Office of Nuclear Energy
Versatile Test Reactor (VTR) Project

Critical Decision-0
Approve Mission Need

PMRC Brief

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Briefing Outline

- Purpose / Program Mission
- Background
- Mission Need / Capability Gap
- Mission Validation Independent Review
- Rough Order of Magnitude (ROM) Cost Range
- Issues
- Summary & Recommendations

Purpose / Program Mission

- **Obtain Chief Executive (CE) approval of Mission Need, CD-0 for Versatile Test Reactor (VTR) Project at a ROM* Cost range of $3.9B to $6.0B.**

- **VTR Mission is to provide leading edge capability for accelerated testing and qualification of advanced fuels and reactor materials enabling the U.S. to regain and sustain technology leadership in the area of advanced reactor systems.**

- **The VTR would:**
  - Be a key facility to revive and expand the nuclear energy sector in the United States
  - Allow the U.S. to regain its global technical leadership in the field of nuclear energy and advance U.S. interests in nuclear safety, security and nonproliferation
  - Contribute to creation of high-paying jobs and economic prosperity
  - Train next generation of scientists and engineers needed for future viability of U.S. nuclear sector

*** ROM – Rough Order of Magnitude**

Presidential and Departmental Nuclear Energy Priorities

- President Trump ordered review of nuclear energy policy:

  “[W]e will begin to revive and expand our nuclear energy sector…which produces clean, renewable and emissions-free energy. A complete review of U.S. nuclear energy policy will help us find new ways to revitalize this crucial energy resource.”

- Nuclear energy role as clean baseload power is key to environmental challenges:

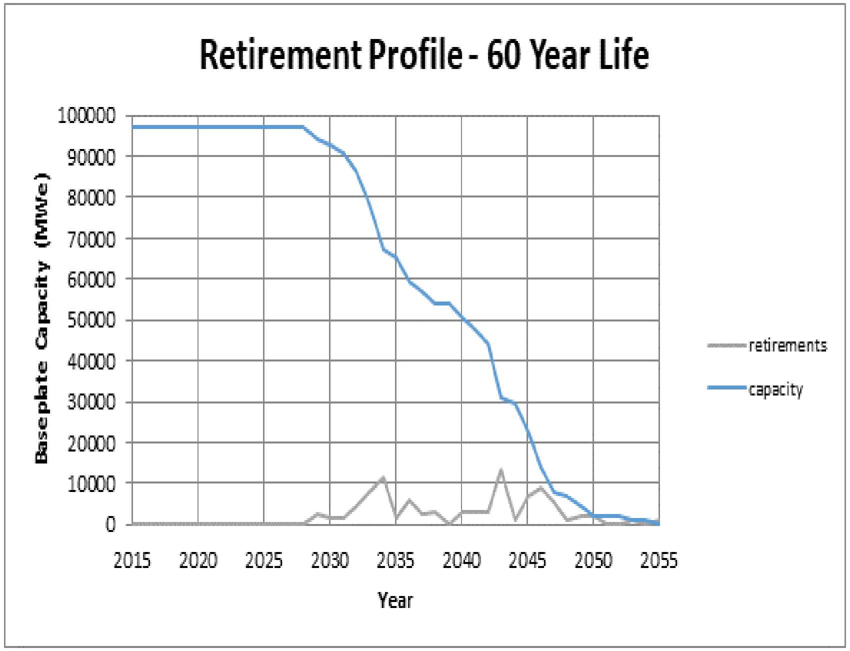
  “If you really care about this environment that we live in…then you need to be a supporter of this amazingly clean, resilient, safe, reliable source of energy.”
  Secretary Rick Perry at Press conference, May 10th

- Executive Order Promoting Energy Independence and Economic Growth
- Commercialization of advanced SMRs crucial to future of US nuclear sector

Russia, China and India have fast reactors and the U.S. does not since the shut down of Experimental Breeder Reactor (EBR)-II in 1994

Nuclear Energy Landscape – U.S.

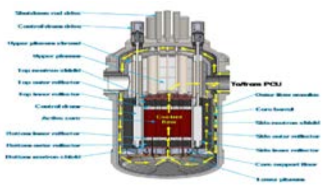
- Over 20 U.S. companies are developing advanced non-Light Water reactors
  - E.g., sodium-, gas-, lead-, molten-cooled reactors (versus LWR-cooled)
  - ThirdWay has estimated that about a billion dollars in private capital has been invested in the development of advanced nuclear systems in North America in recent years
- Motivation for Advanced Reactor Development
  - Potential for improved economics and passive safety of nuclear energy systems
  - Various options for future commercial (civilian), limited-grid and military applications
  - Reactor systems that vastly improve nuclear resource utilization, reduce nuclear waste, and reduce Green House Gases
  - Flexible operation to support the national grid of the future containing many energy-source options
  - Application of advanced manufacturing and modeling techniques to bring nuclear into the 21st century



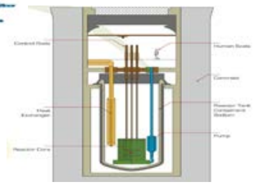
Current US fleet

Nuclear Energy Landscape – World

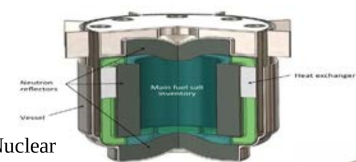
- Worldwide there are ~450 operating nuclear reactors
- Russia is the only country with operational commercial advanced reactors (sodium-cooled fast reactors)
  - BN-600 (operational since1980), BN-800 (operational since 2014), BN-1200 (planned)
- Russia, China and India have operational fast test/experimental reactors
- Some specific concepts being developed are shown below, representing a cross-section of potential new reactors



EM^2 General Atomics
TRANSACTIONS OF FUSION SCIENCE AND TECHNOLOGY Vol 61

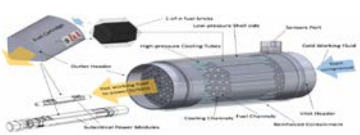


ARC 100
Courtesy ARC Nuclear



Molten Chloride Fast Reactor
Courtesy TerraPower

Traveling Wave Reactor-P
Courtesy TerraPower



HOLOS Very Small Modular
Courtesy LANL

- Russia, China, and India are seeking international leadership in nuclear

Why a Test Reactor?

INDUSTRIAL INTEREST

- Many U.S. companies are pursuing advanced reactor designs to meet the needs of the future clean energy markets
- Advanced fuels/materials/instrumentation &sensors testing is key for licensing and commercial competitiveness
  - Sodium-cooled reactors (e.g. GE-Hitachi, TerraPower)
  - Lead/LBE-cooled reactors (e.g. Westinghouse)
  - Gas-cooled reactors (e.g. General Atomics)
  - Molten salt reactors (e.g. TerraPower)
- Accelerated testing for reactor materials

Domestic deployment for clean energy transition

Global market share (~1 trillion $)

- Some concepts may be ready for a demonstration unit within 10 years
- VTR will help with continuous improvements in operations and economics beyond initial demonstration within 10 years
  - E.g. LWR technology evolution history (progress from 60 to 90% availability)

NATIONAL SECURITY/SCIENTIFIC INTERESTS

- State-of-the art knowledge of fast spectrum reactor technologies
  - Global safety and security policies
  - Safeguards technologies
- Research on long-term fuel cycles
- Potential scientific research on
  - Fusion materials
  - Neutrino science/detector development

Science and technology leadership with strong influence on international standards and policies for the civilian use of nuclear energy and associated fuel cycles.

Currently, the only fast spectrum testing capability is available in Russian Federation.

The U.S. will lose its nuclear technology leadership role to other supplier nations if advanced reactors are not commercialized in the near term, adversely impacting U.S. interests in nuclear safety, security and non proliferation.

NEAC Study Recommended Action

- The need has been established through a series of independent surveys of the potential U.S. user community (industry, DOE programs) resulting in a NEAC* report ("Assessment of Missions and Requirements for a new U.S. Test Reactor" February, 2017) submitted to and accepted by the full NEAC Committee.

- The NEAC report states that "The Ad Hoc NEAC subcommittee recommends that DOE-NE proceed immediately with pre-conceptual planning activities to support a new test reactor (including cost and schedule estimates)."

- Strong bi-partisan congressional support since the start of the pre-conceptual design activities
  - The FY 2018 appropriation of $35M and FY 2019 of $65M
  - Nuclear Energy Innovation Capabilities Act (NEICA), S. 97

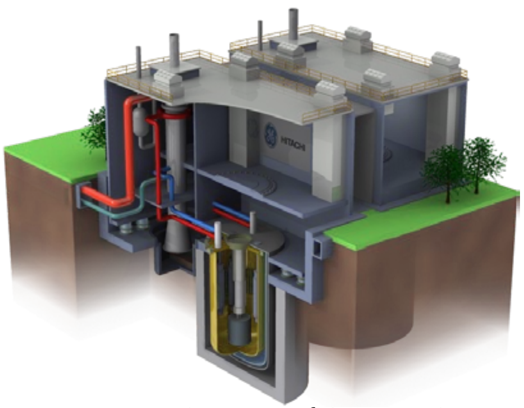
*NEAC - **Nuclear Energy Advisory Committee**

Mission Need / Capability Gap

- **Mission Need Statement**
  - The United States needs domestic fast spectrum testing capability to test advanced nuclear fuels, materials, instruments and sensors in prototypic environments for successful development and deployment of advanced nuclear reactor technologies.
  -
- **Internal or External Drivers**
  - Nuclear Energy Innovation Capabilities Act (NEICA, S.97)
  - Administration Priorities (Civil Nuclear Energy Policy Review)
  - Industry
  - Nuclear Energy Advisory Committee (NEAC)
  - Lack of adequate international facilities
  - Interest from France, Japan, ROK
- **The VTR would provide additional opportunities to:**
  - Nuclear Regulatory Commission (NRC) for enhanced understanding of advanced technology and informing approaches for NRC licensing of future commercial advanced reactors by providing a test bed for their regulatory initiatives such as Licensing Modernization Project.
  - NNSA for development of advanced detection capability for material accountability and control, e.g. neutrino detectors.
  - Fusion community for materials research.

VTR Planning Incorporates Lessons Learned

- Nuclear build risks and mitigations are a focus
  - Design completion
  - Authorization documentation
  - Supply chain and construction planning
  - Cost estimate and schedule
  - Quality and independent review processes
  - Acquisition processes



Courtesy of GE-HITACHI

- VTR planning includes:
  - Strong focus on identification and mitigation of nuclear project risks, such as design completion of high risk items prior to establishing baseline/ start of construction and supply chain efficacy confirmation
  - Independent reviews by a reactor designer: TerraPower
  - Use of proven reactor concepts and mature technology
  - Leverage existing reactor development efforts by modifying an existing design concept, fabrication plans, schedule, and cost estimate

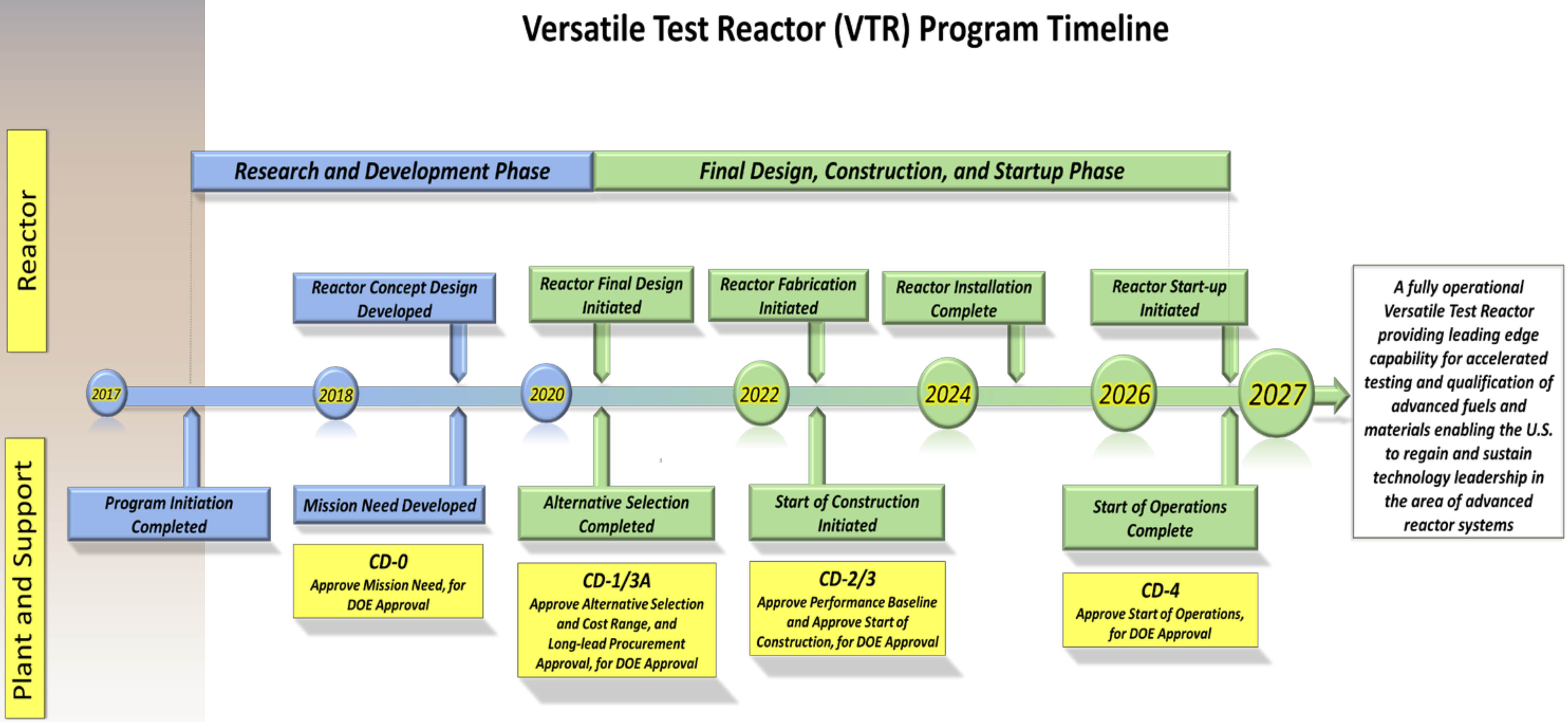
Assumptions and Constraints

- VTR would be ~300MWth, fast spectrum reactor and would not produce electricity
  - DOE Authorization of VTR in conjunction with planned NRC collaboration lowers acquisition risk for safety basis and shortens schedule.
- Effective utilization of expertise from national labs, universities and industry
- Early and strong engagement with PM* and leverage 413.3B requirements to reduce risk; Early performance of some elements to reduce risk
- Plan to seek CD 3A, Long Lead Procurement: Proof of supply chain by utilizing test article fabrication to required quality standards for all potentially problematic components prior to baseline; USNIC* engaged to assist in supply chain
- Fissile source available in time to support deployment schedule
- Sufficient funding appropriated to support deployment schedule

* PM – Office of Project Management

* USNIC – United States Nuclear Industry Council

VTR Program Timeline



Mission Validation Independent Review (MVIR) Results
(For Major System Projects)

- **The MVIR for VTR establishes that the capability requirement is viable, necessary, and validates the mission need.**
- **MVIR summarizes the independent review conducted by the Nuclear Energy Advisory Committee (NEAC). The review included an assessment of user needs and confirmed the need for a U.S. fast spectrum test reactor.**
  - NEAC recommended that, "DOE-NE proceed immediately with pre-conceptual design planning activities to support a new test reactor (including cost and schedule estimates)"
- **Nuclear Energy Innovation Capabilities Act (NEICA, S.97) directs the Secretary, to the maximum extent practicable, complete construction of, and approve the start of operations for the facility by no later than December 31, 2025.**
- **The Office of Project Management (PM) assessment of the Mission Need Statement (MNS) concluded that the mission need aligns with the Department's mission, strategic plan, and priorities of the President and Secretary, and addresses a credible capability gap.**
- **The Office of Nuclear Energy Validates the mission need as documented in the MVIR.**

ROM Cost Range

VTR Cost Ranges ($ billion)

Project Team		ICR Team	
ROM Cost Range	**$3.9–$5.5**	**ROM Cost Range**	**$4.3–$6.0**

- Rationale for the difference:
  - Project team used an escalation of 3.23% whereas the ICR used an escalation of 3.8%. The escalation used by the project team is considered appropriate because of historical data available at Idaho National Lab (INL).
  - Project team estimate utilized very conservative equipment scaling. For example, a hot cell facility that was included in Fast Flux Test Facility (FFTF) was not removed in the project team scaling.
  - Project team use of mature technology assumption has now been validated.
  - ICR used large uncertainty factor in historical systemic cost growth crosscheck due to prior DOE project experience – VTR adopting all best practices such as final design complete prior to construction award.

Issues

- **Funding profile**
  - Funding support will play a significant role in determining the overall cost and completion of the project. The required funding profile for the VTR project is significantly higher than NE’s budget in recent history.

- **Fissile source material**
  - Timely availability of the fissile source material will be critical to the success of the project. A decision on the type and source of the fissile material is required by December 2019 to provide sufficient time for developing the design and establishing the capabilities for fuel fabrication and fuel cycle management.
    - U-Pu-Zr is the preferred fuel alloy
      - Need to decide on Pu feedstock and its characteristics
    - High-Assay LEU-Zr alloy may be an option for startup but does not meet the neutron flux requirement unless a much larger reactor is deployed

CD-0 Check List

- The Project has completed all necessary requirements for CD-0 approval

Deliverable	Status
Mission Need Statement	Complete – December 10, 2018
Mission Validation Independent Review	Complete – January 14, 2019
Project ROM Cost Range (consistent with GAO 12 step best practices)	Rev 0 Complete – September 27, 2018 Revised after ICR – January 11, 2019
Independent Cost Review	Complete – December 13, 2018
Safety in Design Expectations for Hazard Category 1,2,3 Nuclear Facilities	Complete – November 13, 2018

Summary

- **VTR is essential for the U.S. to regain a global leadership role in development of the next generation of advanced reactors and to revive and revitalize our nuclear infrastructure.**
- **If the United States foregoes the timely development and commercialization of advanced reactors, other supplier nations will assume future nuclear technology leadership and will engage in the export of their systems. This scenario would adversely impact US interests in nuclear safety, security and nonproliferation.**
- **Nuclear Energy Innovation Capabilities Act (NEICA, S.97) directs the Secretary, to the maximum extent practicable, complete construction of, and approve the start of operations for the facility by no later than December 31, 2025.**
- **The risks associated with Nuclear Construction are being adequately factored in project planning.**
- **The Mission Need Statement has been approved by the Office of Nuclear Energy.**

Request for Approval

- **Approve CD-0 for the Versatile Test Reactor Project**

- **ROM Cost Range: $3.9B to $6.0B**

Back-Up Material

ICR Results

- **The Office of Project Management Oversight and Assessments (PM) conducted an Independent Cost Review (ICR) per DOE Order 413.3.B in December 2018.**
- **ICR results:**
  - The project team developed a credible estimate in general alignment with the U.S. Government Accountability Office (GAO) best practices.
  - the cost range should be expanded to increase the confidence that appropriate allowances have been made for risks and uncertainties.
  - Determined a ROM range of $3.7B to $5.1B (FY 2019 dollars), and $4.3B to $6.0B in escalated dollars using an escalation of 3.8%, which was outside the cost range the project developed.

Strong Engagement with Mission Stakeholders

- Industry stakeholders will be engaged to participate in the development of experimental vehicles for sodium, lead, gas fast reactor, and molten salt reactor fuels.
- First year goal for industry partners is to concepts for test vehicles required to inform core design.

Key University and Industry Experiment Development Collaborations			
Collaboration Area	Lead Lab	University Collaborator	Industry Collaborator
Sodium Cooled Fast Reactor	ANL	University of Wisconsin Madison	Framatome
Lead/Lead LBE-cooled Fast Reactor	LANL	University of New Mexico	Westinghouse
Molten Salt Reactors	ORNL	University of Utah, University of Idaho	TerraPower
Gas Cooled Fast Reactor	INL	Texas A&M University	General Atomics
Virtual Design & Construction	INL	North Carolina State University	General Electric - Hitachi
Structural Materials Testing	LANL	Oregon State University	EPRI
Data Analytics Combined with M&S	INL	Abilene Christian University, Colorado School of Mines, Georgia Tech, Massachusetts Institute of Technology	Hierarchical Data Format (HDF) Group
Rabbit Systems	PNNL	Texas A&M University	
Strategic Initiatives	INL	University of Pittsburgh	

U.S. Advanced non LWR Concepts

Advanced Non-Water Reactor - Large:							
Power Reactor for Innovative Small Module (PRISM)	SFR	370 – for 165, 311, see below	Metal	Sodium	GE, USA	Reviewed preliminary license application	1980s -1990s, 2013 & 2014
Traveling Wave Reactor (TWR)	SFR	600 (1150)	Metal	Sodium	TerraPower, USA	Under design	2014
Chloride Molten Salt Fast Reactor (CMFR)	MSR	1000	Molten salt	Molten salt	TerraPower/Southern Company, USA	Under design	2015
Transatomic power (TAP)	MSR	520	Molten salt	Molten salt	Transatomic Power, USA	Under design	2016 & 2017
Advanced Non-Water Reactor – SMR:							
Advanced Reactor Concept (ARC-100)	SFR	100	Metal	Sodium	ARC, USA	Under license appli-cation	Collaboration with ANL
Power Reactor for Innovative Small Module (PRISM)	SFR	370, for 165, 311, see above	Metal	Sodium	GE, USA	Reviewed preliminary license application	1980s -1990s, 2013 & 2014
Oklo	SFR	2	Metal	Sodium	Oklo, USA	Under design	2016 & 2017
Demonstration Lead-cooled Fast Reactor (DLFR)	LFR	210	Oxide(Nitride)	Lead	Westinghouse, USA	Under design	2013 & 2014
Amphora-Shaped Lead-cooled Fast Reactor (LFR-AS-200)	LFR	200	Oxide	Lead	Hydromine, USA	Under design	
Columbia Basin Consulting Group	LFR	~100	Oxide (initially)	Lead-bismuth eutectic (LBE)	CBCG, USA	Under design	2016

U.S. Advanced non LWR Concepts - Continued

The Do-able Molten Salt Reactor (Thorcon)	MSR	250	Molten salt	Molten salt	Martingale Inc., USA	Under design	
Thorenco	MSR	40	Molten salt	Molten salt	Thorenco, USA	Under design	
Liquid Fluoride Thorium Reactor (LFTR)	MSR	250	Molten salt	Molten salt	Flibe Energy, USA	Under design	
Energy multiplier module (EM2)	GFR	240	Carbide	Helium	GA, USA	Under design	2013 & 2014
XE-100	HTGR	48	Pebble Bed	Helium	X-Energy, USA	Under design	2015
U-Battery	HTGR	4	TRISO	Helium	URENCO	Under design	
STARCORE	HTGR	20	TRISO	Helium	STARCORE, Canada	Under design	
Kairos Power Reactor	FHR	TBD	Pebble Bed	Fluoride salt	KAIROS, USA	Under design	2017
Advanced Fast Reactor (AFR-100)	SFR	100	Metal	Sodium	ANL, USA	Under design	DOE Concept
Gen4 Module	LFR	25	Nitride	LBE	Gen4 Energy, USA	Under design	2013
Small Modular Advanced High Tempera-ture Rector FHR (SmAHTR)	FHR	50	TRISO	Fluoride salt	ORNL, USA	Under design	DOE Concept
Gas-turbine, modular helium cooled reactor (GT-MHR)	GCR	~300	TRISO	Helium	General Atomic, USA		1980s - 2000s
Next Generation Nuclear Plant (NGNP)	HTGR	100 - 300	TRISO	Helium	INL, USA	Under design	DOE Concept
Hybrid	HTGR	~300	TRISO	Helium	Hybrid, USA	Under design	

Version: July 2015