IAEA
International Atomic Energy Agency
Atoms for Peace and Development

2022 IAEA SMR ARIS Booklet on Advances in SMR Technology Developments

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OUTLINE

❑ Characteristics and Attributes of SMR

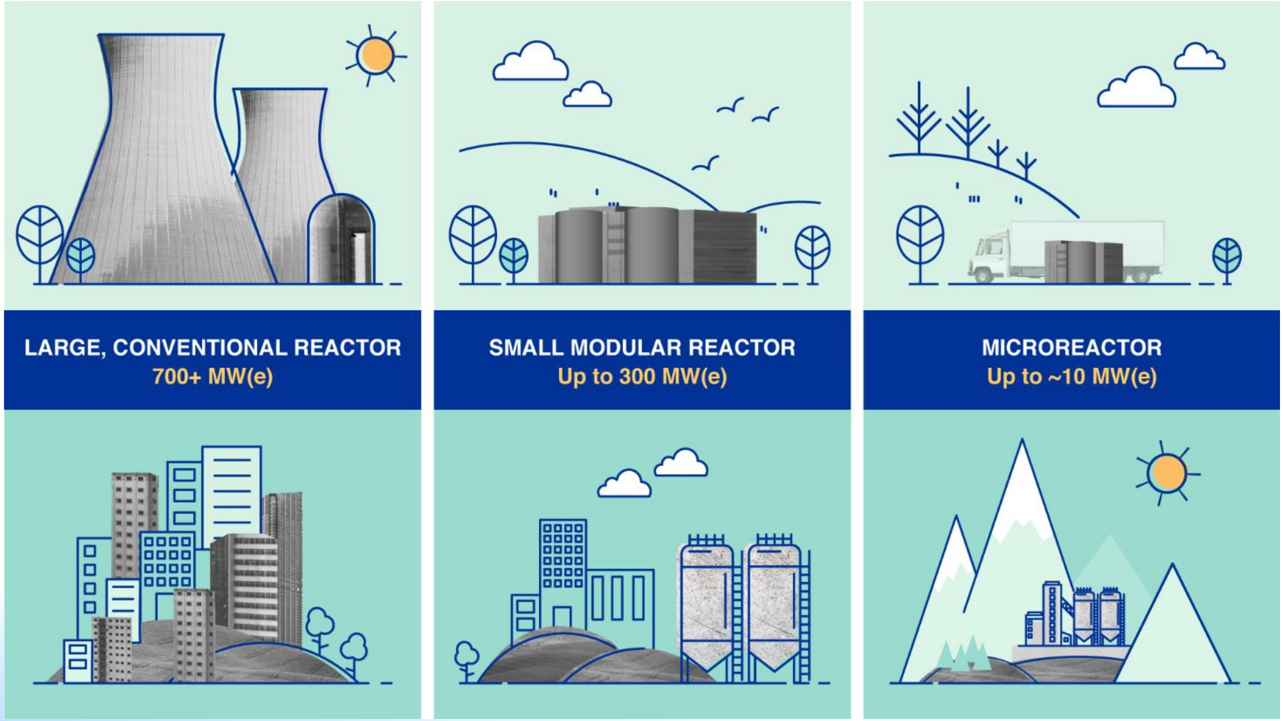
- Major SMR technology lines
- Key attributes
- Salient design characteristics

❑ Advances on SMR Technology

- Global map of development
- Deployment horizon & Stage of development
- Designs of each category
- Examples of Fuel Cycle Approach and Waste Management Plan adopted by SMR Designs

Small Modular Reactors (SMRs)

Advanced Reactors that produce typically up to 300 MWe, built in factories and transported as Modules to sites for Installation as demand arises.



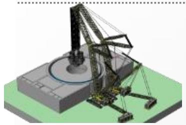
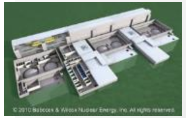
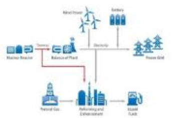
Small: in size, comparing to traditional reactors.

Modular: factory-manufactured, installed onsite.

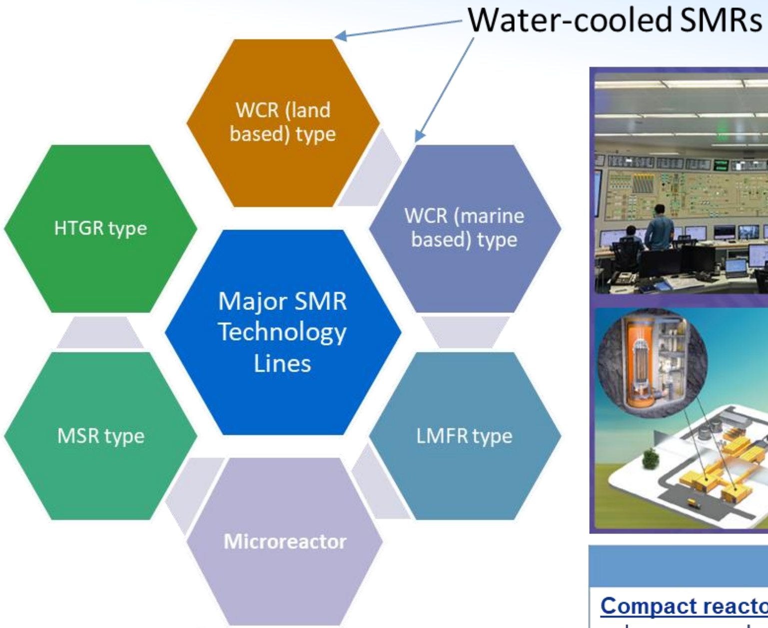
Reactor: energy generation via nuclear fission.

Key attributes of SMRs

- Enhanced Safety
- Versatile
- Modular
- Reduced Waste
- Affordable
- Non-electric applications

	**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

Major SMR technology lines



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.

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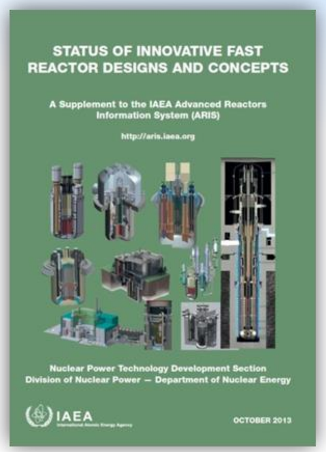
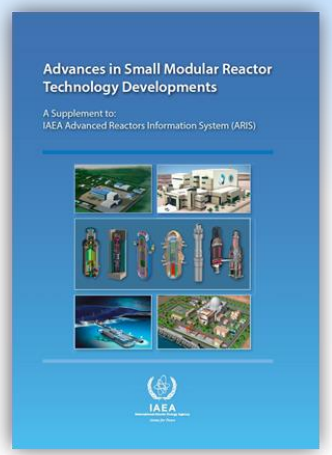
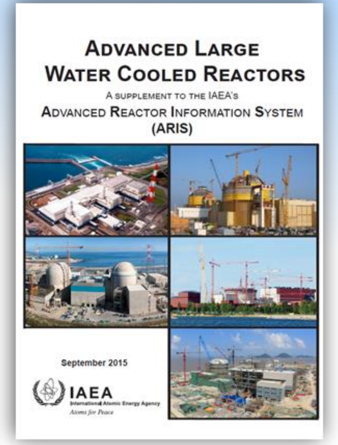
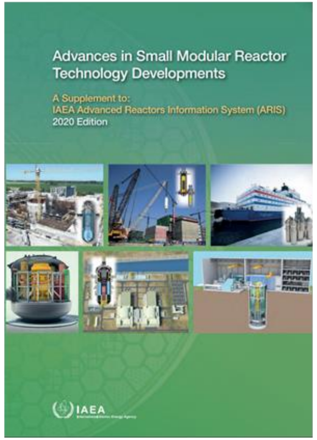
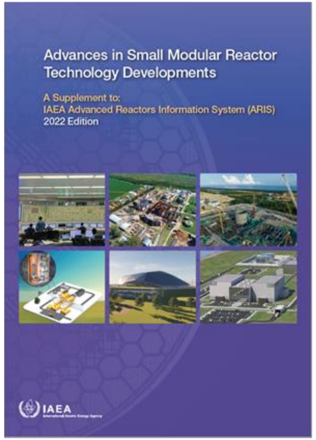




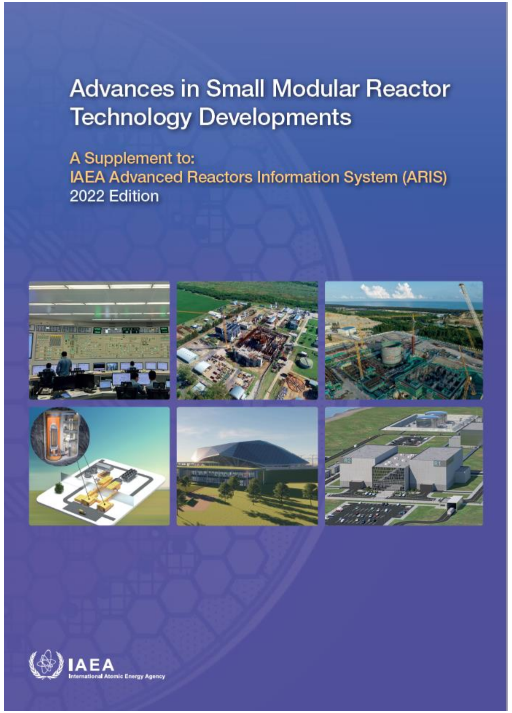






2022 edition to be publicly released soon.

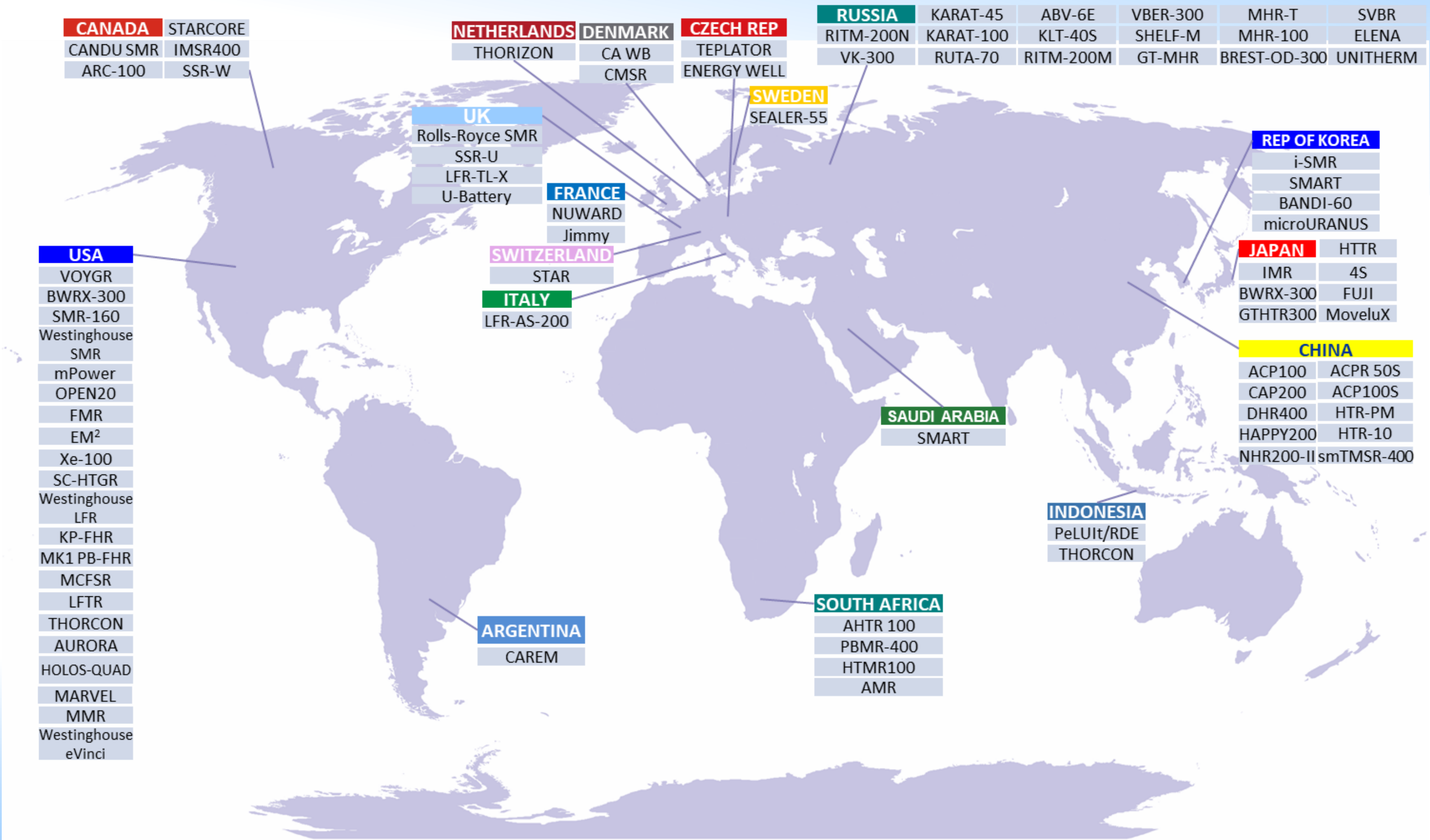
IAEA ARIS SMR Booklet 2022



IAEA SMR Booklet, 2022 Edition	
Number of reactor designs:	**83**
Member states involved:	**18**
Reactor types	1.1. Water-cooled Land Based – **25** 1.2. Water-cooled Marine Based – **8** 2. High temperature Gas-cooled – **17,** including **3** HTGR-type test reactors 3. Liquid Metal-cooled Fast Neutron Spectrum – **8** 4. Molten Salt – **13** 5. Microreactors – **12**
Distinguishing features	• New annexes on **economic challenges, decommissioning, and experimental testing for design verification and validation** • Insightful annexes with various charts and tables
Status	Finished, submitted for publication.
Downloadable version	Coming soon.

The 2022 IAEA SMR ARIS Booklet is a biennial publication as a supplement to the IAEA Advanced Reactor Information System (ARIS) Database. It provides a brief yet comprehensive design description of 83 different reactor designs. The 2022 version is an updated version of the 2020 booklet. It includes 11 more designs and a more comprehensive set of annexes.

Global map of SMR Technology Development



Design development phases

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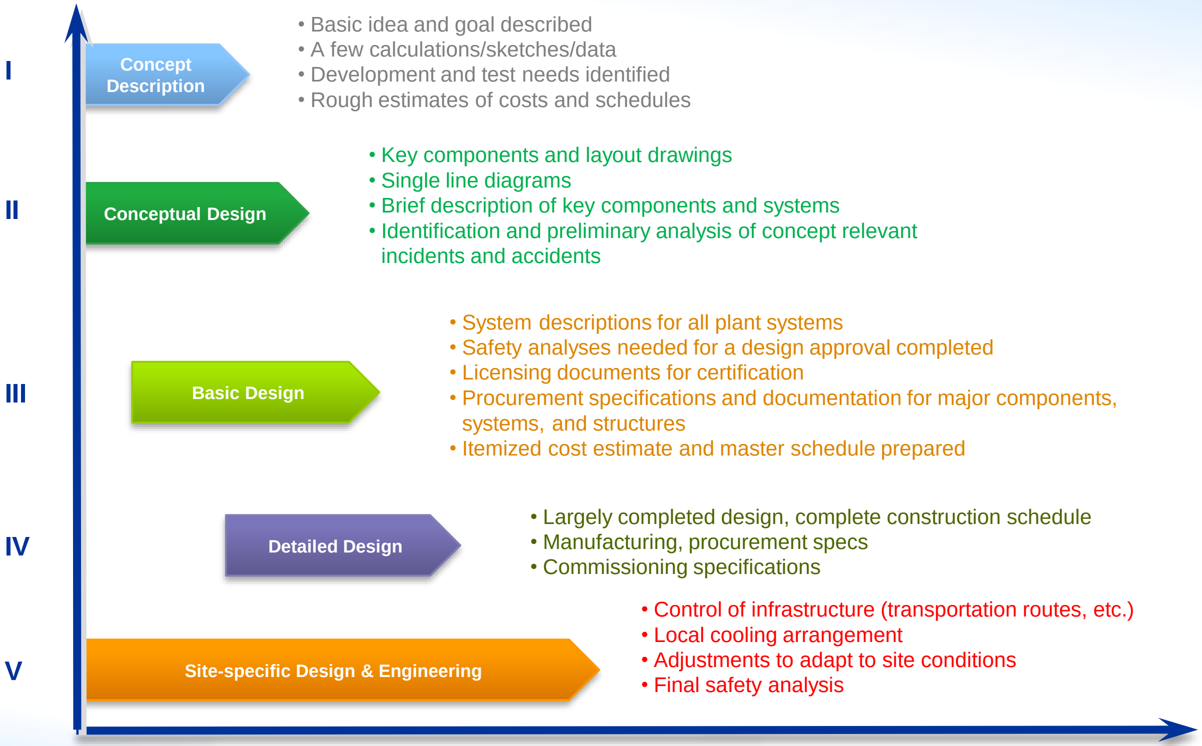
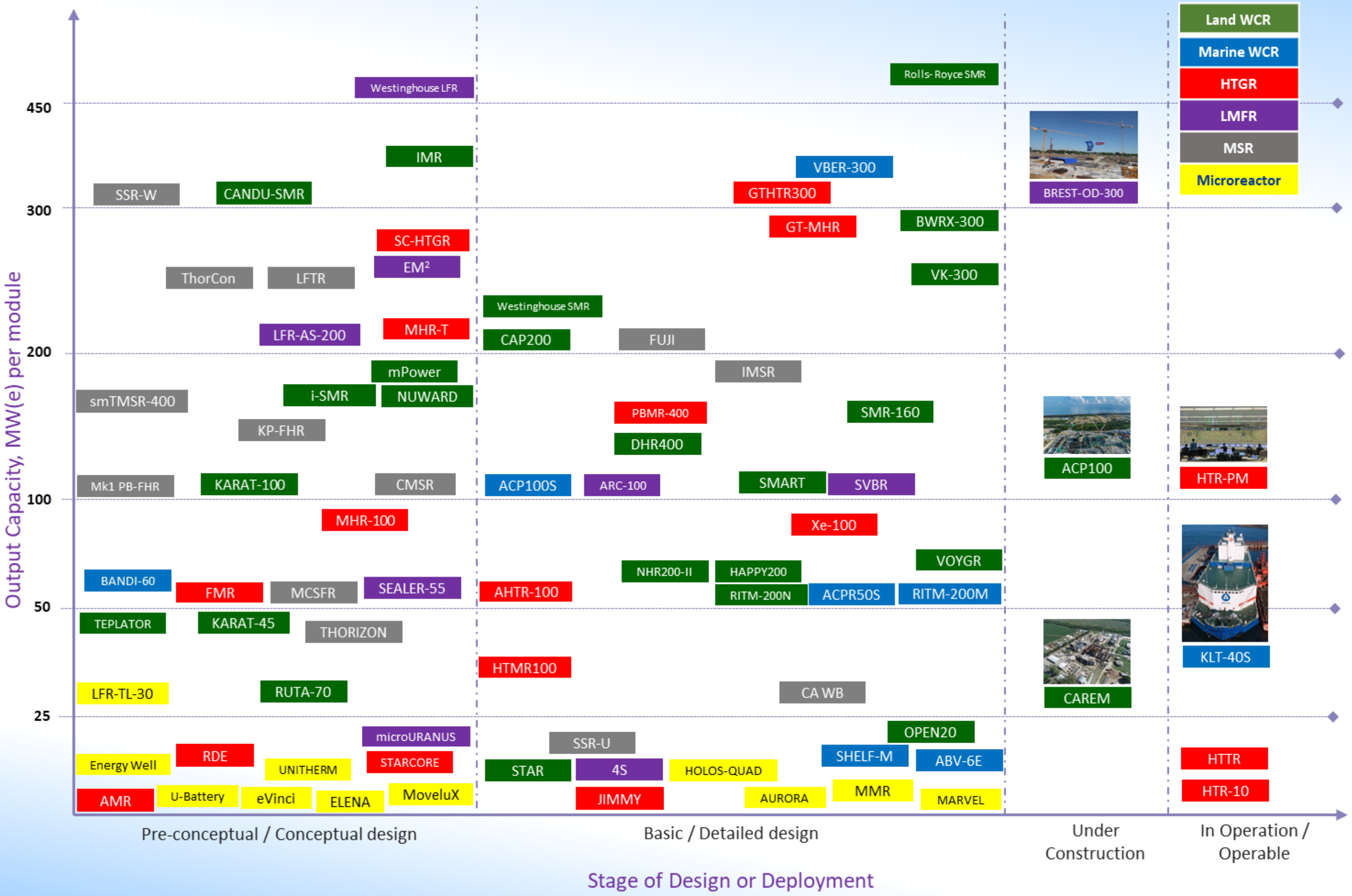


Phases and corresponding activities during design development

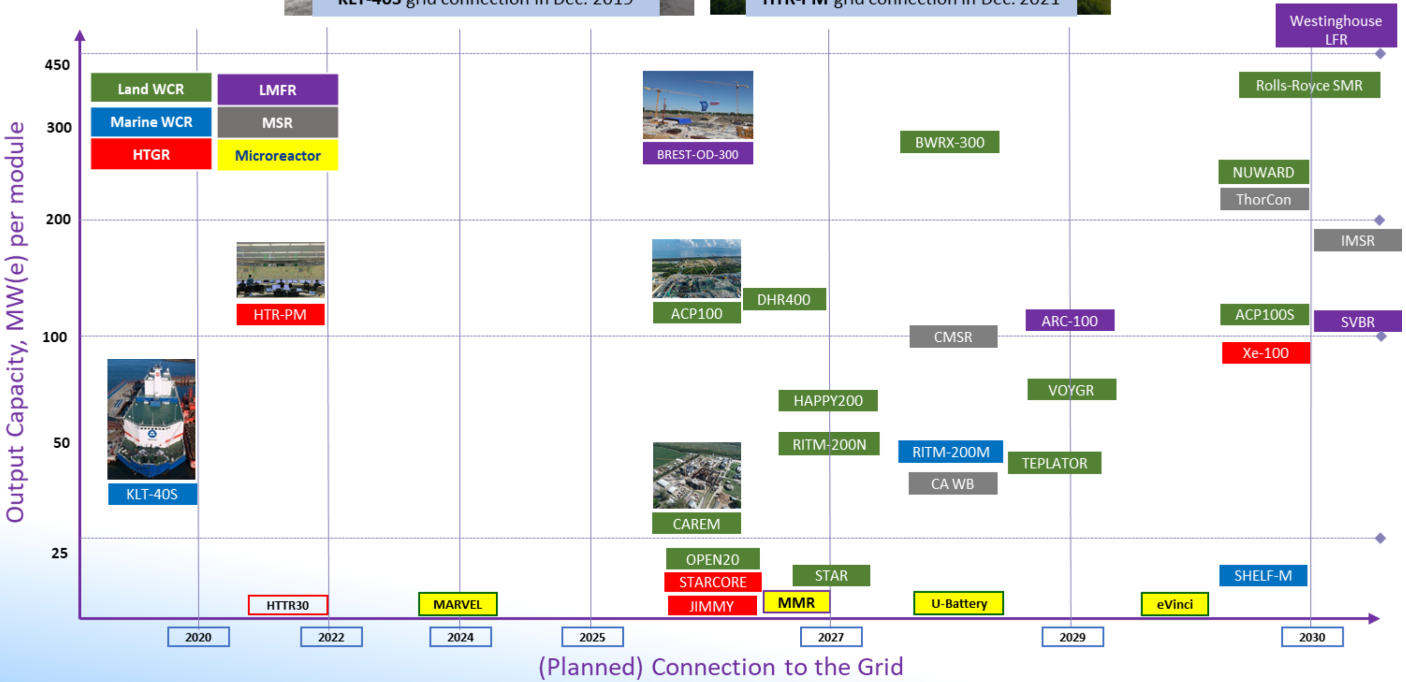
Ref.: IAEA-TECDOC-936 Terms for Describing New, Advanced Nuclear Power Plants

Stage of development or deployment of SMRs

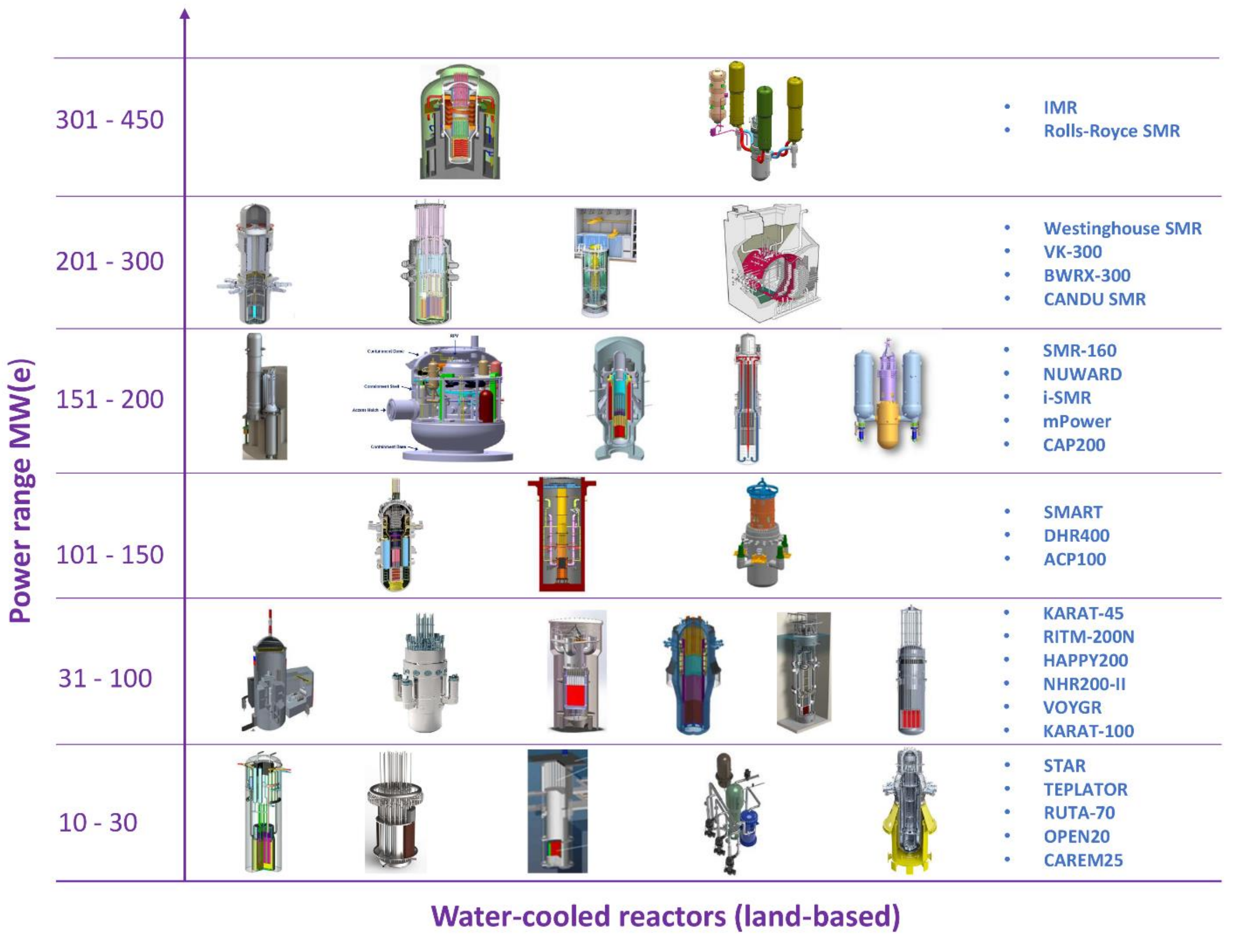


Stage of development or deployment of SMRs

The Forerunners: 2 in operation, 3 under construction. More target at deployment by 2030



Power range of SMRs of each category



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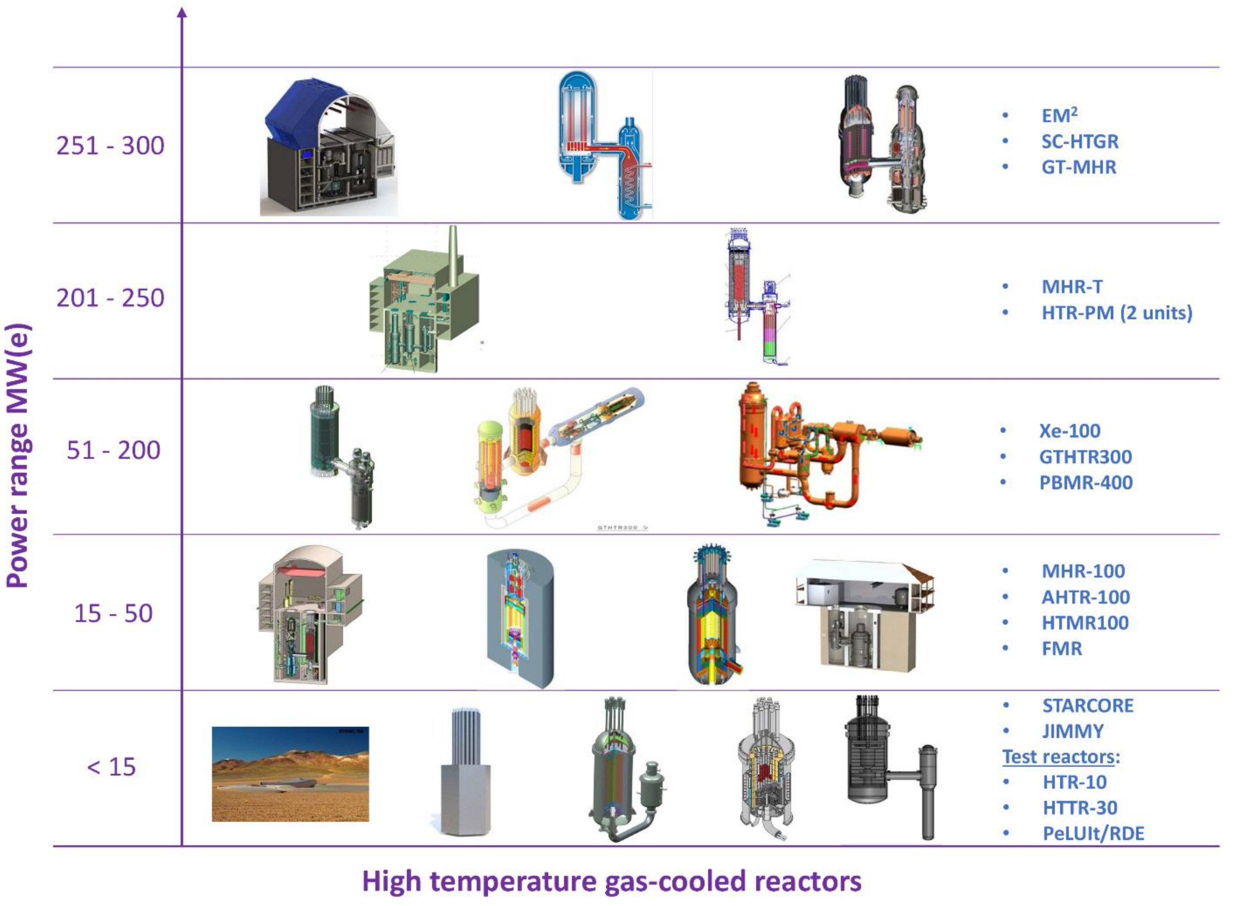
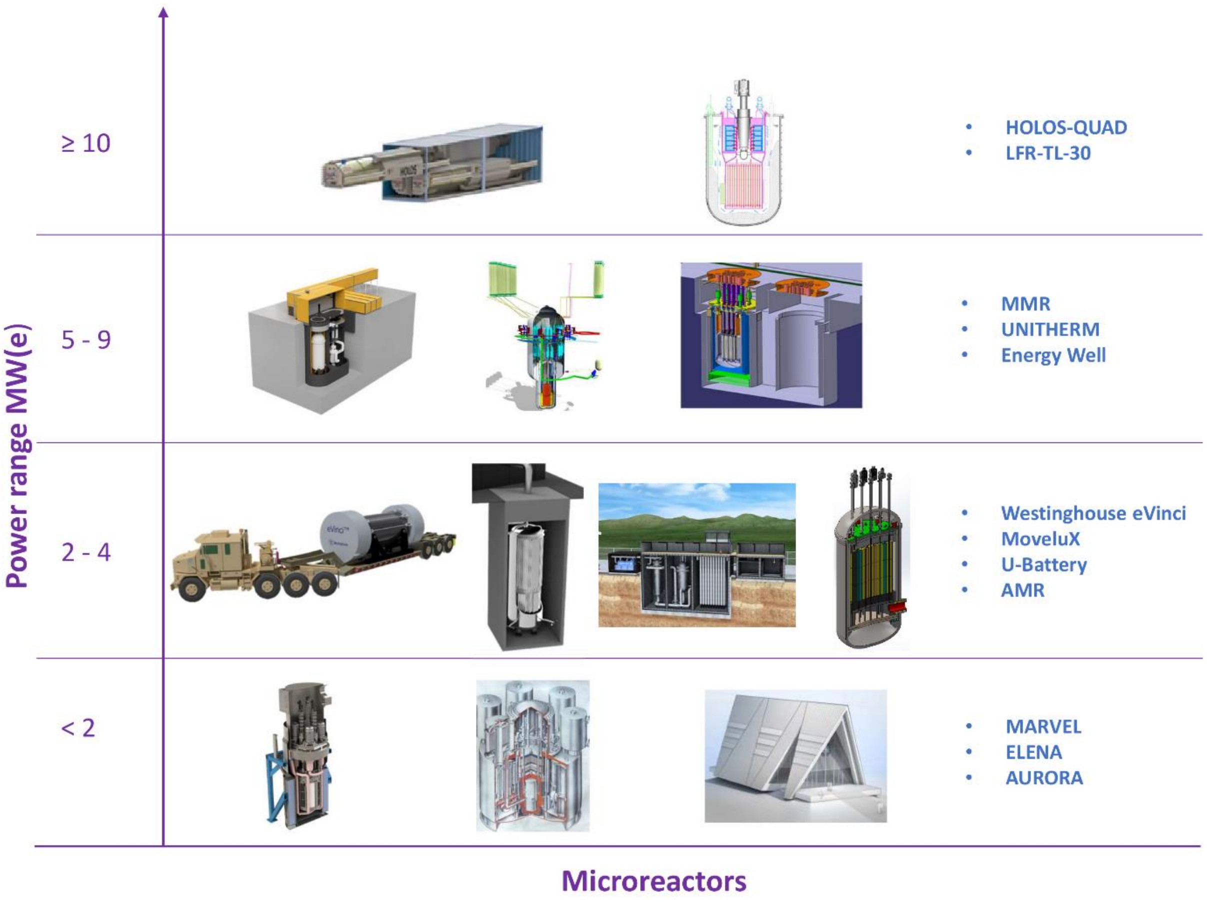


Specific characteristics and applications of microreactors

- Inherent and passive safety features
- Substantially lower upfront capital costs
- Much smaller footprints, reduced-sized or even eliminated EPZ
- Rapid deployability from modularity (even an entire reactor)
- Spent fuel smaller in size (probably easier to manage)
- Scalability, Resiliency, Self-regulating
- Potential to operate in island-mode & to black-start
- High transportability from mobility
- Long refueling interval

Powering secure micro-grids for critical infrastructure	Powering remote off-grid areas
Restoring power quickly	Seawater desalination
Naval: powering nuclear submarines and UUV	Space: powering spacecraft, supporting manned exploration
Replacement for diesel gensets	Remote mining operations: offer reliable power source
Hydrogen production: feasible for HTGR type	Integration with renewables: e.g. integrating solar panels

Power range of SMRs of each category



Comparison of Main Characteristics among Some HTGR-type SMR Designs

	HTR-PM	GTHTR300	GT-MHR	HTMR100	Xe-100	SC-HTGR	EM^2
Country of Origin	China	Japan	Russian Federation	South Africa	USA	USA	USA
Design organization(s)	INET, Tsinghua University	JAEA	JSC “Afrikantov OKBM”	STL Nuclear (Pty) Ltd.	X-energy, LLC	Framatome Inc.	General Atomics
Reactor type	Modular pebble bed HTGR	Prismatic HTGR	Modular Helium Reactor	Pebble-bed HTGR	Modular HTGR	Prismatic HTGR	Modular high temperature gas-cooled fast reactor
Fuel materials	TRISO spherical elements with coated particle fuel	UO_2 TRISO ceramic coated particle	Coated particle fuel in compacts, hexagonal prism graphite blocks	TRISO particles in pebbles; LEU/Th	UCO TRISO/pebbles	UCO TRISO particle fuel in hexagonal graphite blocks	UC pellet / hexagon
Coolant	Helium	Helium	Helium	Helium	Helium	Helium	Helium
Moderator	Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	N/A
Thermal output, MW(t)	2 x 250	< 600	600	100	200	625	500
Electrical output, MW(e)	210	100 - 300	288	35	82.5	272	265
Core inlet temp., ºC	250	587 - 633	490	250	260	325	550
Core outlet temp., ºC	750	850 - 950	850	750	750	750	850
Enrichment, %	8.5	14	14-18% LEU or WPu	10%	15.5	14.5 (avg) 18.5 (max)	~14.5 (LEU)
Core Discharge Burnup (GWd/ton)	90	120	100-720 (depends on fuel type)	80 - 90	165	165	~130
Refuelling cycle, months	Online refuelling	48	25	Online fuel loading	Online fuel loading	½ core replaced every 18 months	360
Reactivity control	Control rods	Control rods	Control rods	Control rods in the reflector	Control rods	Control rods	Control rods
Reactor Vessel’s height/diameter, (m)	25 / 5.7 (inner)	23 / 8	29 / 8.2	15.7 / 5.6	16.4 / 4.88	24 / 8.5	12.5 / 4.6
Design status	In operation	Basic design	Preliminary Design completed	Basic Design	Basic Design	Preliminary Design	Conceptual design

Fuel Cycle Approach adopted by HTGR-type SMRs

- Open fuel cycle: The majority.

  e.g., HTR-PM will adopt close fuel cycle in the future.

- Longer refuelling cycle, e.g., GTHTR300, GT-MHR
- Fuel enrichment: all in the range of (5 – 19.75)%
- Use of Th cycle and/or Disposition of Pu: e.g., GTHTR300 (applicable), MHR-100 (possible), PBMR®-400 (flexible), EM^2 (capable).
- Use of Spent Fuel as Fuel: e.g., GTHTR300 (applicable), EM2 (feasible)

Waste Management and Disposal Plan adopted by SMR Designs

- Volume Reduction and Conditioning:

  Coated particle separation from graphite will reduce volume by up to a factor of 100.

- Waste Processing:

  - Low and intermediate level waste from plant operation will be conditioned by different process technologies.
  - Possible graphite recycling, ^{14}C separation process

- Storage Approach, Spent Fuel Pool Cooling Mechanism:

  - With higher thermal efficiencies the radiotoxicity and decay heat will be lessened by 50% for HTGRs as compared to LWRs.
  - Dry storage with natural convection after short material active cooling.
  - Facilities for long-term storage of spent fuel and solid radwaste are in the NPP complex

- Spent Fuel Take-back Option: to date not considered in HTGRs.

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8 December 1953

1 to 23 October 1957

11 December 1957

1959

10 December 2005

1958 to 1979

23 August 1979

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Thank you for your attention!

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