Technical Meeting on **Advances and Innovations in Fast Reactor Design and Technology**,
Vienna International Centre, 28 September – 3 October 2025

IAEA Activities on SMR Technology Development

M. Hadid Subki

Technical Lead (SMR Technology Development), Scientific Secretary TWG-SMR

Nuclear Power Technology Development Section,
IAEA Division of Nuclear Power

TWG-SMR 2022-2025

TWG-SMR 2022-2025: 20 Members

No		Countries	Designated Member	Affiliation
1		Argentina	Mr. Pablo ZANOCCO	CNEA (Comisión Nacional de Energía Atómica)
2		Brazil	Mr. Jose Orpet PEIXOTO	Brazilian Association for Development of Nuclear Activities (ABDAN)
3		Canada	Ms. Sonia IQBAL	CANDU Owners Group Inc.
4		China	Ms. Liangzi WANG	Nuclear Power Institute of China of China National Nuclear Corporation (NPIC, CNNC)
5		Czech Republic	Mr Jan PRASIL	The Ministry of Industry and Trade
6		France	Mr. Pierre GAVOILLE	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
7		Ghana	Mr. Archibold BUAH-KWOFIE	Ghana Atomic Energy Commission (GAEC)
8		India	Mr. Parimal KULKARNI	Bhabha Atomic Research Centre (BARC)
9		Iran	Mr. Reza SAYYAREH	Atomic Energy Organization of Iran (AEOI)
10		**Italy**	**Mr. Marco RICOTTI [Chairperson]**	**Politecnico di Milano**

TWG-SMR 2022-2025: 20 Members

No		Countries	Designated Member	Affiliation
11		Japan	Mr. Tsutomu IRIE	Japan Atomic Energy Agency (JAEA)
12		Jordan	Mr. Tariq ALSHAKETHEEP	Jordan Atomic Energy Commission (JAEC)
13		Korea, Republic of	Mr. Joo Hyung MOON	Korea Atomic Energy Research Institute (KAERI)
14		Morocco	Mr. Rachid Sekkouri ALAOUI	Office National de l'Electricité - Branche Electricité (ONEE-BE) Morocco
15		Pakistan	Mr. Shaukat PERVAIZ	Pakistan Atomic Energy Commission (PAEC)
16		Philippines	Ms. Alvie ASUNCION-ASTRONOMO	Philippine Nuclear Research Institute (PNRI)
17		Russian Federation	Ms. Nadezhda SALNIKOVA	Rosatom – JSC OKBM Afrikantov
18		Ukraine	Mr. Illia KRASNUKHA	Energoatom
19		United Kingdom	Mr. Daniel MATHERS	Nuclear Innovation and Research Office (NIRO)
20		United States of America	Ms. Melissa BATES	Department of Nuclear Energy

Three Observers to the TWG-SMR 2022-2025

International Organizations:

- European Commission, DG Research & Innovation, Euratom Research
- International Standards Organization
- World Nuclear Association

Formulation of new TSGs for 2022-2025

Technical Sub-Group #1: Updating the SMR Technology Roadmap

Revision of the NE Series No. NR-T.1.18 on Technology Roadmap for SMR Deployment (2021) https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf to publish Rev. 1 **in 2026**.

Technical Sub-Group #2: R&Ds, Industrial & Deployment Schemes and Preparation for Operation

Research & Development of Innovative non-water cooled reactors technologies and designs, including microreactors; Industrial & Deployment Schemes; **and Preparation for Operation**;

Technical Sub-Group #3: SMR Technology Deployment for Cogeneration and Diverse Industries

Identification of issues in technologies and designs to enable SMR deployment for **Cogeneration and Interaction** with end-users of various applications of SMRs in diverse industries **– including MICROREACTORS**

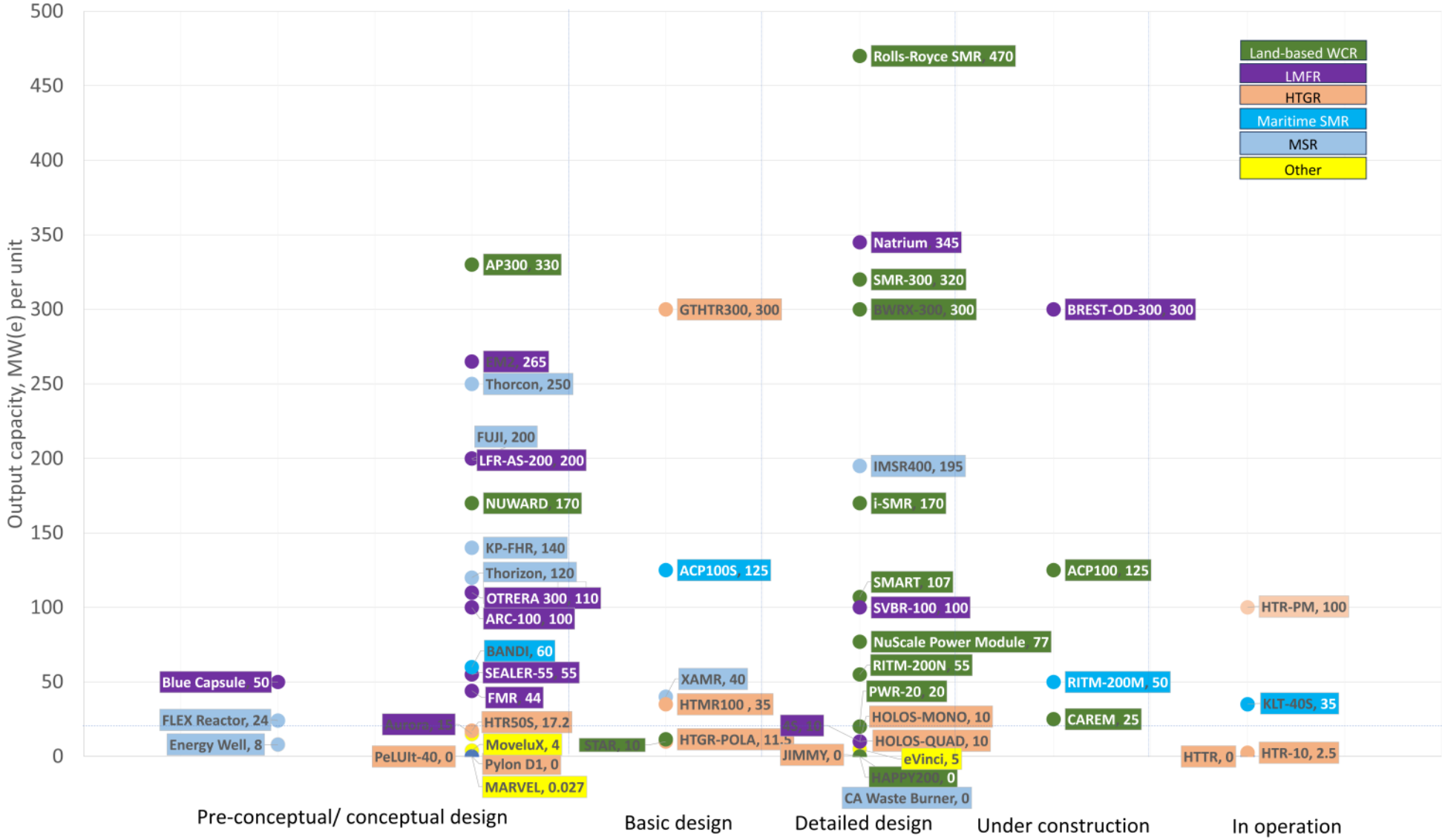
Addressing Common Recommendations from all 3 Technical Sub Groups:

The Agency should convene annual international event on SMR:

- The IAEA is hosting the First **INTERNATIONAL CONFERENCE ON SMALL MODULAR REACTORS AND THEIR APPLICATIONS in October 2024 [Accomplished successfully]**

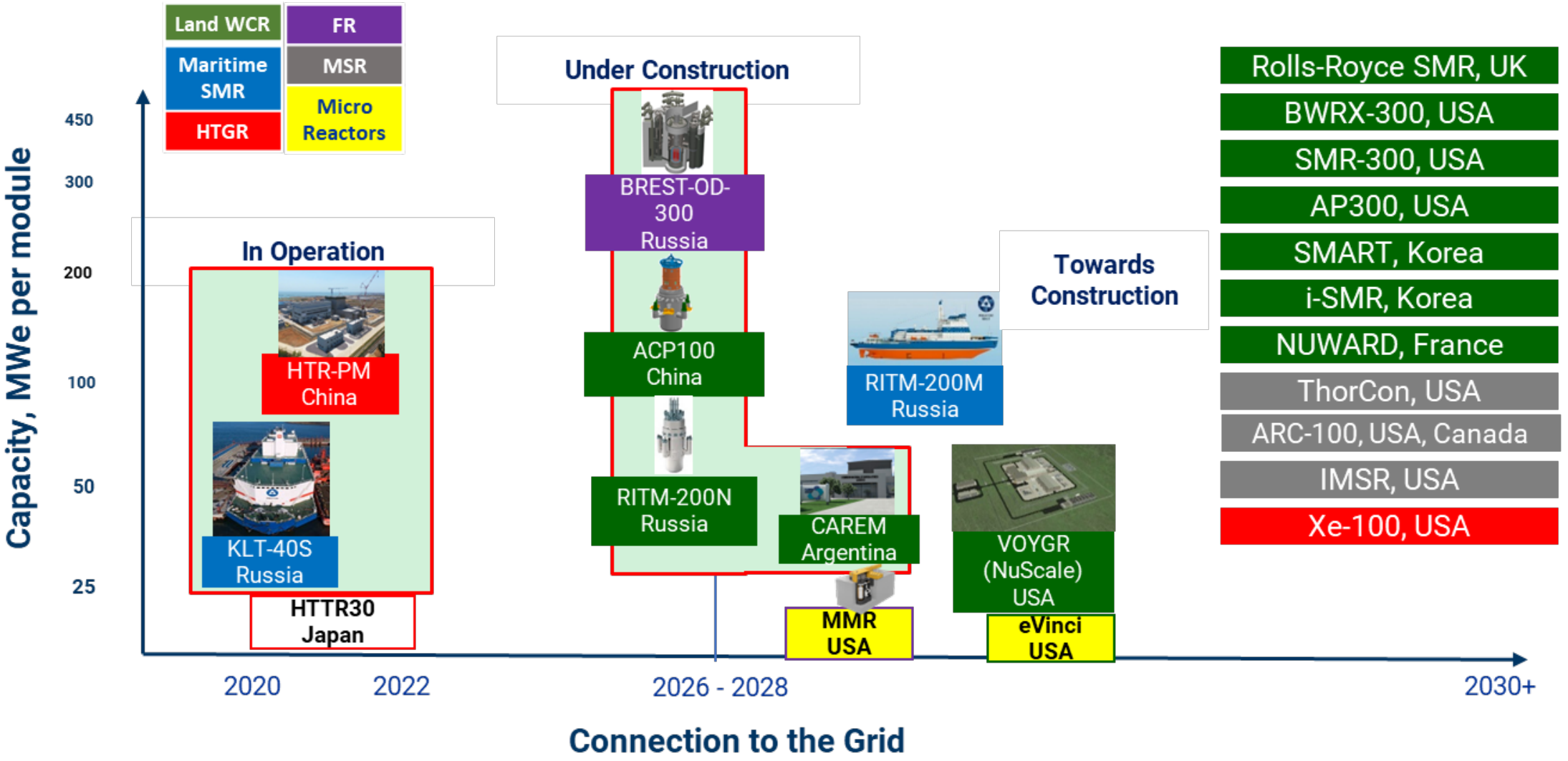
Status of SMR Development and Deployment

Based on updates from technology developers to IAEA in 2024



Note: The value displayed with the design refers to the output capacity in MW(e) per unit.

Deployment Timeline



Coordinated Research Projects

COMPLETED

- **CRPI32010** (2017 – 2021) on Design and Performance Assessment of Passive Engineered Safety Features in Water Cooled Small Modular Reactors – Case Study
  - Participants: CNEA, Ontario Tech, CNNC, BARC, ENEA, ENRRA, BATAN, KAERI, LEI and PAEC
  - Status: Draft TECDOC **approved submission to Publication Committee; to be issued Q4/2025**
- **CRPI31029** (2018 – 2021) on Approaches, Methodologies and Criteria for Determining the Technical Basis for the Emergency Planning Zone for SMR Deployment
  - Participants (including): CNEA, CNL, CNNC, SNERDI, Tsinghua University, VTT Research Centre, BATAN, JAEA, Toshiba, KAERI, PAEC, STEG, Argonne National Lab., Texas A&M, and EC-JRC
  - Status: Draft TECDOC **approved submission to Publication Committee; to be issued Q4/2025**

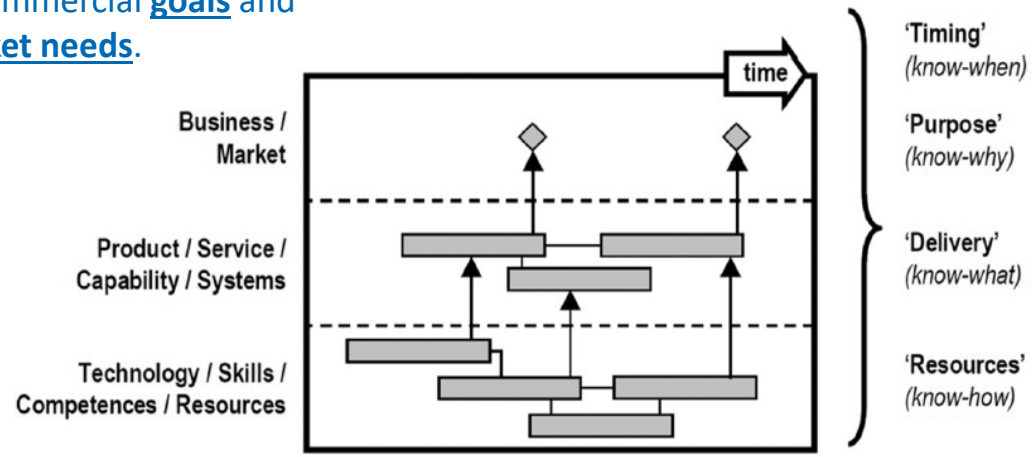
ON-GOING

- **CRPI12007** (2020 – 2024) on Economic Appraisal of SMR Projects: Methodologies and Applications
  - Participating countries including Argentina, Australia, Belgium, Brazil, Bulgaria, Canada, China,
  - Status: **Draft TECDOC approved for submission for in-house review**
- **CRPI31039** (2022 – 2026) on Technologies Enhancing the Competitiveness and Early Deployment of SMRs
  - Participants (including): Centre de recherche nucléaire de Birine – Algeria, CEA, CNPE, Korea Energy & Industry Consulting, National University of Singapore
  - Status: Research Coordination Meetings are being held

Technology Development Roadmap: Concept

Technology Roadmapping is a process that provides an **overview of key activities** required to develop specific technologies or products for an organisation or company.

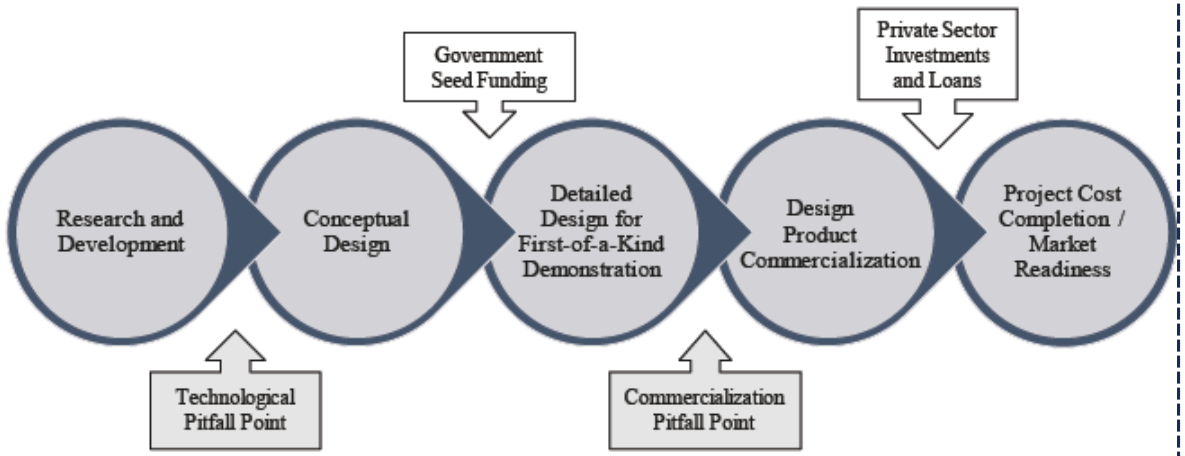
It facilitates the creation of an **innovation strategy** through the **alignment of technology** or product development with an organisation's **capabilities**, its commercial **goals** and **market needs**.



Pearson, R.J.; Costley, A.E.; Phaal, R. and Nuttall, W.J. (2020). Technology Roadmapping for mission-led agile hardware development: a case study of a commercial fusion energy start-up. Technological Forecasting and Social Change, 158, article no. 120064.

For Member States, technology roadmaps can inform the science and technology policy and aid in making investment decisions across government and industry in terms of loan guarantees and incentives, industry lead initiatives and human resource development.

The creation and use of a technology roadmap can accelerate technology development while ensuring the best chance of bridging the 'point of pitfall'



IAEA Activity on Updating Technology Roadmap for SMR Deployment

1-st CM
26-28 February 2024

TM
19-23 August 2024

SMR-24 Conference
21-25 October 2024

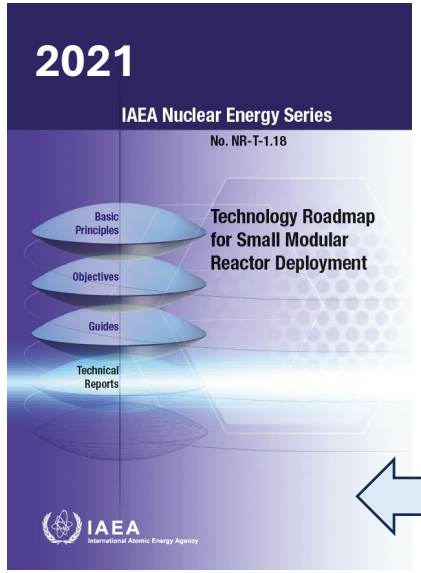
TWG-SMR
09-12 December 2024

2-nd CM
11-14 February 2025

TWG-SMR
08-12 September 2025

3-rd CM
12-14 November 2025

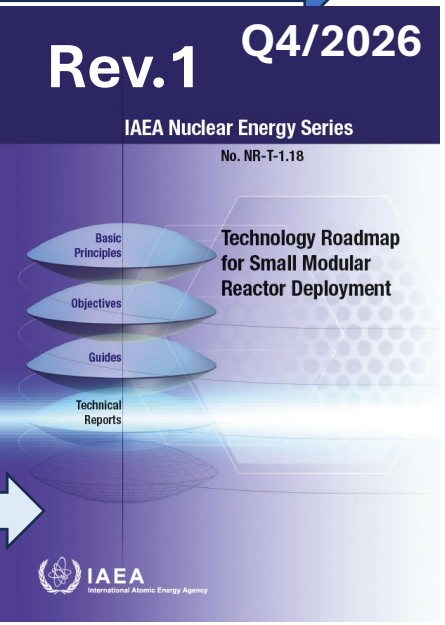
TM
2026



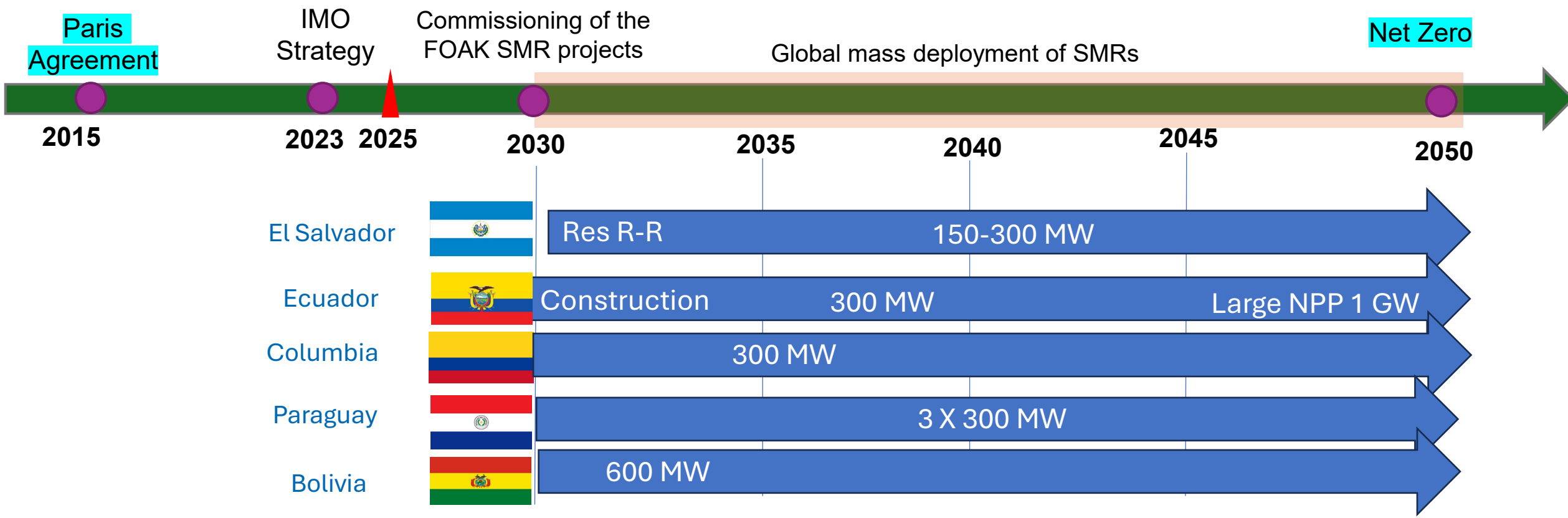
The publication places emphasis on the activities of **owners/operating organizations**, who drive the demand and requirements for reactor designs;

designers, who develop the technologies; and **regulators**, who establish and maintain the regulatory requirements that owners/operating organizations are obliged to meet.

To discuss the status of national nuclear energy programmes from the viewpoints of **designers, utilities, regulators, end-users**; present lessons-learned associated with **transportation associated fuel cycles and supply chain development**; discuss **business and delivery models**, **approaches to funding and financing** to facilitate accelerated deployment of SMRs including **maritime applications**;

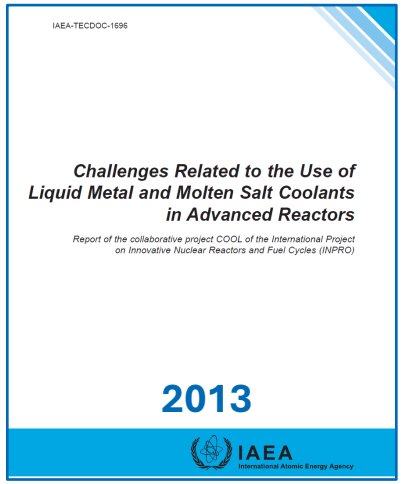


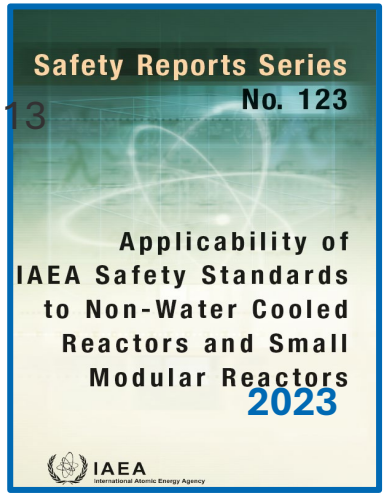
Expectations on Deployment of SMR:s Example of LA Regions

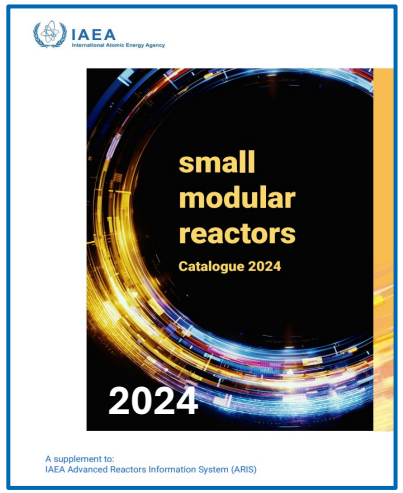


Materials of the SMR School: Regional WS on Key Aspects of SMR Development & Deployment 25-29/08/2025

Important IAEA Publications and Observations on Molten Salt Reactors







Conceptual shift

Breeder/burner/transmuter
(advantage of on-line fuel management)

to

Non-electric application (high temperature)
Maritime application (low pressure)

SMR-MSR

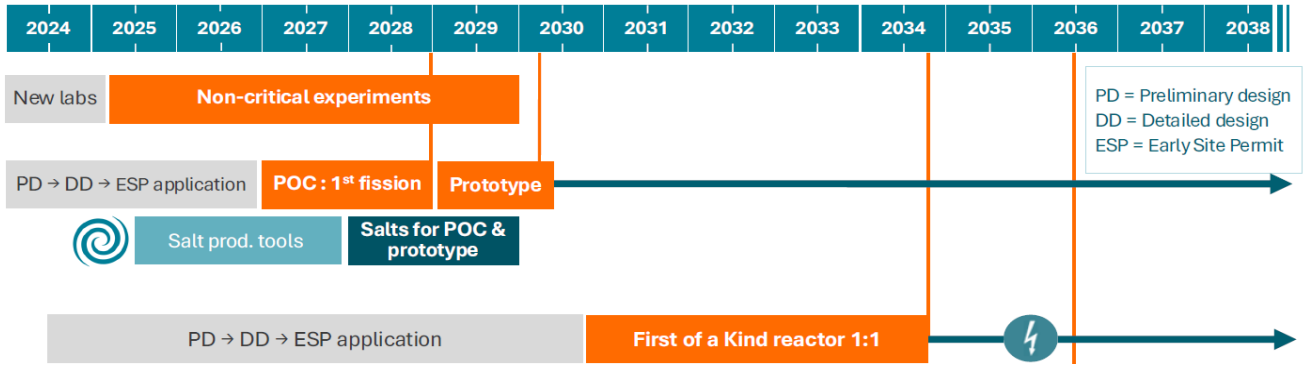
Focusing on Roadmapping: MSR Startups and Advanced Applications

1-st TM on Reactor Physics, Thermal Hydraulics and Plant Design of MSR (22-25 April 2025)

Copenhagen Atomics: tested reactor components for 1 MWt

2025 Order fuel& metal parts
2026 Assemble and test
2026/27 Test at PSI (irradiation)

Stellaria



KAERI

MSR for 15,000 TEU container ship propulsion

2023-26: Conceptual design

+4: Design advancement & Infrastructure for experimental validation

+4: Performance&safety validation/ Licensing documentation

IAEA MSR Technology package

In the IAEA MSRs are considered within the
Dpt of Nuclear Safety&Security,
NEXSHERE (within Nuclear Harmonization and Standardization initiative),
Div of Nuclear Fuel Cycle and Waste Technology and
Div of Nuclear Power (focusing roadmapping and TRL)

1-st TM on Reactor Physics, Thermal Hydraulics and Plant Design of MSR, 22–25 April 2025
Jointly with Div of Nuclear Fuel Cycle and Waste Technology

Consultancy Meeting on Experimental Testing for Verification and Validation of Design Tools for Molten Salt Reactor Technology Development, 28-31 October, 2025
The purpose of the event is to identify available MSR experimental facilities (to enrich the NEXSHARE database) and to define the scope and outcomes of the coordinated research project entitled ""Experimental Testing for Verification and Validation of Design Tools for Molten Salt Reactor Technology Development".

Interregional WS on Technology Readiness Level of MSR system and components
TBD: TC-INT2024 Q3, 2026
WS on the Current Status and Challenges of Structural Material Development for MSR 2026

TM on SMR Component Based TRL (TBD)

Microreactors

What is it?

- US DOE: 1- 20 MWt
  - Market: < 20 MWe or <50 MWt
- But has other characteristics, beyond power definition
  - Few or no on-site assembly
  - Small footprint
  - Semi-autonomous control system
  - Safety systems passively operated
  - Long refueling cycle
  - Do not require water source for cooling

IAEA Work on Microreactors

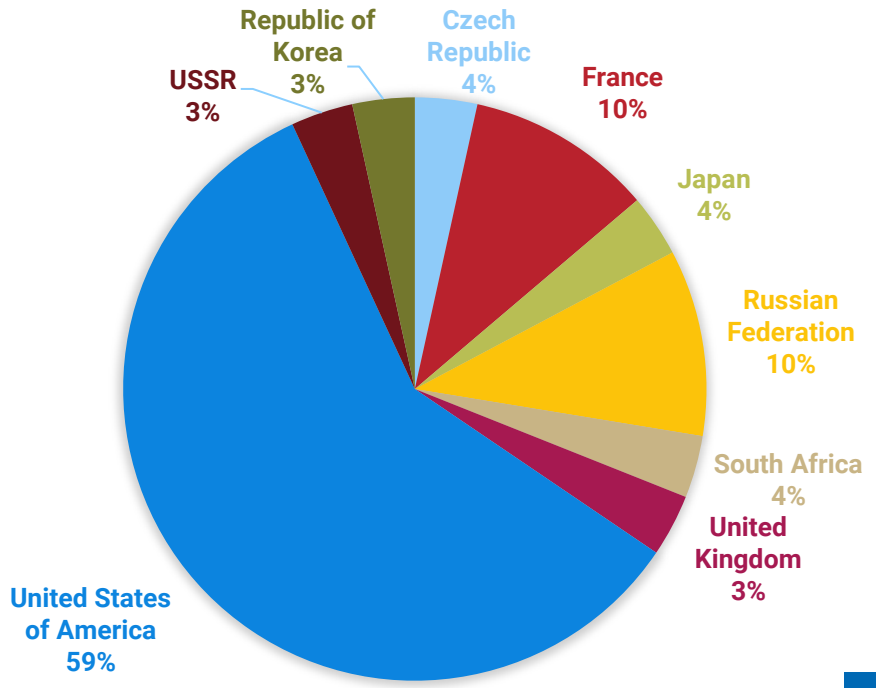
→ CM on Advances in Design and Technology Developments for Microreactors on 2-5 June 2025
→ TM in May 2026
  → TECDOC expected for end of 2026
→ IAEA–UNOOSA Joint Workshop on Nuclear Power Sources in Space in June 2026

Why choosing them?

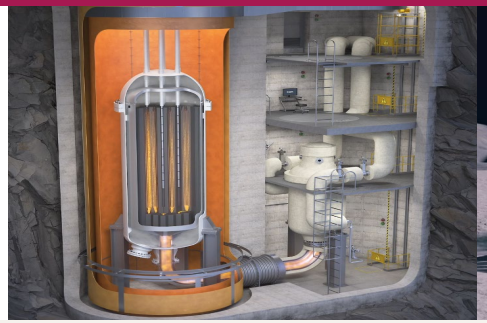
- Regions inaccessible to clean, reliable, resilient and affordable energy
  - Remote areas
  - Replacing diesel generators
  - Regions affected by external incidents (e.g. Natural disasters)
  - Mining Industries
  - Outer-space
- Fostering innovation in technology and advances in IT

Global Perspectives

- 13 microreactors listed on the 2024 SMR Catalogue + 2 over 10MWe
- 29 designs detected on the market



Microreactors Technology Landscape

	MARVEL Idaho National Laboratory (INL), USA	**eVinci** Westinghouse Electric Company LLC, USA	**Holos-Quad Generators** HolosGen, USA	**KRONOS MMR™** NANO Nuclear Energy Inc's, USA	**LOKI MMR** NANO Nuclear Energy Inc's, USA
					
Development Status	Fabrication	Detailed design	Detailed design	Preliminary design	Conceptual design
Reactor type	Sodium potassium eutectic (NaK)-cooled	heat-pipe cooled and monolith-core	distributable modular nuclear power generator	HTGR	HTGR
Power output	100-kWt /5-7 kWe	15 MWt/5 MWe	13 MWe	10-45 MWt/3.5-15 MWe	1.5 –5 MWe
Primary circulation	Natural Convection	Natural circulation	-	Forced circulation	Forced circulation
Primary pressure	0.39 MPa	0.12 MPa	-	1.3 to 6 MPa	2 MPa
Core outlet To	520 °C		-	660 °C	727 °C
Fuel type/enrichment	UZrH/19.75%	TRISO fuel/19.75%	-	FCM™ or TRISO/9.9 to 20%	TRISO/9.9%
Refueling Cycle	> 5 years	no on-site refuelling, 8 years	12–20 EFPYs	20 years	5 years
Plant footprint	8.9 m²	< 2 acres	-	-	-
Design life	2-40 years (depending on transients)	8 years	60 years	20 years	-

TECDOC Summary - draft

1. Introduction

- 1.1. Background
- 1.2. Objective
- 1.3. Scope
- 1.4. Structure

2. Rationale of Microreactors Development

- 2.1. Target Applications
- 2.2. Design Philosophy and system definition
- 2.3. Status of development
- 2.4. Environment analysis

3. Key design features and characteristics

- 3.1. Design and technology description
- 3.2. Fuel cycles
- 3.3. Manufacturing, transport and installation approaches
- 3.4. Civil structures
- 3.5. Reactor Core
- 3.6. Primary Nuclear Heat Transport System
- 3.7. Safety Approach and Safety Systems
- 3.8. Instrumentation and control Systems
- 3.9. Power conversion systems

4. Safeguards by Design for Microreactors

5. Security Measures

6. Computer and Cyber securities, AI/Machine Learning

7. Status of Research and Developments for near term deployments

8. Opportunities, trends, and issues in the development and deployment

- 8.1. Site and environment
- 8.2. Fuel cycle
- 8.3. Nuclear safety
- 8.4. Nuclear island design and performance
- 8.5. Safeguards and protection
- 8.6. Technology readiness and project delivery
- 8.7. Policy and regulatory challenges
- 8.8. Economics and financing

9. Summary and Pathway Forward

Annexes: Description of Microreactor concepts

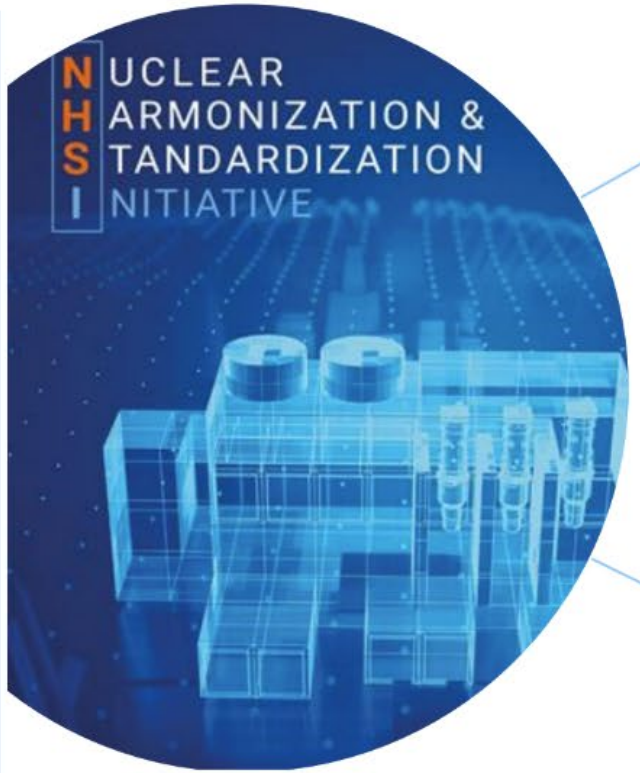
REFERENCES

ABBREVIATIONS

CONTRIBUTIONS TO DRAFTING AND REVIEW

Background: NHSI industry track [reminder]

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 **S**tandardization of Industrial Approaches Track

- **Topic 1:** Harmonization of high-level user requirements
- **Topic 2**: Information sharing on Codes and Standards
- **Topic 3**: Experimental Testing and Validation for Design and Safety Analysis Computer Codes
- **Topic 4:** Acceleration of nuclear infrastructure implementation for SMR

Agreed structure [reminder]

Phase 1

Goals

3S

Performance

Economics

Implementation

Policies

Asset protection	Community consideration	Constructability	Decommissioning	Design margins
Digital engineering	Environmental protection	Flexibility	Human factors engineering	Licensing and permitting preparation
Maintainability	Nuclear fuel management	Operational sustainability	Proven technology and innovation	Quality assurance
Simplification	Spent fuel management	Standardization	Threat protection	Waste management

Technical Meeting on Approaches for Design and System Readiness Evaluation of SMRs for Near-term Deployment
Ref: EVT2404321 [Hybrid Event]
Vienna International Centre, 14 – 17 July 2025

New Project :
Approaches for Design, Technology and System Readiness Level Evaluation of Small Modular Reactors

Dr. M. Hadid Subki

Technical Lead, SMR Technology Development
Nuclear Power Technology Development Section,
Division of Nuclear Power,
IAEA Department of Nuclear Energy

Development of an IAEA-TECDOC

Objective: To enable Member States to keep abreast about the latest approaches or methodologies currently implemented, to evaluate technology readiness levels of advanced nuclear system(s). Collate lessons learned in the specificities of performing readiness assessments on SMRs.

Table of Content

- **Section 1: Introduction**

Background, Objective, Scope and structure and Users

- **Section 2: Overview & Approaches to understand System and Design Readiness Evaluations for Small Modular Reactors**

How to define and frame a “system” in the context of SMRs; Interface between Technology Readiness of SMRs and the Reactor Technology Assessment Methodology; Modularity specificities of SMRs; Influence of Readiness Assessments on Contracting Approaches; Application of computing resources to support SMR design and system evaluations

- **Section 3: Best Practices in Organizations in Member States**

Overview of Technology Readiness Level; Systems Readiness Evidenced based approach to Technology Readiness; Member State Contributions and lessons learned when assessing technology readiness

- **Section 4: Evaluation methodologies as they apply to Small Modular Reactors**

Dynamics of readiness methodologies over the evolution of reactor technology development; Role of readiness evaluations on technology roadmaps and programme development; Risk and uncertainty considerations during technology evaluations

- **Section 5: Strategy and Integration into the RTA Process**
- **Summary and Pathway Forward**

This Event:

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Technical Meeting on Approaches for Design and System Readiness Evaluation of Small Modular Reactors for Near-term Deployment

IAEA Headquarters, Vienna, Austria

14 – 17 July 2025

Ref. No.: EVT2404321

Information Sheet

The objectives of the Technical Meeting were to:

- Provide a forum for the exchange of information on state-of-the-art approaches or methodologies to evaluate technology readiness levels of advanced nuclear reactor system(s) particularly SMRs;
- Discuss key technical issues associated with design development of SMRs at the levels of system, structure, and component;
- Identify pathways of implementing of such approaches and/or methodologies to facilitate product development, licensing and deployment of SMRs.

Nominated participants were from:

China - Tsinghua University, Czech Republic – Ministry of Industry & Trade, Denmark – 92 Ventures, India – Nuclear Power Corporation of India Limited, Jordan - Jordan Atomic Energy Commission, Republic of Korea – KHNP Central Research Institute and KAIST, Poland – ORLEN Synthos Green Energy and National Atomic Energy Agency, Romania – RATEN-ICN, Nuclearelectrica S A and CITON, Russian Federation – IBRAE, Switzerland – ENSI and Apollo+, Thailand – EGAT and NSTDA, United States of America – Idaho National Laboratory

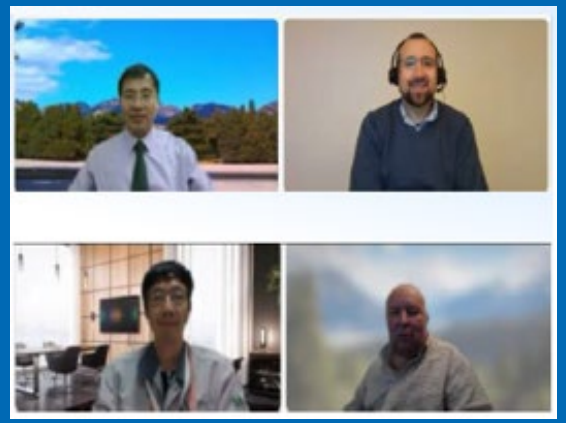
Gas Cooled Reactors – Technical Working Group (TWG-GCR)

- Advises the IAEA DDG-NE on specific topics of relevance to the IAEA programmatic activities in the field, since 1978
- Shares information and knowledge on national and international programme
- Contributes to the development and/ or review of selected IAEA publications, in particular from the IAEA Nuclear Energy Series, assesses existing gaps and advises on the preparation on new publications or e-learning materials
- Upon request, presents to the Standing Advisory Group on Nuclear Energy (SAGNE) the key findings of the TWG meeting
- Shares experience and advice on increasing the participating of young professionals and improving the gender balance in the nuclear sector
- Focus today on HTGRs
- **15 Member States** with designated member (**2021-2024**)
- **2 Observers**: European Commission, OECD/NEA

No	Country	Name and Affiliation
1	Canada	**Mr Ali SIDDIQUI** Canada Nuclear Laboratories (CNL)
2	China *The Chair of TWG-GCR (2021-2024)*	**Mr Yujie DONG** Tsinghua University, Institute of Nuclear and New Energy Technology (INET)
3	Finland	**Mr Ville TULKKI** VTT Technical Research Centre of Finland
4	France	**Mr Christoph DÖDERLEIN** Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
5	Germany	**Mr Hans-Josef ALLELEIN** RWTH Aachen
6	Indonesia	**Mr Topan SETIADIPURA** National Research and Innovation Agency (BRIN)
7	Japan	**Mr Tetsuo NISHIHARA** Japan Atomic Energy Agency (JAEA)
8	Republic of Korea	**Mr Chan Soo KIM** Korea Atomic Energy Research Institute (KAERI)

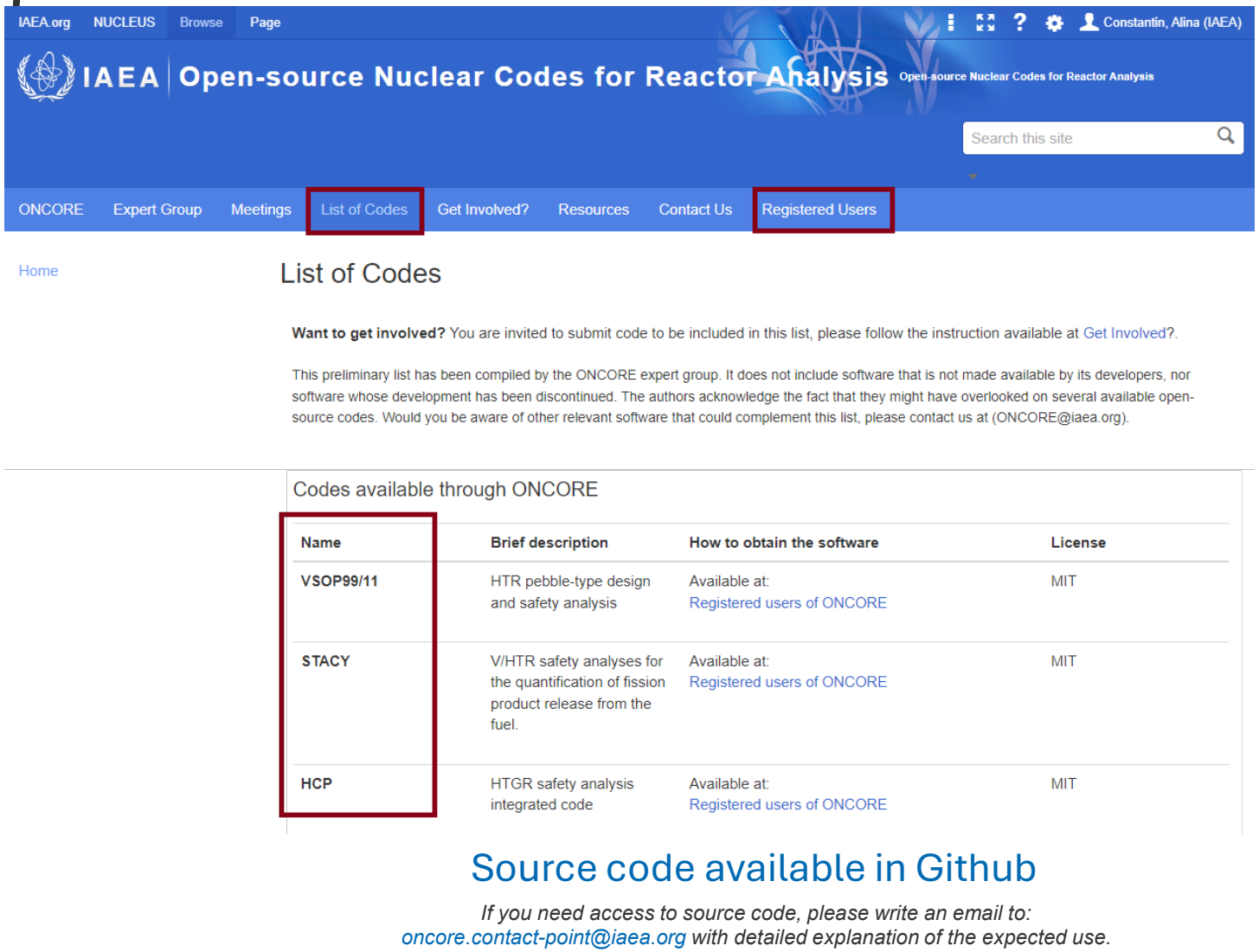
No	Country	Affiliation
9	Poland	**Ms Agnieszka BOETTCHER** National Centre for Nuclear Research (NCBJ)
10	Russian Federation	**Mr Peter FOMICHENKO** National Research Centre Kurchatov Institute
11	South Africa	**Ms Vishana NAICKER** North-West University
12	Switzerland	**Mr Manuel POUCHON** Paul Scherrer Institute (PSI)
13	Ukraine	**Mr Mykola ODEYCHUK** Kharkov Institute for Physics and Technology
14	United Kingdom	**Mr Timothy ABRAM** University of Manchester
15	United States of America	**Mr Gerhard STRYDOM** Idaho National Laboratory (INL)

No	Country	Name and Affiliation
1	OECD/NEA	**Mr Brent WILHELM**
2	EC-JRC	**Mr Michael FUETTERER**



HTR Codes (HCP, STACY, VSOP)

- HTR codes are accessible through the Open-Source Nuclear Codes for Reactor Analysis (ONCORE)
  - The ONCORE initiative is an IAEA-facilitate international collaboration framework for the development and application of open-source multi-physics simulation tools to support research, education and training for the analysis of advanced nuclear power reactors. Institutions and individuals participating in ONCORE can collaborate in, and benefit from, the development of open-source software in the field of nuclear science and technology.
  - https://www.iaea.org/topics/nuclear-power-reactors/open-source-nuclear-code-for-reactor-analysis-oncore
  - https://nucleus.iaea.org/sites/oncore



Source code available in Github

If you need access to source code, please write an email to: oncore.contact-point@iaea.org with detailed explanation of the expected use.

2025: Workshop on High Temperature Gas Cooled Reactor Technology and Training on the High Temperature Reactor Code Package (2-7 November 2025, hosted by TUM)

IAEA Expert mission on the High Temperature Gas-cooled Reactor Package (HCP) and STACY code (4-8 November 2024, Bandung, Indonesia)

- Organized locally by the National Research and Innovation Agency (BRIN), at the premises of Bandung Institute of Technology, Bandung (ITB), with IAEA support from TC Programme INS2019
- Agenda included lectures and practical sessions, illustrating the capabilities of the version available in the IAEA ONCORE platform and also the capabilities of the HCP version under development at the Technical University of Munich and of the STACY version developed in Becker Technologies
- Training provided by:

❑ Mr Andre Xhonneux (former developer of HCP code in FZJ, Germany)

❑ Mr Chunyu Liu (Technical University of Munich)

❑ Meryll Colomber (Becker Technologies, Germany)

- 9 Indonesia BRIN staff and 5 online South African participants joined the event
- It is expected that the new version developed by TUM to be transferred to IAEA during 2025 and make available to Member States through the IAEA ONCORE platform
- The need of having a comprehensive documentation of the HCP code and its modules (including training material, developer manual and theoretical manual) was highlighted by the participants; however, currently the developers have limited resources and the focus is to complete the expected enhanced versions of both HCP and STACY
- Participants (both users and developers) agreed on the need to have a dedicated HCP Forum to exchange data, models, work on further developments, report bugs/issues, create test cases

Upcoming HTGR Events (rest of 2025)

- International Nuclear Graphite Specialists Meeting, INGSM-25 (organized in cooperation with the IAEA) (29 September – 3 October 2025), this week taking place in Press Room
- Workshop on High Temperature Gas Cooled Reactor Technology and Training on the High Temperature Reactor Code Package (3-7 November 2025, Technical University of Munich, Germany) – selection of participants completed
- Meeting of the Technical Working Group on Gas Cooled Reactors (1-4 December 2025)

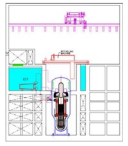
Key IAEA Activities on SMR

Technology Development and Deployment
- TWG-SMR/GCR
- ARIS Database
SMR Booklet

Reactor Technology Assessment
- Updated Method incorporates SMR

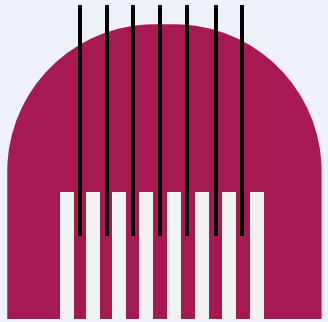
Fuel, Safe management of Spent Fuel, Radioactive Waste and Decommissioning

Approaches to Commissioning and Operation
- Issues on the conduct of operation, OLC and MCR for multi-unit plant



Economics
- Economic Appraisal of SMR Projects: Methodologies and Applications

IAEA Platform on SMRs and their Applications



Nuclear Harmonization and Standardization Initiative

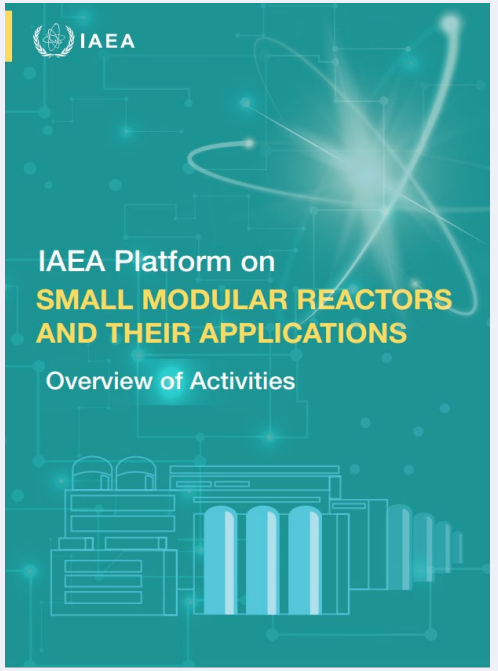
Legal Frameworks for safety, security, safeguards and civil liability for nuclear damage

Safety & Security
- Applicability of Safety Standards and Security Guides
- Emergency Preparedness and Response

Safeguards-by-Design
- Facilitation of safeguards inspection early in reactor design stage

Infrastructure Development
- IAEA Milestones Approach applicable to SMR
- New deployment models

Technical Cooperation
- Capacity Building



New publication available (launched at GC68)

See SMR Portal (https://smr.iaea.org)

Thank you for your attention.

For inquiries, please contact:
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