Highlights of DOE Nuclear Reactor Technologies Program

SFANS Meeting
Paris France

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Outline

Nuclear Energy

- Small Modular Reactors

- Generation IV Reactors
  - Supercritical CO₂ Brayton Cycle
  - Licensing Framework
  - Advanced Test / Demonstration Reactor
SMRs can be Game Changers

“Small Modular Reactors represent a new generation of safe, reliable, low-carbon nuclear energy technology and provide a strong opportunity for America to lead this emerging global industry.”

“To cut pollution from our power plants, we will need to deploy an all-of-the-above strategy that leverages the work DOE is already doing on nuclear energy, natural gas, carbon capture, along with renewable energy and energy efficiency.”

Secretary Moniz’ response to President Obama’s Clean Power Plan – Aug 3, 2015
SMRs Could Potentially Replace Retiring Coal Plants

Clean Energy Market

Σ = 120 GW(e)
In 2012, DOE initiated a 6 year/$452M program

Accelerate commercial SMR development through public/private arrangements
- Deployment planned in 2022 to 2025

Provide financial assistance for design, certification and licensing of promising SMR technologies with high likelihood of being deployed at domestic sites

mPower and NuScale have been selected for the Department of Energy’s $452M SMR Licensing Technical Support Program
Tennessee Valley Authority Clinch River Site

- Developing Early Site Permit (ESP)
  - Reference generic Plant Parameter Envelope, not a specific technology
  - Clinch River Site Environmental Report – late 2015
  - ESP application to NRC – early 2016

- Reactor Technology selection mid-2017

NuScale Utility Partnered with Utah Associated Municipal Power Systems (UAMPS)

- Site-related activities needed to develop license application
- UAMPS COLA submittal – early 2018
DOE Evaluating Federal Siting Options for SMRs

- Long Island/NYC
- Washington Metro
- Hampton Roads, VA
- Eastern North Carolina
- Eastern Tennessee
- South Carolina/Eastern Georgia
- Chicago Metro
- Western Ohio
- Southern California
- Central Colorado
- Oklahoma/North Texas
- South Central Texas
- Florida Panhandle

Plant Size by Zip Code (Combined Sites - MWe)
- ▪ 1.0 - 5.0
- ▫ 5.1 - 10.0
- ◼ 10.1 - 20.0
- ▼ 20.1 - 40.0
- ☣ 40.1 - 80.0
- ☢ More than 80.0
Emerging Domestic Driver for SMRs

Climate Action Plan – June 2013
- Reduce greenhouse gas emissions by 30% by 2030

Executive Order #13693 - March 19, 2015
- Reduce Federal facility greenhouse gas emissions 40% by 2025
- Defines "clean energy" to include alternative energy
  - Definition of “alternative energy” includes “small modular nuclear reactor technologies”

Clean Power Plan – August 3, 2015
- Sets flexible and achievable standards to reduce carbon dioxide emissions by 32% from 2005 levels by 2030
- Provides flexibility to States to choose how to meet carbon standards
  - Include renewables, energy efficiency, natural gas, nuclear and carbon capture and storage
  - New nuclear power (including under construction) and nuclear uprates count towards compliance
Generation IV International Forum

U.S. DEPARTMENT OF ENERGY

Early prototypes
- Calder Hall (GCR)
- Douglas Point (PHWR/CANDU)
- Dresden-1 (BWR)
- Fermi-1 (SFR)
- Kola 1-2 (PWR/VVER)
- Peach Bottom 1 (HTGR)
- Shippingport (PWR)

Large-scale power stations
- Bruce (PHWR/CANDU)
- Calvert Cliffs (PWR)
- Flamanville 1-2 (PWR)
- Fukushima II 1-4 (BWR)
- Grand Gulf (BWR)
- Kalinin (PWR/VVER)
- Kursk 1-4 (LWGR/RBMK)
- Palo Verde (PWR)

Evolutionary designs
- ABWR (GE-Hitachi; Toshiba BWR)
- ACR 1000 (AECL CANDU PHWR)
- AP1000 (Westinghouse-Toshiba PWR)
- APR-1400 (KHNP PWR)
- APWR (Mitsubishi PWR)
- Atmea-1 (Areva NP-Mitsubishi PWR)
- CANDU 6 (AECL PHWR)
- EPR (AREVA NP PWR)
- ESBWR (GE-Hitachi BWR)
- Small Modular Reactors
  - B&W mPower PWR
  - CNEA CAREM PWR
  - India DAE AHWR
  - KAERI SMART PWR
  - NuScale PWR
  - OKBM KLT-40S PWR
- VVER-1200 (Gidropress PWR)

Innovative designs
- GFR gas-cooled fast reactor
- LFR lead-cooled fast reactor
- MSR molten salt reactor
- SFR sodium-cooled fast reactor
- SCWR supercritical water-cooled reactor
- VHTR very high temperature reactor

Arriving – 2030
Advanced Reactor Technologies

R&D focused on Advanced, Small and Modular Reactor Concepts

• Fast Reactor Technologies
• High Temperature Reactor Technologies
• Advanced Reactor Generic Technologies
• Advanced Reactor Regulatory Framework
• Advanced Reactor System Studies

Supercritical Transformational Electric Power (STEP) Initiative

• Investigating commercialized Supercritical Carbon Dioxide (sCO₂) Brayton cycle energy conversion system
During 2012 DOE and NRC concluded that regulatory guidance for non-light water reactor designs was needed
- Existing licensing guidance is written for light water reactors.
- A regulatory framework is needed to support reasonable timelines for design certification and licensing.

NE and NRC initiated a joint project for development of General Design Criteria (GDC) for non-light water reactor concepts

Key actions of this initiative:
- Prepared draft Design Criteria / conducted workshops - 2014
- Completed Design Criteria – October 2014
  - Generic set, SFR set and HTGR set
- Issued a report to the NRC that proposed the draft Design Criteria and requested development of Regulatory Guidance – Dec 2014
- The NRC will hold public meetings and receive public comment - The first public meeting took place in January 2015.
- NRC to develop and issue regulatory guidance by end of 2016.
Supercritical CO\textsubscript{2}: Transformational Energy Systems

- Rankine efficiency is 33%
- Supercritical CO\textsubscript{2} (sCO\textsubscript{2}) potential to surpass 50% efficiency
- Greatly reduced cost for sCO\textsubscript{2} compared to the cost of conventional steam Rankine cycle
- sCO\textsubscript{2} compact turbo machinery is easily scalable

Comparison

5-stage Dual Turbine
Lo ↔ Hi ↔ Lo

20 meter Steam Turbine (300 MWe)
(Rankine Cycle)

3-stage Single Turbine
Hi ↔ Lo

1 meter sCO\textsubscript{2} (300 MWe)
( Brayton Cycle)
Supercritical CO₂ has Broad Applicability

Solar SunShot Power Cycle

Space Solar Electric Propulsion

Fossil Sequestration Ready

Nuclear

Geothermal
Supercritical CO$_2$ Development Roadmap

Current Program

Future Program

Development

350-550-700+ C

Research

Small System Test
Low/Med Temp

Current Program

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Current Program

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Research

Small System Test
Low/Med Temp
Congressional language in June 2014

- “… and $7,000,000 is for an advanced test/demonstration reactor planning study by the national laboratories, industry, and other relevant stakeholders of such a reactor in the U.S.”

In April 2015, DOE launched an advanced test/demonstration reactor planning study to evaluate advanced reactor technology needs, current capabilities, requirements and options within the context of national needs and public policy to support innovation in nuclear energy and if warranted, develop pathway for design/licensing/construction of an advanced reactor project(s)

Expected draft report in April 2016

- Report will provide options for test reactors and for demonstration reactors depending on the technology
Options Under Evaluation in AT/DR Planning Study

Fuel and Material Testing
- Fast Spectrum
  - Moderated zones for thermal spectrum testing
- Thermal/Epi-thermal Spectrum
  - Boosted zones for fast spectrum testing
- Different coolant loops for scaled-down component testing

Hybrid Test & Technology Demonstration Reactor
- Core is used as a test reactor
- Sub-systems and components relevant to multiple reactor systems can be demonstrated at a relevant-scale
  - i.e. I&C, components of the primary or secondary loops
- More complicated design and operations

Prototype Reactor System
- Scaled down prototype of a commercial reactor
  - Sodium Fast Reactor
  - HTGR
  - Floride salt cooled reactor
  - Reduced moderation LWR
- Capability of testing advanced sub-systems and component
  - Technology upgrades