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Overview of Small Modular Reactor Technology Development

Summary / Objectives:

Nuclear electricity generation started with prototype and test reactors of a small size and low power. Relatively quickly these were replaced **by increasingly larger nuclear power plants due to increased needs, economy of scale and limited available sites.** For several years the interest in small modular reactors (SMRs) has increased with over 50 concept designs now under development. The IAEA defines SMRs as advanced nuclear power plants with one or more individual modules that each produce electric power up to 300 MWe. A module may be built in factories and shipped to nuclear sites for installation and added as the need arises. All advanced technologies are included (water cooled, Gen-IV systems and micro-reactors). **SMRs claim enhanced passive safety features, simplified design and operations, economy by numbers and the flexibility in hybrid energy systems and non-electric applications**. The webinar highlights the attractive features of SMRs, major challenges, the current status of SMR technology and near-term deployment plans.

Meet the Presenter:

Mr. Frederik Reitsma is the **Team Leader for SMRs** in the Nuclear Power Technology Development Section of the International Atomic Energy Agency (**IAEA**) in Vienna. He joined the IAEA nearly 7 years ago and manages, coordinates and supervises the projects in this area. He provides technical and program leadership by identifying key future trends and technology development needs in cooperation with Member States. Previously, he was head of the High Temperature Gas Cooled Reactor project. Frederik holds a master's degree in Reactor Science and has published more than 90 papers. He has been invited as a speaker to many international workshops and conferences and led several international cooperation projects (such as OECD/NEA and GIF). He is a reactor physicist by training with extensive experience in SMRs and HTGRs nuclear engineering and analysis with core neutronics design and safety as focus areas. He worked on the South African PBMR project in different leadership positions for 13 years. For the first 10 years of his career, he contributed to the OSCAR reactor calculational system development and performed cycle and reload analysis.

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SMR has gotten interest from the point of **Affordability of Economics, Modularization, Flexible application, Integration with Renewables, etc.**

Small Modular Reactors (What is it?)

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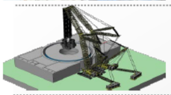
Advanced NPP that produces up to 300 MW(e). Individual modules built in factories and transported to sites for installation as demand arises.

A nuclear option to meet the need for flexible power generation for a wide range of users and 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

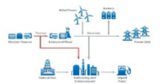
→ Wider range of Users

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

SMR Designs around the World

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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	

IAEA already released **SMR booklet** and **ARIS database** included SMR concepts.

IAEA SMR Booklet

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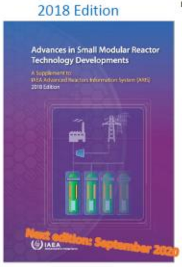
The booklet contains information provided by vendors and designers on their SMRs

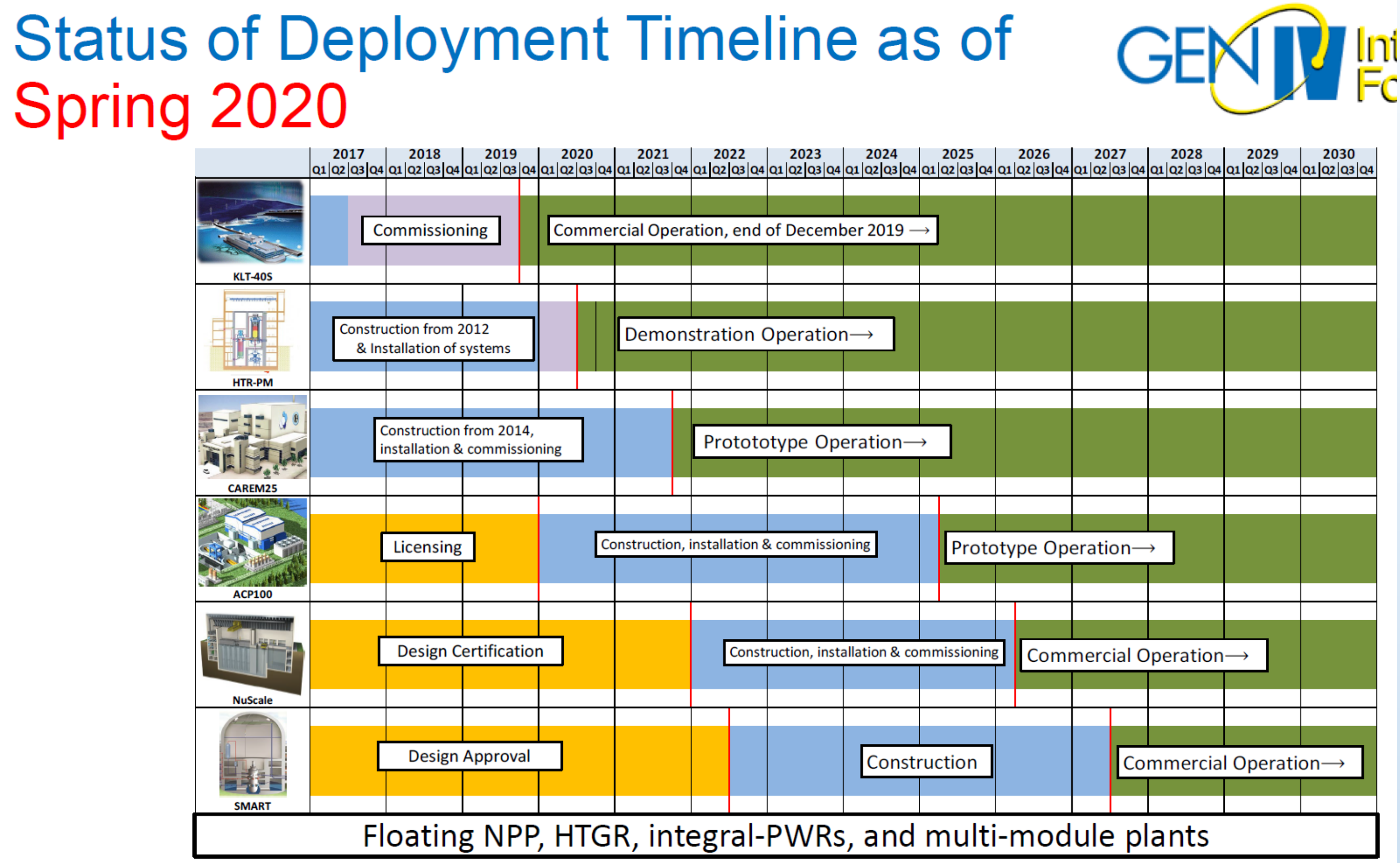
2018 Edition



- SMRs are categorized in types based on coolant type/neutron spectrum:
  - Land Based WCRs
  - Marine Based WCRs
  - HTGRs
  - Fast Reactors
  - MSRs
  - Micro reactors
  - Test reactors (to be included with the types above as applicable)
- Design description and main features of ~70 SMR designs being updated (56 in 2018)
- Include information on fuel cycle, decommissioning and final disposal (for the first time)

IAEA ARIS Database Includes SMR Designs

Several SMR moved into
Construction phase from Licensing phase.



Around 100 concepts were proposed and they are **not only water cooled type** but also from **liquid metal, gas to molten salt**, and from **Marine-based to micro reactors**.

SMR Key Design Features are introduced in the presentation as **Modularization, Site specific considerations, physical security, Emergency Planning Zone**, etc.

SMR Site Specific Considerations

- SMRs promise much smaller sites
  - EPZ can possible be reduced
  - Located close to population centers / end users
  - Located next to heat users / industries
- The first SMRs currently built / to be deployed has selected existing NPP / nuclear sites (HTR-PM, CAREM, NuScale plan)
- Important factor is physical security (smaller site and close proximity of other buildings / industries will present new challenges)

The HTR-PM - (Two-reactor unit) = 210MWe
The Vogtle 3 and 4 Nuclear power plant USA - 2 units = 2220 MWe

Progress made in applying a graded approach

- Nuclear Regulatory Commission staff agreed with the Tennessee Valley Authority that scalable emergency planning zones (EPZs) for small modular reactors are feasible

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US regulators discuss smaller SMR emergency zones

28 August 2018

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CLARIFICATION: NRC staff have concluded the TVA methodology can be used in the future to determine if a reduced emergency planning zones is justified, and has not made a decision on EPZ criteria for small modular reactors.

The US Nuclear Regulatory Commission (NRC) has concluded that Tennessee Valley Authority's (TVA's) methodology can be used in the future to determine if a reduced emergency planning zone is justified for small modular reactors, a spokesman for the Commission told *World Nuclear News* today. It has not yet agreed that an EPZ around small modular reactors can be scaled to reflect their reduced risks rather than the mandatory ten-mile EPZ required for the USA's current light-water reactor fleet.

SMR Renewables Hybrid concepts and Flexible applications including co-generations were introduced with some examples.

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Role of SMRs in Climate Change

SMR Renewables Hybrid Energy System to Reduce GHG Emission

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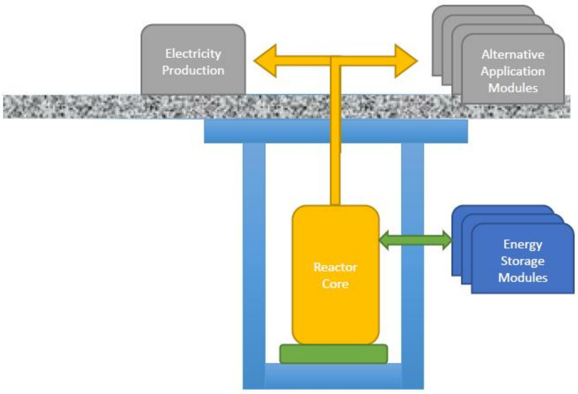
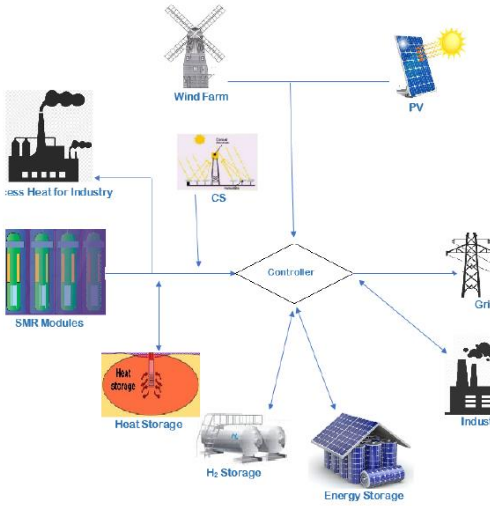
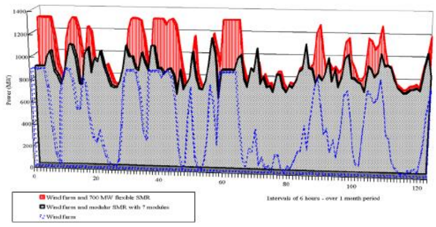


Modules:

- Electricity production
- Process heat
  - Petro-chemical industry
  - Desalination plant
  - Oil and gas reforming
  - Hydrogen production
  - Ammonia production
  - District heating / cooling
  - Waste reforming
- Energy storage
- Load follow capabilities
  - Switch between applications





Example of load follow with renewables

TECDOC:
Options to Enhance Energy Supply Security using Hybrid Energy Systems based on SMR;
being finalised in 2020

Capital costs for SMRs

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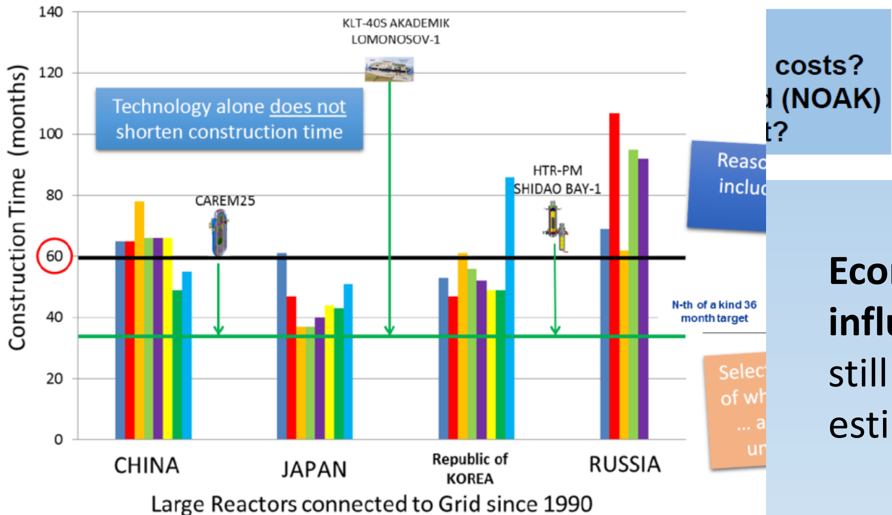
Key Topics	Prospects	Impediments
Capital component of levelized cost of power	Potential decrease in case of large scale and serial production	Require large initial order *(e.g. 50 – 80 modules)*
Comparison of material quantities	Design saving	Standardization of new structure, system, components and materials
Impact of local labour and productivity	○ Reduced construction time for proven design ○ Lesser work force required with modular construction (case by case)	FOAK deployment of multi-module plant with modular construction technology versus stick-build
Cost of licensing	Based on LWRs technology - easier licensing, but still could take long in established nuclear regulators	First of a kind; Time required for modifying the existing regulatory and legal frameworks
Ensuring all necessary equipment is included in the cost estimate, e.g. there is no 'missing equipment'	Learning curve: the higher the number of SMR built on the same site is, the better the cost effectiveness of construction activities on site	Cost impact by delayed component delivery or defect during shipping
Assurance of reliable estimates of technology holder equipment prices	Similar among vendors	Manufacturing of FOAK components



We will only know after we build and operate SMRs

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Economics factors to make influenced into were introduced but still lots of uncentres in the cost estimations.

Key Barriers vs Challenges:
Many barriers exist but also many advantages, challenges continue.

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Key Barriers/Challenges to Deployment

- Limited ***near-term commercial availability***
- Technology developers ability to secure investors for design development and deployment: *first domestically, then international markets*
  - *may be an opportunity to cooperate*
- **Economic** competitiveness
  - Need economy of numbers (vs economy of scale) …
- Regulatory, licensing and **safety issues**.
  - *FOAK, passive features, integrated designs, different technologies*
- Technology Maturity
  - Water cooled SMRs (iPWR and BWRs) based on mature technology
  - HTGR mature technology (with steam generator and Tout < 850 °C)
  - MSR has limited operation experience –some challenges to be solved

NEED GOVERNMENT COMMITMENT TO REALIZE DEMONSTRATIONS PROJECTS!

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