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Presentation: SMR Current Status: Development Needs and Global Perspectives

October 2024

Changing the World's Energy Future

Palash Kumar Bhowmik, Todd Michael Anselmi, George W Griffith, Piyush Sabharwall, Youssef A Ballout

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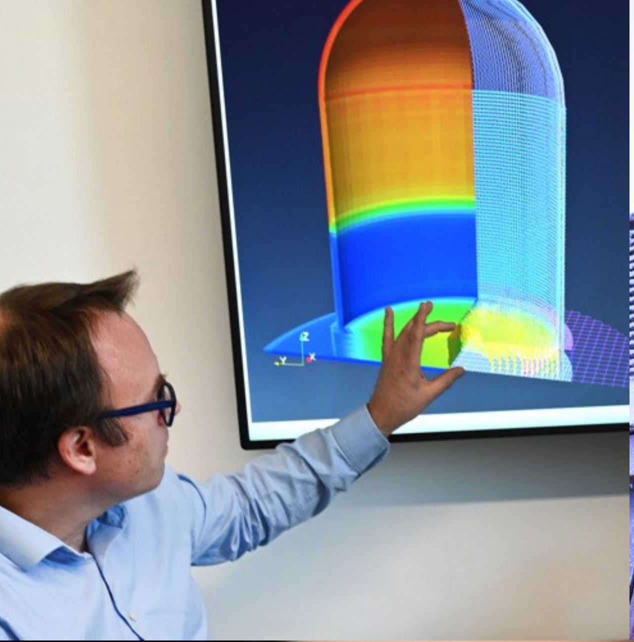
International Conference on

small modular reactors

and their applications

21–25 October 2024, Vienna, Austria



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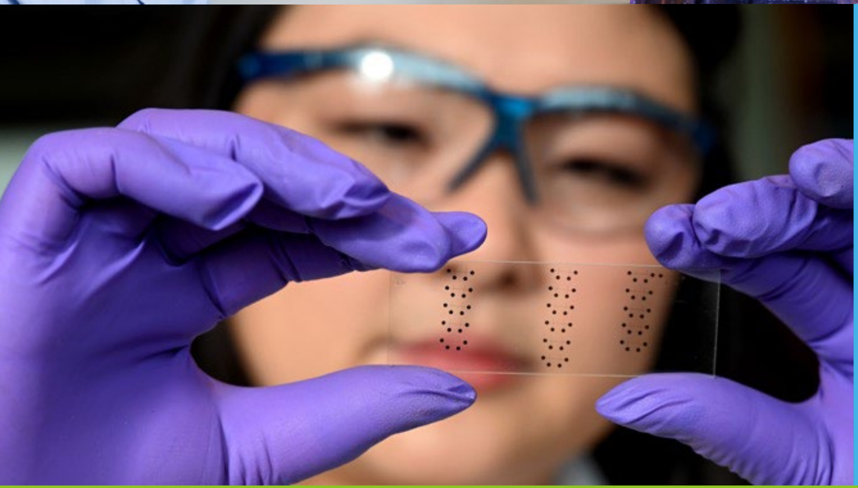

SMR Current Status: Development Needs and Global Perspectives

INL/CON-24-81429

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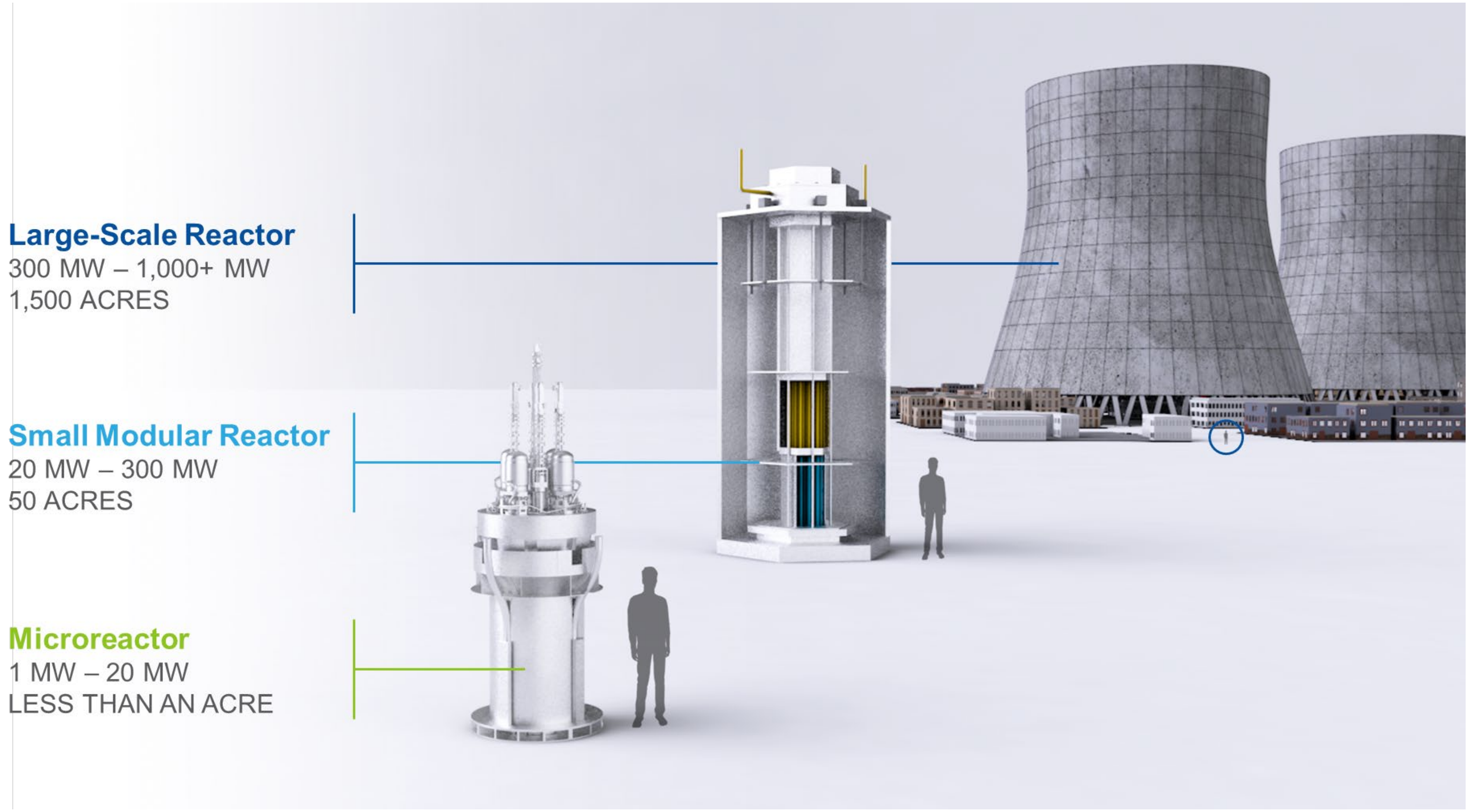
Outline

- **Overview of Small modular reactors (SMRs)**
  - Reactor capacity
  - Reactor development phases
- **Status of SMRs**
- **SMRs development needs: Challenge addressed**
- **Solution approach and conclusion**.

Overview of SMRs: reactor sizes

Small modular reactors (SMRs): reactor capacity up to 300 MWe defined by IAEA, have been recognized as clean, affordable, and sustainable energy sources [1].



Despite the recent surge in interest, the basic SMR concept is not a novel one. Initial plant designs in the 1950s—including the very first commercial reactors—were, in many ways, SMRs with power output ranges of 10–100 MWe [2].

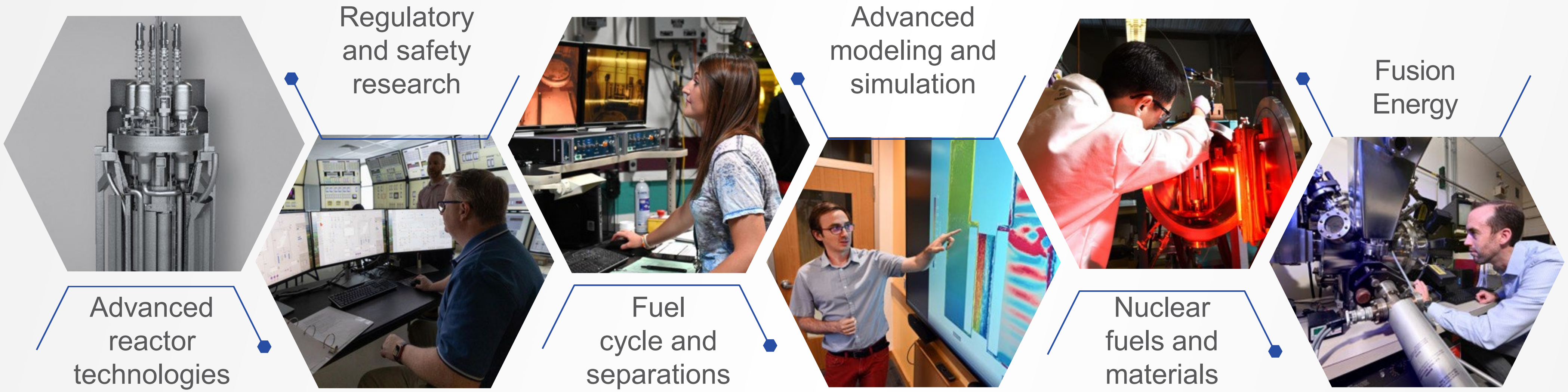
SMRs Development phases: more than 80 SMRs are under design, development, demonstration, deployment, and beyond (4D+) phases worldwide.

Overview of SMRs: Challenges in accelerated deployments

Major challenges identified for accelerated deployment are:

(a) qualifying the advanced fuel-to-reactor design;
(b) supporting rapid scaled/prototypic experimentations;
(c) maintaining local and global codes, standards, and licensing;
(d) supply chain issues;
(e) effective cradle-to-grave nuclear fuel cycle and fuel material transportation, and
(f) mitigating financial and environmental risks.

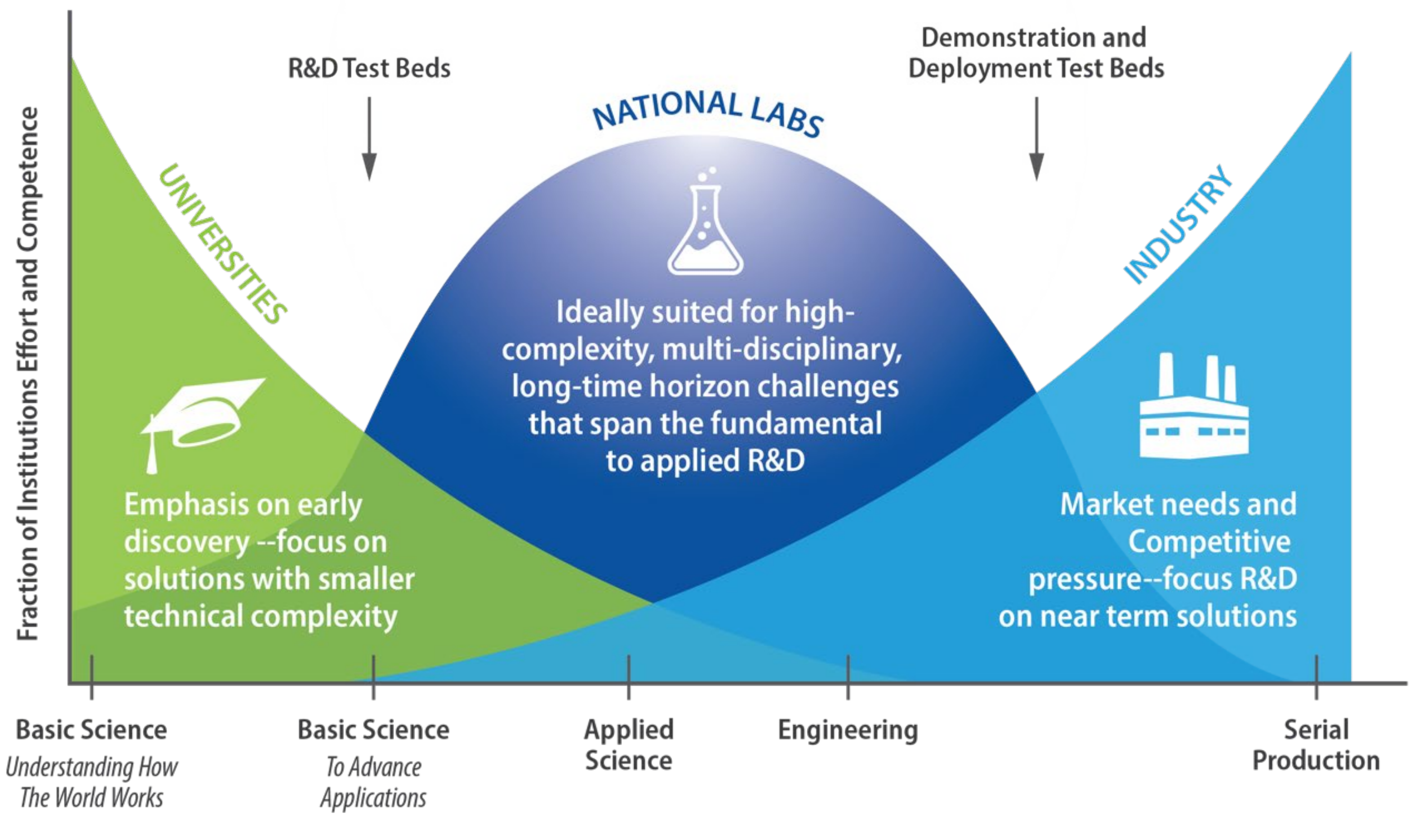
Sustaining the existing commercial reactor fleet and expanding deployment of nuclear energy



Overview of SMRs: Solution approaches

Solution approach: A synergistic approach among industry, academia, government.

- **Licensing Focus:** SMRs 4D+ phase should maintain global codes, standards, customer expectation and regulatory requirements.
- **Safety Integration:** SMRs should incorporate defense-in-depth safety strategies, including safety barriers, margins, and fail-safe design goals.
- **Risk Management:** A risk-informed decision-making approach and best estimate plus uncertainty analysis are essential to ensure safety for people, facilities, and the environment.



SMRs Status: worldwide

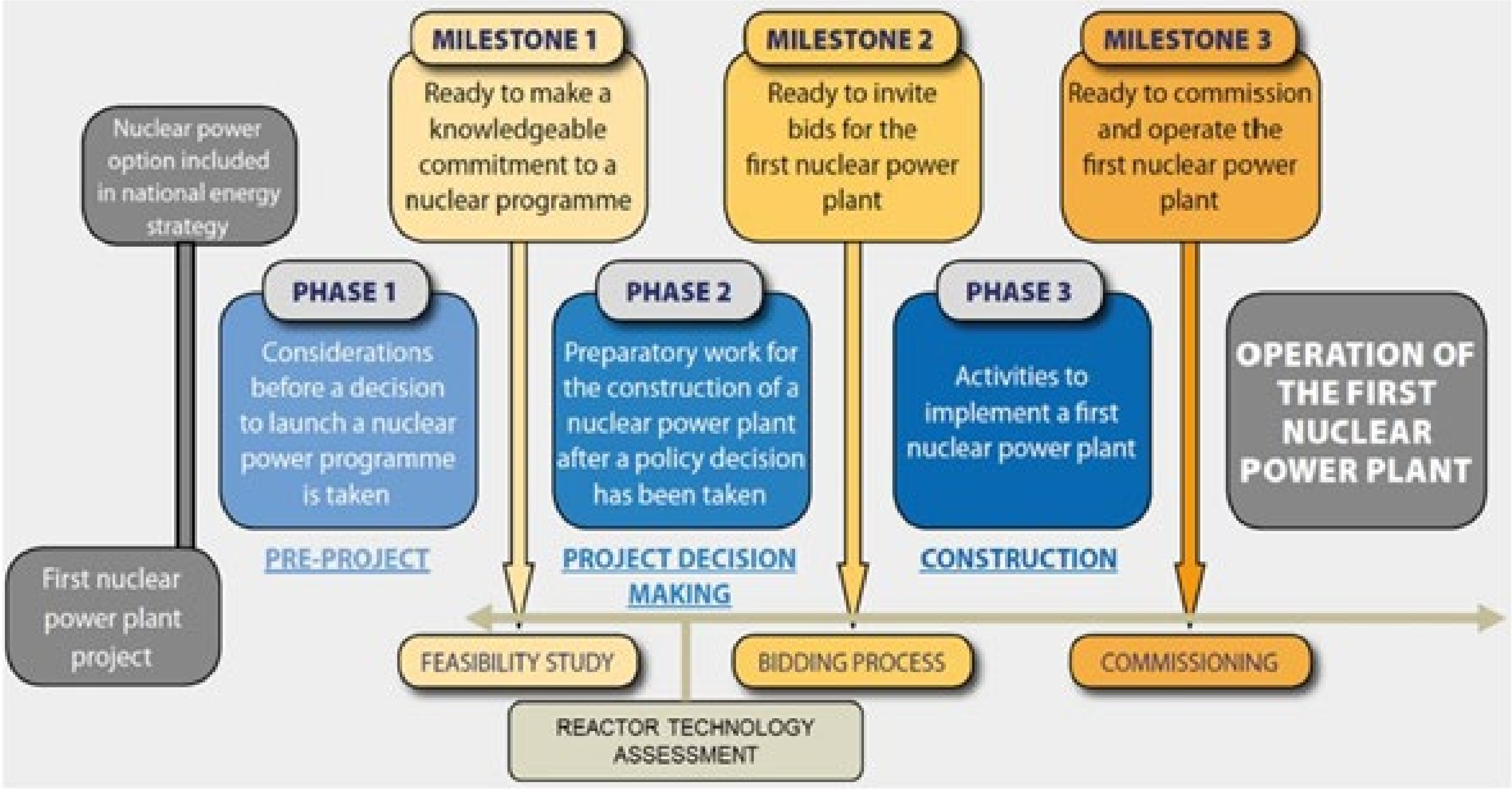
- **Types:** SMR designs vary in terms of target application, reactor type (e.g., fuel type, coolant type, power conversion type), safety system (e.g., active, passive, hybrid), fuel cycle, and plant layout.
  - Design types: Water-cooled (land or marine-based), high-temperature gas-cooled, fast neutron spectrum, Molten-salt, and micro-sized
- **Final construction stage and initial operation:** Only two SMRs
  - the Russian-Federation (RF)-developed floating power SMR, KLT4S, which began commercial operation in May 2020;
  - a high-temperature gas-cooled SMR developed by China that recently began commercial operation [2].
- **Delayed construction status: CAREM** an integral pressurized-water reactor (i-PWR)-type SMR developed by Argentina, which was scheduled to begin its civil construction in 2024, but since has been delayed due to several challenges [2][3].

SMRs Status: worldwide (cont'd)

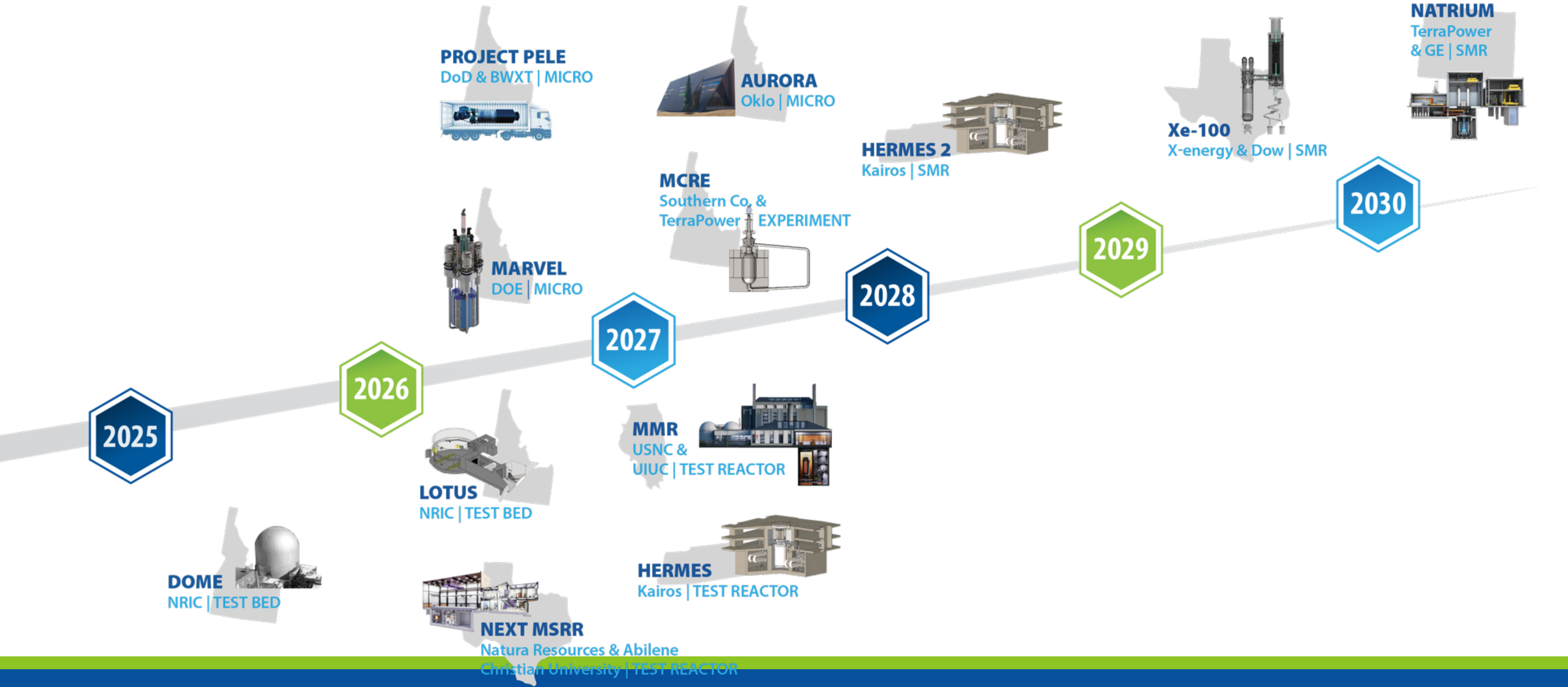
IAEA nuclear power program and reactor technology assessment and deployment phases and milestones [4], **which is equally applicable for SMRs and advanced reactors**.

Large-capacity reactors entail the following unavoidable challenges, which make SMRs more competitive, as listed below:

- Construction delays leading to increasing costs.
- Lengthy and challenging regulatory approvals:
- Supply chain challenges



SMRs and Advanced Reactor Demonstration Status: in the U.S.



SMR Status: in the U.S. (cont'd)

Our Heritage: *The National Reactor Testing Station drove nuclear innovation in the U.S. and around the world*

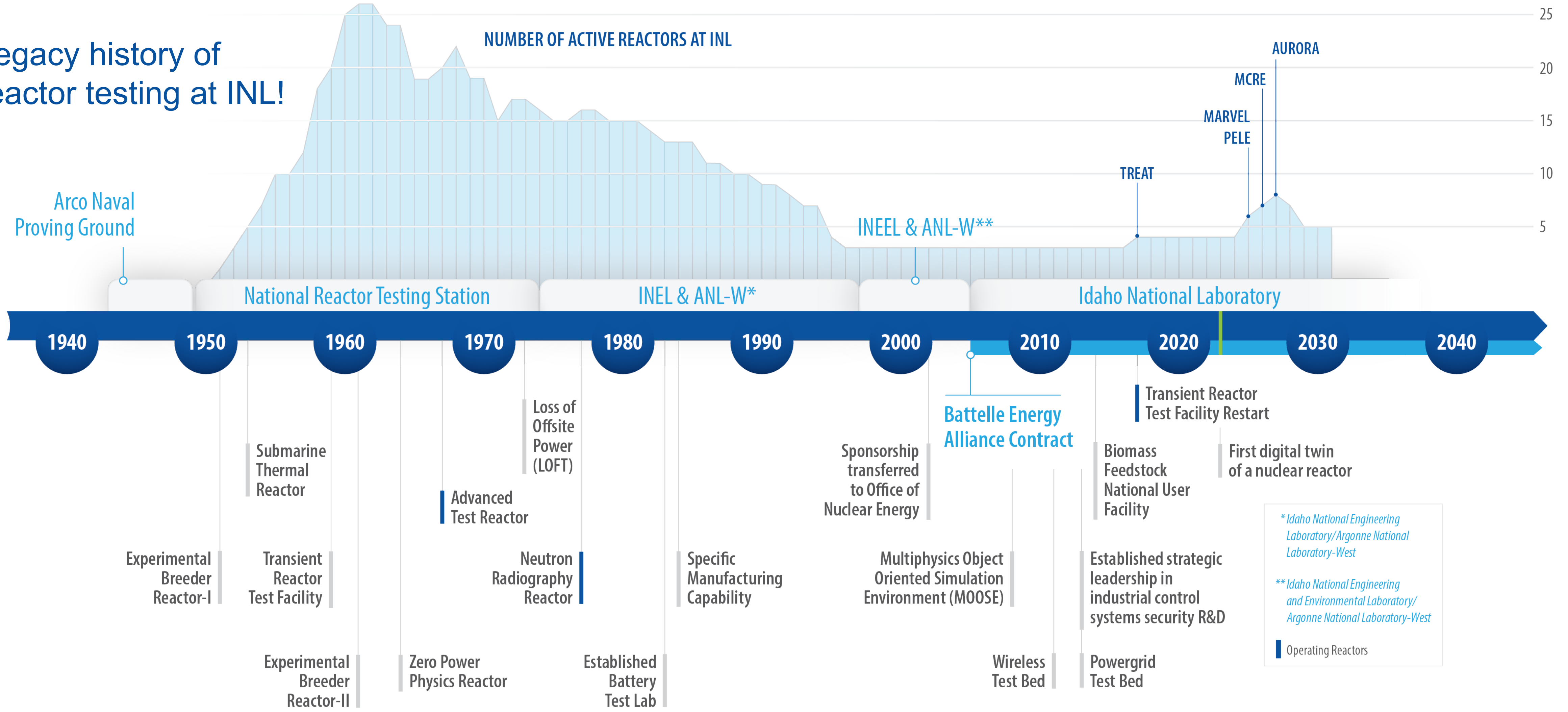
1st

- Nuclear power plant
- U.S. city to be powered by nuclear energy
- Submarine reactor tested; training of nearly 40,000 reactor operators until mid-1990s
- Mobile nuclear power plant for the army

Demonstration of self-sustaining fuel cycle	Basis for LWR reactor safety	Aircraft and aerospace reactor testing	Materials testing reactors

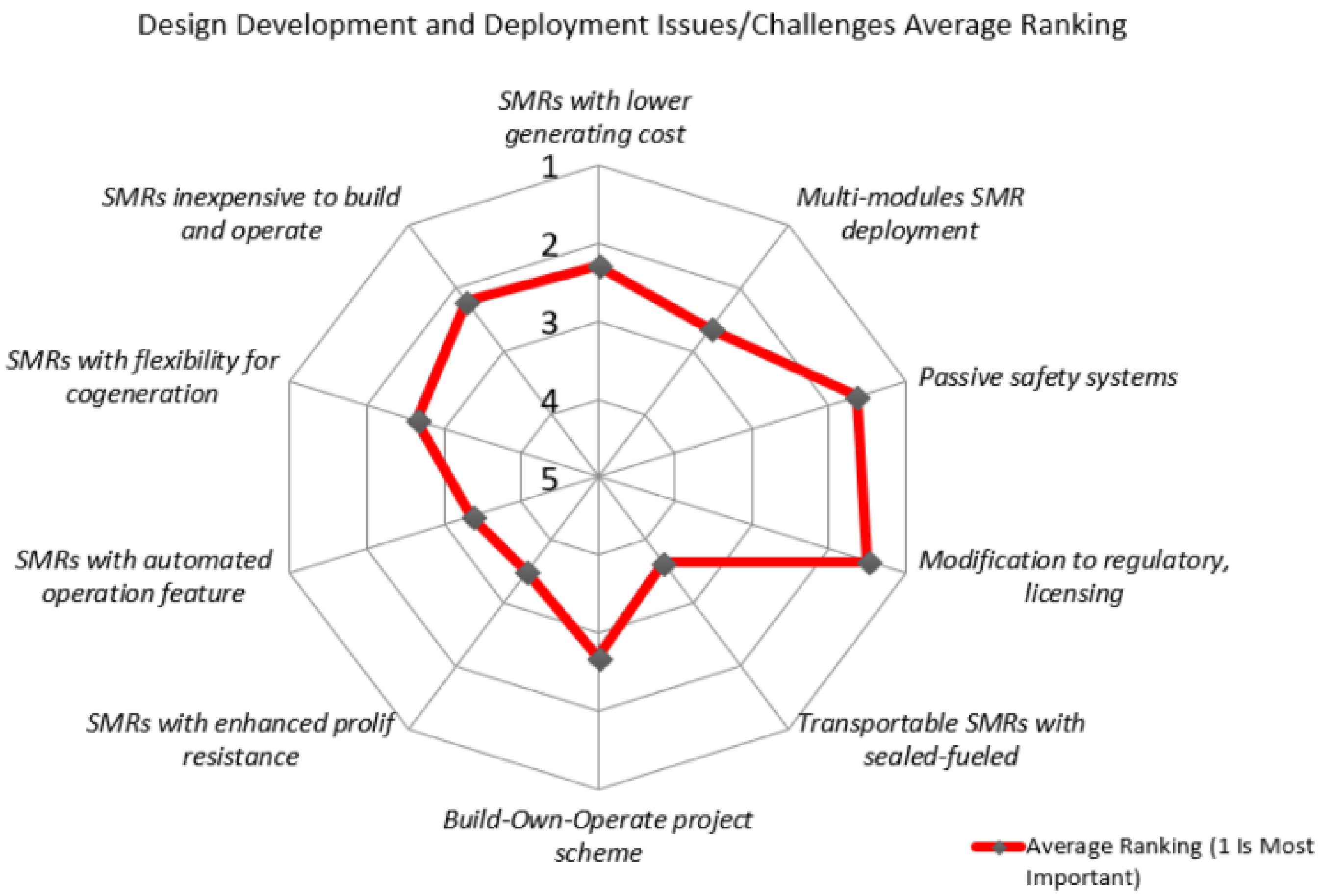
SMR Status: in the U.S. (cont'd)

Legacy history of reactor testing at INL!



SMRs Development Needs

- The general **SMR challenges are related to** new technology, complex engineering tasks, reliability issues, economic viability, licensing, and regulatory issues [5].
- Subki [6] used **expert surveys to categorize and rank the major challenges for SMR deployment**. The priorities that are indicated include: (a) necessary regulatory and licensing changes, (b) economics, (c) instruments and control, and (d) proliferation resistance.



SMRs Development Needs: Creating a secure, resilient, clean energy future

Nuclear Science & Technology

Advanced Test Reactor Complex

Materials and Fuels Complex

Energy & Environment Science & Technology

National & Homeland Security Science & Technology

SMRs Development Needs (cont'd)

- **Qualifying the advanced fuel-to-reactor design:** For a new nuclear fuel material, the time required from fuel material identification to passing the qualification process is estimated to be 20 years in the U.S. [7].

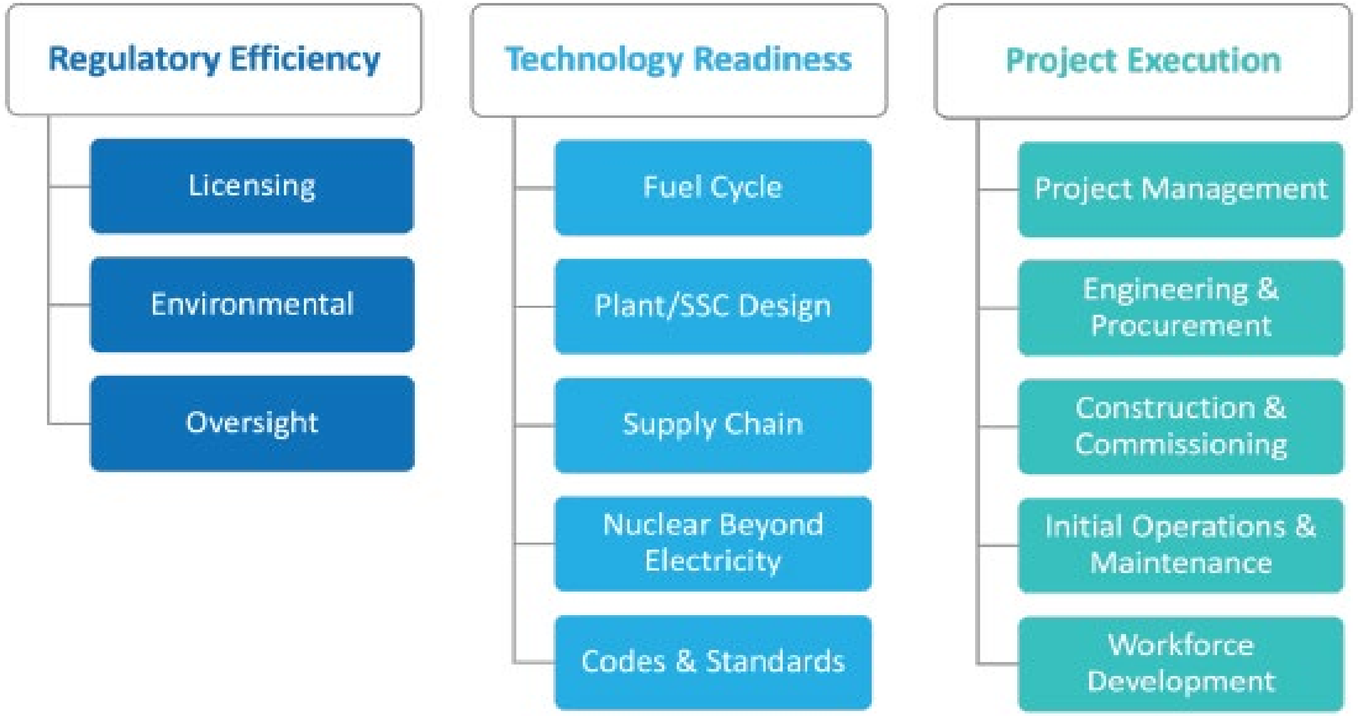
- Thus, many **SMR conceptual designs consider matured fuel materials, with final-state R&D being conducted to commercialize them**. Examples of such cases are tri-structural isotropic (TRISO) particle fuel, high-assay low-enriched uranium (HALEU) fuel, and accident-tolerant fuel (ATF) concepts.

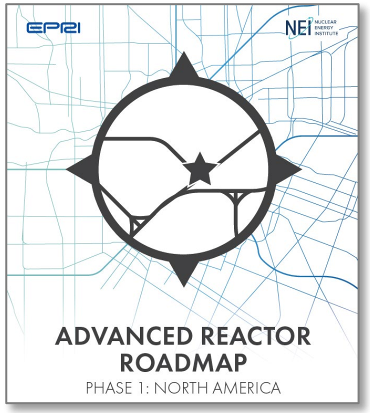
- **Supporting rapid scaled/prototypic experimentations:** Reactor system design and analysis requires appropriate use of M&S tools, and scaled-facility test data supports the Evaluation Model and Development Assessment Process (EMDAP) specified by the NRC Regulatory Guide (RG) 1.203 [8].

- **Maintaining local and global codes and standards, and meeting regulations**
- **Resolving supply chain issues**
- **Cradle-to-grave nuclear fuel cycle, including transportation**
- **Mitigating financial, environmental, and other related risks**

SMRs Development Needs: Advanced Reactors Codes and Standards Collaborative (ARCSC)

- The ARCSC was established to ensure coordination and collaboration among standards design organizations (SDOs) in the USA and Canada to support reactor designers, regulators, and other stakeholders.
- The ARCSC was established to support the Advanced Reactor Roadmap established by the Nuclear Energy Institute (NEI) and Electric Power Research Institute (EPRI)





ARCSC and its constituent SDOs and stakeholders interface with the Roadmap through the Codes & Standards element.

Source: https://arcsc.nei.org/Home

SMRs Development Needs: Priority Codes and Standards

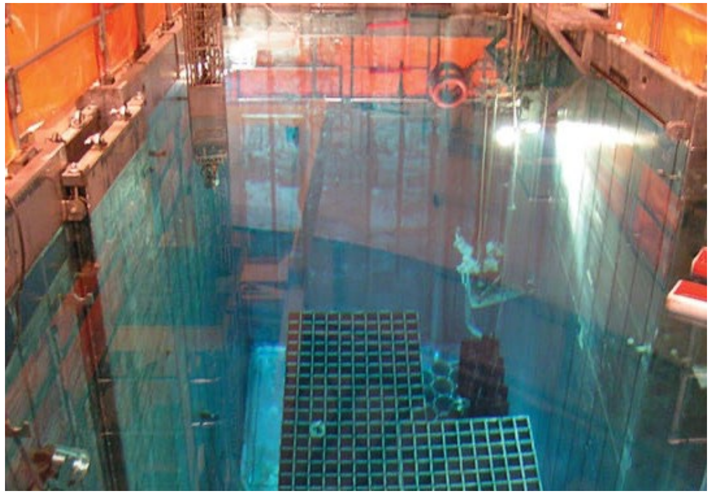
The standards that the industry identified for attention spans a broad set of technical subjects including (not limited to):

- **Performance and integrity of materials used in high temperature environments**
- **Fire protection for advanced reactor facilities**
- **Qualification and condition monitoring of electrical equipment**
- **Categorization of structures, systems and components used for seismic design**

- **Although the ARCSC focus is on codes and standards issued by organizations in the USA and Canada, there is continual engagement with international efforts to preclude duplication of efforts.**
- **International participants (WNA, IAEA, SDO Convergence Board)**

Source: https://arcsc.nei.org/Home

SMRs Development Needs: Disposition of nuclear waste is a policy and social issue, not a technical challenge



Safe, secure interim **WET** storage exists

Safe, secure long-term **DRY** storage exists

We need a national, consent-based dialogue to identify a permanent geological repository

Nuclear Waste Policy Act AS AMENDED
WITH APPROPRIATIONS ACTS APPENDED

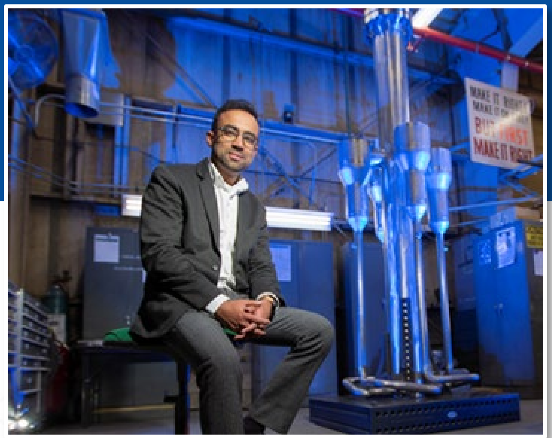
wnn
world nuclear news
Celebrating 15 years

DOE to work on relationships as waste programme develops
16 September 2022

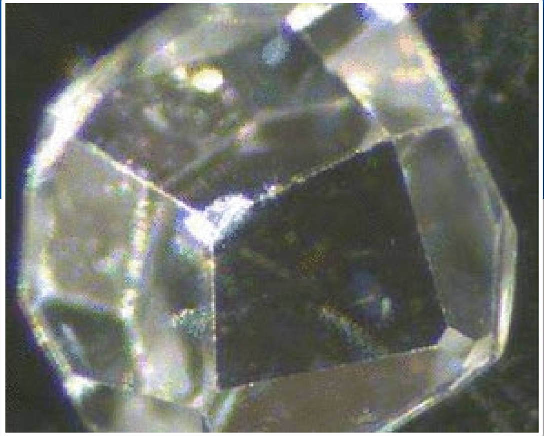
DOE Unveils Next Steps for Nuclear Waste Consent-Based Siting Process

SMRs Development Needs:
Enabling the future of nuclear energy through innovation

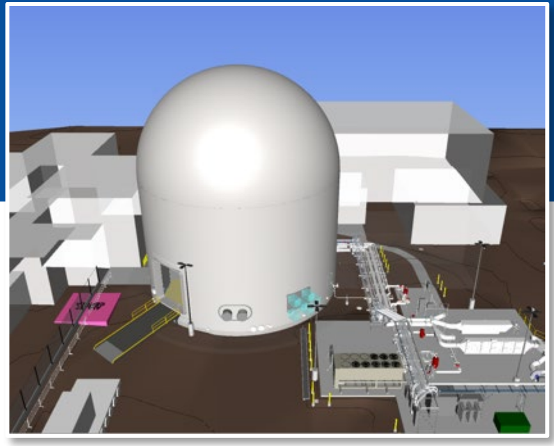
Achieving battery-like functionality for nuclear systems



Advanced Reactors



Advancing technology through fundamental science

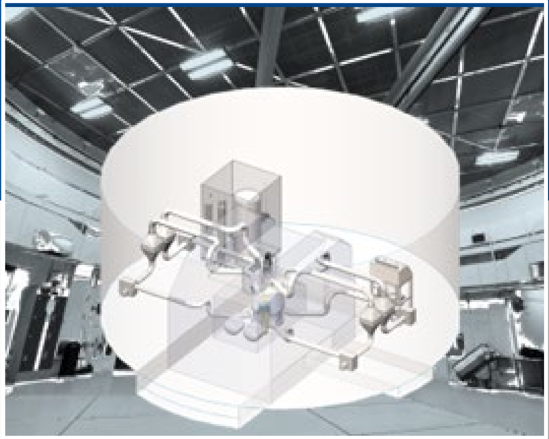


Digital Engineering

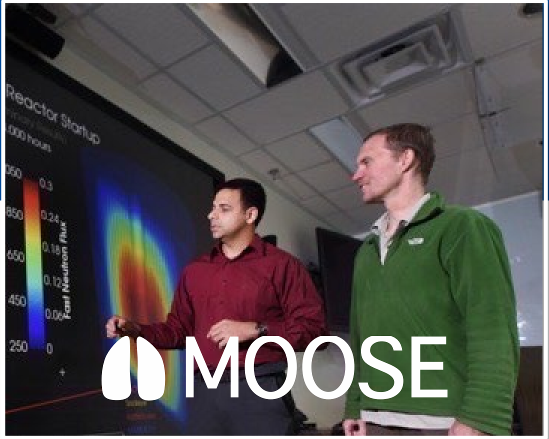
SMRs Development Needs: Expanding and deploying national nuclear energy strategic infrastructure

Advanced Post Irradiation Examination Capabilities

ATR retrofit to expand irradiation capabilities

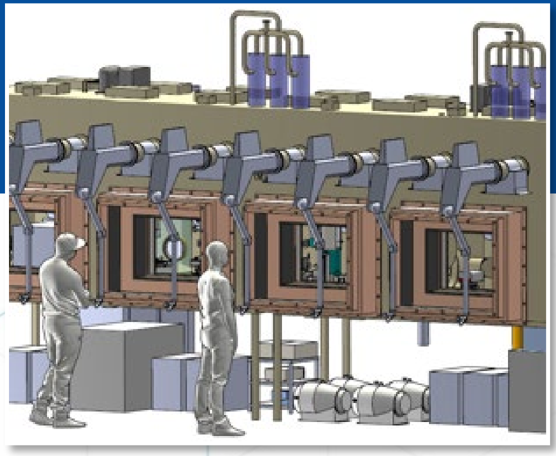


Establishing Testbeds for reactor demonstrations



High performance computing and advanced modeling and simulation capabilities

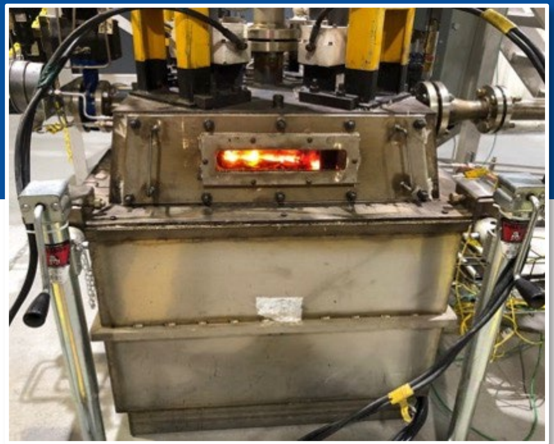
SMRs Development Needs: Leading advanced reactor fuel cycle development through RD&D test beds



Molten Salt Thermophysical Examination Capability (MSTEC)

Moran – uranium-based spent fuel test bed

Beartooth – special nuclear material test bed



Veolia's GeoMelt Engineering Scale Melt Unit

SMRs Development Needs: Discovering new technologies for sustainable clean energy integration for electricity, transportation, and industry

High-efficiency thermal energy use

Critical materials recovery

Integrated energy systems solutions

Nuclear H_2

Sustainable fuels through waste recycling

Secure vehicle charging

SMRs Development Needs: Impact of Advanced modeling and simulation tools

An Example modeling and simulation tools is MOOSE developed by INL

- Citations for Multiphysics Object Oriented Simulation Environment (MOOSE): 1,240
- 2020 MOOSE paper is the most cited paper in Elsevier Software-X
- INL papers using MOOSE: ~200
- Citations of INL papers using MOOSE: ~3,000
- 5,000+ unique visitors a month to the MOOSE website

Nuclear Entities Using INL MOOSE-Based Applications:

U.S.NRC United States Nuclear Regulatory Commission *Protecting People and the Environment* · RADIANT · BWXT Nuclear Energy Canada Inc. · *Structural Integrity Associates, Inc.®* · Kairos Power · EPRI · Westinghouse

MOOSE · BISON · Blackbear

Falcon · Griffin · Grizzly

Magpie · Marmot · Mastodon

RELAP-7 · Sockeye · Pronghorn

Conclusion and Final Remarks

The development of advanced SMRs is currently ongoing. These new reactors are being designed by prioritizing customer needs with an accelerated innovation in design, development, demonstration, deployment, and beyond (4D+) by minimizing engineering, regulatory, and economical challenges.

The following characteristics were highlighted:

- **SMRs are not a new concept; however, SMRs adopt an optimized economic scaled design for rapid deployment.** Several SMR designs are in the process of obtaining design approvals.
- **Addressing SMR engineering and regulatory challenges will support broader nuclear innovations,** including Generation IV designs. While financial hurdles are common, **SMR vendors must adhere to cost and schedule commitments for customers and regulators.**

New nuclear reactor technology providers need to understand the potential challenges and regulatory compliances to appropriately utilize their resources. Customers of these reactor technologies need to understand and evaluate the reactor design feature to select the appropriate SMR technology, associated TRL, and required regulatory approvals to make a well-informed decision.

Acknowledgements and References

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