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Technical Meeting on Topical Issues in the Development of
Nuclear Power Infrastructure,
Vienna International Centre, 12 – 15 March 2024

Small Modular Reactors Development for Near Term Deployment

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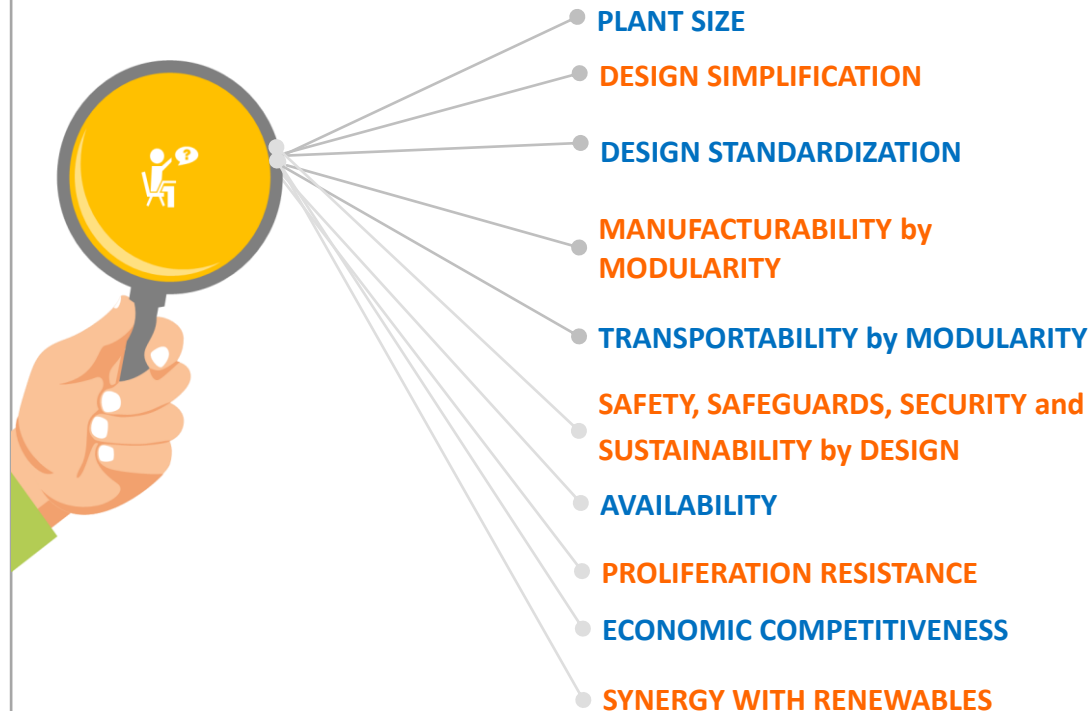
Division of Nuclear Power, Department of Nuclear Energy

SMRs: Development Objectives & Attributes

Developmental Objectives

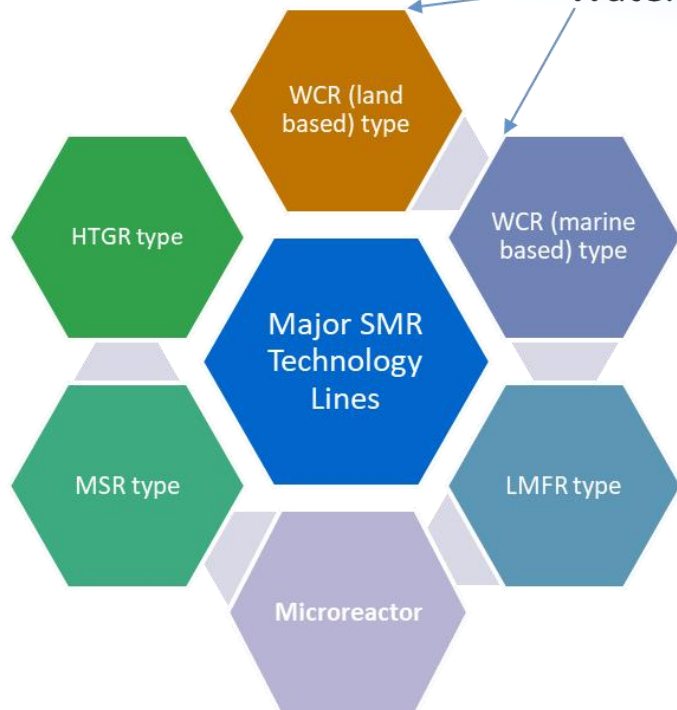
- Smaller power, simplified design, deployed with high modularity
- Cost benefit, e.g., lower upfront capital cost and risk; economy of multiple
- Flexible to meet higher demand using multiple-module power plants
- Various applications for electric and non-electric, including H₂ production
- Salient features comparing to Large NPPs
- A value proposition for enhancing social acceptance by public

Key Attributes and Requirements



Major SMR Technology Lines

Water-cooled SMRs



Microreactor (U.S. DOE Glossary)

Compact reactors that will be small enough to transport by truck and could help solve energy challenges in a number of areas. They are capable of producing 1-20 Megawatts of thermal energy used directly as heat or converted to electric power.

Ref. [What is a Nuclear Microreactor?](#) | Department of Energy

Other Descriptions of Microreactor

- 1) **A subset of small modular reactors** of 1-20 MWe capacity;
- 2) Advanced reactors of power up to 10MWe, **with common features** including modularity, passive safety, flexibility, simpler designs, more factory-based manufacturing possibilities, reduced site construction time and easier and more cost-effective reproduction, etc.

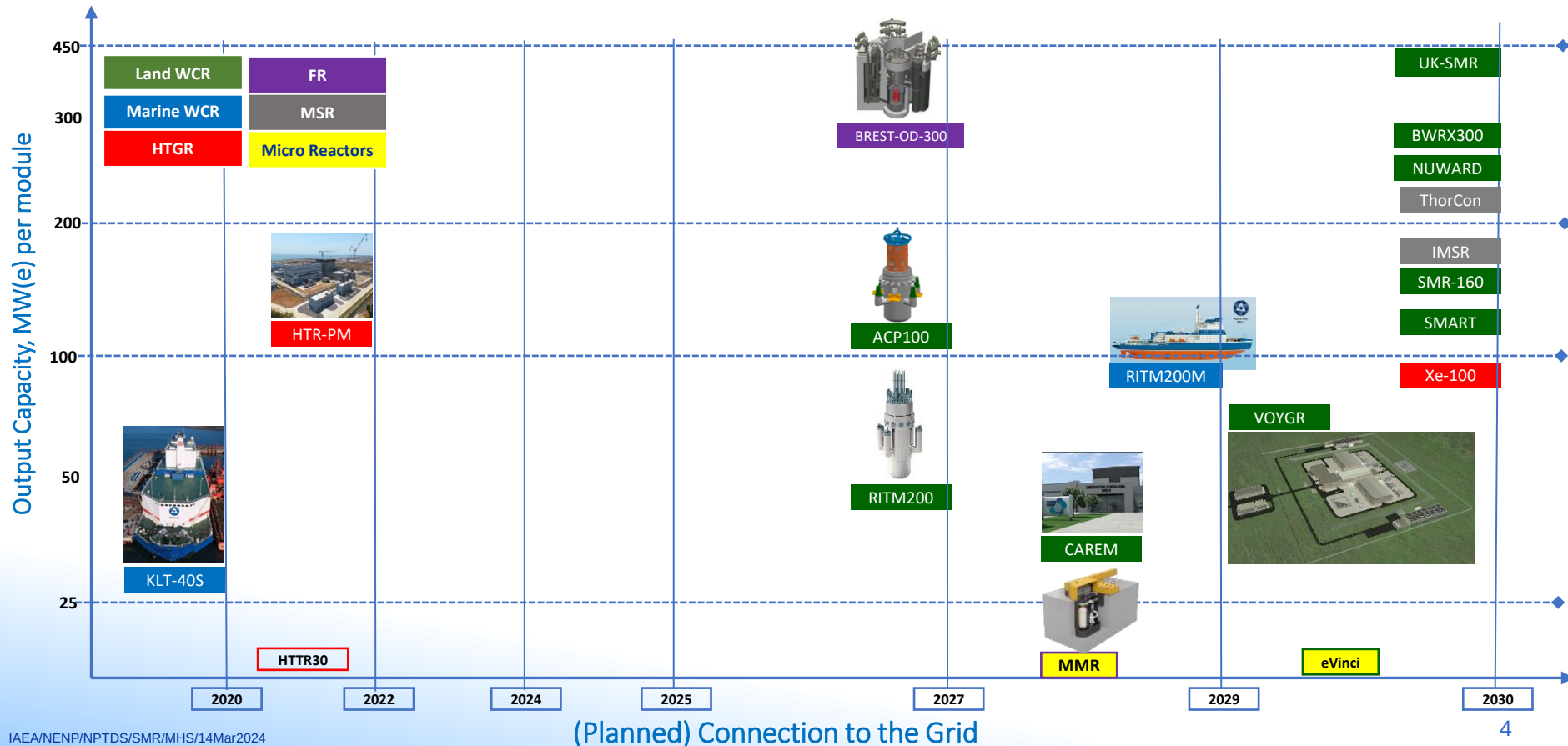
Notes: Commonly seen but lacking consensus.



First 10-year Deployment Horizon

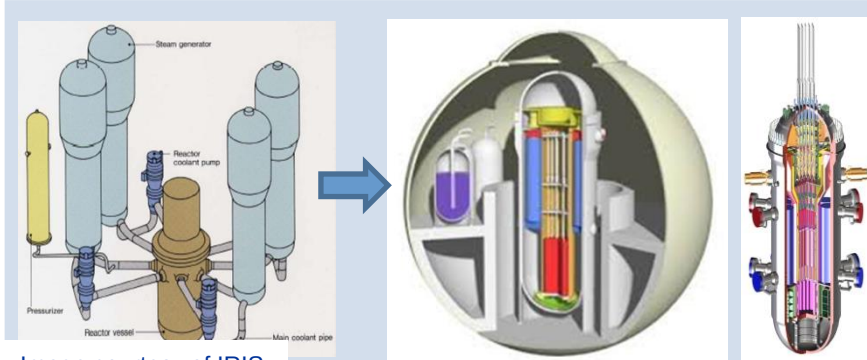
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SMR Forerunners: 2 in operation, 4 in advanced stage of construction



Salient Design Characteristics

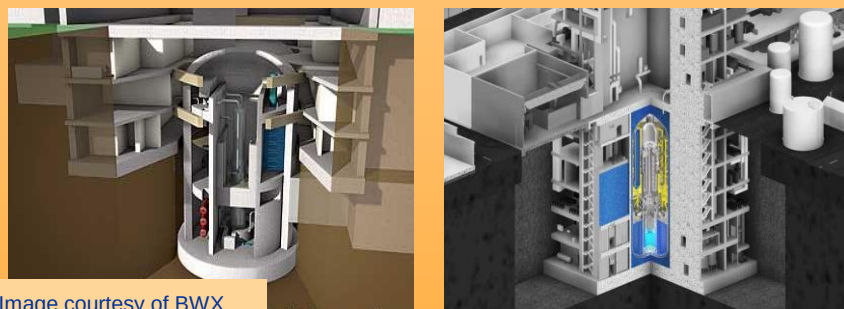
Simplification by Modularization and System Integration



Multi-module Plant Layout Configuration

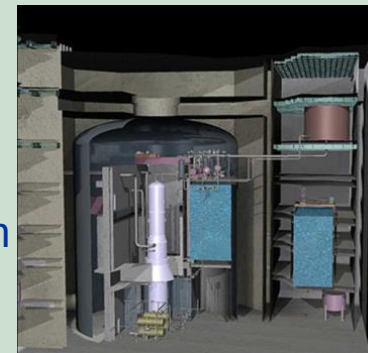


Underground construction for enhanced security and seismic

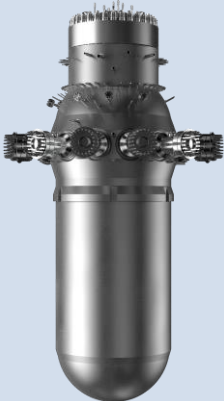


Enhanced Safety Performance through Passive System

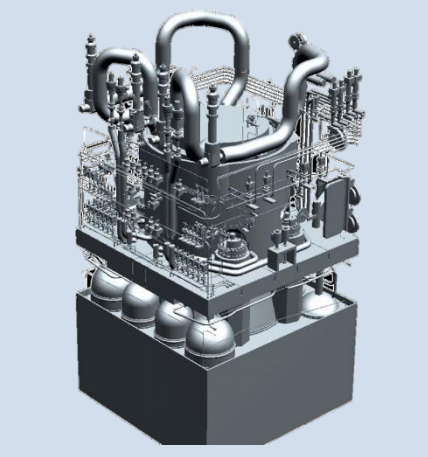
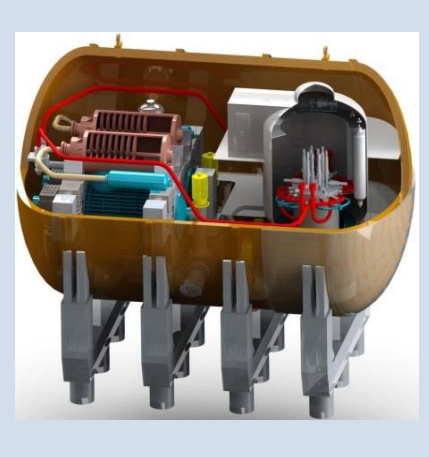
- Enhanced severe accident features
- Passive containment cooling system
- Pressure suppression containment



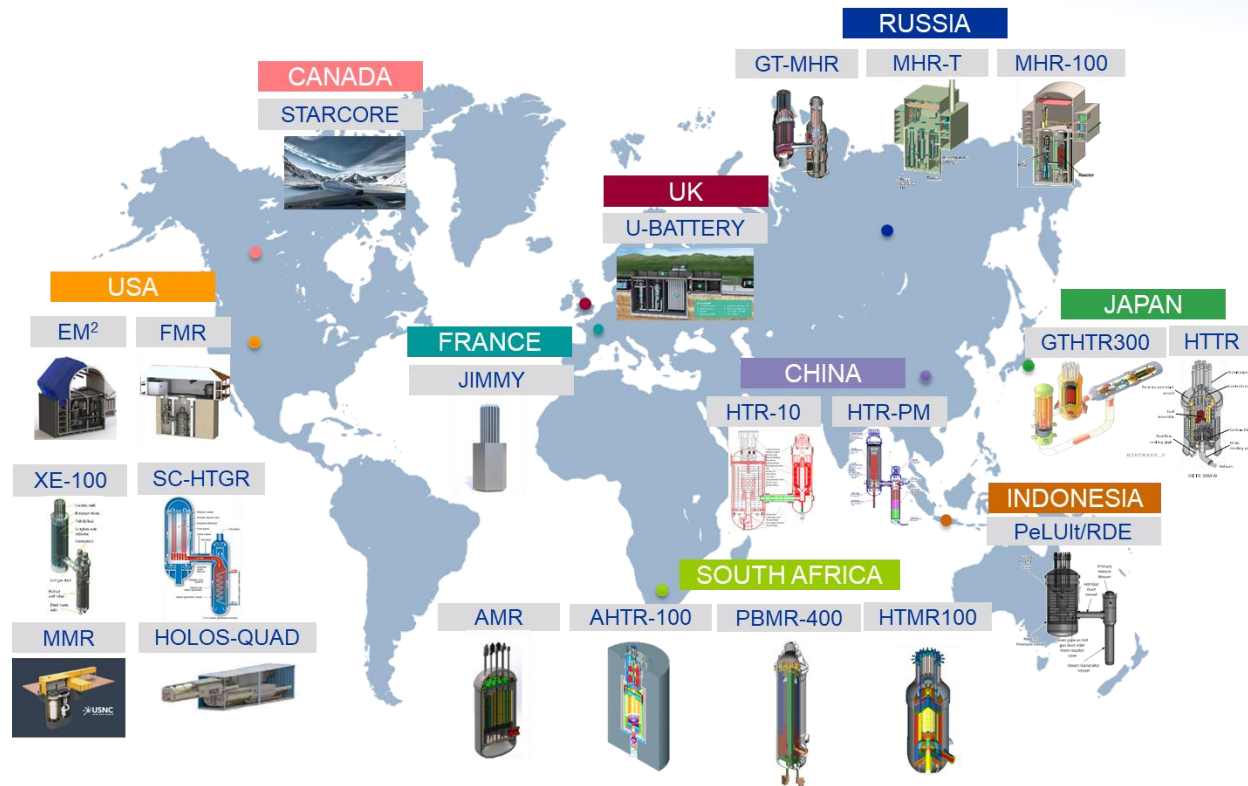
LWR-type SMRs (Examples)

 CAREM	 ACP100	 NUWARD	 SMART 	 VOYGR	 BWRX-300
					
<u>Design Status:</u> Advanced stage of construction in Atucha site, Argentina	<u>Design Status:</u> Detailed design; received license for construction in July 2019	<u>Design Status:</u> Conceptual design; Consortium launched in September 2019	<u>Design Status:</u> Licensed/Standard Design Approval (July 2012), Pre-Project Engineering completed	<u>Design Status:</u> Design Certification Approval received in September 2020, to start construction by 2025	<u>Design Status:</u> Pre-licensing initiated in UK, Canada, US, aiming for construction start in 2024, operation in 2027
• CNEA, Argentina • Integral-PWR • 100 MWt / 30 MWe • Natural Circulation • Core Outlet Temp: 326°C • Enrichment: 3.1% (prototype) • Refuel interval: 14 months (prototype)	• CNNC, China • Integral-PWR • 385 MWt / 125 MWe • Forced circulation • Core Outlet Temp: 319.5°C • Enrichment: <4.95% • Refuel interval: 24 months	• EDF led consortium, France • Integral-PWR • 540 MWt x 2 / 170 MWe x 2 modules • Core Outlet Temp: 307°C • Enrichment: <5% • Refuel interval: 24 months	• Joint Design of KAERI, Republic of Korea with K.A.CARE, Saudi Arabia • Integral-PWR • 365 MWt / 107 MWe per module • Core Outlet Temp: 322°C • Enrichment: <5% • Refuel interval: 30 months • For cogeneration	• NuScale Power, LLC, United States of America • Integral-PWR • Natural Circulation • 200 MWt / 60 MWe per module x 12 Modules • Core Outlet Temp: 321°C • Enrichment: <4.95% • Refuel interval: 24 months	• GE-Hitachi & Hitachi-GE Nuclear Energy, USA and Japan • Boiling Water Reactor • Natural Circulation • 870 MWt / 290 MWe • Core Outlet Temp: 287°C • Enrichment: <4.95% • Refuel interval: 24 months

Marine-Based SMRs (Examples)

On-Shore Deployment		Off-Shore Deployment	
 KLT-40S	 RITM-200M	 ACPR-50S	 SHELF
			
<u>Design Status:</u> Full Commercial Operation since May 2020 in the Akademik Lomonosov Floating NPP	<u>Design Status:</u> 6 prototype reactors were manufactured and installed on icebreakers (2 ones are in the process of testing)	<u>Design Status:</u> Completion of conceptual/ program design, preparation of project design.	<u>Design Status:</u> Detailed design underway
• OKBM Afrikantov, Russian Federation • Compact Loop PWR • 150 MWt / 35 MWe per module x 2 modules for the FNPP • Core Outlet Temp: 316°C • Enrichment: 18.6% • Refuel interval: 36 months • Without onsite refuelling • Spent fuel take back	• OKBM Afrikantov, Russian Federation • Integral-PWR • 175 MWt / 50 MWe per module • Core Outlet Temp: 318°C • Enrichment: <20% • Refuel interval: Up to 120 months • Without onsite refuelling • Spent fuel take back	• CGNPC, China • Integral-PWR • 200 MWt / 50 MWe per module • Core Outlet Temp: 321.8°C • Enrichment: <5% • Refuel interval: 30 months • Whole heap refuelling	• NIKIET, Russian Federation • Integral-PWR • 28.4 MWt / 6.6 MWe per module • Core Outlet Temp: 310°C • Enrichment: 19.7% • Refuel interval: 6 years (8 for SHELF-M) • Without onsite refuelling • Spent fuel take back

Global Activities on HTGR-SMR development



Under wide-range of development and deployment stages

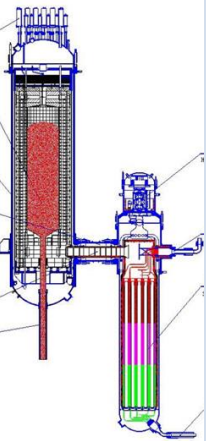
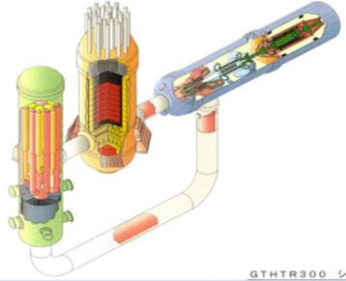
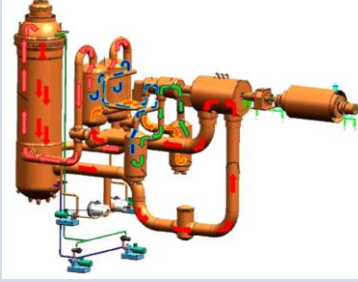
HTGR-type SMRs (Examples)



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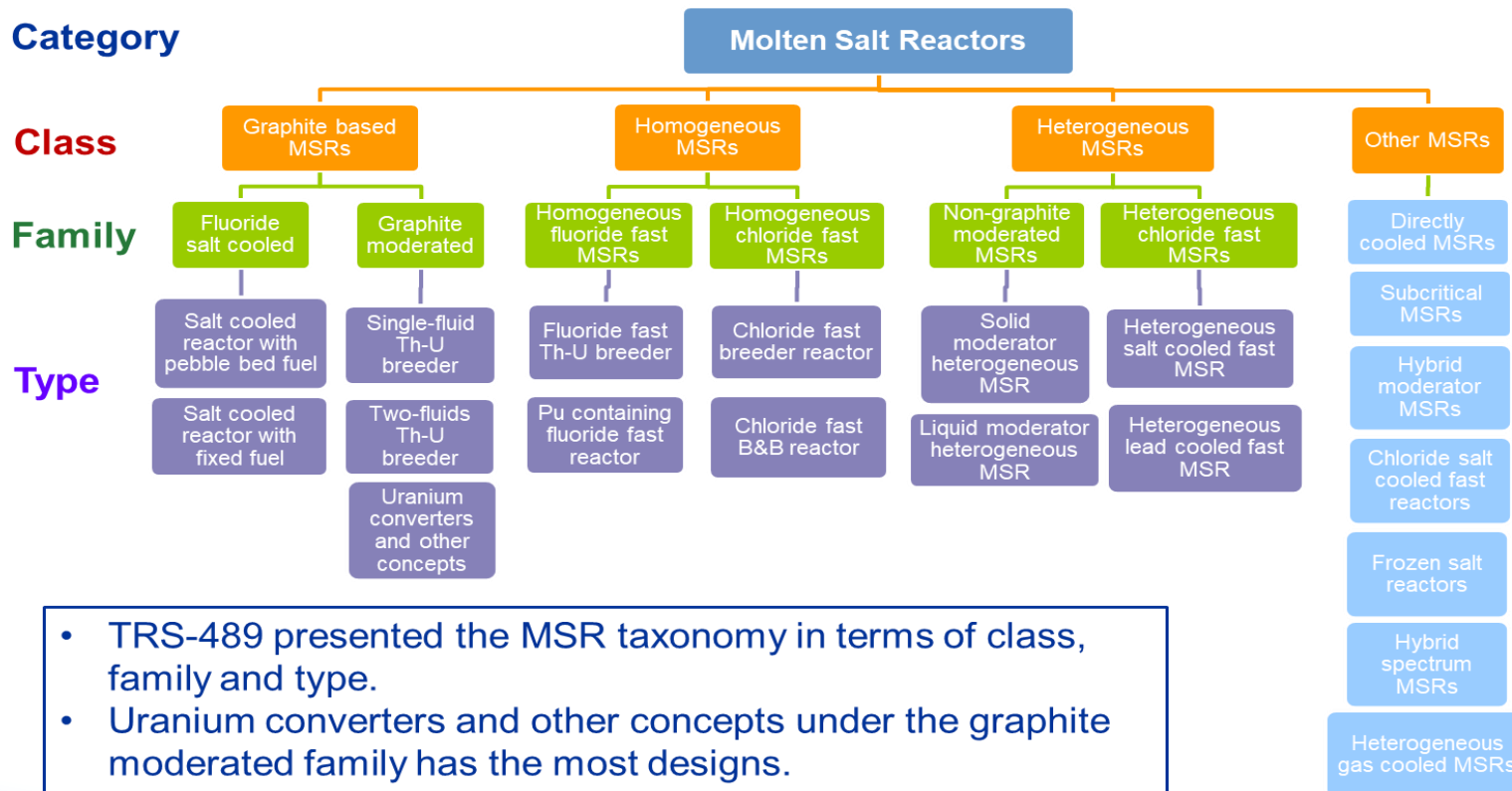
 HTR-PM	 GTHTR300	 PBMR-400	 RDE / Micro-PeLUit
			
<u>Design Status:</u> Finalizing construction in Shidao Bay for operation by 2021	<u>Design Status:</u> Pre-Licensing; Basic Design Completed	<u>Design Status:</u> Preliminary Design Completed, Test Facilities Demonstration	<u>Design Status:</u> Site license issued in 2017, conceptual design completed, detail design is in progress
• INET Tsinghua University, China • Modular pebble-Bed HTGR • 250 MWt / 210 MWe x 2 modules • Forced Circulation • Core Outlet Temp: 750°C • Enrichment: 8.5% • Refuel interval: Online refuelling	• JAEA, Japan • Prismatic HTGR • <600 MWt / 100~300 MWe • Core Outlet Temp: 850-950°C • Enrichment: <14% • Refuel interval: 48 months • Multiple applications	• PBMR SOC, Ltd, South Africa • Pebble-Bed HTGR • Forced Circulation • 400 MWt / 165 MWe per module • Core Outlet Temp: 900°C • Enrichment: 9.5% • Refuel interval: Online refuelling	• National Nuclear Energy Agency (BATAN), Indonesia • Pebble-Bed HTGR • Forced Circulation • 10 MWt / 3 MWe • Core Outlet Temp: 750°C • Enrichment: 17% • Refuel interval: Online refuelling

Advances in Molten Salt Reactor development



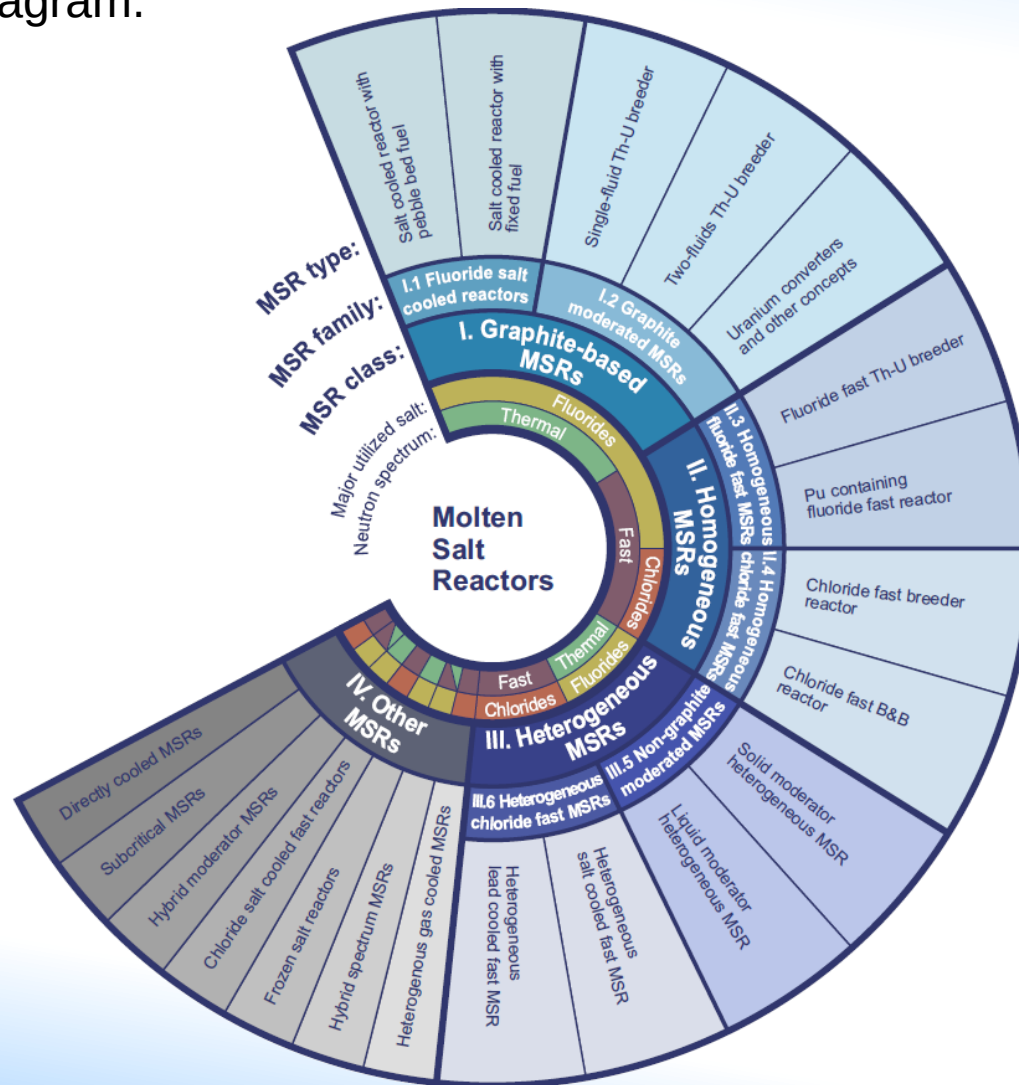
Taxonomy of Molten Salt Reactor

Courtesy of J. Křepel, Paul Scherrer Institute, Switzerland



MSR Taxonomy

- Taxonomy can also be illustrated as a circular chart which is transposed from the block diagram.



Published

Written to assist individuals in academia and industry and in relevant regulatory and policy roles, this publication provides a summary of the current knowledge on the status of research, technological developments, reactor designs and experiments in the area of advanced reactors that are fuelled or cooled by a molten salt. Identification of challenges and areas where research and development are still required in preparation for commercial deployment gives context to current and planned work. The aim of this publication is to share information on programmes and projects on molten salt reactors in Member States, which will shape future collaborative efforts.

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA

TECHNICAL REPORTS SERIES NO. 489

Status of Molten Salt Reactor Technology

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Status of Molten Salt Reactor Technology

Advantages, Issues & Challenges



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Technology aspects

- Shorter construction period (modularization)
- Potential for enhanced safety and reliability
- Design simplicity
- Suitability for non-electric application (desalination, etc.).
- Replacement for aging fossil plants, reducing GHG emissions

Non-Techno aspects

- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site flexibility
- Reduced emergency planning zone
- Lower upfront capital cost (better affordability)
- Easier financing scheme



Technology issues

- Licensing of FOAK designs, particularly non-LWR technologies
- Prove of operability and maintainability
- Staffing for multi-module plant;
- Supply chain for multi-modules
- Optimum plant/module size
- Advanced R&D needs

Non-technology issues

- Time from design-to-deployment
- Highly competitive budget source for design development
- Economic competitiveness: affordability & generation cost
- Availability of *off-the-shelf* design for newcomers
- Operating scheme in an integration with renewables

Common Issues of Deployment

Demonstration of Safety and Operational Performance of FOAK, Novel Designs & Technologies

Continuity of Orders, cost competitiveness against alternatives, robust supply chain, and viable financing Option

**Deployment Competitiveness:
How and When**

Regulatory framework, licensing pathways: global deployment, need of harmonization?

Development of Nuclear Infrastructure for near-term deployment particularly in Embarking countries

Summary – take aways

- Two NPPs with SMRs are already in commercial operation:
 - Two (2) units of KLT-40S for the Akademik Lomonosov floating NPP in Pevek, Russian Federation [2 x 35 MWe]
 - Two (2) reactor modules of HTR-PM for the Shidao Bay HTGR demonstration HTGR, in China [200 MWe from 2 x 250 MW-thermal]
- Three SMR-NPPs are under construction:
 - CAREM in the Atucha-II site, Argentina [30 MWe by 2028]
 - BREST-OD-300, a Gen-4 lead fast reactor demonstration in Seversk, Russian Federation [300 MWe in 2026]
 - ACP100 for Linglong-1 NPP in Changjiang, China [125 MWe in 2026]
- Dozen of SMR designs in various licensing progress:
 - VOYGR (USA); BWRX-300, MMR and ARC-100 for Canada, NUWARD in France; RR-SMR in the United Kingdom, RITM-200 and -400 in Russian Federation, KP-FHR with Hermes demonstration in the United States, innovative-SMR and SMART in Republic of Korea, etc.
- New Startup design organizations in France, Italy and the United States with microreactors and non-water cooled Gen-IV reactors
- Embarking countries with on-going national capacity building project on SMRs, including Poland, Jordan, Estonia, Indonesia, etc.



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Thank you!

For inquiries on SMR, please contact:

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