium	prototype	**714/280**	1994	decommissioning
USA	FFTF	sodium	experimental	**400/--**	1980	decommissioning



MBIR, Russia

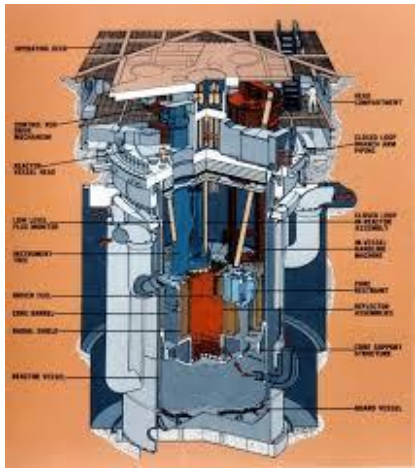
BREST-OD-300
Russia





CFR600, China

MONJU, Japan



FFTF, USA

Fast Reactors under Developing and Design

Country	Name	Type	coolant	Purpose	Power (th/e), MW	Status
Russia	**BN-1200**	SFR	sodium	Gen-IV, industrial	2900/1220	design
	SVBR-100	LFR	LBE	prototype	280/100	design
	MOSART	MSR	molten salt	prototype	2400/	concept
China	**CFR1000**	SFR	sodium	Gen-IV, industrial	2512/1000	design
	CLFR-300	LFR	LBE/lead	demonstrator	740/300	concept
	CLEAR-M10a	LFR	LBE	experimental	10/1-3	concept
	CLEAR-I	LFR	LBE	experimental	10/-	design
	CLEAR-M10d	LFR	lead	demonstrator	25/10	concept
EU	ALFRED	LFR	lead	Gen-IV, prototype	300/120	design
	ALLEGRO	GFR	helium	Gen-IV, demonstrator	75/-	design
	MSFR	MSR	molten salt (LiF-AFn)	Gen-IV, prototype	3000/	concept
Belgium	MYRRHA	LFR ADS	LBE	experimental	100/-	design
France	ASTRID	SFR	sodium	demonstrator	1500/600	suspended
Italy	newcleo LFR-AS-30/200	LFR	lead	experimental/prototype	/30 or /200	concept
R. of Korea	KALIMER-600	SFR	sodium	GEN-IV, prototype	1523/600	design
	PGSFR	SFR	sodium	GEN-IV, demonstrator	400/150	suspended
Sweden	**SEALER-55**	LFR	lead	demonstrator	140/55	design
UK	**Westinghouse LFR**	LFR	lead	demonstrator	950/450	design
USA	**Westinghouse LFR**	LFR	lead	demonstrator	950/450	design
	NATRIUM	SFR	sodium	demonstrator	1000/345-500	design
	VTR	SFR	sodium	experimental	300/-	design
	SSTAR	LFR	lead	experimental	45/20	supended
	MCFR	MSR	chloride salt	experimental	1800/800	design
	EM2	GFR	helium	demonstrator	500/265	concept
	KP-FHR	MSR	fluoride salt	demonstrator	310/140	concept
	PRISM	SFR	sodium	demonstrator	840/311	concept
	LLC ARC-100	SFR	sodium	demonstrator	260/110	concept

Main IAEA Activities on Fast Reactor Technology in 2022 - 2023

- CRPs/Benchmarks/Studies
  - Completed (in publishing)
    - NAPRO (2013 - 2018)
    - PSFR Source Term (2016 - 2020)
  - 3 Ongoing CRPs:
    - CEFR Start-Up Tests (2018 - 2022) – extended to 2024
    - 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+):
    - PLANDTL: PLANt Dynamics Test Loop Decay Heat Removal Thermal Hydraulics Tests
    - CRP with the S-ALLEGRO facility
    - Modelling of Total Instantaneous Blockage of SFR F/A (Delayed)
    - Benchmark Analysis of STELLA-2 LOHS/LOF Tests
  - TM on Development and Application of Open-Source Modelling and Simulation Tools for nuclear Reactors (Milan, June 2022)
  - TM on State-of-the-art Thermal Hydraulics of Fast Reactors: (ENEA Brasimone, September 2022)
  - TM on the Safety Approach for Liquid Metal Cooled Fast Reactors and the Analysis and Modelling of Severe Accidents (March 2023- with NSNI)

- FR22- International Conference on Fast Reactors and related fuel cycles (April 2022)
- Technical Working Group on Fast Reactors
  - 55th TWG-FR Meeting (Virtual), May 2022
  - 56th TWG-FR Meeting (Vienna), June 2023
- Joint IAEA-GIF Workshops on LMFR Safety
  - 10th GIF-IAEA Workshop on LMFR Safety (2022)
  - 11th GIF-IAEA Workshop on non-WCR Safety (2023)
- Basic Principles SFR Simulator
  - Ready for Distribution to Member States
- Training Courses and Workshops
  - Webinar on Repurposing Sites of Retired Fossil Plants with Advanced Nuclear Reactors (May 2022)
  - Webinar Series on Multiphysics Modelling of Nuclear Reactors using OpenFOAM (Aug-Sep 2022)
  - Regional Workshop on Advances in Modelling & Simulation of Thermal Hydraulics in LMFRs, India (Nov 2022)
  - Joint ICTP-IAEA Workshops on the Physics and Technology of Innovative Nuclear Energy Systems, Trieste (Dec 2022)
  - Joint ICTP-IAEA Workshop on Open-Source Nuclear Codes for Reactor Analysis, Trieste (Aug 2023)

IAEA Coordinated Research Projects

CRPs on Fast Reactors Technology

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

Completed CRPs

PHENIX – EOL Tests

MONJU – Na Natural Convection

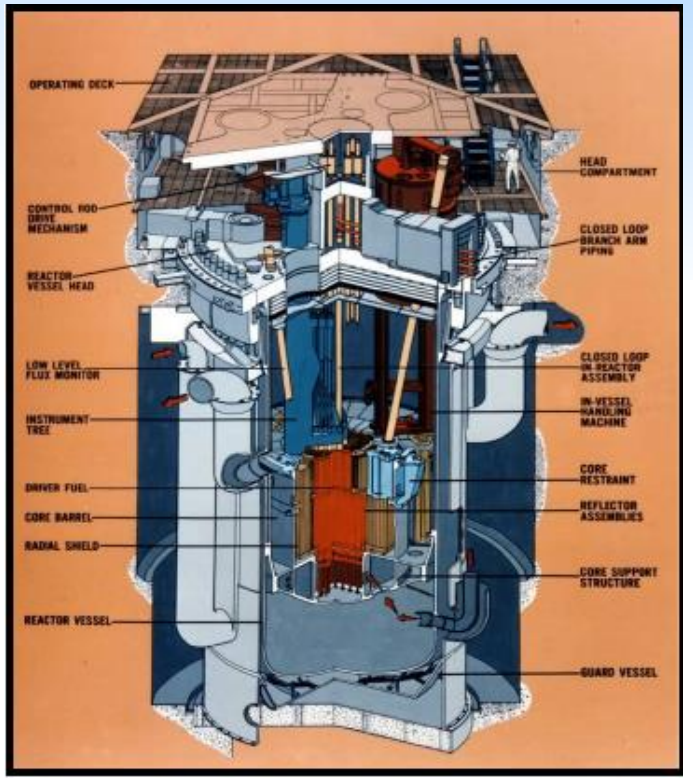
Analytical and Experimental Benchmark Analysis of **ADS**

EBR-II Shutdown Heat Removal Tests

PSFR Source Term – Radioactive Release Under Severe Accident Conditions

CRP: **Benchmark Analysis of FFTF Loss of Flow Without Scram Test**

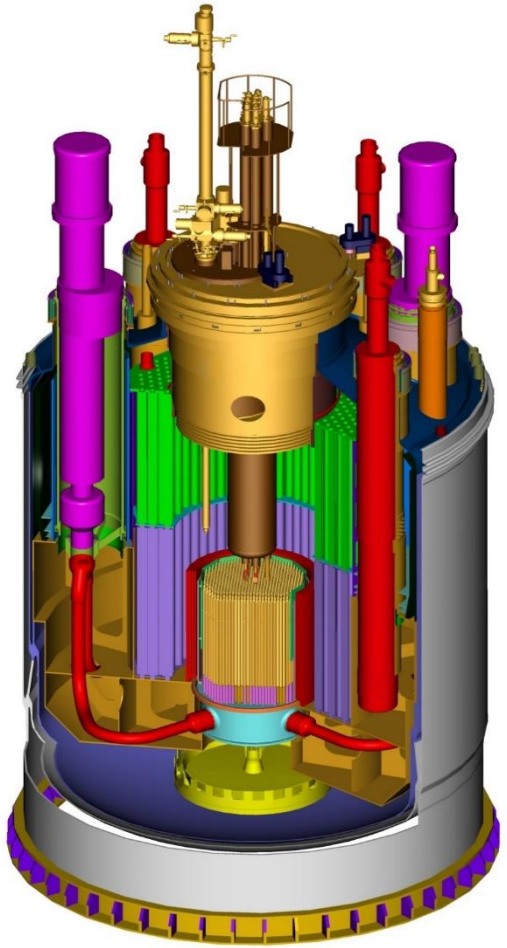
- FFTF (Fast Flux Test Facility) Reactor:
  - 400 MW_{th} sodium cooled fast test reactor
  - Mixed UO_2-PuO_2 (MOX) fuel
  - Loop type plant, axial and radial reflectors
  - Prototypic size
    - ~1m^3 core volume
    - ~91 cm high, ~120 cm diameter
  - Built to assist development and testing of advanced 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: Neutronics Benchmark of CEFR Start-Up Tests

CEFR (China Experimental Fast Reactor)

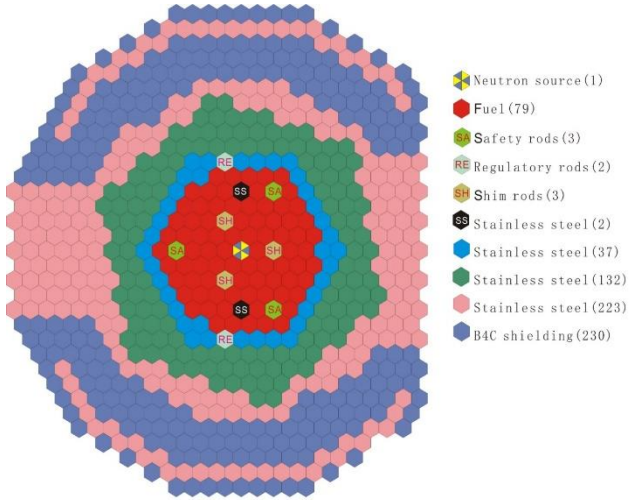
- Located in China Institute of Atomic Energy
- 65MWt (20MWe) sodium cooled fast reactor with a high neutron leakage core fuelled with uranium oxide and stainless-steel radial reflector.
- The primary system is a pool-type design, liquid sodium working fluid for the primary and secondary circuits.
- 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.



CEFR Reactor Block

中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

China Experimental Fast Reactor Plant



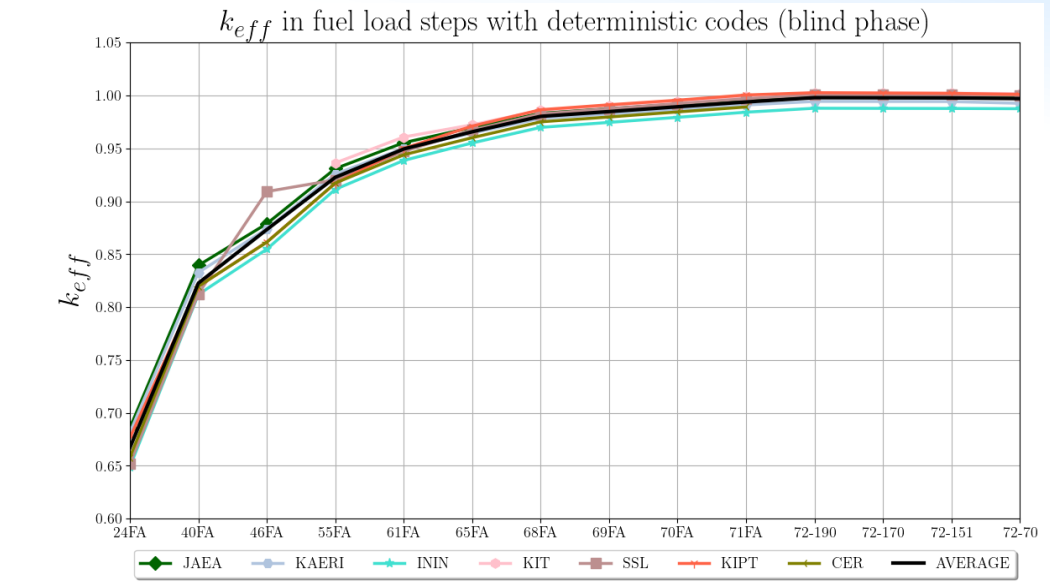
Core layout of the CEFR First Loading

CRP: Neutronics Benchmark of CEFR Start-Up Tests

WP1	Net criticality
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

WP1. Net criticality



Country	Organization
Belgium	SCK•CEN
China	CIAE
China	INEST (FDS)
China	~~SNERDI~~
China	XJTU
Finland	VTT
France	CEA
Germany	HZDR
Germany	GRS
Germany	KIT
Hungary	~~BME~~
Hungary	CER
India	IGCAR
Italy	NINE
Italy	UNIPI
Japan	JAEA
Korea, Rep. of	KAERI
Korea, Rep. of	UNIST
Mexico	ININ
Romania	RATEN-ICN
Russia	~~IBRAE~~
Russia	IPPE
Russia	SSL
Russia	Kurchatov Ins. (NRCKI)
Slovakia	VUJE
Switzerland	PSI
Ukraine	KIPT
UK	Un. of Cambridge
United States	ANL
United States	NRC

30 Participating Organizations from 18 Countries

CRP: **Neutronics Benchmark of CEFR Start-Up Tests**
Training Course Series

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.

Joint ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems

- In 2016, 2018 and 2022 Trieste, Italy
- Contributed by NPTDS, INPRO, GIF, and other external experts

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If you are a candidate who has previously submitted a general application to the IAEA (e.g.: Internship, Consultant), please be informed that the IAEA has recently introduced a new IT platform for all its recruitment activities.

So if you wish to be considered for IAEA job opportunities in the future, please resubmit your application through our website at this link.

Current Vacancies

WEBINAR OF THE MONTH

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International Atomic Energy Agency

Atoms for peace and Development…

Thank You!

email: FR@IAEA.ORG

Workshop Programme

- Lectures during mornings and afternoons
- Evenings for group activities and poster sessions
- **Poster Session**: Please be present on the day assigned to you. The other groups and the lecturers will be invited to review the posters
- **Group Activities**

Monday, 07 Aug		Tuesday, 08 Aug		Wednesday, 09 Aug		Thursday, 10 Aug		Friday, 11 Aug	
08:30 – 09:00	Registration	09:00 – 10:30	Hands-on OpenMC introduction (Patrick Shriwise, Jiwon Choe)	09:00 – 10:30	Introduction to GeN-Foam (Carlo Fiorina)	09:00 – 10:30	Introduction to ContainmentFOAM (Stephan Kelm)	09:00 – 10:30	Open-source digital design supporting the development of fusion (Andrew Davis)
09:00 – 09:10	Welcome Remarks by IAEA								
09:10 – 09:35	Introduction of IAEA Activities on Innovative Nuclear Energy Systems (V. Kriventsev)								
09:35 – 09:55	IAEA Activities on Computational Tools for Simulation of Fast Reactors (N. Morelová)								
09:55-10:10	Coffee Break	10:30-10:45	Coffee Break	10:30-10:45	Coffee Break	10:30-10:45	Coffee Break	10:30-10:45	Coffee Break
10:10-10:15	Group Photo	10:45-12:30	Hands-on OpenMC - Setting up a simple model (Patrick Shriwise)	10:45-12:30	Group Activity 1, Multiphysics simulation of the MSFR using OpenFOAM	10:45-12:45	Introduction to OFFBEAT (Alessandro Scolaro)	10:45-11:30	Fusion neutronics applications: OpenMC calculations for the design of fusion reactors (James Hagues)
10:15-12:20	Multi-physics modelling and simulation of nuclear reactors using OpenFOAM (Carlo Fiorina, Stephan Kelm, Stefano Lorenzi)							11:30-12:30	Group Presentations (All)
12:20-13:20	Lunch Break	12:30-13:30	Lunch Break	12:30-13:30	Lunch Break	12:45-13:45	Lunch Break	12:30-13:30	Lunch Break
13:20-15:00	A practical introduction to OpenFOAM (Stefano Lorenzi)	13:30-15:15	OpenMC- Application on IAEA CRP – Neutronic Benchmark on CEFR Start-up Tests (Jiwon Choe)	13:30-15:15	Group Activity 1, Multiphysics simulation of the MSFR using OpenFOAM	13:45-15:45	Introduction to ARMI Framework (N. Touran-Online)	13:30-14:15	Certificates distribution and closing session
15:00-15:20	Coffee Break	15:15-15:30	Coffee Break	15:15-15:30	Coffee Break	15:45-16:00	Coffee Break		
15:20-17:30	Group Activity 1, Multiphysics simulation of the MSFR using OpenFOAM	15:30-16:30	Group Activity 2, OpenMC CEFR Model	15:30-16:30	Discussion on Group Activities	16:00-17:30	Discussion on Group Activities		
		16:30-18:00	Poster Session (All)	16:30-18:00	Poster Session (All)				

Our Lecturers: **Prof Carlo Fiorina**

OpenFOAM

IAEA

- Since Jan 2023, Associate Professor at the Department of Nuclear Engineering at Texas A&M University
- 2015-2022. Post-doc -> Scientist -> R&D Program Manager at the Laboratory for Reactor Physics and System Behavior at the EPFL, Switzerland
- PhD (2013), MSc (2009), BSc (2007) from Politecnico di Milano (Italy)
- Dr. Fiorina's expertise is in the field of modeling and simulation, scientific computing, software development, and technology of advanced reactor systems

Our Lecturers: **Dr Alessandro Scolaro**

OpenFOAM

IAEA

- Scientist at the Ecole Polytechnique Fédérale de Lausanne (EPFL)
- Main role at EPFL is to manage the computational activities of the Laboratory for Reactor Physics and System Behavior (LRS)
- Specializes in fuel behavior and multi-physics analysis of nuclear reactors, with a strong focus on the advancement of OpenFOAM-based tools
- Master of Science in Nuclear Engineering (2016) followed by PhD (2021) from EPFL
- Prior to PhD, he has worked at Nagra (Switzerland) in the field of NPP waste characterization

Our Lecturers: **Dr Stephan Kelm**

OpenFOAM

- After his PhD (Mech.& Nuc. Eng) from RWTH Aachen, Germany in 2010,
- Stephan founded a research group and became Principal Investigator and Head of the ‘Thermo-Fluid Dynamics and System Analysis’ group at Forschungszentrum (Research Center) Juelich, Germany.
- His research on CFD for reactor safety, severe accident phenomena, and passive safety systems and concepts led to the development of containment∇FOAM a tailored OS package for containment analyses
- Besides, Stephan is engaged in
  - Teaching at RWTH Aachen University and FH Aachen University
  - IAEA ONCORE Expert Group
  - OECD/NEA WGAMA ‘CFD Task Group’ Coordination Team
  - OECD/NEA WGAMA PANDA Program Review Group
  - European severe accident community and related R&D activities

@ NuScale simulator at TAMU, 2023

Our Lecturers: **Dr Stefano Lorenzi** OpenFOAM

- Senior researcher and Assistant Professor at Politecnico di Milano. Teaching courses “Experimental Nuclear Reactor Kinetics” and “Integration of Nuclear and Renewable Energy for Carbon Neutral Scenarios”
- His research expertise includes control-oriented simulation of Nuclear Power Plants (NPPs), control scheme investigation for NPPs, multiphysics and reduced order modelling, nuclear hybrid system and integration with cogenerative applications.
- He participated in different European research projects on Lead-cooled Fast Reactors (LEADER and PASCAL Projects), Molten Salt Reactors (SAMOFAR and SAMOSAFER projects), Small Modular Reactors (ELSMOR and TANDEM projects) analysis and develpment
- He is author of more than 70 international papers with 685 citations (h-index 15 – Scopus database)

Our Lecturers: **Dr Jiwon Choe**

OpenMC

- Senior Researcher at Advanced Reactor Technology Development Division of Korea Atomic Energy Research Institute (KAERI), Daejeon, South Korea Since 2021
  - SFR core analysis code development
- Ph.D., M.S., and B.S. in nuclear engineering from Ulsan National Institute of Science and Technology (UNIST) in 2021, 2015, and 2013, respectively
  - Linear source approximation for 2D/3D MOC/DD neutron transport method
  - Development and verification & validation for 2-step approach code for PWR core analysis
  - Boron-free small modular pressurized water reactor design
- Internships at KAERI, ANL, and IAEA
  - Fast reactor team of those organization

Our Lecturers: **Dr Patrick Shriwise**

OpenMC

- Scientist at Argonne National Laboratory and adjunct professor at UW -- Madison
- Dr. Shriwise specializes in Monte Carlo particle transport methods, ray tracing, multiphysics, and open-source software development. He is a developer of OpenMC, DAGMC, and Cardinal.
- Before ANL, Patrick received his PhD at the University of Wisconsin – Madison with a focus on advanced particle transport techniques in CAD-Based geometry.
- Dr. Shriwise is a member of the American Nuclear Society, a software carpentry instructor, and a member of the the IAEA ONCORE initiative.

Our Lecturers: **Dr James Hagues** OpenMC for Fusion

- Neutronics Scientist at UK Atomic Energy Authority, Oxfordshire, United Kingdom
- James specializes in radiation transport and performs neutronics analysis for tokamak concepts (STEP, DEMO). This primarily focuses on critical Tritium Breeding Ratio (TBR), radiation shielding, and nuclear heating calculations for the early design phase of a fusion reactor.
- Before joining UK Atomic Energy Authority, James worked in the fission and defence industries and carried out graphite dosimetry calculations for AGR reactors (EDF Energy), shielding design for nuclear submarines (BAE Systems), and criticality safety assessments (Magnox Limited).
- James is an experienced user of multiple radiation transport codes (OpenMC, MCNP, MCBEND and ATTILA) for which he has developed in-house modifications.

Our Lecturers: **Dr Andrew Davis**

- Graduated from the University of Birmingham PhD in Nuclear Physics (2009)
- Joined UKAEA as staff in the Neutronics and Nuclear Data Group (2009)
- Joined UW-Madison Computational Nuclear Energy Research Group (2012)
- Rejoined UKAEA as staff into the High Performance Computing Group (2017)

- Group Lead for Engineering Computation (2018 to date)
- Lead for STEP Digital Enablers (2018 to date)
- Head of Advanced Engineering Simulation (2021 to date)
- Visiting Professor of Engineering at Swansea University

Our Lecturers: **Dr Nick Touran**

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IAEA

- Worked at TerraPower, LLC on SFR core design and software since 2009
  - Current role: Manager of Digital Engineering
  - After 2021: focus on configuration management and design control
- Initiated the Advanced Reactor Modeling Interface (ARMI) software
  - Now open source on github
- PhD from University of Michigan in Nuclear Engineering from 2012
  - Modal expansion perturbation method for equilibrium fuel cycle
  - SFR core optimization
- Runs whatisnuclear.com public education platform
  - Likes to digitize old nuclear films

IAEA Organizers

Dr Nikoleta Morelová

- Since 2021, Nuclear Engineer in Fast Reactor Technology Development Team, IAEA
  - Nikoleta supports all IAEA activities on fast reactors, such Coordinated Research Projects (CRPs), Education and Training Workshops, International Conferences, etc.
- Nikoleta has been working in nuclear engineering and technology since 2016
- MSc from École polytechnique fédérale de Lausanne (EPFL) and Swiss Federal Institute of Technology in Zürich (ETH) in Nuclear Engineering (2016)
- PhD from Karlsruhe Inst. of Technology (KIT) in Natural Sciences (2020)

Dr Vladimir Kriventsev

- Since 2016, Team Leader of Fast Reactor Technology Development Team, IAEA
  - Vladimir serves a Scientific Secretary for the IAEA activities on fast reactors, such Coordinated Research Projects (CRPs), Education and Training Workshops, International Conferences, etc.
- PhD from Obninsk Inst. for Nuclear Engineering in 1994
- Dr. Eng. from Tokyo Institute of Technology in 1999
- Vladimir has been working in nuclear engineering and fast reactor technology in
  - IPPE (Obninsk)
  - TITech (Tokyo Inst. of Technology)
  - JNC (JAEA now)
  - INPE (Obninsk) and
  - KIT (Germany, former FZK).