FISA EURADWASTE 2025

SNETP Forum

FROM CONCEPTION TO TECHNOLOGICAL IMPLEMENTATION - SMR`s TECHNOLOGY READINESS LEVELS

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1. Introduction

The transition of Small Modular Reactors (SMRs) from conceptual design to technological implementation represents an important milestone in the advancement of nuclear energy solutions. SMRs represent an innovative approach to nuclear energy, offering enhanced safety, modularity, and economic feasibility. However, their widespread deployment depends on their progress through defined Technology Readiness Levels.

2. Technology Readiness Levels (TRLs) in SMR Development

TRL is a systematic metric used to assess the maturity of emerging technologies.

TRL9
- **Full Commercial Deployment**
- Technology is fully operational and commercially available.

TRL8
- **Actual System Completed and Qualified**
- Technology proven in real-world applications, meeting performance requirements.

TRL7
- **System Prototype Demonstration in Operational Environment**
- Full-scale prototype tested in an operational setting.

TRL6
- **Technology Demonstrated in Relevant Environment**
- System prototype tested under more realistic conditions.

TRL5
- **Technology Validated in Relevant Environment**
- Prototype tested in an environment that mimics real-world conditions.

TRL4
- **Technology Validated in Lab**
- Key components tested in a controlled lab environment.

TRL3
- **Experimental Proof of Concept**
- Initial experiments conducted in a laboratory setting to validate the concept.

TRL2
- **Technology Concept Formulated**
- Potential applications of the technology are proposed.

TRL1
- **Basic Principles Observed**
- Scientific research begins; basic principles of technology are identified.

The scale ranges from TRL 1 (basic principles observed) to TRL 9 (full-scale deployment in an operational environment). The application of TRLs in nuclear energy provides insights into the feasibility and commercialization prospects of SMR designs.

3. Challenges for SMR technology to achieve high TRL

SMR technology overview

SMR Type	TRL Level	Key Challenges
Water-Cooled SMRs (PWR/BWR)	3-8	Licensing, supply chain, deployment strategies
HTGRs	3-9	Fuel qualification, heat exchanger design
MSRs	3-5	Salt chemistry, corrosion, licensing
LMFRs	2-5	Material challenges, liquid-metal behavior, regulatory acceptance

The average technology readiness level is between 3-5. Only a few designs have exceeded his level.

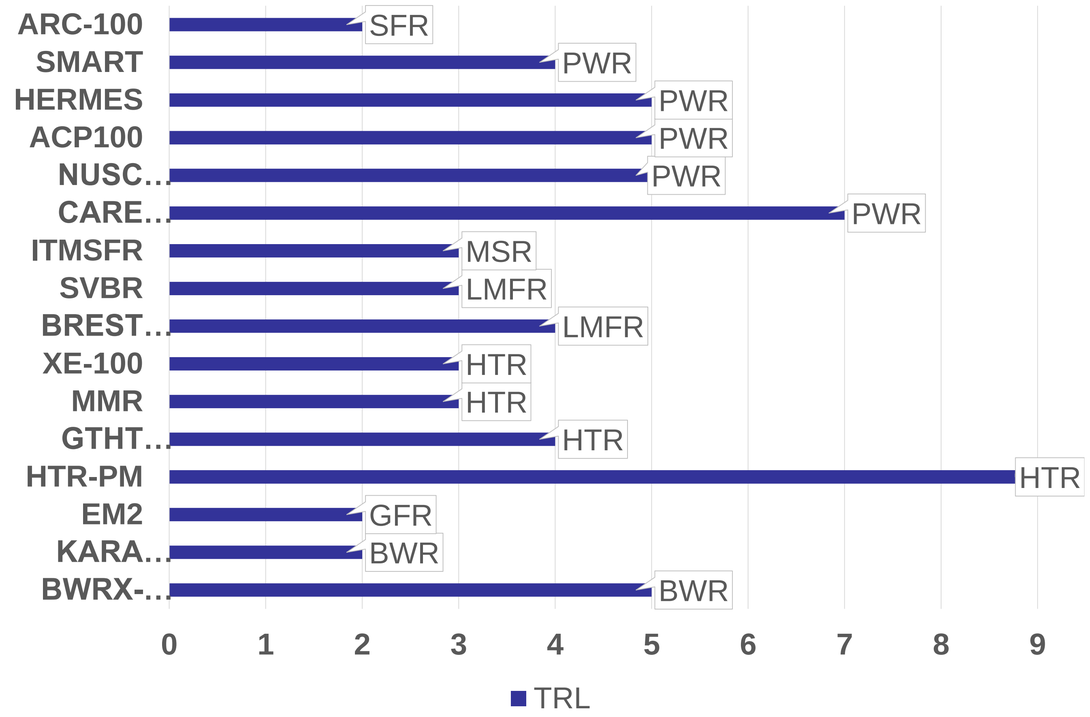
SMR Concepts by OECD 2024 NEA No.7671

Water-cooled	Gas-cooled	Fast neutron spectrum	Micro SMR	Molten salt
AP300™ SMR	Xe-100	Westinghouse LFR	eVinci microreactor	Thorizon One
TEPLATOR	Pylon D1	4S	Pylon D1	ThorCon 500
HAPPY200	MMR	Thorizon One	MMR	IMSR
RITM-200M	HTR-PM	Natrium Reactor Plant	MoveluX	CMSR
RITM-200S	HTMR-100	Otrera 300	Energy Well	Energy Well
RITM-200N	Kaleidos	Aurora Powerhouse	Kaleidos	XAMR
KLT-40S	HTGR-POLA	LFR-AS-200	Aurora Powerhouse	FLEX
RR SMR	Jimmy SMR	XAMR	PWR-20	SSR-W
NUWARD SMR	HTTR	BREST-OD-300	Jimmy SMR	Hermes
VOYGR	GTHTR300	SSR-W	Calogena	LFTR
PWR-20	SC-HTGR	HEXANA	Project Pele	
SMART	A-HTR-100	DF300	BANR	
SMR-300	Project Pele	SEALER-55		
Calogena	BANR	ARC-100		
BWRX-300				
ACP100				
ACPR50S				
CAREM				

More than 68 modular reactor concepts based on Generation III and IV reactors have been developed. Most of these designs never exceeded TRL 2-3. Despite promising advancements, several challenges hinder the commercialization of SMRs:

- **Regulatory Framework:** complex licensing processes and lack of harmonization between international regulators.
- **Supply Chain & Manufacturing:** need for robust supply chains to support modular factory production.
- **Economic Viability:** high initial costs and financing challenges compared to conventional energy sources.
- **Public Acceptance & Policy Support:** concerns regarding nuclear safety and waste management.

Examples of TRL for different SMR's designs
(based on OECD NEA and IAEA))



4. Conclusion

SMRs offer a promising pathway to sustainable nuclear energy, but their commercial success depends on overcoming technical, regulatory, and economic hurdles. To accelerate SMR deployment and achieve high TRL, the strategic actions are recommended:

- Strengthening international cooperation on regulatory harmonization.
- Enhancing research funding for prototype testing and demonstration.
- Encouraging public-private partnerships for investment and commercialization.
- Developing policies to integrate SMRs into existing energy grids.

Acknowledgments

The paper was created as a result of the project: "Plan of decarbonisation of the domestic power industry through modernization with the use of nuclear reactors", financed by the National Center for Research and Development under the Program "Social and economic development of Poland in conditions of globalizing markets" GOSPOSTRATEG (Contract No.: Gospostrateg VI/0032/2021-00 dated 15.03.2022).