Assessing the Potential of Advanced Reactor Concepts and Advanced SMRs

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Overview

- The Technical Review Panel Process
- Identifying R&D Needs of Advanced Reactors and SMRs
- Challenges and Potential Benefits of Advanced Reactors
- Representative Advanced Reactor Designs
Develop improvements in the affordability of new reactors

- Support R&D of advanced reactor technologies that offer lower costs and waste generation
- Investigate revolutionary concepts that promise to significantly reduce costs and improve performance
- Support R&D of nuclear energy’s potential to displace fossil fuels in production of process heat
Advanced Reactor Technologies

- **New innovative technologies**
  - GEN IV based designs

- **Advanced Reactor Concepts**
  - Fast Reactors
  - High Temperature Reactors
    - Next Generation Nuclear Plant Demonstration Project
  - Supercritical CO₂ Brayton Cycle Energy Conversion

- **Advanced SMR Program**
  - Instrumentation, Controls and Human-Machine Interface
  - Materials, Components and Technology Development
  - Safety, Regulatory Framework, and Safeguards
  - SMR Assessments (Performance and Economic Analysis)
Purpose

- DOE has been seeking greater interaction with industry and other external entities for development of the Advanced Reactor R&D program.
- Reactor Concepts Technical Review Panel was formed to evaluate attributes of advanced reactor concepts and to identify R&D needs.
- DOE/NE will use TRP results to inform and prioritize R&D activities.

Process

- A Request for Information (RFI) was issued by DOE-NE in early 2012 to solicit inputs on proposed advanced reactor concepts
- Eight concept submittals from vendors were received in response to the RFI
- TRP evaluated concepts and identified R&D needs
- Laboratory team and DOE prepared three reports on the results:
  - A detailed report for DOE use
  - A 20 page public report – now on the NE website (http://energy.gov/ne)
  - Concept specific reports that are excerpts of the detailed report
TRP process will have several positive benefits by providing:

- An opportunity for industry, universities and national laboratories to put forward viable concepts for R&D funding consideration.
- A fair and equitable process for evaluating concepts, including advanced reactors and advanced SMRs.
- A means to justify R&D resource allocation to stakeholders such as OMB and Congress.
- Strong technical basis in identifying R&D gaps, R&D needs, priorities and funding requirements.
Concepts Received:

- **GE Hitachi Nuclear Energy** – GE PRISM and Advanced Recycling Center Sodium Fast Reactor (SFR)
- **Gen4 Energy** - Lead-Bismuth Fast Reactor (LFR)
- **Toshiba Corporation** – 4S Reactor Sodium Fast Reactor (SFR)
- **Westinghouse Electric Company** – Thorium-fueled Boiling Water Reactor
- **Westinghouse Electric Company** – Thorium-fueled Advanced Recycling Fast Reactor
- **General Atomics** – EM2, High Temperature Gas-Cooled Fast Reactor
- **Flibe Energy** – Liquid Fluoride Thorium Reactor (LFTR)
- **Hybrid Power Technologies** – Hybrid-Nuclear Advanced Reactor (HTGR + natural gas plant)
TRP Evaluation Criteria

1. Safety
2. Security
3. Ability to improve uranium resource utilization and minimize waste generation
4. Operational capabilities
5. Concept maturity
6. Fuel and Infrastructure considerations
7. Market attractiveness
8. Economics (construction, manufacturing, and operating costs)
9. Potential regulatory licensing environment (advantages and uncertainties/risks)
10. Nonproliferation
11. Research and development needs.
Technical Review Panel Membership

- **DOE National Laboratories**
  - Six panel members from four national laboratories

- **Academia**
  - Three panel members from universities

- **Nuclear Industry**
  - Four panel members from industry
Common need areas that apply to a majority of advanced concepts

- Development of licensing approaches for advanced reactor concepts
  - Development of an advanced reactor regulatory strategy. (Identified by most TRP members and concept providers.)
  - Development of advanced safety analysis tools.
- Accelerated demonstration and development of Brayton cycle technologies
  - Supercritical CO2 cycle offers compelling reductions in size and cost of the power conversion system.
- Development of validated advanced reactor analysis methods
  - Development of advanced neutronics, thermal-hydraulics, and mechanical analysis tools to provide credible capabilities to design advanced concepts, and understand the design margins.

Reactor technology areas (with concepts participating in the TRP process) for which priority R&D investments are warranted.

- Sodium-cooled Reactors
- Gas-Cooled Fast Reactors
- Lead-Bismuth Eutectic-cooled Reactors
Specific R&D Needs Identified by TRP Members and Concept providers

- SFR thermal hydraulic analysis
- SFR steam generator operations under extreme modes.
- Technologies for under sodium viewing
- Advanced metal fuels for sodium cooled reactors
- Development/qualification of EM pumps
- LBE natural circulation fluid dynamics validation
- Advanced structural materials resistant to erosion/corrosion by LBE
- Trade study associated with oxide and nitride fuel for the LBE reactor
- Erosion/corrosion mechanisms and control approaches in LBE
- Ceramic reflector system for a gas fast reactor
- Silicon Carbide Composite material
- Fuel cladding system for high burnup, high temperature fuel
- Safety system for GFRs
- Safety studies for advanced designs
- Design and testing of reactor components
Actions Taken After Completion of TRP Review

- Posted TRP public report
- Provided TRP concept specific reports to concept providers
- Issued solicitation for cost-shared funding for industry to lead select R&D activities identified by TRP process
  - Award announcement expected in June 2013
- Continued support for supercritical CO$_2$ Brayton Cycle energy conversion system
- Initiated project with NRC to develop a Regulatory Strategy for Advanced Reactors
Both TRP members and advanced reactor designers noted need for regulatory strategy for non-light water advanced reactors.

DOE and NRC have agreed to pursue development of General Design Criteria (GDC) for advanced reactors as a first step in establishing a Regulatory Strategy for advanced non-light water reactors.

This initiative will pursue the following objective:

- Develop GDC for advanced reactors to address compliance with 10CFR50.34, Principal Design Criteria.
Challenges for Advanced Reactor Deployment

- Licensing
- Solving Design Issues
  - Materials
  - Fuel Design and Qualification
  - I&C issues
  - Component design and testing
  - Erosion corrosion

- Lack of Cost information – both Overnight Construction Costs and Levelized Cost of Electricity
- Resistance to procurement of a First of a Kind design
- Risks associated with cost and licensing
- Proving that there are advantages to advanced reactors
Potential Benefits of Advanced Reactors

- Inherent safety characteristics
- Improved economic competitiveness through efficiency improvements
- Process heat applications
  - Expand use of nuclear energy beyond electricity generation
- Modular construction
  - Ability to build on gains made in constructing LWR SMRs
- Resource management
  - Potential uranium utilization savings
- Waste management
  - Use of fast spectrum neutrons for transmutation/actinide burning
- Long-lived cores
  - Higher burn-up fuel
Representative Advanced Reactor Designs

**Advanced SMRs**
- Gen4Energy*
- General Atomics EM2*
- GE-Hitachi PRISM*
- Toshiba 4S*
- FLIBE Thorium Reactor Concept*

**Advanced Reactors**
- TerraPower
- Westinghouse Thorium Fast Reactor*
- Westinghouse Thorium BWR*
- Hybrid Power Technologies’ Nuclear Advanced Reactor Concept*

*TRP process participants*
Gen4Energy Concept

- **Small Fast Reactor**
  - 25 MWe
  - Lead-bismuth eutectic (LBE) coolant
  - Uranium nitride fuel
  - No onsite refueling
  - Focus on transportable, small size concept
General Atomics EM2 Concept

- **Small Fast Reactor**
  - 245 MWe
  - Helium coolant
  - Uranium carbide fuel
  - Vented fuel for high burnup
  - 30 year refueling cycle
  - High temperature process heat
  - Brayton cycle with 49% efficiency
  - Focus on high temperature applications
GE-Hitachi PRISM Concept

- **Small Fast Reactor**
  - 300 MWe
  - Sodium coolant
  - U-TRU metal alloy fuel
  - 1.5 year refueling cycle
  - Design life of 60 years
  - RVACS passive decay heat removal from vessel by air
  - Modular construction
  - Barge transportable
  - U.S. ALMR Program concept for closed fuel cycle
  - Recent proposal by GE-Hitachi for use by UK for plutonium disposition
Toshiba 4S Concept

- Small Fast Reactor
  - 50 MWe
  - Sodium coolant
  - Uranium metal alloy fuel
  - Design life of 60 years
  - 10 year refueling cycle
  - Long, thin core with reflector control
  - Focus on distributed customers at remote sites
TerraPower Traveling Wave Reactor

**Fast Reactor**

- 550 MWe prototype
- Sodium coolant
- Uranium metal alloy fuel
- Once-through high burnup targeted
- Design life of 60 years
- Focus on uranium utilization

![Diagram of Fast Reactor](image)

- Turns depleted uranium into electricity, using a simple fuel cycle without requiring separations.

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Westinghouse Thorium-Fueled Fast Reactor Concept

- **Fast Reactor**
  - 410 MWe
  - Sodium coolant
  - Thorium-TRU fuel
  - 1 year refueling cycle
  - 60 year design life
  - Pool design without intermediate loop
  - Double-walled steam generator
  - Focus on consumption of recycled TRU
Westinghouse Thorium-Fueled Boiling Water Reactor Concept

**Boiling Water Reactor**

- 1356 MWe
- Water coolant
- Thorium-TRU fuel
- 1 year refueling cycle
- 60 year design life
- Ex-vessel features similar to the Advanced Boiling Water Reactor (ABWR) design
Hybrid Power Technologies’ Nuclear Advanced Reactor Concept

- **High Temperature Gas Reactor**
  - 850 MWe
  - Helium coolant
  - UO2 TRISO fuel
  - 2 year refueling cycle
  - 40 year design life
  - Reactor powers the compressor for a natural gas combustion turbine
FLIBE Thorium-Fueled Reactor Concept

**Thermal Reactor**
- 40 MWe
- Lithium-Fluoride/Beryllium Salt coolant
- Thorium-fuel in the coolant
- 5-10 year design life
- Nitrogen Brayton Cycle conversion system
The Technical Review Panel process:
- Evaluated reactor concepts from industry
- Identified research needs and priorities
- Highlighted need for an advanced reactor regulatory strategy.

DOE and NRC seek to develop a Regulatory Strategy for advanced reactors and advanced SMRs

U.S. fast reactor R&D is focused on key technology innovations for performance improvement (cost reduction)
- Advanced Structural Materials
- Advanced Energy Conversion
- Advanced Modeling and Simulation

U.S. reactor vendors are proposing fast reactor concepts for
- Small reactor applications
- Fuel cycle applications