

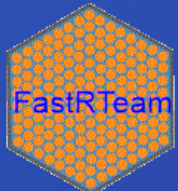
IAEA Interregional Training Course on Advances in Design of Generation-IV SMRs *Beijing, 3-7 June 2024*

IAEA Activities on Technology of Innovative Reactors and SMRs

Vladimir Kriventsev

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

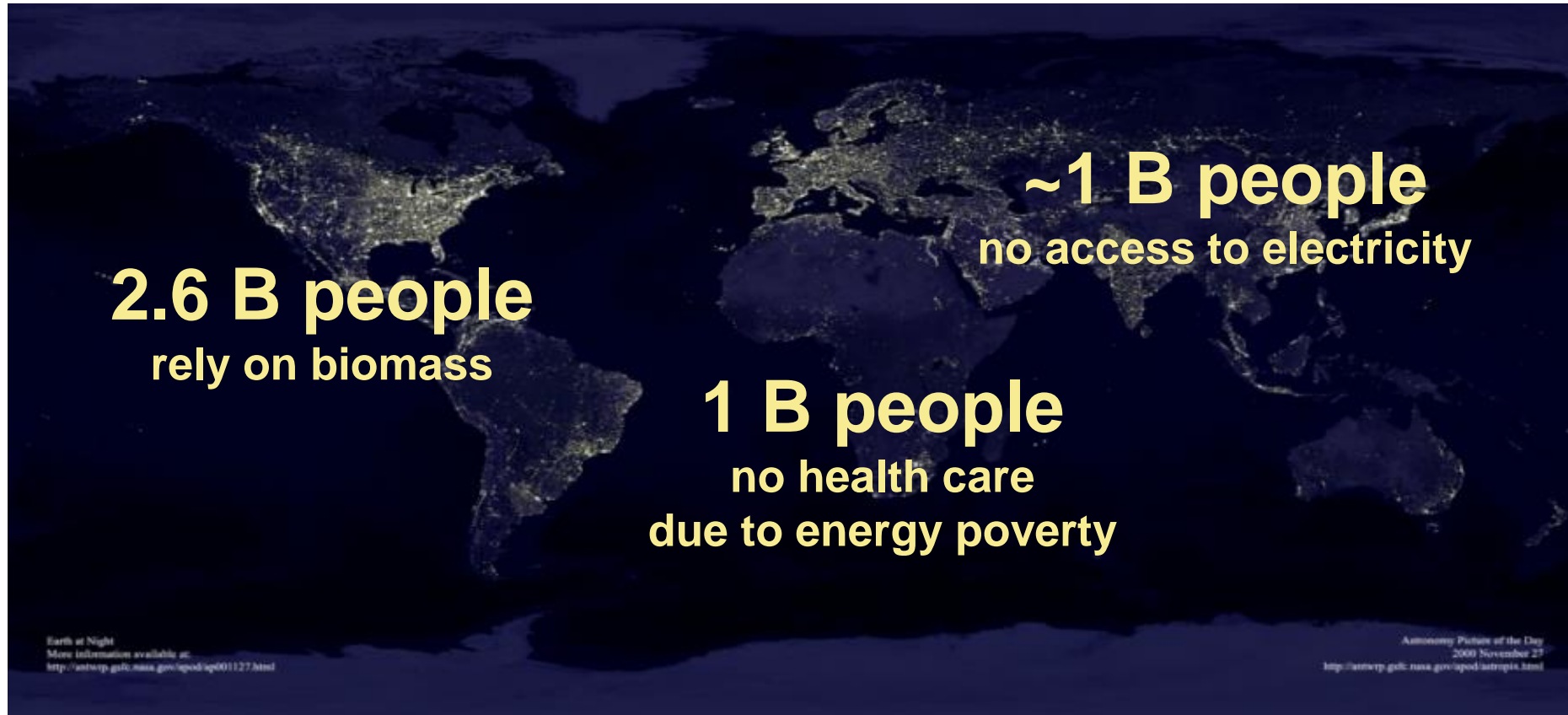
<https://www.iaea.org/topics/fast-reactors>



email: FR@IAEA.ORG

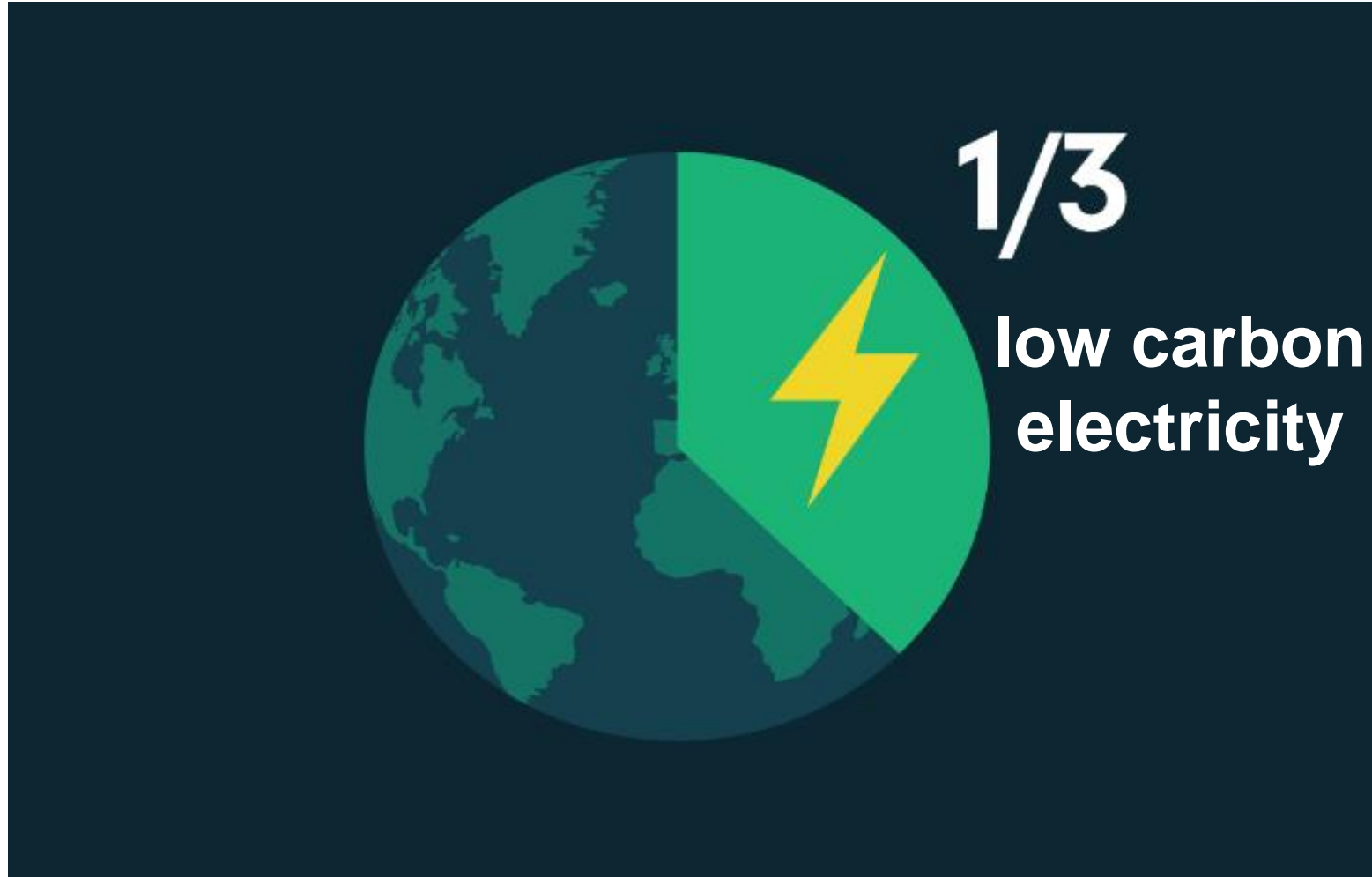
Why Consider Nuclear Energy to Produce Electric Power?

Energy access



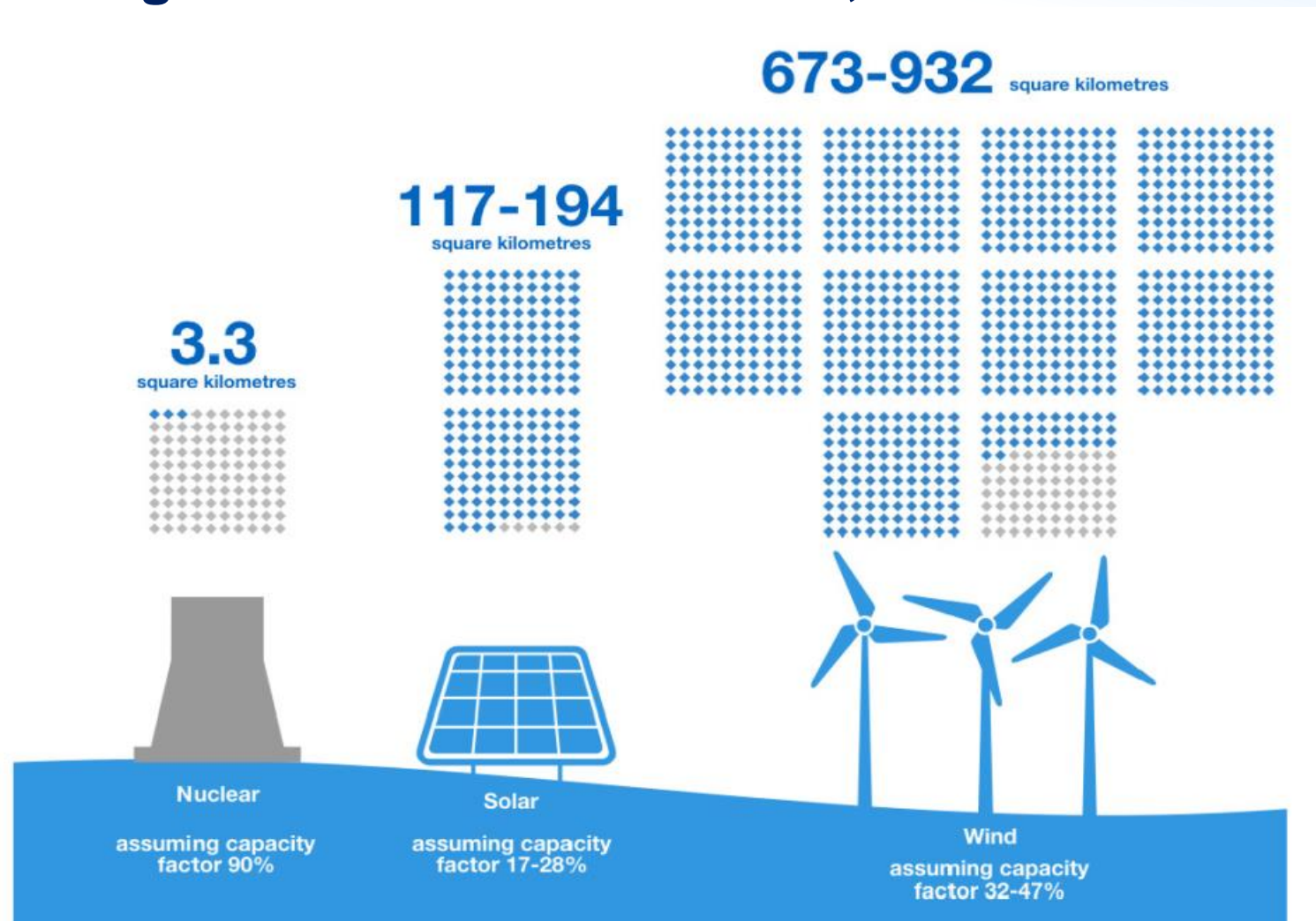
Why Consider Nuclear Energy to Produce Electric Power?

Low carbon



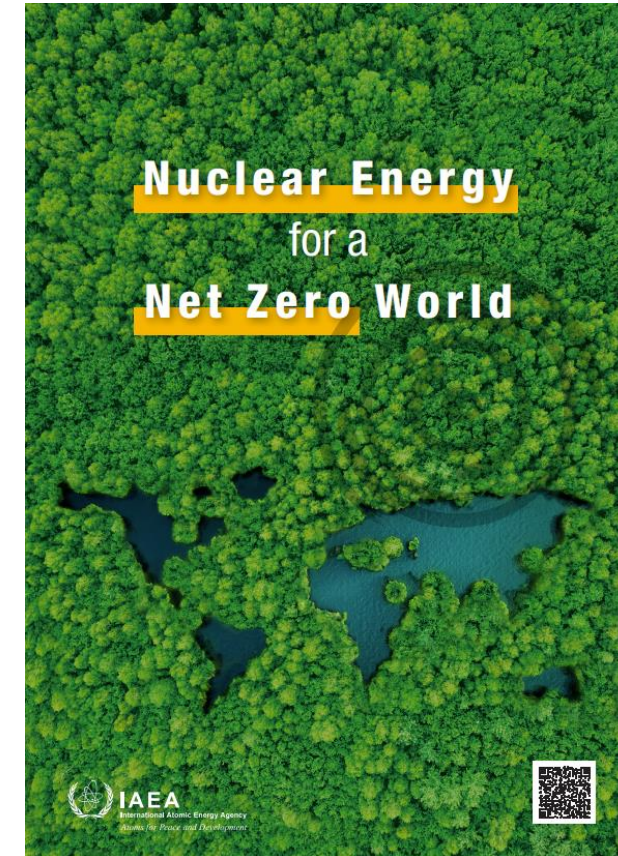
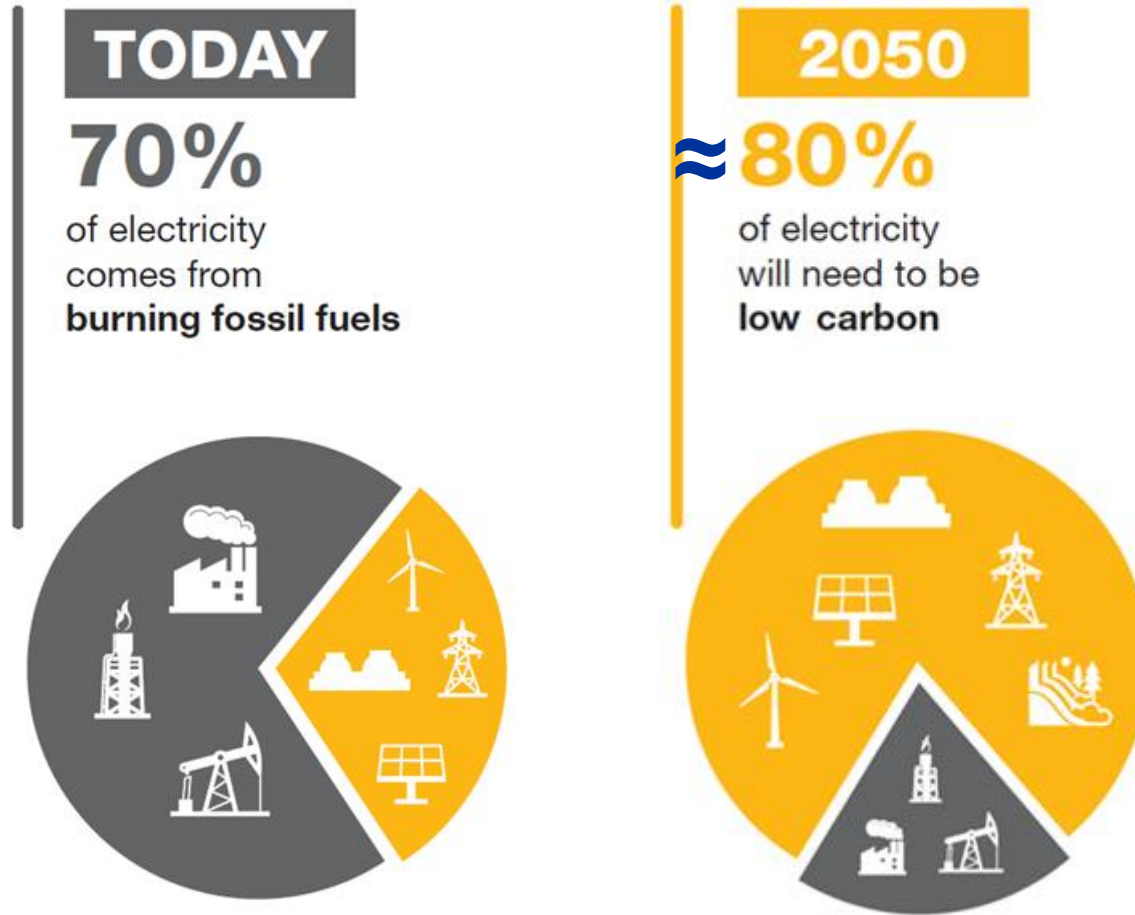
Why Consider Nuclear Energy to Produce Electric Power?

To generate 1000 MW electric, we need

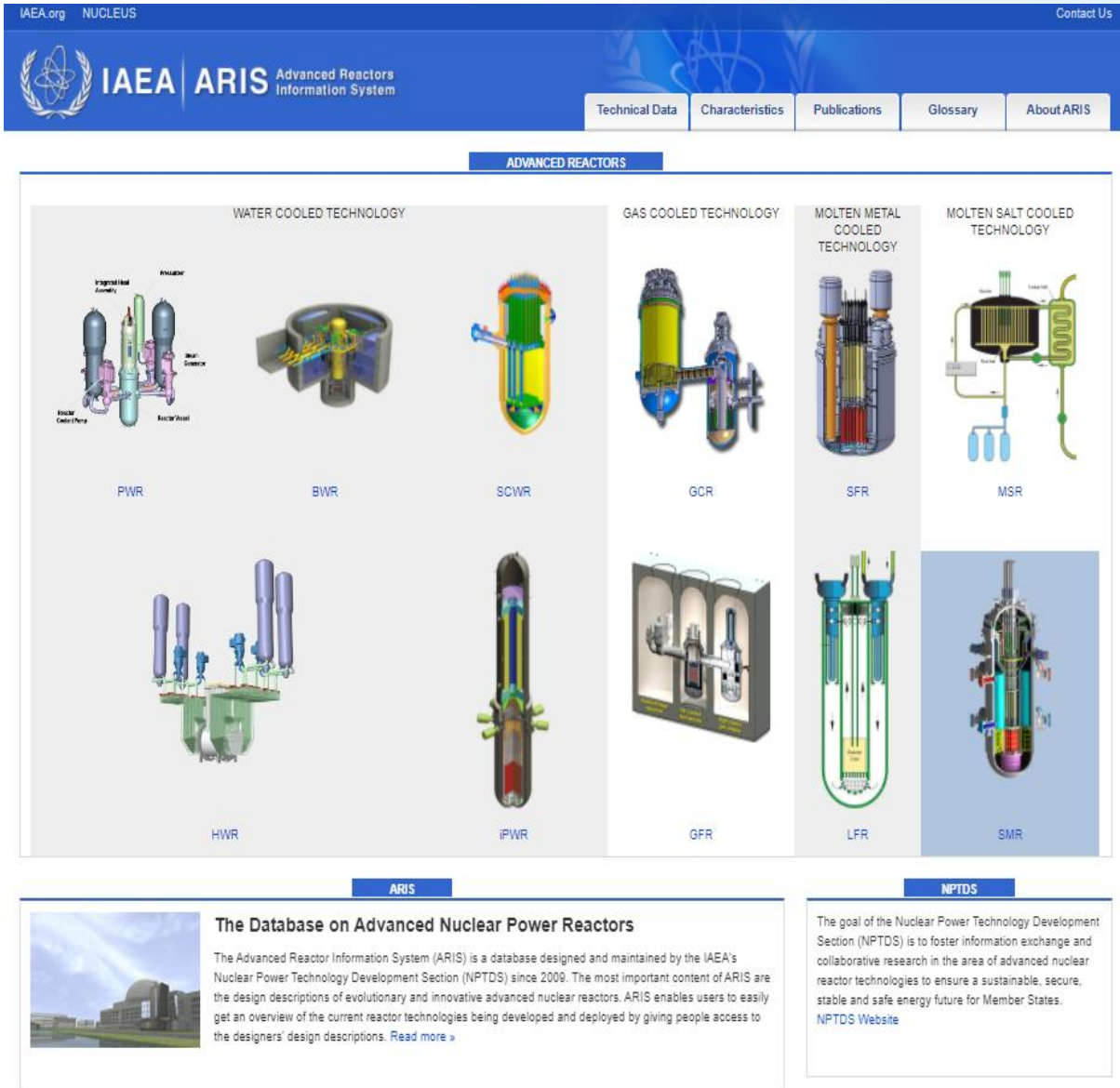


Why Consider Nuclear Energy to Produce Electric Power?

1.5°C Challenge



IAEA Advanced Reactors Information System (ARIS)



The screenshot shows the ARIS website interface. At the top, there is a navigation bar with 'IAEA.org', 'NUCLEUS', and 'Contact Us'. Below this is the IAEA logo and the text 'IAEA ARIS Advanced Reactors Information System'. A secondary navigation bar includes 'Technical Data', 'Characteristics', 'Publications', 'Glossary', and 'About ARIS'. The main content area is titled 'ADVANCED REACTORS' and is divided into four columns: 'WATER COOLED TECHNOLOGY', 'GAS COOLED TECHNOLOGY', 'MOLTEN METAL COOLED TECHNOLOGY', and 'MOLTEN SALT COOLED TECHNOLOGY'. Each column contains several 3D cutaway diagrams of reactor designs, labeled with abbreviations: PWR, BWR, SCWR, GCR, SFR, MSR, HWR, IPWR, GFR, LFR, and SMR. Below the diagrams, there are two text boxes. The first, under the 'ARIS' heading, is titled 'The Database on Advanced Nuclear Power Reactors' and describes the system as a database designed and maintained by the IAEA's Nuclear Power Technology Development Section (NPTDS) since 2009. The second, under the 'NPTDS' heading, states the goal of the NPTDS is to foster information exchange and collaborative research in the area of advanced nuclear reactor technologies to ensure a sustainable, secure, stable and safe energy future for Member States. A link to the 'NPTDS Website' is provided.



New User Interface



Display Contents

- More Organized Way
- More Filters



Comparison of Several Designs



Dynamic Graphs/Maps for Plant Sites



Dashboard for Vendor and Admins



New Reporting System

Main IAEA Activities on Advanced Reactor Technology



Knowledge Sharing

- Publications
- Conferences
- TMs



Technology Development

- Coordinated Research Projects (CRPs)



Capacity Building

- Training Courses
- Workshops
- Webinars
- e-Learning
- 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 | Belgium |
| China | Czech Republic |
| France | Germany |
| India | Italy |
| Japan | Kazakhstan |
| Korea, republic of | Mexico |
| Netherlands | Romania |
| Russian Federation | Sweden |
| Switzerland | UK |
| Ukraine | USA |

Observers

- | | |
|--|-----------------|
| <i>European Commission/JRC</i> | <i>OECD/NEA</i> |
| <i>Generation-IV International Forum (GIF)</i> | |

From 2022: 20 MSs as members; 3 IOs as observers

57th TWG-FR Meeting: **25-28 June 2024**

- 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

Technical Working Group on SMR

- **Members:** 20 MSs and 4 International Organizations as observers



- **Technical subgroups**

- **SG-1:** Update of SMR Technology Roadmap
- **SG-2:** R&D, Codes & Standards, Deployment Models and Preparation for Operation
- **SG-3:** Microreactors and SMR Technology Deployment for Cogeneration

Technical Cooperation INT-2023 Project

Supporting Member States' Capacity Building on Small Modular Reactors and Microreactors and their Technology and Applications – A Contribution of Nuclear Power to the Mitigation of Climate Change

Period: 2022 – 2025

Field of Activity (#6 Nuclear Power Reactors)

Objective

To improve technical knowledge, capacity building and safety review capability in developing countries addressing the fundamental aspects of SMRs/MRs and their electric and non-electric applications.

Outcome

Awareness raised on SMRs/MRs technology and their applications to enhance nuclear energy contribution in social-economic development in Member States

SMR: Small and Medium-sized or Modular Reactor

- There is **growing interests in SMRs** to address climate change and energy security with specific national needs
- There are **various SMR designs** under development at various stages
- **Challenges** should be addressed in a timely manner
- **IAEA SMR Platform** provides coordinated support in the areas of technology development and demonstration, legal frameworks, high standards of safety, security, and safeguards

IAEA SMR Platform

- Created in 2021
- Serves as a **focal point** for the IAEA's activities on the field of small modular reactors and their applications
- Provides **coordinated support and expertise from across the entire Agency**, encompassing all aspects relevant to the development, early deployment, and oversight of small modular reactors
- **SMR Portal** provides latest news, IAEA events, and publications on SMRs
- Enquiries and requests for assistance:
SMR.Platform@iaea.org



<https://smr.iaea.org>

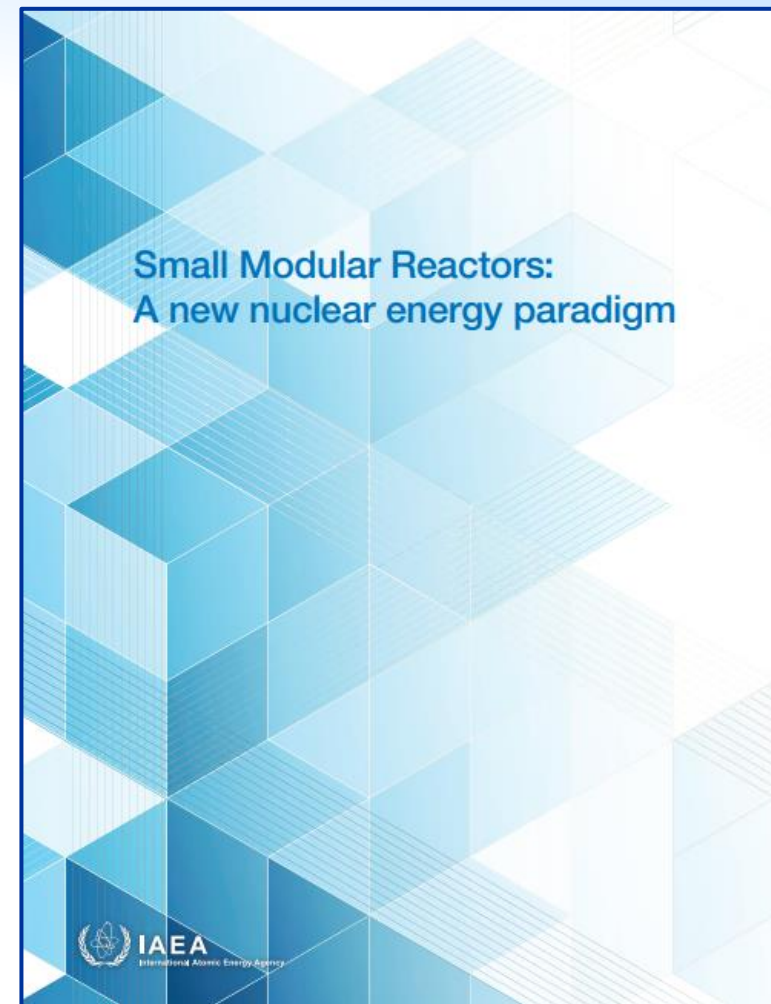
High Level SMR Booklet

SMRs: A new nuclear energy paradigm

- SMRs and What They Can Offer – Understanding Technological and Global Perspectives
- Success – what will it look like?
- What's Next for SMRs?
- IAEA Agency-Wide Support and Services

Target audience:

- **Primarily policymakers and government officials** interested in SMRs



IAEA Conference on Fast Reactors and Related Fuel Cycles FR22

Vienna
19-22 April 2022

FR 22

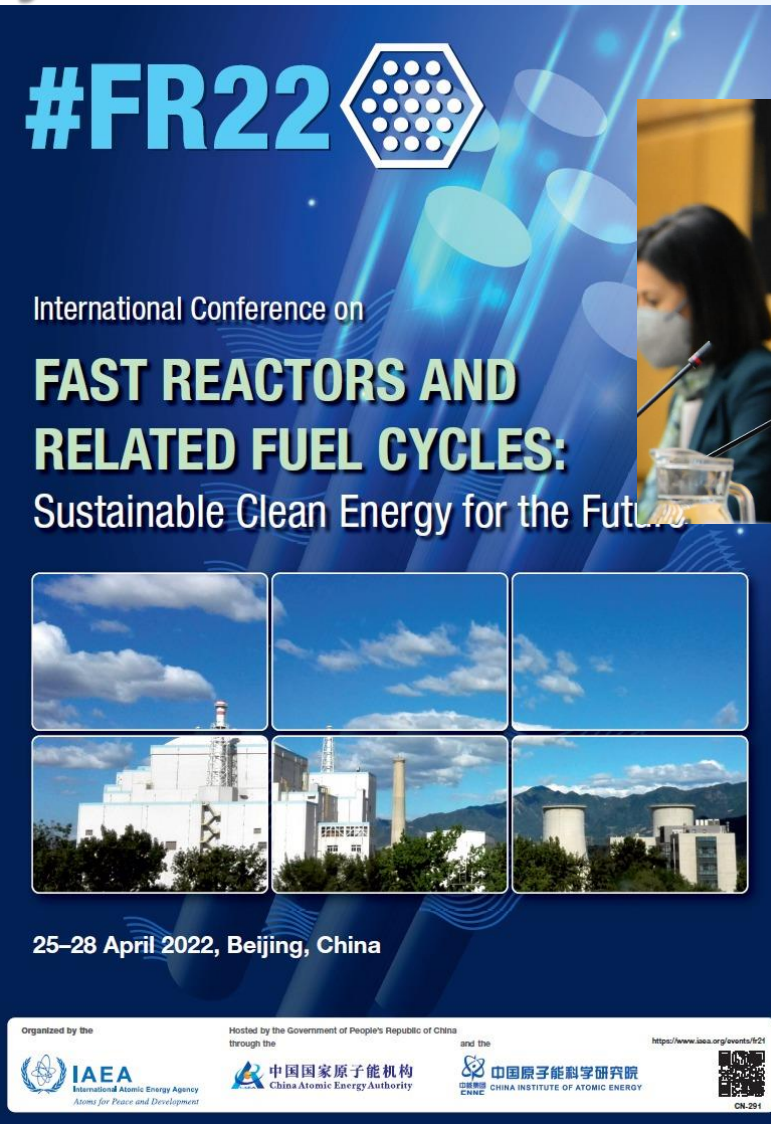
DG Grossi opens FR22



Mr Bhaduri,
General Chair




FR26 in Beijing?





#FR22

International Conference on
FAST REACTORS AND RELATED FUEL CYCLES:
Sustainable Clean Energy for the Future

25-28 April 2022, Beijing, China

Organized by the
 IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Hosted by the Government of People's Republic of China
through the
 中国国家原子能机构
China Atomic Energy Authority

and the
 中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

<https://www.iaea.org/events/fr21>

CH-291



International Conference on
Fast Reactors and Related Fuel Cycles:
Safe Technologies and Sustainable Scenarios
FR13

7-11 December
Kyoto, Japan

Organized by the
International Atomic Energy Agency
Hosted by the
Japan Atomic Energy Agency

In cooperation with the
Japan Atomic Energy Commission
Ministry of Education, Culture, Sports, Science and Technology
Japan Atomic Industrial Forum, the
Noboru Mori Energy Research Center
American Nuclear Society
Atomic Energy Society of Japan
European Nuclear Society
Institute of Electrical Engineers of Japan Society for Nuclear Energy
Korea Atomic Energy Research Institute
European Commission
OECD Nuclear Energy Agency

Fast Reactors and Related Fuel Cycles
Next Generation Nuclear Systems
for Sustainable Development
FR17

Proceedings of an International Conference
Yekaterinburg, Russian Federation, 26-29 June 2017

Organized by the
 IAEA
International Atomic Energy Agency

Hosted by the
Government of France

Through the
 French Alternative Energies and Atomic Energy Commission (CEA)
 French Nuclear Energy Society (FEN)

www.iaea.org/iaea/fr17

TM on Benefits and Challenges of Fast SMRs

Country	Participants /Papers
Belgium	4/1
China	2/2
France	1/1
Germany	2/0
India	1/1
Italy	13/5
Japan	3/2
Korea, Rep. of	2/3
Luxembourg	1/1
Netherlands	1/1
Russia	3/2
Slovakia	1/0
Switzerland	1/1
Sweden	1/1
USA	1/1
EC/JRC	3/1
Total: 16	40/23

*24-27 September 2019, Milan, Hosted by CIRTEN:
Consortium of Italian Nuclear Universities*

Six Technical Sessions:

- Sodium Cooled Fast SMRs
- Heavy Liquid Metal Cooled Fast SMRs
- Safety Investigations
- Technology and Research in Support of Fast SMRs

Three Group Discussions:

- In-factory construction
- Benefits of Fast SMRs including market needs
- Technological Challenges

TECDOC Proceedings to be published in 2020



TECDOC published in 2021



Thanks to advanced coolants, Fast SMRs can be safer and of simplified design

BUT:

- Fast construction (in- factory) is required to win economic competition;
- Extended R&D are needed to fit technological gaps
- LFRs require more R&D to prove material compatibility and develop new materials
- Licensing challenges

TM on Structural Materials for



Heavy Liquid Metal Cooled Fast Reactors

Country	Participants /Papers
Belgium	2/1
China	7/4
Czech Rep.	3/1
Germany	1/1
Italy	5/3
Korea, Rep. of	4/1
Luxembourg	1/0
Netherlands	1/0
Romania	2/2
Russia	3/3
Slovakia	1/1
Sweden	2/1
UK	1/0
Ukraine	1/1
EC/JRC	1/1
Total: 14	34/20

Three Technical Sessions:

- HLM Compatibility with Structural Materials
- Corrosion Mitigation Measures
- Qualification Programmes of Structural Materials

Three Group Discussions:

- Outstanding Research Challenges
- New Materials and Coating Techniques
- Technology Readiness

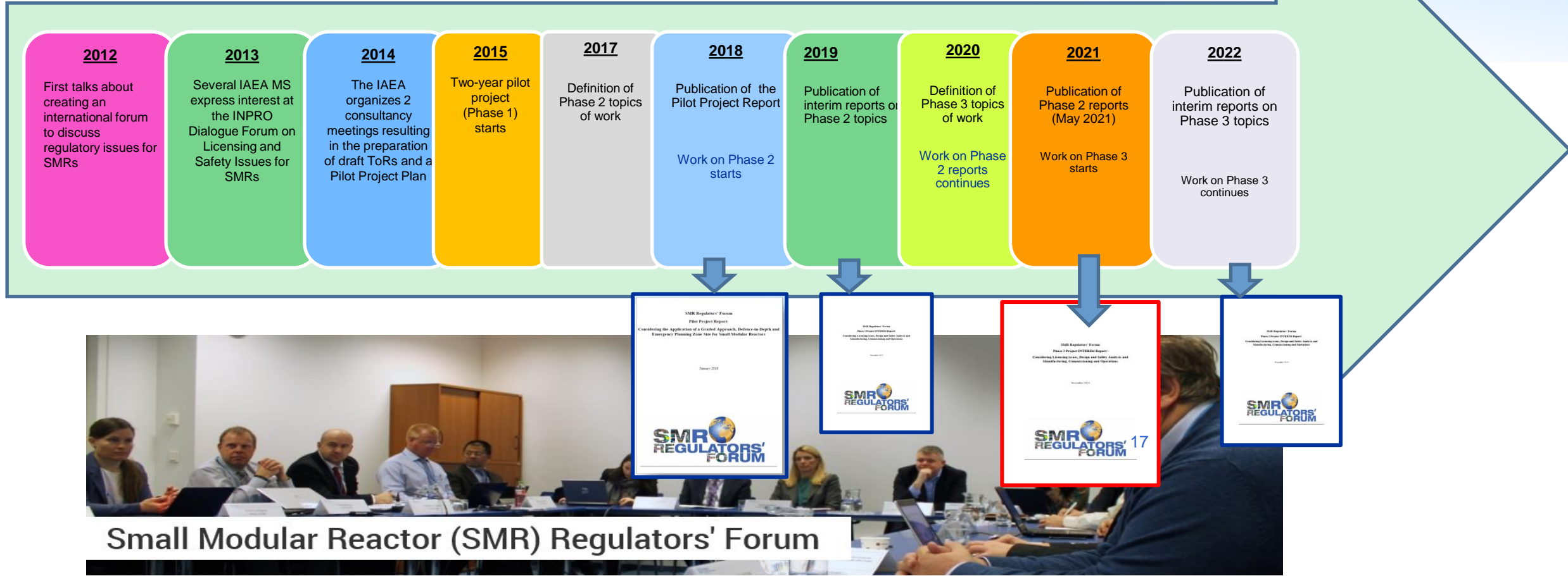
15-17 October 2019, Vienna



TECDOC Proceedings published in September 2021
Free download

Gathering Experience on Licensing SMRs

SMR Regulator's Forum



Nuclear Harmonization and Standardization Initiative



Effective Global Deployment of
Safe and Secure Advanced
Nuclear Reactors



Harmonization of
Regulatory Approaches
Track

- **WG1:** Framework for information exchange
- **WG2:** International pre-licensing regulatory reviews
- **WG3:** Leveraging other regulatory reviews

**IAEA as facilitator
within and between the tracks**

Harmonization and
Standardization of
Industrial Approaches
Track

- **TG1:** Harmonization of high-level user requirements
- **TG2:** Common Approaches to Codes and Standards ¹⁸
- **TG3:** Experimental Testing and Validation for Design and Safety Analysis Computer Codes
- **TG4:** Acceleration of nuclear infrastructure implementation for SMR

Regulators

Governments

Technology Holders

Operators and other end-users

International Organisations and Associations

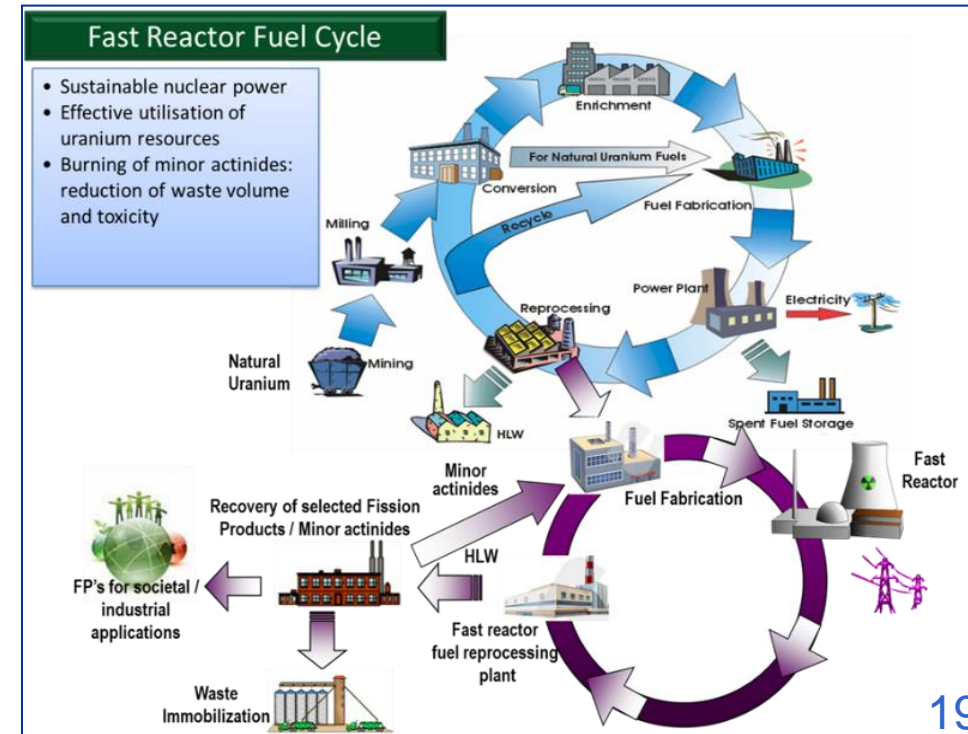
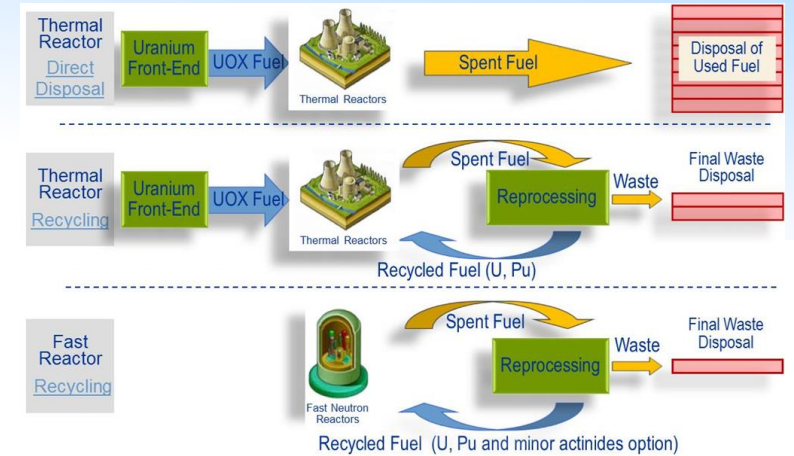
IAEA and Innovative Nuclear Power Technologies

In parallel with technical activities in area of Advanced / Innovative Nuclear Reactors:

- **Activities on Advanced Fuel Cycles** – technical advances and innovations
- **INPRO** (International Project on Innovative reactors and Fuel Cycles) Project – strategic studies, international, regional and national scenarios, role of innovations

Some last INPRO studies:

- Cooperative approaches to Back End of fuel cycle
- The Limited Scope NESAs (Nuclear Energy System Assessment) for **BN-1200 Fast Reactor** Systems
- Wastes from Innovative Types of Reactors and Fuel Cycles
- Scenarios to Support Multi-recycling of Fuel in a Nuclear Energy System – STEP FORWARD



IAEA Coordinated Research Projects on FRs



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)**.

CRPs on Fast Reactors Technology

On-going CRPs

NAPRO – Na Properties and Safe Operations of Exp. Facilities
 Ended in Sept 2018
 1st TECDOCs published in 2024
 2nd in Publishing

Neutronics Benchmark of **CEFR**
 Start-Up Tests >> 2024

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

Benchmarking **S-ALEGRO** Tests (LOCA)

Benchmark Analysis of **STELLA-2** LOHS/LOF Tests

PLANDTL: Decay Heat Removal Thermal Hydraulics Tests

Completed CRPs

PHENIX – EOL Tests

MONJU – Na Natural Convection

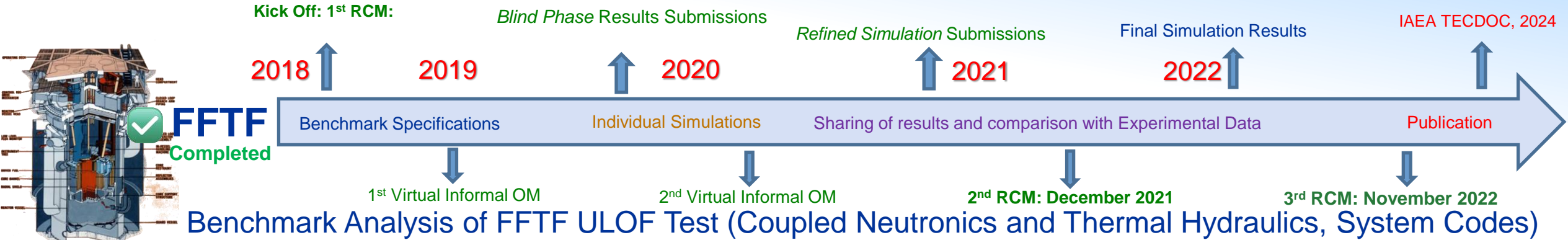
Analytical and Experimental Benchmark Analysis of **ADS**

EBR-II Shutdown Heat Removal Tests

PSFR Source Term – Radioactive Release Under Severe Accident Conditions

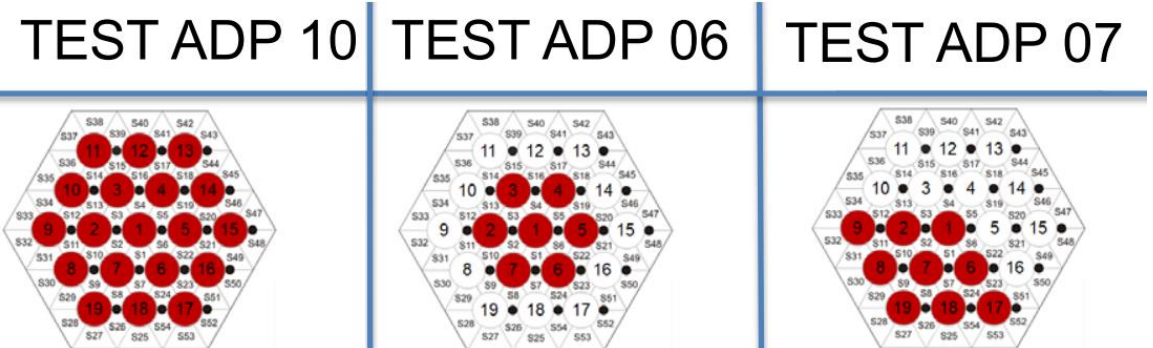
Fast Reactors: On-going CRPs

Full Details on CRPs on Wednesday



NACIE CRP: Benchmark of Transition from Forced to Natural Circulation Experiment with Heavy Liquid Metal Loop

- The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) proposed this CRP to TWG-FR 2020. It was launched in 2022. 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.
- First CRP dedicated to TH of lead and lead bismuth eutectic technology.



CRP: Benchmark of Transition from Forced to Natural Circulation Experiment with Heavy Liquid Metal Loop

Motivation:

- Lead and LBE reactors offer significant safety and reliability enhancements compared to sodium cooled fast reactors such as low chemical reactivity with water and air and high boiling point of lead and LBE coolants.
- Modelling and simulation combined with material testing is necessary to further develop heavy liquid metal cooled reactors and support engineers in both the design process and the preparation for licensing.

The Coordinated Research Project (CRP) will focus on thermal-hydraulic analysis of the tests performed at the forced to natural circulation experimental (NACIE) facility at ENEA in 2017.

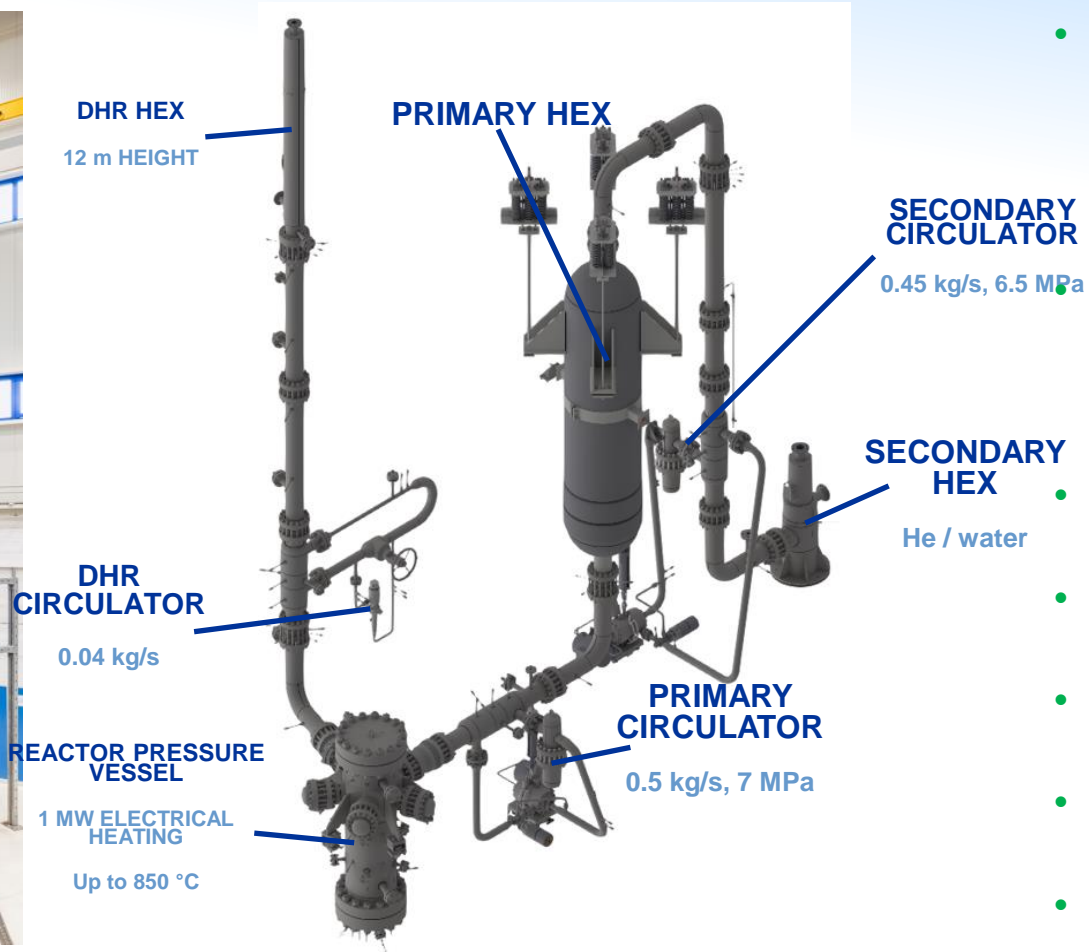
Aim of the Benchmark:

- CRP allows Member States to advance their fast reactor analytical capabilities for simulation and design using system, computational fluid dynamics (CFD), and subchannel analysis codes by providing experimental data.
- The obtained experimental data are used to study the test assembly and for transition from forced to natural circulation.

22 Participating Organizations from 10 Countries + EC

Country	Organization
China	CIAE
	CNPRI
	IANS
	XJTU
EC	JRC
Germany	KIT
India	IGCAR
Italy	ENEA
	La Sapienza
	newcleo
	NINE
	UNIPI
Rep. of Korea	KAERI
Netherlands	NRG
Romania	PUB
Romania	RATEN ICN
Russia	Gidropress
	IBRAE
	NIKIET
Switzerland	PSI
USA	ANL
	Westinghouse

Proposal for New CRP: S-Allegro Tests



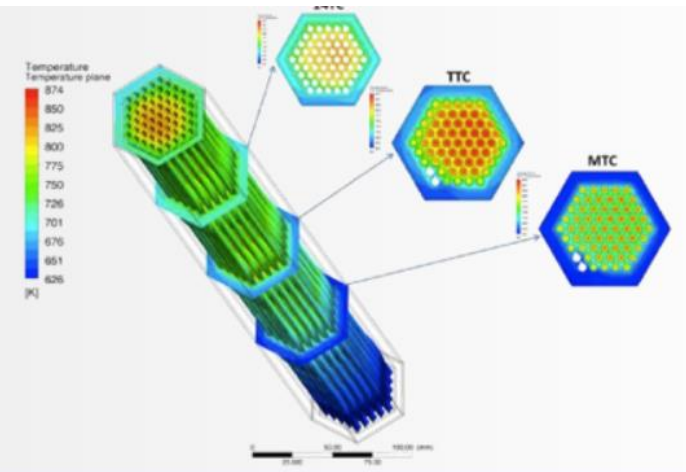
- Scaled-down mockup of the GFR concept ALLEGRO → to support development of ALLEGRO or other GFR concepts
- To verify the basic safety features and system behavior of the high-temperature GFR helium systems
- To verify the passive decay heat removal system
- To simulate the accidental conditions
- Testing of components of HTH systems at relevant parameters
- Generation of data for codes validation
- To gain design, construction and operational experience with the high-temperature helium systems

S-Allegro facility in support of Gen-IV GFRs

Technical Meetings on

State-of-the-art Thermal Hydraulics of Fast Reactors

Technical Meeting on State-of-the-art Thermal Hydraulics of Fast Reactors



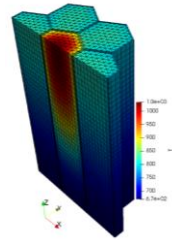
26-30 September 2022
C.R. ENEA, Lago Brasimone, Italy

Technical Meetings on

Development and Application of Open Source Modelling and Simulation Tools for Nuclear Reactors

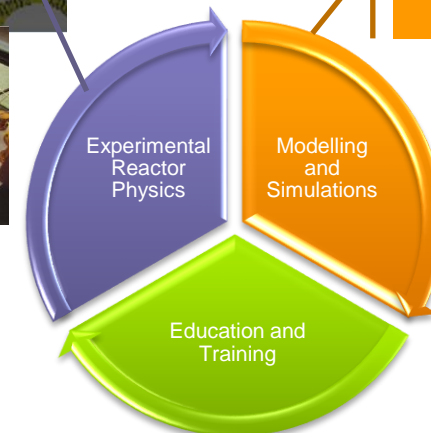
Technical Meeting on the Development and Application of Open-Source Modelling and Simulation Tools for Nuclear Reactors

Using open access data



Using open source tools

20-24 June 2022
Milano, Italy



Joint GIF-IAEA Workshops on Safety of SFRs, LMFRs, and non-WCRs



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

- Review of GIF Report on “Safety Design Guidelines on Structures, Systems and Components for Gen-IV SFRs”
 - Discussion of review comments

10th GIF-IAEA Workshop on LMFR Safety

28 June – 1 July 2022

- Organized by NSNI

11th GIF-IAEA Workshop on non-WCR Safety

30 May – 2 June 2023

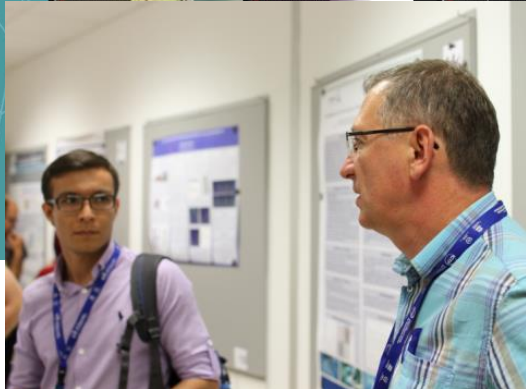
- Organized by NSNI

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

Joint ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems | (smr 3700)



- In 2016, 2018 and 2022 in Trieste, Italy
- Contributed by NPTDS, INPRO, GIF, and other external experts
- Next 11-15 Nov 2024



Joint ICTP-IAEA Workshop on Open-Source Nuclear Codes for Reactor Analysis (IAEA ONCORE Initiative)



7-11 August 2023 in Trieste, Italy

This workshop offers a comprehensive journey in cutting-edge computational techniques for nuclear reactor analysis, providing an in-depth understanding of reactor neutronics, thermal hydraulics and system analysis at different scales. Participants will be led through the essential stages required to conduct engineering-level multi-physics simulations.

General overview, theoretical background and practical exercises will be offered for

- **OpenFOAM** and its derivatives for CFD simulation of multi-physics and multi-scale problems
- **GenFOAM** for core thermal hydraulics, neutron transport and structural mechanics modelling
- **Offbeat** for fuel performance simulation
- **ContainmentFOAM** for severe accidents simulation
- **OpenMC** Monte-Carlo neutron transport
- **MOOSE** parallel finite element framework for multi-physics, multi-scale simulations
- **ARMI** Advanced Reactor Modelling Interface

Joint ICTP-IAEA
Workshop on Open-Source
Nuclear Codes for
Reactor Analysis



7 - 11 August 2023
An ICTP - IAEA Hybrid Meeting
Trieste, Italy

Further information:
<http://indico.ictp.it/event/10199/>
smr3865@ictp.it

Webinar Series on Multiphysics Modelling of Nuclear Reactors using OpenFOAM



OpenFOAM* is a well-known open-source toolbox for industrial-level computational fluid dynamics (CFD), but also a library for the finite-volume discretization and parallel solution of Partial Differential Equations (PDEs) for nuclear-related applications.

Directly supports the education and training part of the ONCORE initiative.

The Webinar Series provided the audience with up-to-date information about the modelling possibilities provided by OpenFOAM and OpenFOAM based codes, its strengths and challenges as well as practical guidelines, thus allowing for more informed decisions about the opportunity to employ OpenFOAM, or existing OpenFOAM-based tools, for one's own applications. It has also served as an entry point for further autonomous learning and using of these tools.

12 lectures in the series covering:

- Overview of using OpenFOAM as a multi-physics library for nuclear reactor analysis
- Brief introduction to the use of finite-volume methodologies
- Basics of Partial Differential Equations (PDEs)
- Problem definition
- Geometry and mesh generation
- Introduction to OpenFOAM's source code and object-oriented programming
- ContainmentFOAM tool for system-scale CFD analysis of containment atmosphere pressurization, H₂/CO mixing and mitigation.
- GeN-Foam tool as multi-physics solver in nuclear reactor design and safety analysis
- OFFBEAT tool, a solver for fuel behavior analysis in nuclear reactors. As a multi-dimensional code, it allows studying the evolution of the fuel in 1-D, 2-D or 3-D, and it can simulate both transient and steady-state conditions.
- GeN-ROM, a data-driven model-order reduction tool for nuclear applications based on GeN-Foam

Recordings of all Lectures available here: <https://elearning.iaea.org/m2/course/view.php?id=1286>

NAPRO: Sodium Properties Calculator



Home About NAPRO References Temperature Independent Table Property Table Figure

Na¹¹
Sodium

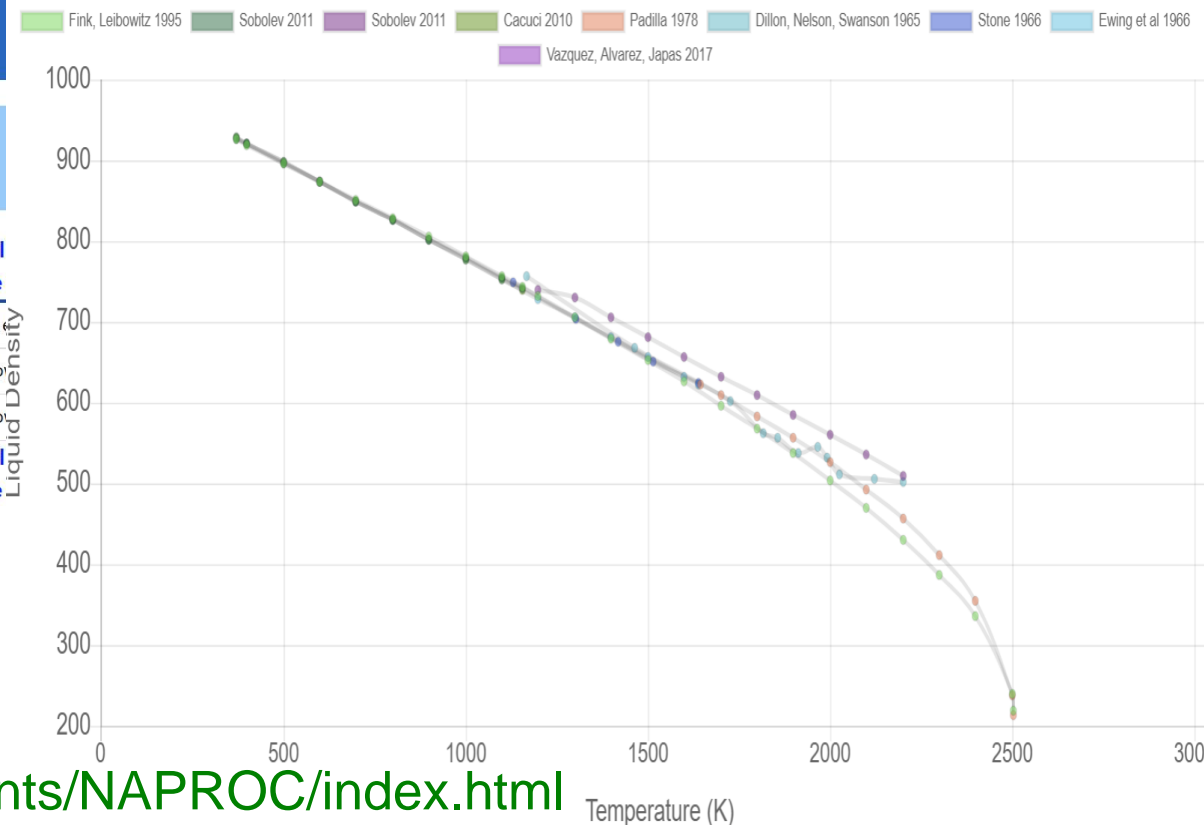
ProC
Sodium Properties Calculator

Enter Temperature (K) T = 800 K

800 SUBMIT CLEAR

TEMPERATURE INDEPENDENT PROPERTIES		Value	Units	Principal Reference
MELTING POINT		370.90	K	Ohse
BOILING POINT		1154.7	K	Fink, Leibo
CRITICAL TEMPERATURE		2503.7	K	Fink, Leibo
THERMODYNAMIC	TRANSPORT	Value	Units Function	Principal Reference

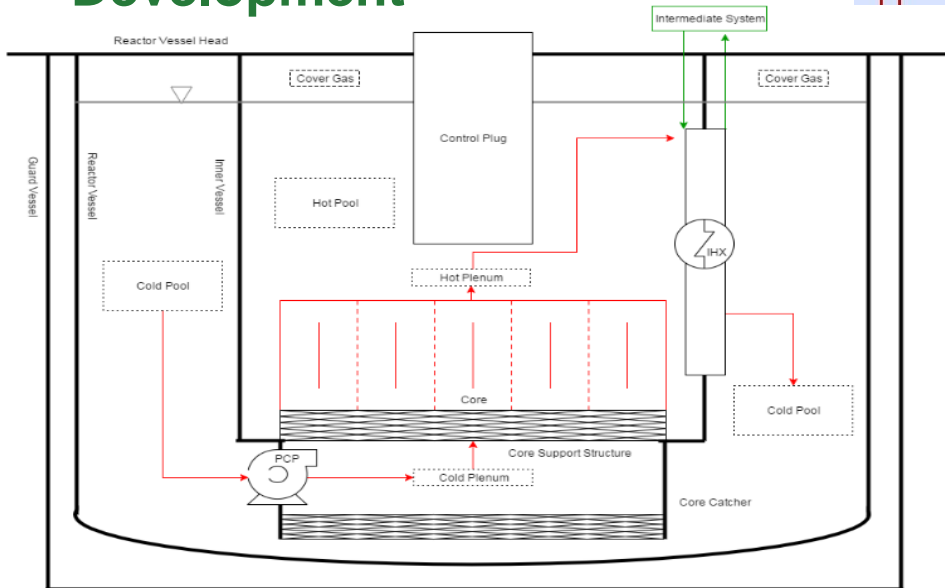
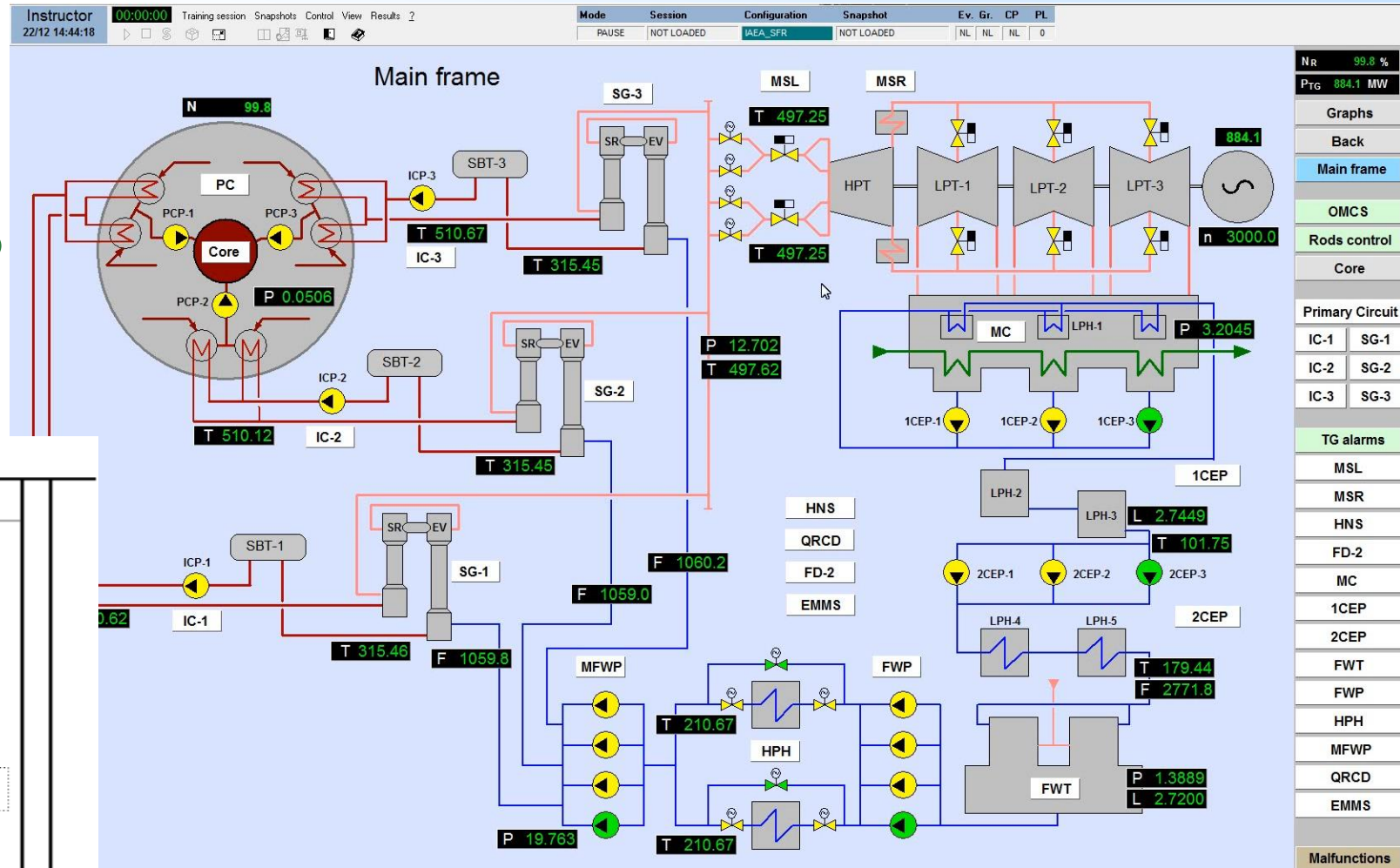
Liquid Density vs Temperature



<https://nucleus.iaea.org/sites/fr/Shared%20Documents/NAPROC/index.html>

SFR Educational Simulator

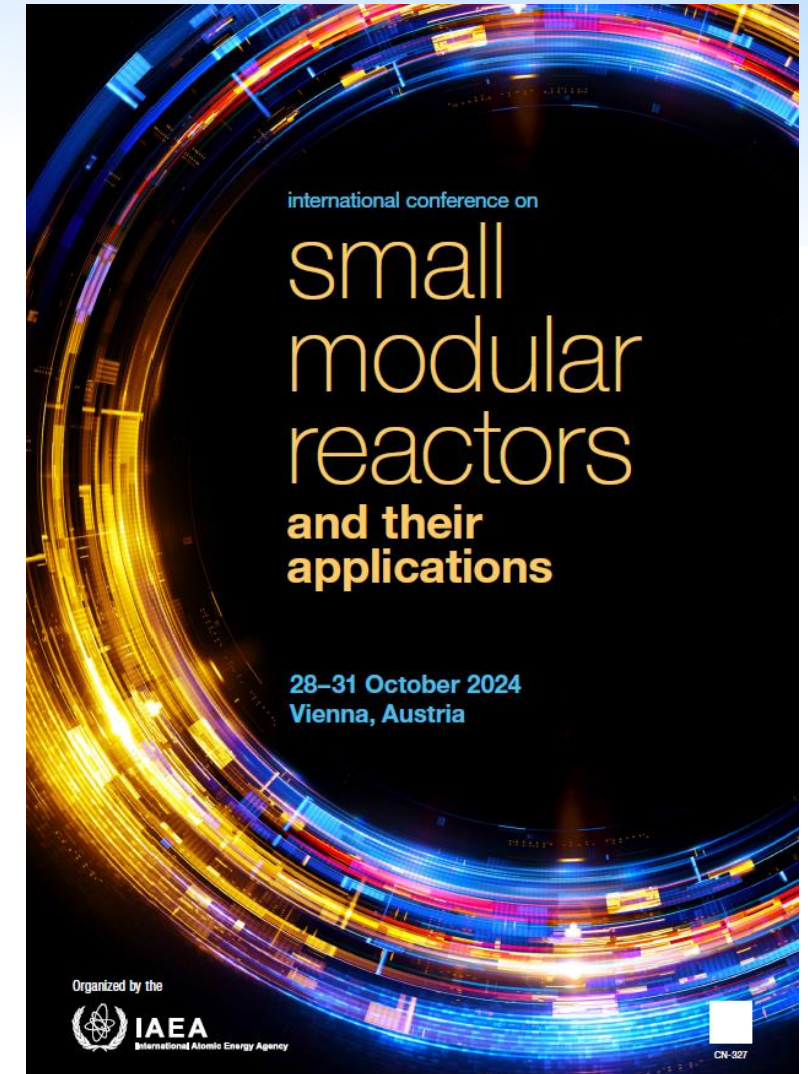
- Pool type sodium cooled fast reactor simulator for education and training
- **2023: Ready for Distribution to Member States**
- **Exercise Manual under Development**



IAEA International Conference on SMRs: 21-25 October 2024

The First International Conference on Small Modular Reactors and their Applications in Vienna on 21-25 October 2024.

- The Conference is being prepared as a joint event organized with inter-Agency cooperation between:
 - *Department of Nuclear Energy*
 - Division of Nuclear Power
 - *Department of Nuclear Safety and Security*
 - Division of Nuclear Installation Safety
- Supported by
 - Department of Safeguards, and
 - Department of Technical Cooperation
- About 450 contributions have been accepted





Thank You!

email: FR@IAEA.ORG