Small Modular Reactor Designs

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Interregional Workshop on Aspects of Modelling and Simulation in Gen-IV Type SMR Development

3–7 November 2025, Moscow, Podolsk, Russia Federation

The International Atomic Energy Agency

The International Atomic Energy Agency is the world's central intergovernmental forum for scientific and technical cooperation in the nuclear field. It works for the safe, secure and peaceful uses of nuclear science and technology, contributing to international peace and security and the United Nations' Sustainable Development Goals.

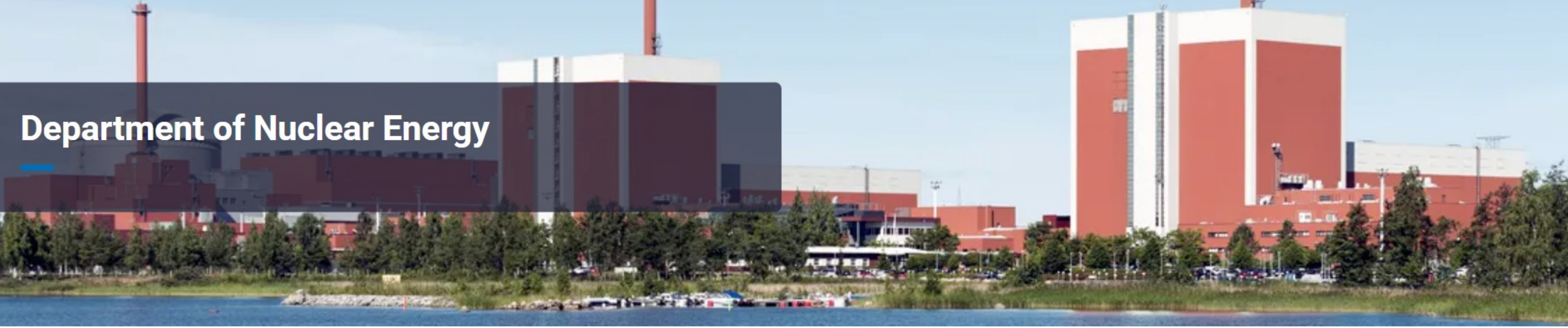
6 Departments

ORGANIZATIONAL STRUCTURE

Offices Reporting to the Director General

- Management
- Technical Cooperation
- Nuclear Energy
- Nuclear Safety and Security
- Nuclear Sciences and Applications
- Safeguards

Department of Nuclear Energy



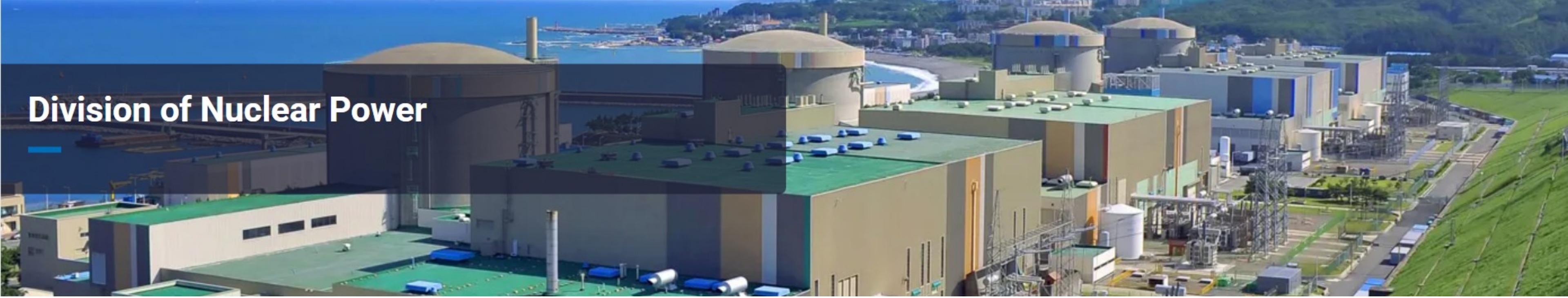
Nuclear Fuel Cycle and Waste Management

Nuclear Power

Planning, Information and Knowledge Management

- Fosters sustainable nuclear energy development by supporting existing and new nuclear programmes around the world.

- Provides technical support on the nuclear fuel cycle and the life cycle of nuclear facilities, and builds indigenous capability in energy planning, analysis, and nuclear information and knowledge management.



Division of Nuclear Power

Nuclear Power Engineering Section

The Section supports countries operating nuclear power plants or expanding their existing programmes to improve engineering, performance, management systems, human resource management, stakeholder involvement and technical infrastructure. It shares best engineering practices and innovations consistent with the global objectives of nuclear safety, security and non-proliferation. Read more →

Nuclear Power Technology Development Section

Fostering information exchange and collaborative research and development for advanced nuclear reactor technologies, this Section provides information to the IAEA's Member States on technology status and development trends for advanced reactor systems and their applications. Read more →

Nuclear Infrastructure Development Section

This Section is responsible for coordinating IAEA assistance to Member States considering or embarking on nuclear power programmes. It supports capacity-building, conducts review missions and offers guidelines, standards and workshops on developing the infrastructure for a safe, secure and sustainable nuclear power programme. Read more →

International Project on Innovative Nuclear Reactors and Fuel Cycles Section

The Section coordinates the activities of the membership-based International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to increase international cooperation on global nuclear energy sustainability, long term strategies and institutional and technical innovations for nuclear energy development and deployment. Read more →

Nuclear Power Engineering Section

- Supports countries operating nuclear power plants or expanding their existing programmes to improve engineering, performance, management systems, human resource management, stakeholder involvement and technical infrastructure.
- Delivers engineering support for operating and expanding nuclear power programmes
- Provides management support for nuclear power plant projects
- Develops human resources and strengthening stakeholder involvement

Nuclear Infrastructure Development Section

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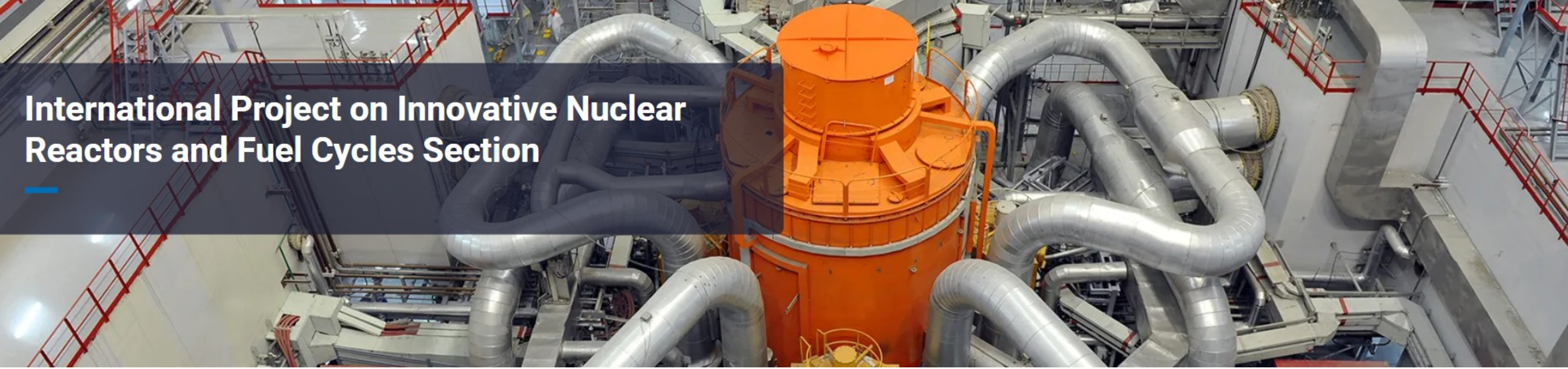
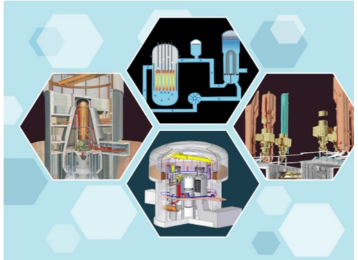


International Project on Innovative Nuclear Reactors and Fuel Cycles Section

- Coordinates the activities of the membership-based International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to increase international cooperation on global nuclear energy sustainability, long term strategies and institutional and technical innovations for nuclear energy development and deployment.
- Supports INPRO’s activities in the following main areas:
  - Global scenarios
  - Innovations
  - Sustainability assessment and strategies
  - Policy and dialogue

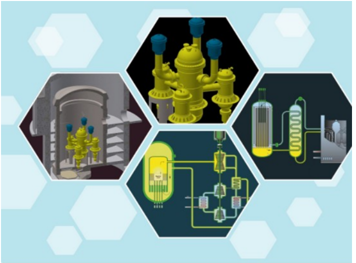
Nuclear Power Technology Development Section

Provides information to the IAEA's Member States on technology status and development trends for advanced reactor systems and their applications



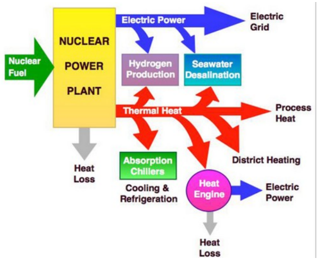
Advanced Water-Cooled Reactors

Advanced Technology for Fast Reactors



High Temperature Reactors

SMRs



Non-Electric Applications

Department of Nuclear Safety and Security

Radiation and Transport Safety

Safety of Nuclear Installations

Nuclear Security

Incident and Emergency Preparedness and Response

Office of Safety and Security Coordination

The protection of people, society and the environment from the harmful effects of ionizing radiation is at the heart of the Department for Nuclear Safety and Security’s work. Whether the cause is an unsafe act or a security breach, it aims at providing a strong, sustainable and visible global nuclear safety and security framework.

Outline

- Challenges in the Member States on the Subject
- Driving Factors & Opportunities for SMRs
- SMR: Categorization and Deployment Timeline
- SMR: Major Technology Lines
- SMR: Non-Electric Applications and Cogeneration
- Advantages, Issues & Challenges
- Issues and Actions for Deployments

Challenges in the Member States

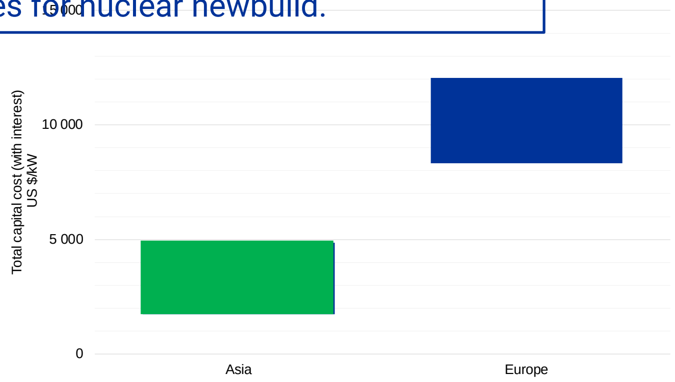
- Unless nuclear energy adapts to the new energy or portfolios by being flexible, expansion of nuclear power will be hard
- Even more significant when the grid capacity and energy distribution is limited, such as in case of several embarking countries
- Dynamic energy market and governments' energy policies to increase share of renewables causes increasing need for NPPs to operate in "flexible" modes(*)
- SMRs will be a part of the nuclear generation

"Every new NPP is the first NPP for the grid"

(*) i.e. load following, frequency control, or abrupt changes to output upon requests from grid operators

De-risking NPP Newbuild Project

Long construction times, design and manufacturing complexity, and FOAK issues, are reasons behind the high construction costs and delivery times for nuclear newbuild.



Construction cost ranges for recent nuclear newbuild projects in Western Europe (France, Finland and the UK) and Asia (the UAE, Japan, Republic of Korea and China). Source: *Climate Change and Nuclear Power 2020, IAEA.*

Key success factors:

- Robust supply chain
- Simple and proven designs (with an operating ‘reference plant’);
- Close cooperation with the regulator;
- Sensible, risk informed contracting models;
- Proven contractors with experienced teams;
- ‘Lessons learned’ from other NPP projects;
- State of the art approaches to project and risk management;
- Reliance on IAEA peer review missions and advisory services

Driving Factors & Opportunities for SMRs

Cost Affordability

Small Power, Innovation, Standardization

Short Construction Span

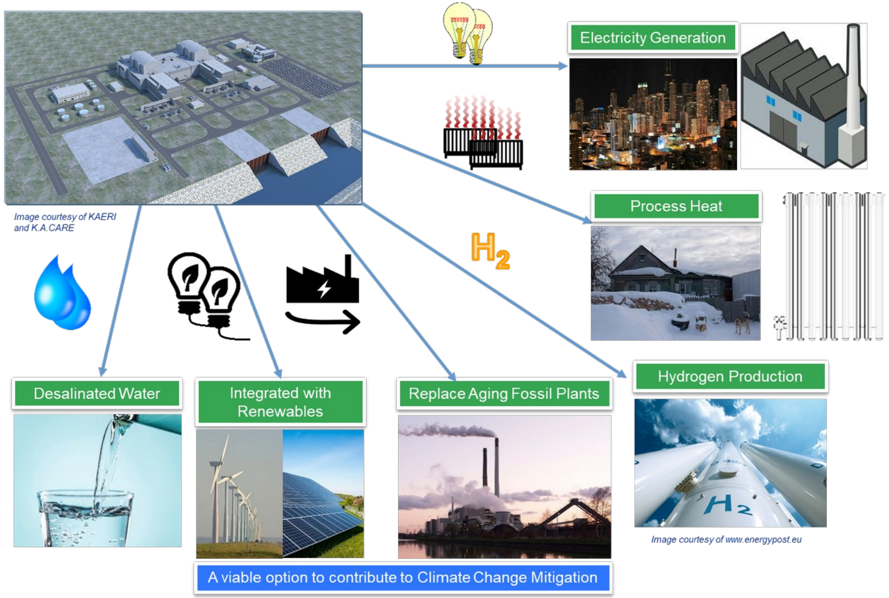
Design Simplification, Modularization

Energy Resilience

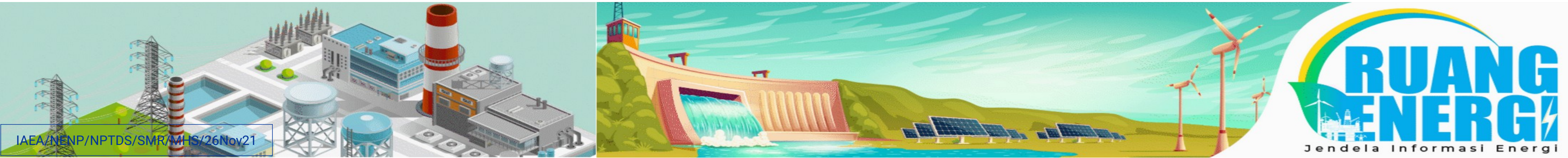
Flexibility and ensured energy supply

Energy Sustainability

Hybrid with Renewables,
Replace Retiring Fossil Plants



Typically up to 300 MWe, High Degree of Modularity, Option to Energy Supply in Countries with Smaller Grids; Contribute to Climate Change Mitigation



Development Objectives of Small Modular Reactors

Enhanced Safety

Versatile

Modular

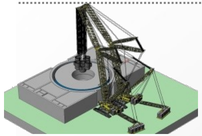
Enhanced Constructability

Affordable

Non-electric application s

Economic
- Lower Upfront capital cost
- Economy of serial production

Better Affordability



Modularization
- Multi-module
- Modular Construction

Shorter construction time

Flexible Application
- Remote regions
- Small grids

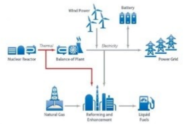
Wider range of Users

Smaller footprint
- Reduced Emergency planning zone

Site flexibility

Replacement for aging fossil-fired plants

Reduced CO_2 production



Potential Hybrid Energy System

Integration with Renewables

90+ SMR Designs in the World

Land Based Water Cooled Reactors

CAREM	SMART	RUTA-70	DHR400
ACP100	UNITHERM	NuScale	RITM-200
CAP200	VK-300	mPOWER	NUWARD
IRIS	KARAT-45	W-SMR	BWRX-300
DMS	KARAT-100	SMR-160	HAPPY200
IMR	ELENA	UK-SMR	CANDU SMR

Micro Reactors

IHTR	MMR-5
IMSBR	MMR-10
eVinci	AURORA
U-Battery	MoveluX

Fast Reactors

4S	W-LFR	SSTAR LFR
BREST-OD-300	SEALER	URANUS
SVBR-100	LFR-AS-200	ARC100
EM²	LFR-TL-X	

High Temperature Gas-cooled Reactors

HTR-PM	MHR-100	XE-100	HTTR-30
DPP-200	PBMR-400	A-HTR 100	HTR-10
GT-MHR	HTMR-100	MMR	RDE
MHR-T	SC-HTGR	GTHTR300	StarCore

Marine Based Water Cooled Reactors

ACPR50S	VBER-300
KLT-40S	ABV-6E
RITM-200M	SHELF

Molten Salt Reactor

IMSR	SSR-WB	CA WB
CMSR	SSR-TS	KP-FHR
THORCON	LFTR REACTOR	MCSFR
FUJI ITMSF	MK1 PB-FHR	

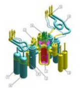
Technology Categorization

SMR Technology Lines

Water Cooled (Land based)

PWRs, BWRs and HWR type SMRs

Marine-based Reactors

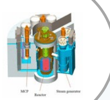


Mainly PWRs; Some are non-water-cooled reactors with capacity less than 100 MWe

Molten Salt Reactors

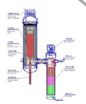
Can operate at high temperature under atmospheric pressure

Liquid Metal Cooled Fast Reactors



Better utilization of uranium resources with lower radioactive waste

High Temperature Gas Cooled Reactors



Suitable for cogeneration purposes due to high exit temperatures

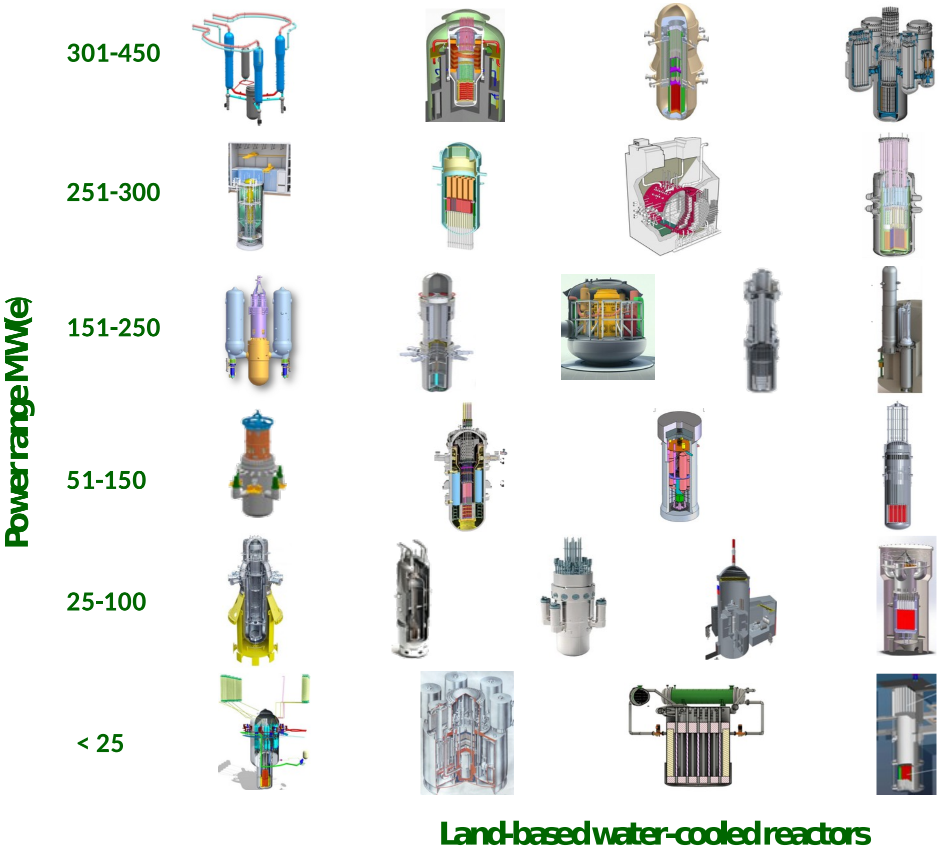
Microreactors

A subset of small modular reactors with the power up to 10 MWe

Microreactors are intended for another niche market such as off-grid remote regions, small islands, and as power source for mining industries

Small Modular Reactors are advanced reactors that produce typically up to 300 MWe, built in factories and transported as *modules* to sites for installation to shorten construction span thus reduce the cost.

Power Range of LWR-based SMRs



- UK-SMR
- IMR
- IRIS
- VBER-300 (Land Based)

- BWRX300
- DMS
- CANDU SMR
- VK-300

- CAP200
- Westinghouse SMR
- NUWARD
- mPower
- SMR-160

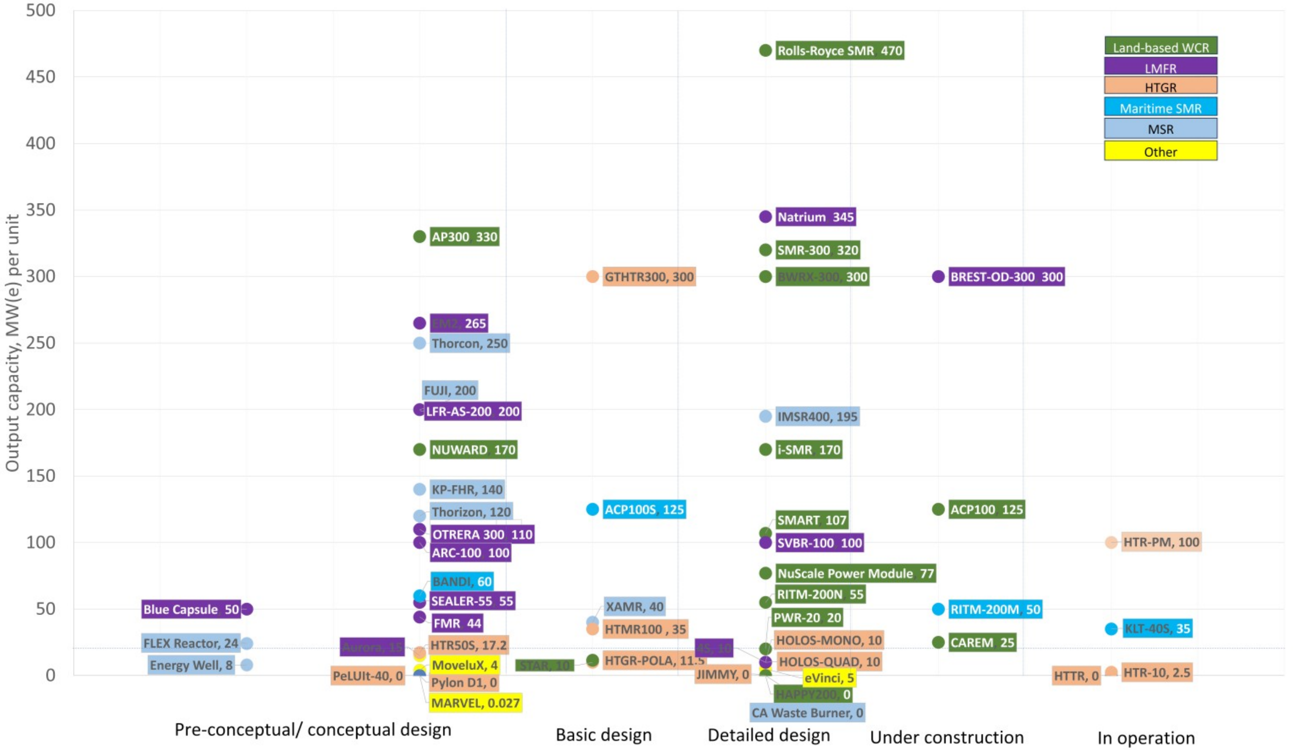
- ACP100
- SMART
- DHR
- KARAT-100

- CAREM25
- NuScale
- RITM-200
- KARAT-45
- HAPPY200

- UNITHERM
- ELENA
- TEPLATOR
- RUTA-70

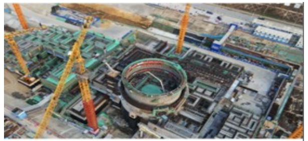
Status of SMR Development and Deployment

Based on updates from technology developers to IAEA in 202



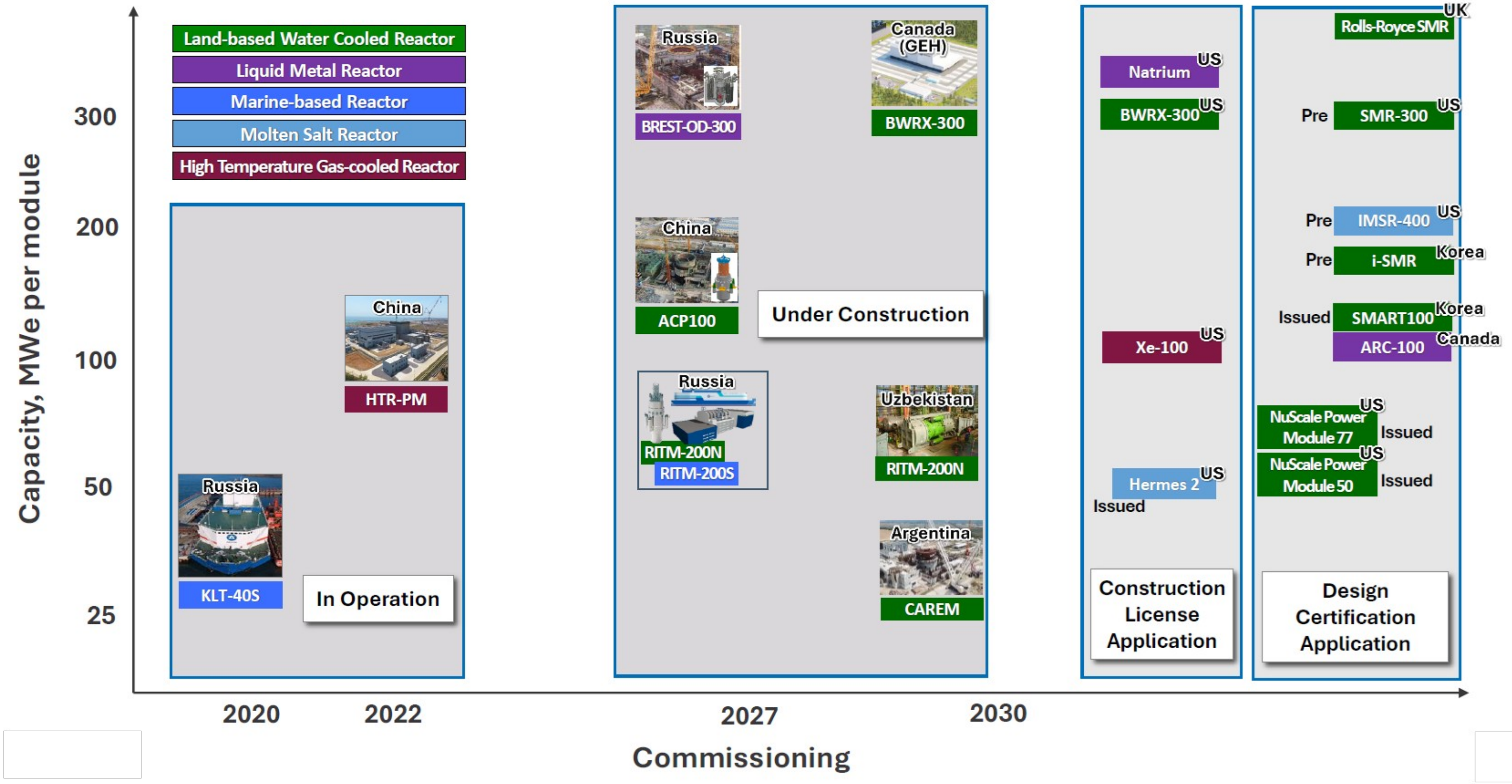
Note: The value displayed with the design refers to the output capacity in MW(e) per unit.





More than 90 SMR Technology Developers in 18 Member States

Deployment Timeline



Deployment and Development Status in Brief (1/2)

In operation

Floating NPP "Akademik Lomonosov"

- *Russian Federation*
- *2 units of KLT-40S (PWR), 35 MW(e) per unit*
- *Commercial operation started May 2020, first fuel cycle completed*

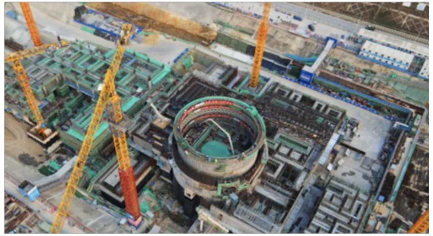
HTR-PM

- *China*
- *2 units of high temperature gas cooled reactor pebbled-bed module, 200 MW(e) generated from single Turbine Island*
- *Operation started in 2023*

Under construction

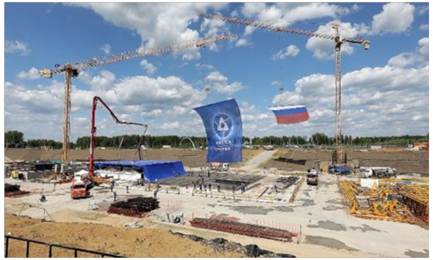
ACP100

- *China*
- *Integral PWR, 125 MW(e)*
- *Operation expected in 2026*



BREST-OD-300

- *Russian Federation*
- *Lead-cooled fast reactor, 300 MW(e)*
- *Operation expected in 2026*



CAREM

- *Argentina*
- *Integral PWR, 32 MW(e)*
- *Op*

Deployment and Development Status in Brief (2/2)

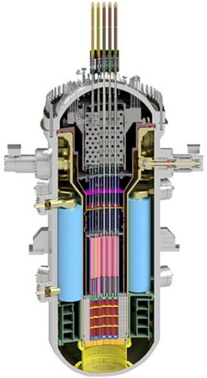
Advanced stage of licensing

RITM-200N (Russian Federation)

- Integral PWR, 55 MWe
- License permit for construction received in April 2023
- Commissioning expected in 2028

i-SMR (Republic of Korea)

- Integral PWR, 170 MWe
- Completion of standard design expected by the end of 2025 and obtaining standard design approval in 2028
- **Simulator launched for development of i-SMR**



VOYGR (United States)

- Integral PWR, 77 MWe
- Certified by the US NRC in January 2023 (50 MWe)

NUWARD (France)

- In 2022 NUWARD was chosen as case study for a European Early Joint regulatory Review (JER), led by the French Safety Authority (ASN) with the participation of the Czech (SUJB) and Finnish (STUK) safety authorities
- EDF is refining its SMR strategy to fully meet the expectations of the utilities and industry, relying on well-known and mastered technological building blocks within the nuclear sector

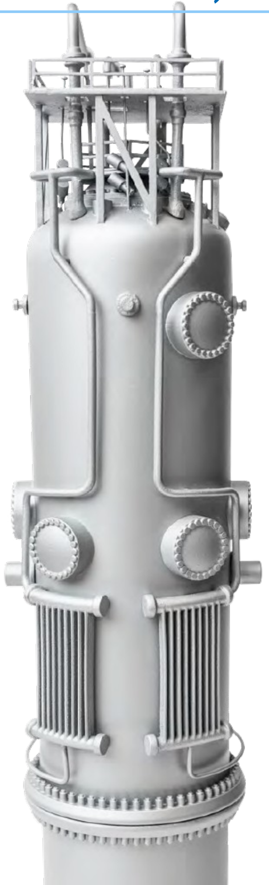
BWRX-300 (United States)

- BWR, 290 MWe
- Contract awarded to BWXT to manufacture the RPV for the first BWRX-300 to be constructed at OPG's Darlington site.
- Commissioning expected in 2029

Design Example: Integral-PWR type SMR

(2000 – 4500) MWth

(100 – 1000) MWth



iPWRs: Safety Advantages and Challenges

Advantages	Issues / Challenges
No large piping connected to RPV No Large-LOCA	Increased numbers of small-bore piping connections to the RPV
Coolant Pumps connected to RPV Reduced leakage probability	Structural strength of RPV and joints; mechanical vibration; flow stability
Internal Control Rod Drive Mechanism No CRD ejection accident	In-service inspection approach for in-vessel components
Wide use of Passive Safety Systems Independence of power source	Passive system has lower driving heads; ADS reliability is critical
Modularization and NSSS components integration compact reactor building	Larger and taller RPV to house NSSS components: steam generators, etc.

BWRX-300

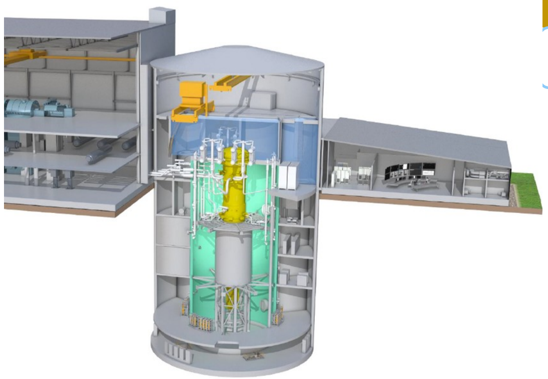
GE-Hitachi Nuclear Energy

HITACHI

Status:
Detailed design with licence permit for construction for 4 units in Darlington site, Ontario, Canada for operation by Ontario Power Generation (OPG)

Site preparation in Darlington site has started with target FCE in a year.

Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Boiling Water Reactor	Natural circulation, gravity driven	Light Water/Light Water	870 MW_{th} / 300 MW_e
Design Life	**Reactivity Control**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
60 yrs.	Control rod drive	270°C/288°C	7.171 MPa (primary side)
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
12 - 24 months	< 4.95 %	~ 55 GWD/tonnes	UO_2 / Square lattice



Unique Features — Simplified BWR design, natural circulation, passive safety features, cost-competitive with natural gas plants

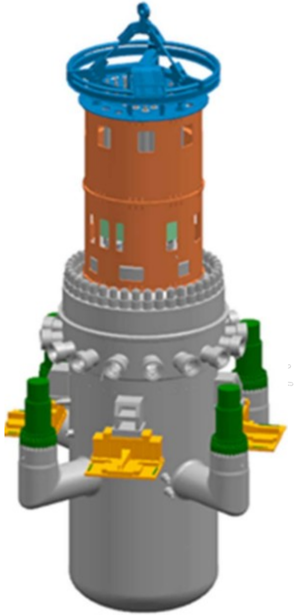
Target Application — Base load electricity generation, load following electrical generation, hydrogen production, synthetic fuel production, district heating and other process heat

Design Philosophy — The BWRX-300 utilizes natural circulation and passive safety systems. It leverages the U.S. NRC-licensed ESBWR design and aims to minimize construction, operation, maintenance, and decommissioning costs.

ACP100, China

NPIC, CNNC

Status:
Under construction in China for grid connection in mid 2026



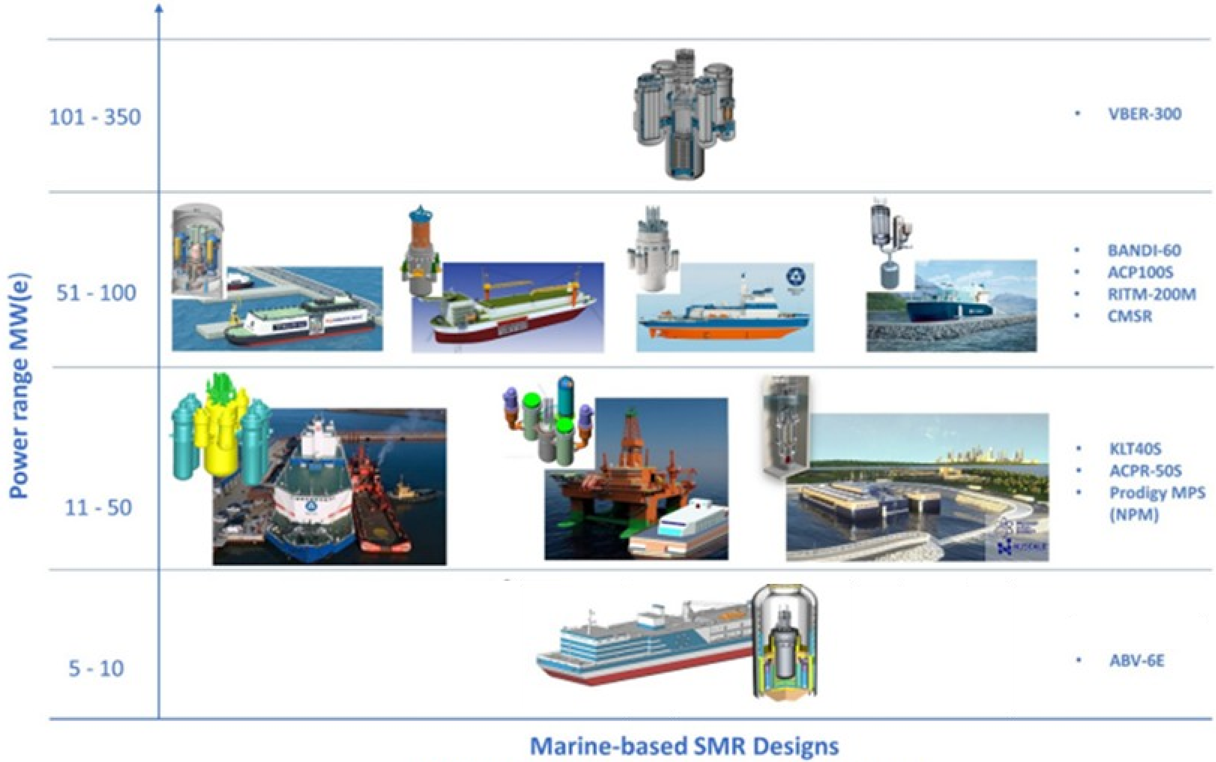
Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Integral PWR	Forced, Pumps	Light Water/Light Water	385 MW_{th} / 125 MW_e
Design Life	**Reactivity Control**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
60 yrs.	Control rod, …	286.5 °C/319.5 °C	15 MPa/4.6 MPa
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
24 months	< 4.95 %	<52 GWD/tonnes	UO_2 / 17× 17 Square

Unique Features
Integrated Reactor with tube-in-tube once through steam generator, and underground nuclear island

Target Application
The ACP100 is a multipurpose power reactor designed for electricity production, district heating, steam production or seawater desalination and is suitable for remote areas that have limited energy options or industrial infrastructure

Design Philosophy
The ACP100 realizes design simplification by integration the primary cooling system and enhanced safety by means of passive safety systems

Power Range of Marine-based SMRs



POWER RANGE OF MARINE-BASED SMR DESIGNS

Associated shipbuilders for FNPPs

СЕВМАШ BALTIC SHIPYARD

Akademik Lomonosov Floating Nuclear Plant

HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING

HD Korea Shipbuilding Unveils Nuclear-powered Container Ship Design

wison

Chinese-made hulls for Russian floating nuclear plants

China Unveils Plans For 'Largest Ever' Container Ship, Powered By Thorium Reactor

PAL INDONESIA

ThorCon plans 4 GW of nuclear power by 2035 in Indonesia

RITM-200M

A design by OKBM-Afrikantov

Status: Developed for the Optimized Floating Power Unit (OFPU). The OFPU is a compact non-self-propelled vessel having two RITM-200M reactor plants.
6 prototypes were manufactured and installed on icebreakers.
2 reactors are in testing.
The OFPU is being developed for commissioning in 2028

Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Integral PWR	Forced	Water/Water	198 MW$_{th}$ / 50 MW$_e$
Design Life	**Primary Circulation**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
60 yrs.	Pumps	284°C/321°C	15.7 MPa/3.83 MPa
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
Up to 120 months	< 20 %	---	UO2 (cermet fuel) pellets / hexagonal

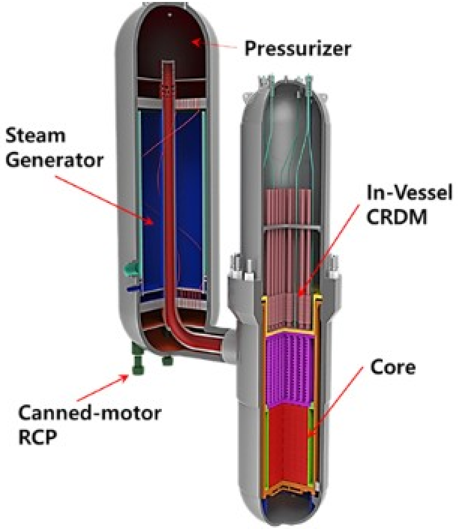
Unique Features	Integral reactor, in-vessel corium retention, double containment
Target Application	The FPUs based on RITM-200M may satisfy the needs of small residentials or industrial facilities. The OFPU can provide electricity to domestic and industrial consumers. Can be also used for water desalination and heat supply.
Design Philosophy	RITM series reactors are the evolutionary development of the reactors (OK-150, OK-900, KLT-40 series) for Russian nuclear icebreakers with a total operating experience of more than 60 years (more than 400 reactor-years).

BANDI

A design by KEPCO E&C

Status: The first phase of the conceptual design of BANDI was performed from 2016 to 2022. The second phase started in 2023. The projected construction of the FNPP is expected by 2031.

Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
PWR	Forced	Water/Water	200 MW_{th} / 60 MW_e
Design Life	**Primary Circulation**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
60 yrs.	Pumps	293°C/322°C	15.5 MPa/5.5 MPa
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
48-60 months	4.95 %	29.4 GWd/t	UO_2 ceramic fuel, 17x17 square array



Unique Features	Semi-integral design, blocktype RCS, and passive safety systems
Target Application	The primary target is FNPPs that provide clean, safe, reliable and affordable energy for remote isolated communities. It can also be designed for carbon-free propulsion power of big merchant ships like bulky containers.
Design Philosophy	Nuclear safety functions of reactor shutdown, decay heat removal and radiation protection are further enhanced by inherent and passive safety features.

Market Potential of Marine-based SMRs

East and South-East Asia

high seismicity and tsunami risk, high coastal population density, and limited domestic energy resources

Middle East

Massive water desalination plants

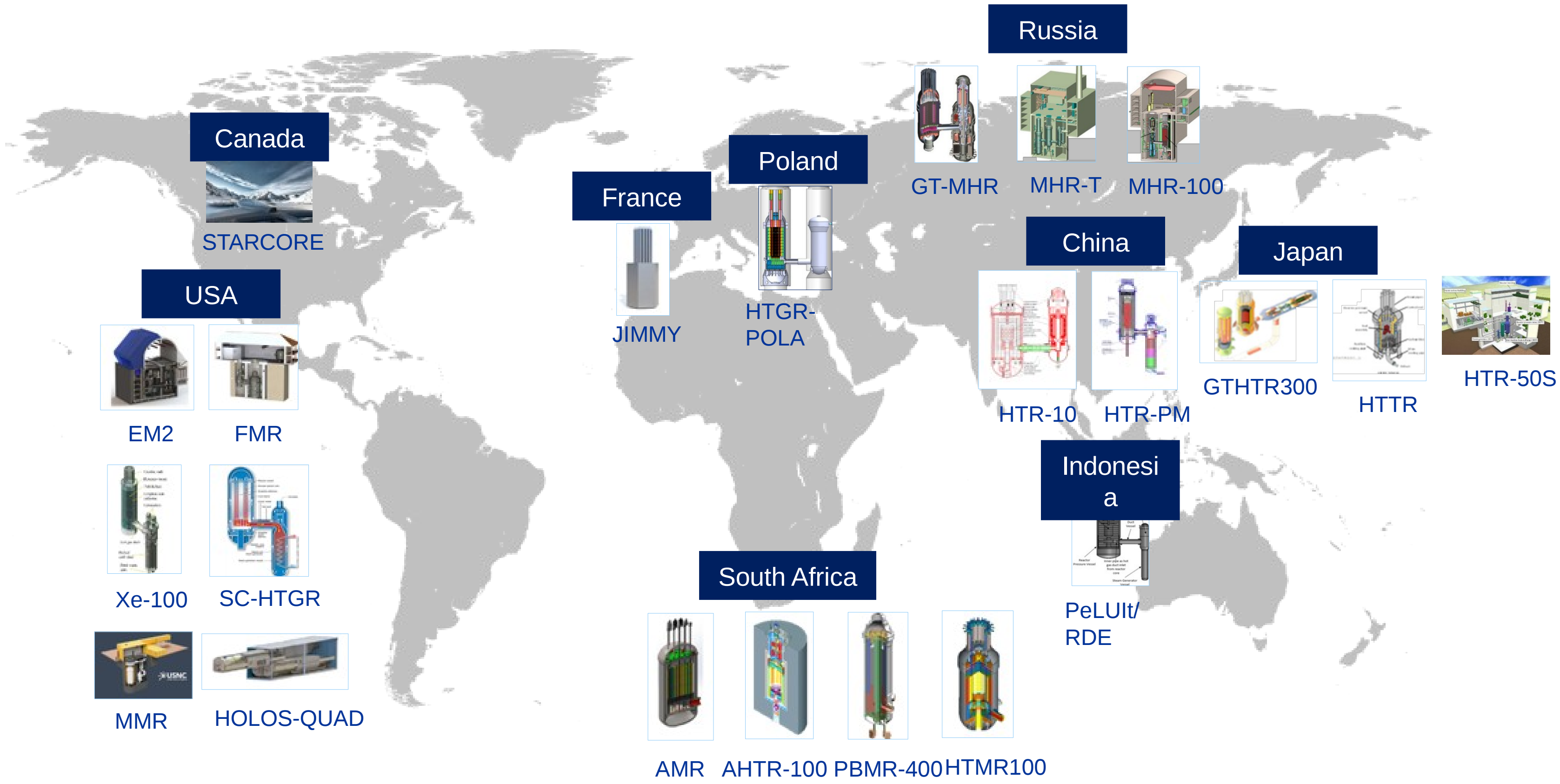
Africa and South America

small grids, high prices of electricity, water desalination, no incentives to develop large domestic nuclear infrastructure

Russian Federation and northern Europe

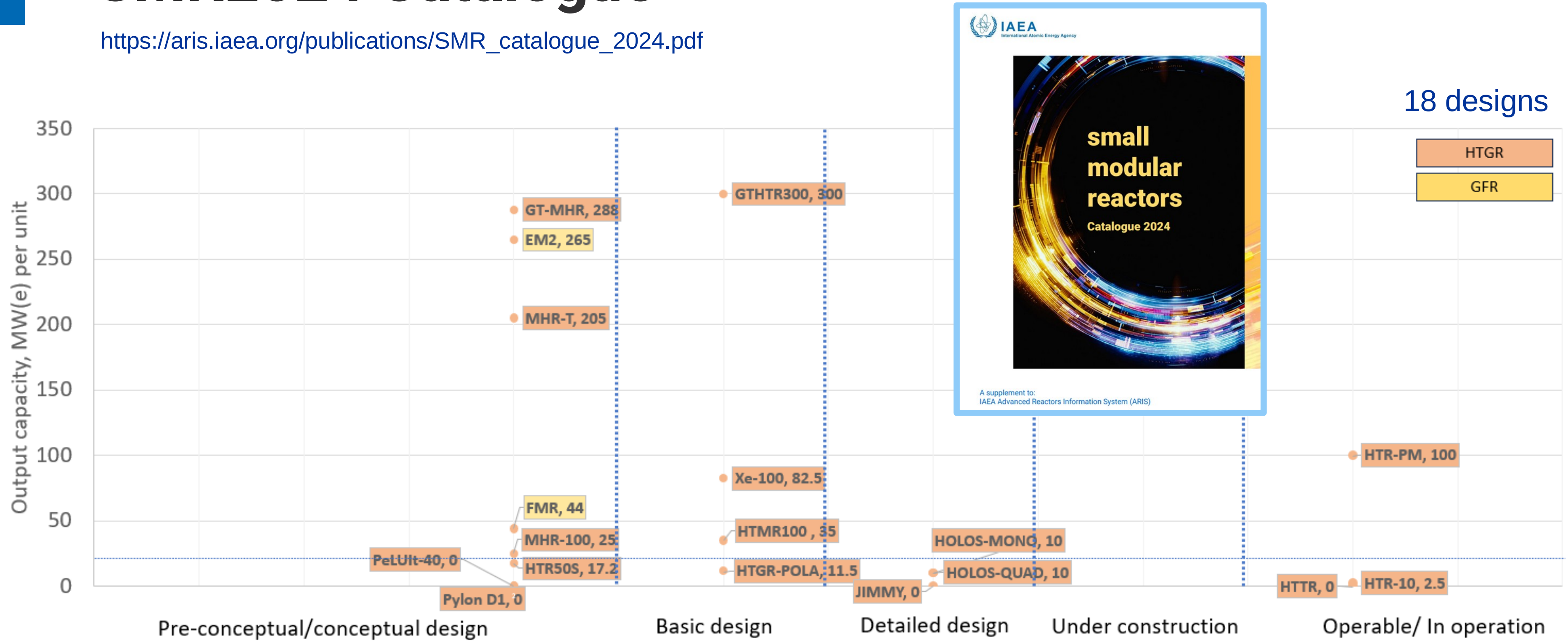
Remote Arctic region power and heat supply, large mining operations, large offshore oil/gas operations

Global Activities on HTGR-SMR development



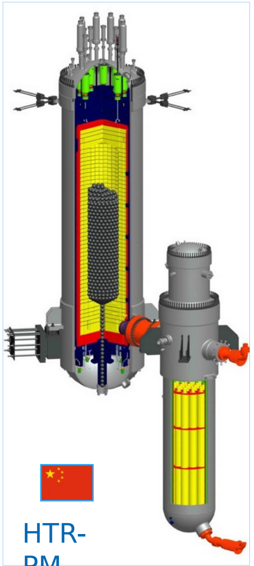
SMR2024 Catalogue

https://aris.iaea.org/publications/SMR_catalogue_2024.pdf



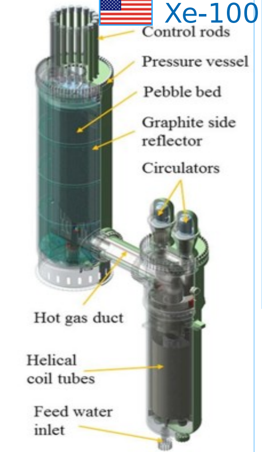
Note: The value displayed with the design refers to the output capacity in MW(e) per unit.

Multiple designs from Member States

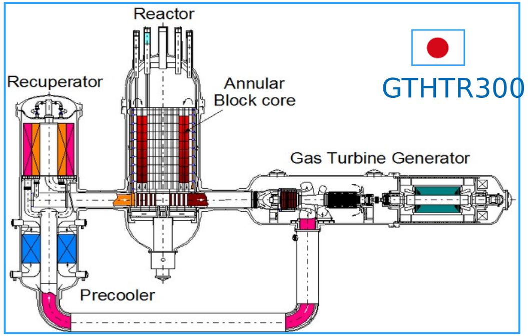


HTR-PM

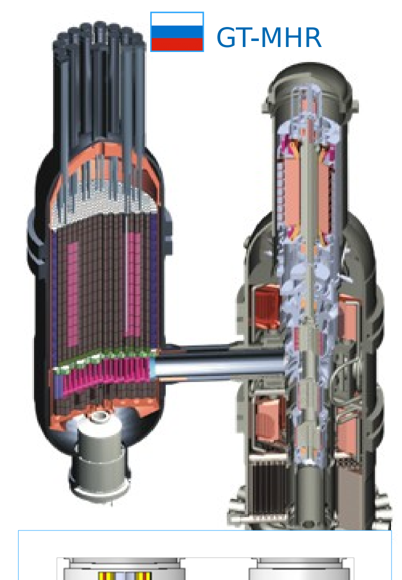
AHTR-100



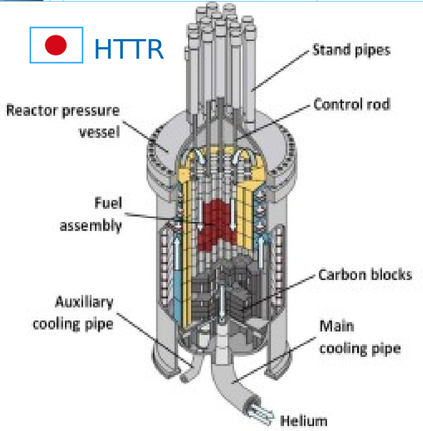
Xe-100



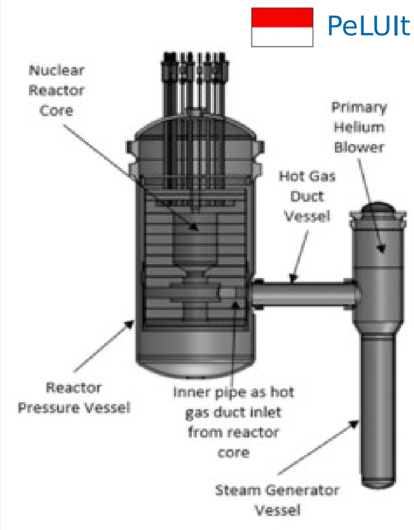
GTHTR300



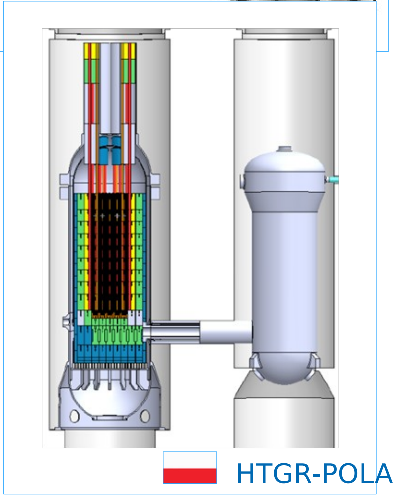
GT-MHR



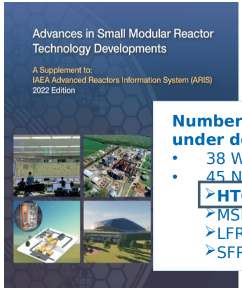
HTTR



PeLUIt



HTGR-POLA



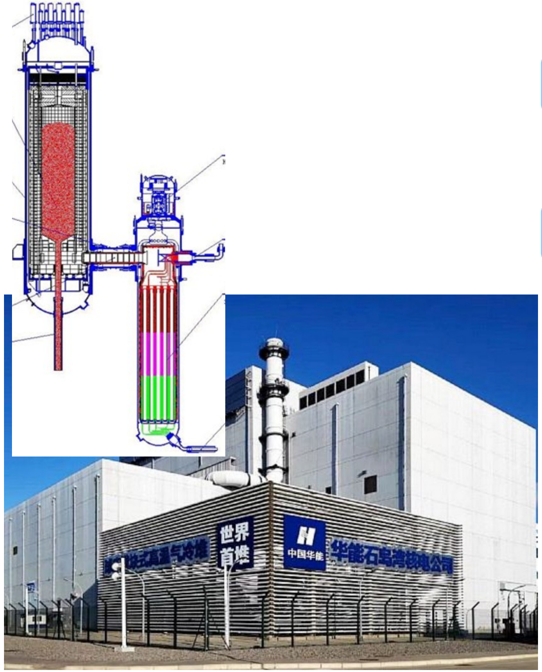
Number of SMR designs under development (2022)
- 38 Water-cooled
- 45 Non-water cooled
  - ➢**HTGR 21**
  - ➢MSR 13
  - ➢LFR 8
  - ➢SFR 3

HTR-PM, China

INET, Tsinghua University

CHINA HUANENG

Status:
In operation since December 2022



Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Modular HTGR	Forced, Pumps	Helium/Graphite	2 x 250 MW_{th} / 210 MW_e
Design Life	**Reactivity Control**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
40 yrs.		250 °C/750 °C	7 MPa/13.25 MPa
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
Online Refuelling	< 8.5 %	90 GWD/tonnes	Spherical elements with coated TRISO particle fuel

Unique Features

420 000 spherical elements with coated TRISO particle fuel, online refuelling, helium gas cooled, graphite moderated.

Target Application

The HTR-PM is a commercial demonstration unit for electricity production. The twin reactor modules driving a single turbine configuration.

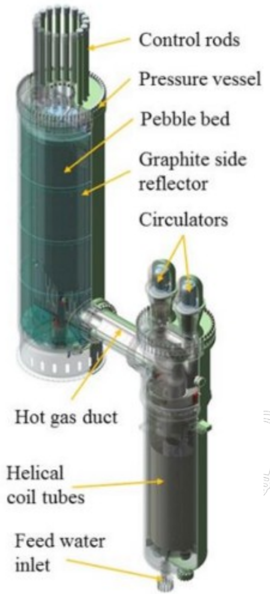
Design Philosophy

HTR-PM consists of two NSSS modules coupled with a 210 MW(e) steam turbine. Each module includes reactor pressure vessel; a steam generator; a main helium blower; and a hot gas duct. The thermal power of each reactor module is 250 MW(t)

Xe-100

X Energy

Status:
Basic Design



Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Modular HTGR	Forced helium	Helium/Graphite	200 MW_{th} / 82.5 MW_e
Design Life	**Reactivity Control**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
60 yrs.	Control rods and thermal feedback	260°C/750 °C	6.0 MPa/16.5 MPa
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
Online	15.5 %	165 GWD/tonnes	UCO TRISO/pebbles

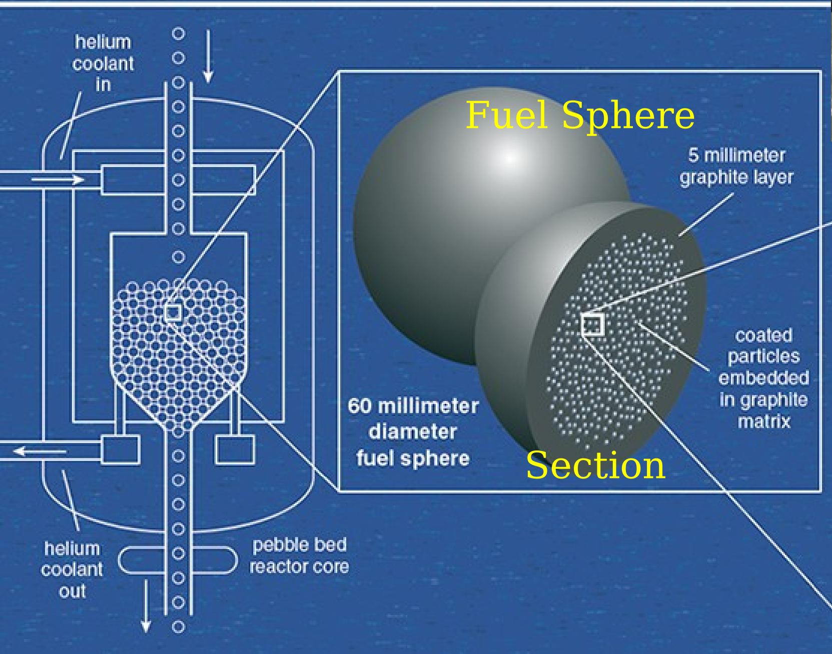
Unique Features: Online refuelling, core cannot melt and fuel damage is minimized by design, independent radionuclide barriers, potential for advanced fuel cycles

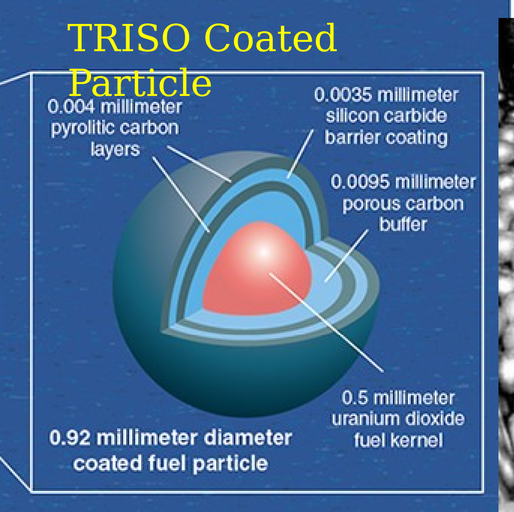
Target Application: Process heat applications, desalination, electricity and cogeneration.

Design Philosophy: A major aim of the Xe-100 design is to improve the economics through system simplification, component modularization, reduction of construction time and high plant availability.

Pebble-bed type HTGRs

Spherical graphite fuel element with coated particles fuel
On-line / continuous fuel loading and circulation
Fuel loaded in cavity formed by graphite to form a pebble bed





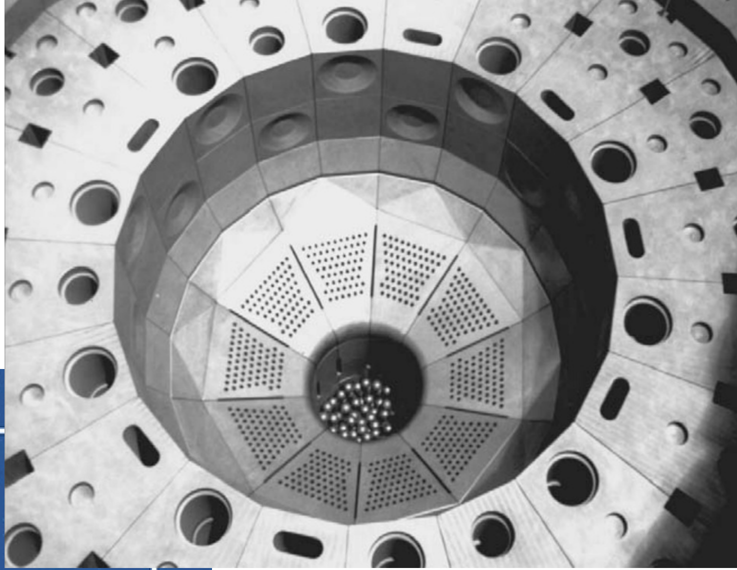
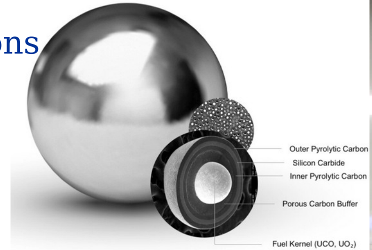


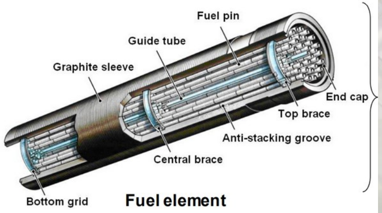
Image: American Scientist, HTR-10, THTR

HTGR – Benefits

FEATURES

- ✓ Non-electric applications
- ✓ Walk away safe
- ✓ Inert gas coolant
- ✓ High efficiency
- ✓ High Burnup possible



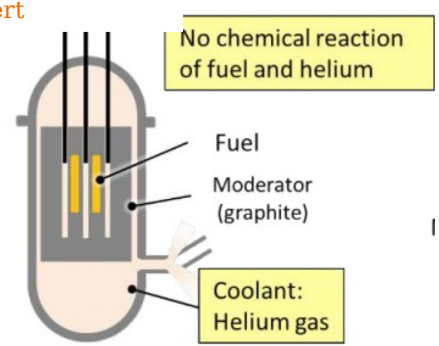


Very different from first generation gas cooled graphite moderated reactors

- Different fuel type (coated particle) – retain radioactive material at 1600 °C
- Different coolant (Helium) – stable at high temperatures
- (similar) Graphite core structure – high thermal inertia

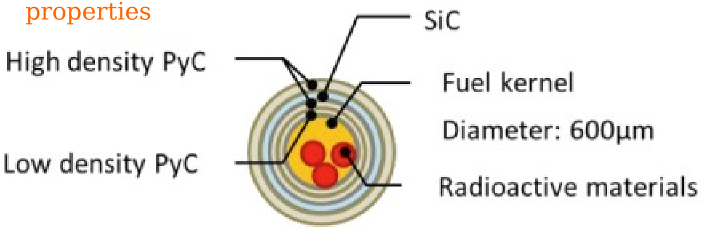
Image: X-energy, JAEA, Wikipedia

Chemically inert



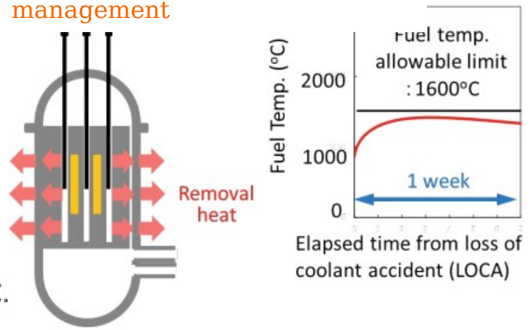
In case of vapor or air ingress accident, the surface of graphite oxidizes but safety of the core never be lost

Excellent heat resistant properties



Fission products is released from intact particles over 2200 °C. (Fuel is recyclable under 1600 °C)
In case of a loss of coolant accident, reactor can be cooled passively and fuel temperature never exceeds 1600 °C.

No immediate accident management



In case of a loss of coolant accident, large heat capacity and high thermal conductivity of graphite absorbs heat.

HTGRs – Challenges

The low power density leads to large reactor pressure vessels (but site requirements not larger)

- Forging capability can also set limit on RPV diameter and power (e.g.∅6.7 m < 350 MWth in South Korea)

Helium coolant has low density and thus requires high pressurization

Helium coolant is non-condensable – so a traditional containment cannot be used

Coated particle fuel costs are expected to be higher

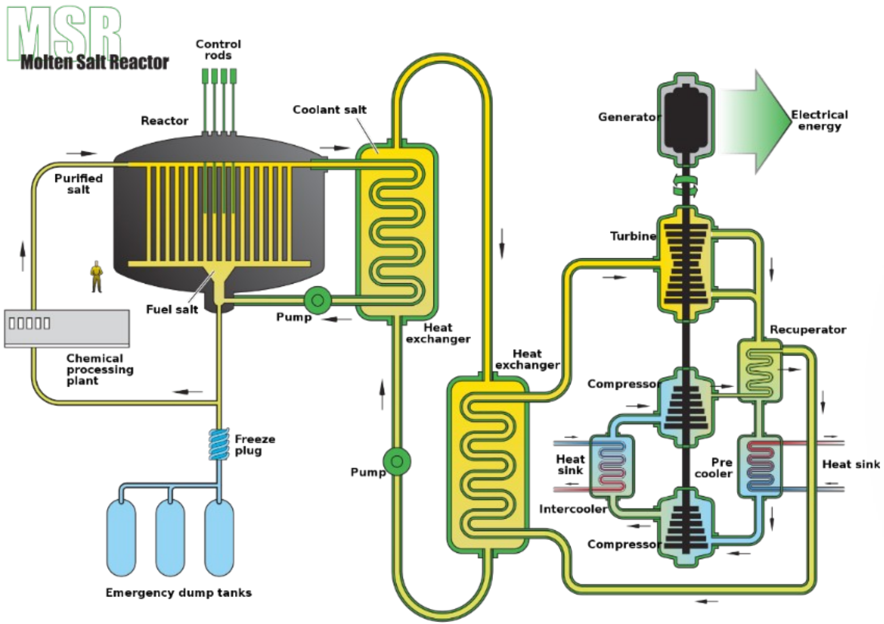
Availability of licensing framework

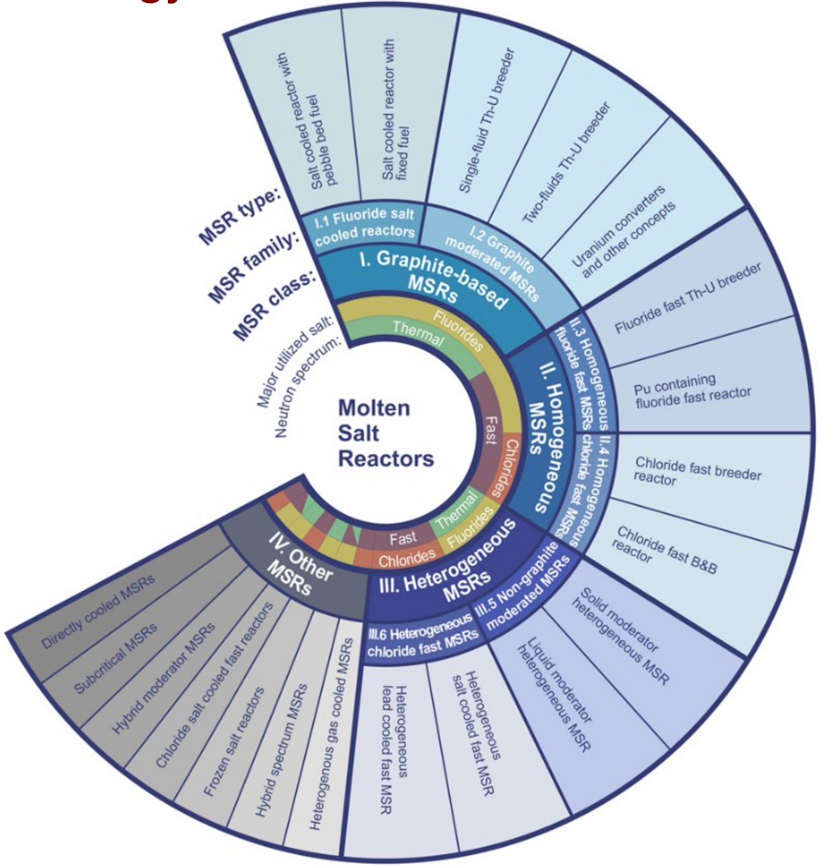
Supply Chain

Image: HTR=PM, X-energy

Molten Salt Reactor

A promising advanced nuclear reactor technology





IAEA references:

[SMR Booklet (2020 Edition)]

[TRS No. 489 Status of Molten Salt Reactor Technology (preprint)]

KP-FHR

Kairos Power

Kairos Power

Status:
Conceptual Design

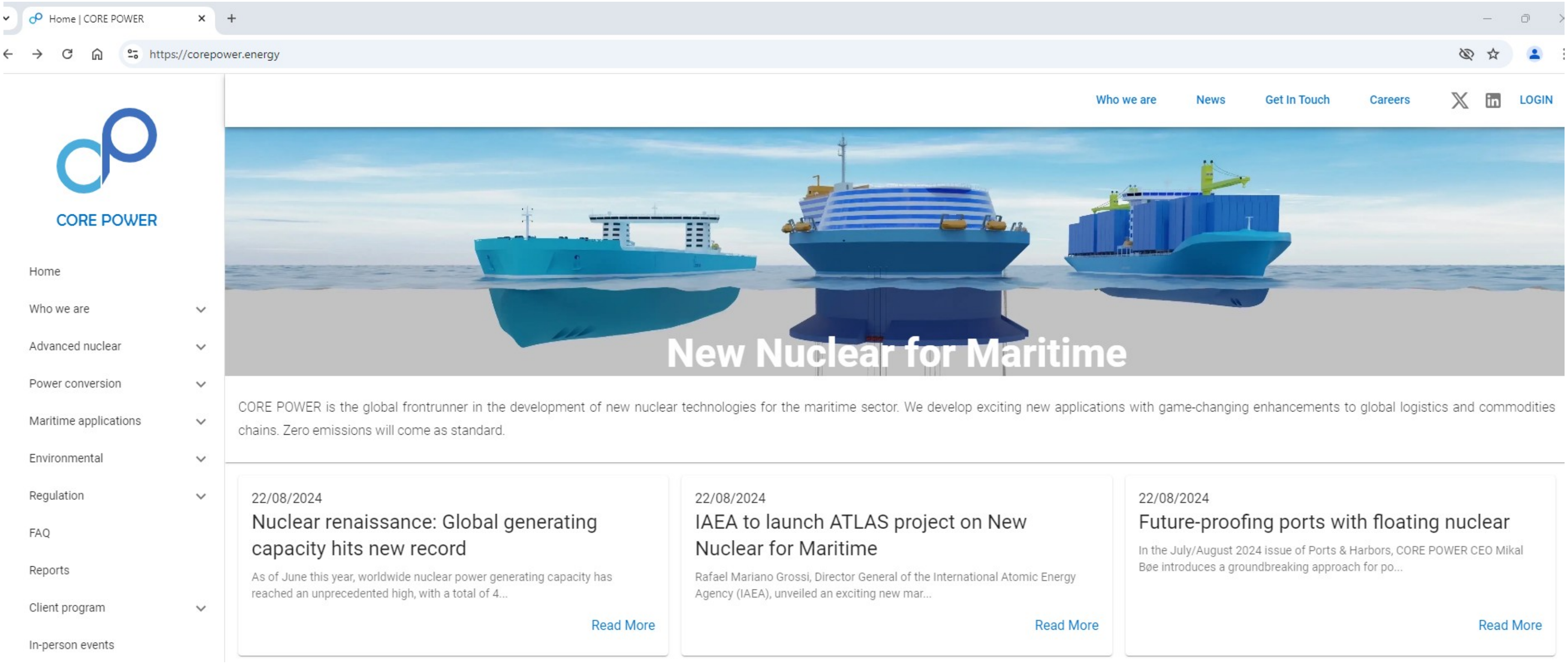
Reactor Type	Primary Circulation	Coolant/Moderator	Thermal/Electric Power
Modular, salt cooled reactor	Forced circulation	Li_2BeF_4 Flibe/Graphite	320 MW_{th} / 140 MW_e
Design Life	**Reactivity Control**	**Core Inlet/Outlet Temperature**	**NSSS Operating Pressure Primary/Secondary**
80 yrs.	Control elements and boron	550°C/650 °C	<0.2 MPa/--
Refuelling Cycle	**Fuel Enrichment**	**Core Discharge Burnup**	**Fuel Type / Assembly Array**
Online	19.75 %	--	TRISO in graphite pebble / Pebble bed

Unique Features: Longer than 72-hour coping time for core cooling without AC or DC power, or operator action

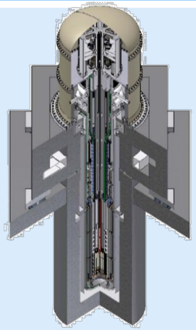
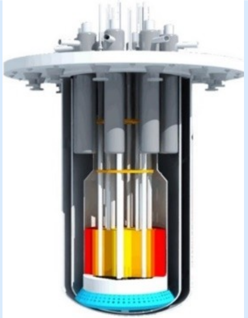
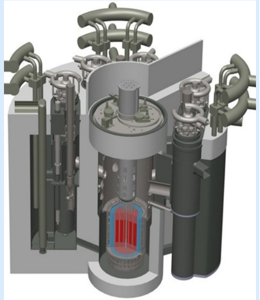
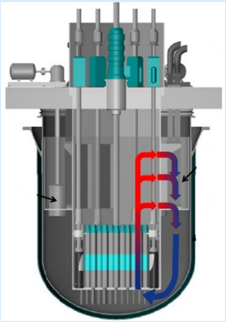
Target Application: Dispatchable power to improve grid resilience and security. The KP-FHR aims to be cost competitive with natural gas

Design Philosophy: Combination of TRISO particle fuel coupled with molten fluoride salt coolant (2LiF:BeF2, Flibe) to result in a high temperature, low-pressure reactor with robust, passive safety systems.

Maritime Applications of MSR



Liquid Metal, Fast-Neutron-Spectrum SMRs
(Examples)

4S	MicroURANUS	BREST-300-OD	EM^2	Westinghouse-LFR
				
Design Status: Detailed design	Design Status: Pre-conceptual design	Design Status: Started construction in Seversk on 8 June 2021	Design Status: Conceptual Design	Design Status: Conceptual design
• Toshiba, Japan • Liquid metal cooled fast reactor (pool type) • 30 MWt / 10 MWe • Forced Circulation • Core Outlet Temp: 510°C • Enrichment: <20% • Refuel interval: N/A	• UNIST, Republic of Korea • Lead-bismuth cooled reactor • 60 MWt / 20 MWe • Electromagnetic pump • Core Outlet Temp: 350°C • Enrichment: 3 radial zones (8, 10 and 12%) • Refuel interval: No	• NIKIET, Russian Federation • Led-cooled fast reactor • 700MWt / 300MWe • Core Outlet Temp: 535°C • Enrichment: <14.5% • Refuel interval: 900-1500 effective days	• General Atomics, United States of America • Modular high temperature gas-cooled fast reactor • 500 MWt / 265 MWe • Core Outlet Temp: 850°C • Enrichment: <14.5% • Refuel interval: 360 months	• Westinghouse, United States of America • Liquid metal cooled fast reactor (pool type) • Forced Circulation • 950 MWt / 450 MWe • Core Outlet Temp: 600°C • Enrichment: <19.75% • Refuel interval: 24 months

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

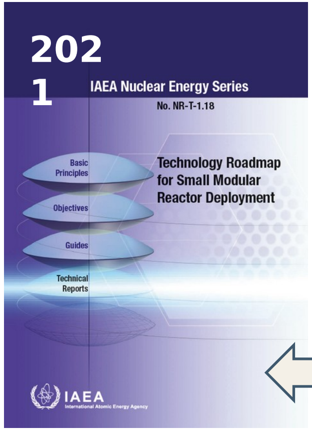
TWG-SMR — 09-12 December 2024

2-nd CM — **11-14 February 2025**

TWG-SMR — 08-12 September 2025

3-rd CM — **12-14 November 2025**

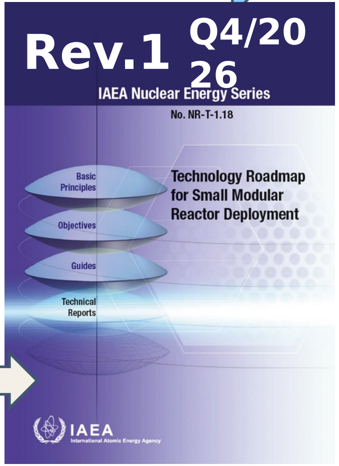
TM — **2026**



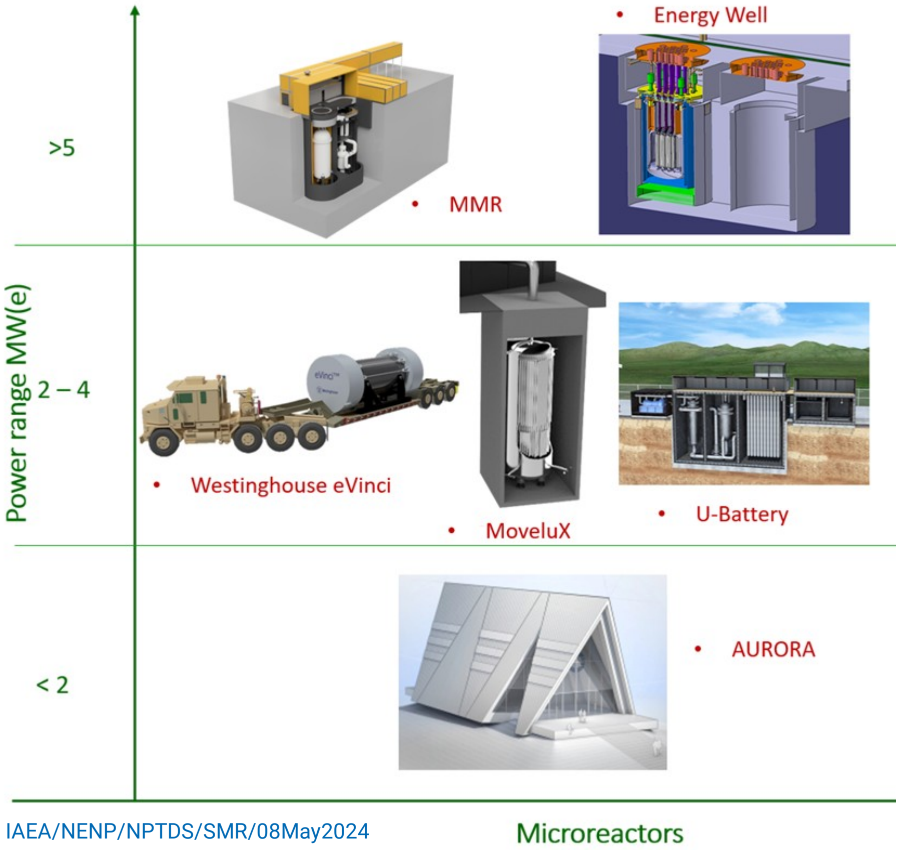
The publication places emphasis on the activities of **owners/operating organizations**, who drive the demand and requirements for reactor designs;

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**;

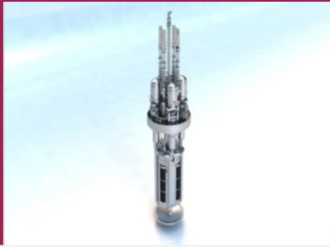
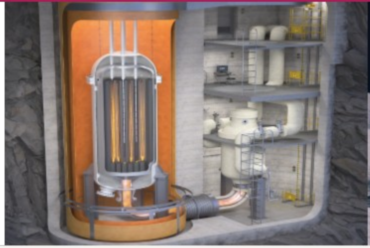


Microreactors



- Several countries are developing Microreactors technology for potential deployment by 2030;
- *Typically* to generate from 1 to 10 MWe; designed for enhanced transportability to site by modularity;
- To supply power at remote sites with mining operations, island communities, oil platforms and maritime shipping.
- Deployment opportunities in remote areas in North America, Middle East, Africa, and the South-East Asian archipelagos.

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 m^2	< 2 acres	-	-	-
Design life	2-40 years (depending on transients)	8 years	60 years	20 years	-

Specificities of Microreactors

04

Heat-pipe technology
proven by LANL for space application

03

Transportability
Within standard shipping containers

05

Compact and simplified

02

Multi-applications
- Energy generation; or
- Production of heat and electricity

06

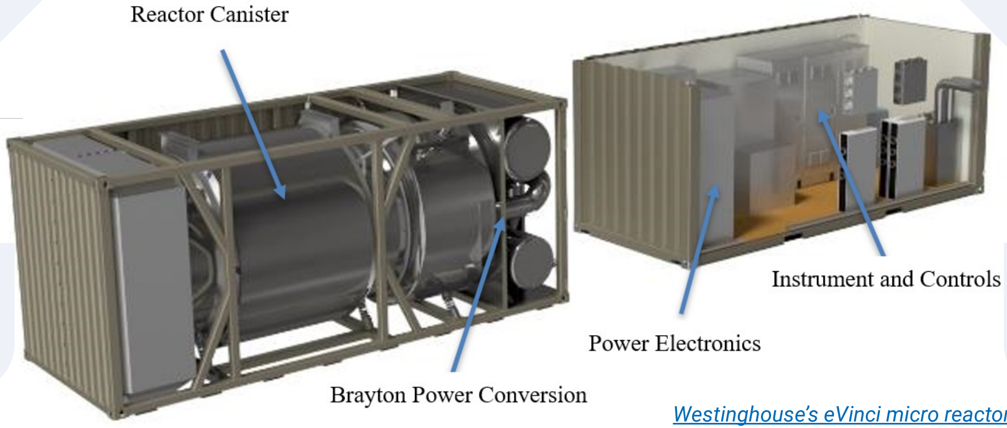
Manufactured and fueled in a factory

01

Specifically designed to serve
- Remote communities;
- Mining operations; or
- military installations.

07

Packageable
in standard transport containers



Westinghouse's eVinci micro reactor schematic (Image: SMR Booklet edition 2020)

Factors in Microreactors Development

Rationales

- More specific nuclear portfolios beyond ‘known’ SMRs
- The need for energy resiliency
- Power needs in regions inaccessible by known power generators / plants
- Power needs in cities / techno parks

Pursued Advantages

- New technologies with innovative inherent safety features
- Substantially lower capital cost
- Modularity, Mobility, more of “installation” than construction
- Long refueling interval or no refuel

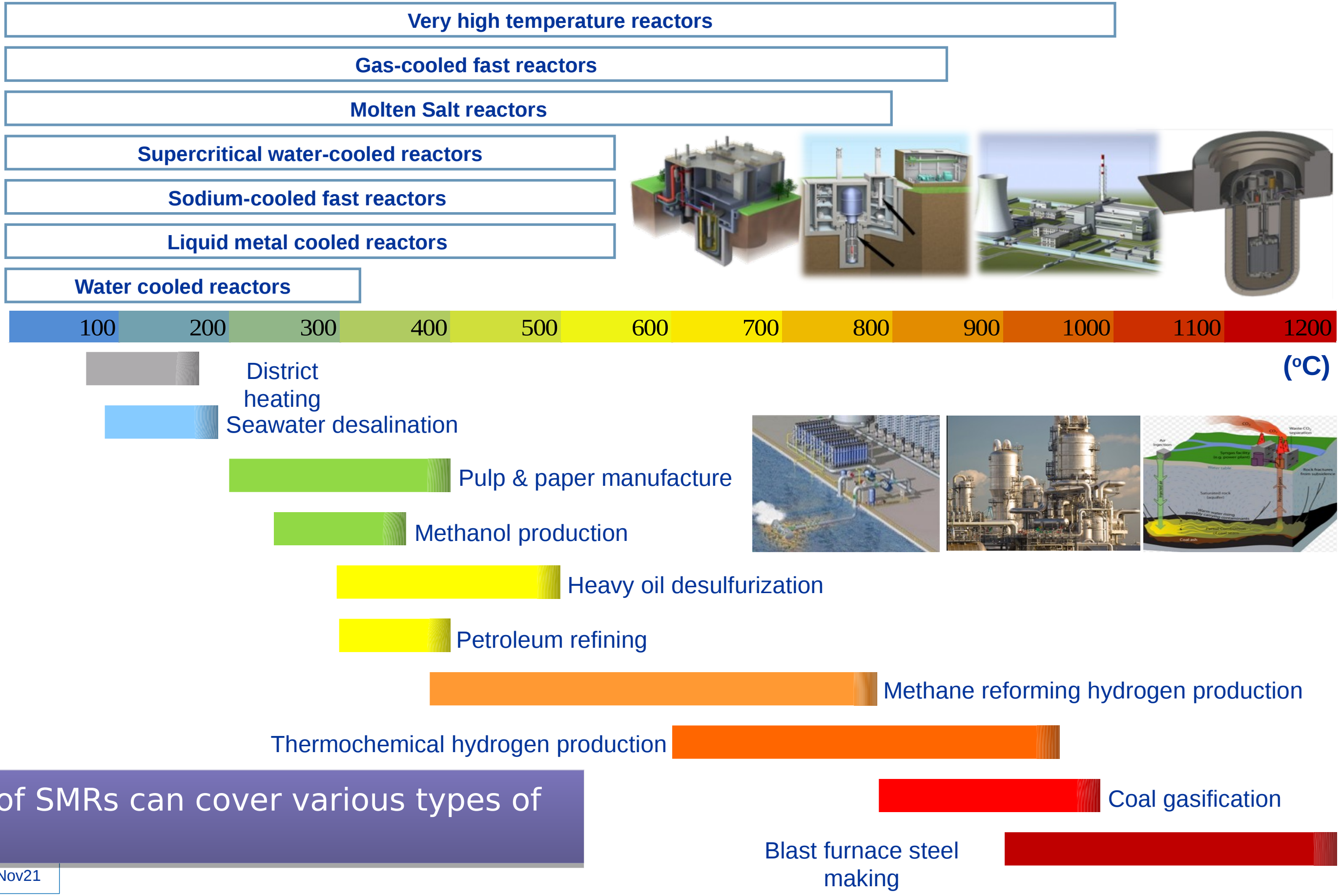
Target Applications

- Microgrids for critical infrastructures
- Remote off-grid areas, minings
- Emergency power supply
- Wide spectrum non-electric apps
- Space and Naval applications (UUV)

Potential Issues and Key Challenges

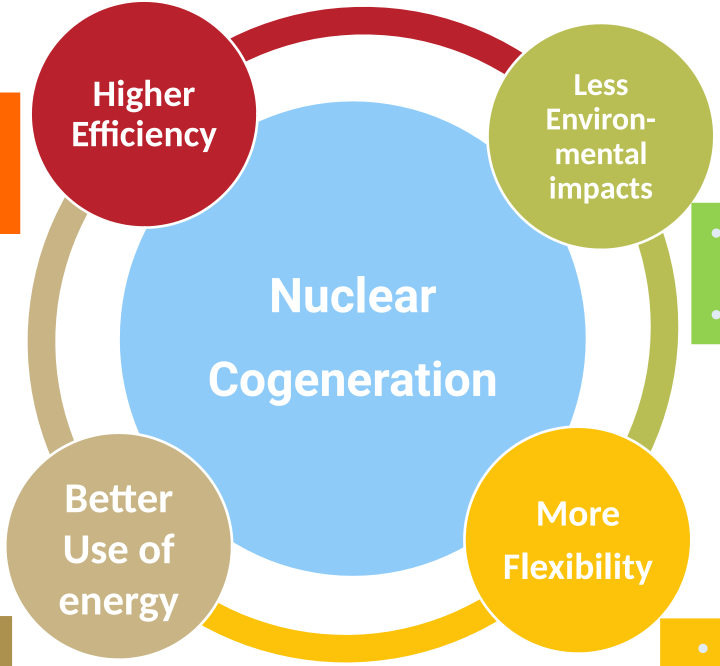
- Safeguards: *factory-sealed cores, new configs.*
- Security: *remote off grid areas, attractive theft target of new fuels / higher enrichment*
- Strategies for waste treatment and disposal
- Operator requirements, oversights / inspections

SMR for Non-Electric Applications



Wide spectrum of SMRs can cover various types of applications

Values of Nuclear Cogeneration



- Up to 80% energy efficiency
- Open new sectors for nuclear power

- Reduce the waste heat dumped to environment
- Additional heat sink

- Optimize energy efficiency
- Match industrial application needs at the right temperature

- In future energy planning
- In operating NPPs & Grid
- In diversifying energy outputs

SMRs and Power Systems

- What are the competitors of **SMRs**?
  - **Small** SMRs will compete with gas-fired plants (50 MWe to 600 MWe)
  - **Modular** SMR’s plants will compete with gas or coal fired plants (from several hundreds of MW to several thousands of MW)
  - **Reactors** Flexible units can bring flexibility to optimize power / cogeneration/ non-electric applications. SMR’s will compete also with gas turbines and boilers

- SMRs need to be flexible as gas/coal fired units
- Difference in CO_2 taxation (+) and in decommissioning (-)

SMRs’ Ability to Load Follow

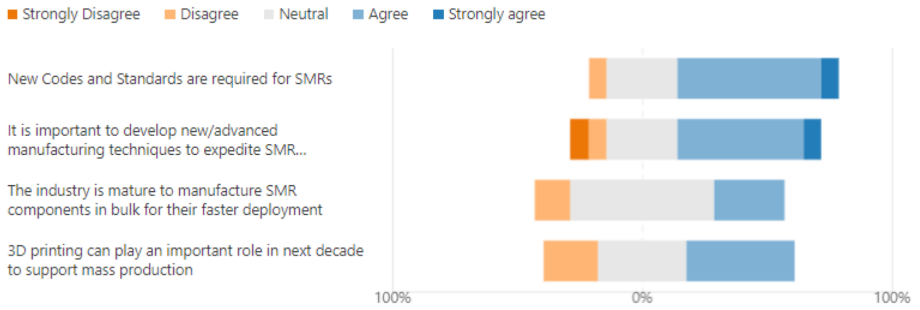
Physics of SMRs	Impact to Load-Follow Requirements
Small Core	Reduced xenon oscillations
Large number of Reactivity Control Cluster Assemblies (RCCA)	Flexible power control modes
Boron-free	• reactivity management & power change • power pics and asymmetries? • ability to load-follow during stretch-out?
Integrated Primary Circuit	• reduced source of wear and tear • innovations to be carefully assessed
New digital I&C	high degree of power control automation

SMRs have intrinsic characteristics to address modern
load-follow requirements of manoeuvring capability of modern LWRs

Codes and Standards for SMRs

Key discussion points:

- Are the existing international nuclear codes and standards adequate to facilitate the development and licensing of SMR technologies worldwide?
- What are the key issues, prospects and impediments on design engineering, manufacturing process and technology qualification of novel components for SMRs?
- How can SMR industries learn from other industrial sectors to support a diversified/ larger supply chain and enable factory modular construction?
- What significant changes are foreseen for In-Service Inspection (ISI) and component In-Service Testing (IST) for SMRs compared to existing large reactors?



Experts' Survey result

Codes & Standards – Applicability to SMRs

Key Advantage #1: Enabling Design Simplification

- Minimized number of systems and components without compromising safety;
- Simplification to improve economics, maintainability and availability of components – without compromising safety.

Key Advantage #2: Confirm a robust supply chain:

- Assure ‘diverse’ supply for replacement by manufacturers other than the original manufacturers;
- Improve the assurance of sustainable operation of the nuclear power plant.

Findings on Standardization:

- Standardization alone will not solve all issues in advanced reactor product development;
- *Excellence* in applying *advanced manufacturing* and *NDE techniques* are often proprietary; not readily shareable or standardized because it would benefit competitors
- The biggest challenge to quality product is to having the capability of designing, manufacturing and delivering, within time and budget, products that meet the requirements

SMR Development should increasingly apply codification and standardization of Advanced Manufacturing Techniques to realize high degree of Modularity

Advantages, Issues & Challenges

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

Potential Challenges on Safeguards on SMRs

Reference: Jeremy Whitlock, SH-CA, SGCP, 2 November 2021

- **New fuels and fuel cycles:** pebble-bed, molten salt, Th/U-233, MOX, transuranic (TRU) fuels, fast reactors, higher enrichment (HALEU), pyroprocessing, other new processes
- **Longer operation cycles:** continuity of knowledge between refuelling, high excess reactivity of core (target accommodation)
- **New supply arrangements:** factory sealed cores, transportable power plants, transnational arrangements
- **Spent fuel management:** storage configurations, waste forms
- **Diverse operational roles:** district heating, desalination, hydrogen + electricity
- **Remote, distributed locations:** access issues, accessibility of nuclear material fo

IAEA independent verification capabilities must be ready

Prospects and Actions for Deployments

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

SMR Deployment Competitiveness

Regulatory framework, licensing pathways: global deployment,

need of harmonization?

Development of Nuclear Infrastructure for near-term deployment particularly

in Embarking countries

Acknowledgments

This presentation includes information kindly provided by the colleagues from the IAEA Nuclear Power Technology Development Section Team.

Their help is gratefully appreciated!

Thank you!

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