Nuclear Energy

_Past, Present and Future_

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Outline

Nuclear Energy

- History of nuclear energy development
- Nuclear energy today
- Challenges to nuclear energy expansion
- DOE’s research and technology development
- Nuclear energy in space
- Building a clean energy future
- Conclusions
The Early Years

1939 – Uranium atom split in Germany and fear that Germany was working on an atomic bomb

- Einstein signs Leo Szilard Letter to President Roosevelt relaying possibility of chain reaction
- Briggs Committee appointed to study chain reactions

1941 – Fermi and Szilard suggest possible design for uranium chain reactor

1942- First controlled, self-sustaining nuclear chain reaction at University of Chicago

Chicago Pile–1, Dec 2, 1942 at 3:20 pm for 33 minutes
The Early Years (cont.)

1942 – Army Corps of Engineers District “Manhattan Project” at Los Alamos, NM
- Brigadier General Leslie Groves – US Army Corps of Engineers
- Scientific research led by Physicist Robert Oppenheimer

Three primary research and production sites
- Los Alamos, NM – Weapons research and design laboratory
- Hanford Site, WA – Plutonium production
- Oak Ridge, TN – Uranium enrichment

1946 – President Harry Truman
- Established Atomic Energy Commission (AEC)
- Argonne National Lab was created as the successor of Metallurgical Lab of Univ. Chicago
The Early Years (cont.)

1947 – Atomic Energy Commission (AEC) established
- Lewis Strauss appointed as one of five Commissioners
- 1953 – President Eisenhower appoints him as chairman of the AEC

1949 – Hyman Rickover assigned to dual role as Atomic Energy Commission's Division of Reactor Development and made Director of the Naval Reactors Branch
- Leads efforts to develop Nautilus and oversee development of Shippingport Atomic Power Station

Experimental Breeder Reactor I (EBR-I) – Idaho National Lab
- December 20, 1951, world's first electricity generated from nuclear power
“Peaceful power from atomic energy is no dream of the future. That capability, already proved, is here – now – today.”

President Dwight D. Eisenhower
December 8, 1953
United Nations General Assembly

President Eisenhower signs the Atomic Energy Act of 1954

- Private ownership of nuclear reactors
- Leasing of nuclear fuels for private use
- Industrial access to classified data needed for nuclear power development
- Encouraged international development of nuclear power
Nuclear Power “Firsts”

- **Shippingport Atomic Power Station** – World’s first full-scale nuclear power plant
  - 1954 – Construction begins
  - 1957 – Plant becomes operational, distributing to the Duquesne Light Company grid

- **USS Nautilus** - World’s first operational nuclear-powered submarine
  - 1955 – USS Nautilus maiden voyage
  - 1958 – Operation Sunshine, submerged transit to North Pole
  - 1979 – Final voyage
Key Events Influencing Commercial Nuclear Power

- Chernobyl accident
- NWPA amendment
- EPAct
- Fukushima accident
- India atomic bomb test
- DOE created/Pres. Carter defers reprocessing
- AEC split into NRC & ERDA
- TMI-2 accident/INPO created
- DOE created/Pres. Carter defers reprocessing
- AEC split into NRC & ERDA
- India atomic bomb test
- Fukushima accident
United States Committed to “All of the Above” Clean Energy Strategy

“By 2035, 80% of America’s electricity will come from clean energy sources. Some folks want wind and solar. Others want nuclear, clean coal and natural gas. To meet this goal we will need them all.”

~2011 State of the Union

“All-of-the-above is not merely a slogan, but a clear-cut pathway to creating jobs and at the same time reducing carbon emissions, which recently stood at their lowest level in 20 years... President Obama has made clear that he sees nuclear energy as part of America’s low carbon energy portfolio. And nuclear power is already an important part of the clean energy solution here in the United States.”

~Secretary of Energy, Dr. Ernest Moniz at National Press Club, February 19, 2014
• 434 nuclear reactors are operable in 31 countries
• 73 reactors currently under construction in 14 countries
• More than 300 reactors are proposed in 36 countries over the next 15 years

--- *World Nuclear Association as of June 1, 2014*
Role of U.S. Department of Energy for Sustainable and Innovative Nuclear Energy

Conduct Research, Development, and Demonstration to:

- Reduce technical risk
- Reduce financial risk and improve economics
- Reduce regulatory risk
- Used fuel management
- Minimize the risks of nuclear proliferation and terrorism
- Foster international and industry collaboration
Potential Challenges to Global Nuclear Power Expansion

- Safety / Public Acceptance
- Economics
- Nuclear Waste
- Proliferation risk
**LWRS Program Goal**

- Develop fundamental scientific basis to allow continued long-term safe operation of existing LWRs (beyond 60 years) and their long-term economic viability

**LWRS program is developing technologies and other solutions to**

- Enable long term operation of the existing nuclear power plants
- Improve reliability
- Sustain safety

**LWRS focus areas**

- Materials Aging and Degradation
- Advanced Instrumentation and Controls
- Risk-Informed Safety Margin Characterization
- Reactor Safety Technology
First new reactors being built in U.S. in 30 years

V.C. Summer Units 2 & 3
- Substantial Completion forecast:
  - Unit 2 (late 2018/early 2019)
  - Unit 3 (12 months after Unit 2)
- Cost per unit ($4.5 billion 2007 $) pending adjustment

Vogtle Units 3 & 4
- Commercial operations Unit 3 (2017) & Unit 4 (2018)
- Estimated construction cost $5.3 billion/unit (CY $)

"The cost and schedule performance of the new reactors being built in South Carolina and Georgia will be very critical.”
- Secretary Moniz, April 10, 2014
Government Incentives for Nuclear

Standby Support Delay Risk Insurance
- Designed to reduce risk of licensing delays caused by NRC failing to meet its own schedules or by certain litigation

Production Tax Credit
- Provides $0.018/kWh with a maximum of $125M per year per each 100MW allocated for 8 years
- Only those plants that began construction by 2014 and placed into service by 2021 are eligible

Loan Guarantees
- Reduces cost to build a nuclear power plant by reducing the cost of financing
- In February 2014, DOE provided $6.5 B in guarantees to support the construction of Vogtle Units 3 and 4 in Georgia
- In September, DOE announced plans for another $12.6B in guarantees for advanced nuclear reactors; small modular reactors; uprates and upgrades at existing facilities; and advanced nuclear facilities for the front-end of the nuclear fuel cycle
Accident Tolerant Fuel Behavior

High temperature during loss of active cooling

**Improved Reaction Kinetics with Steam**
- Heat of oxidation
- Oxidation rate

**Improved Fuel Properties**
- Lower operating temperatures
- Clad internal oxidation
- Fuel relocation / dispersion
- Fuel melting

**Slower Hydrogen Generation Rate**
- Hydrogen bubble
- Hydrogen explosion
- Hydrogen embrittlement of the clad

**Improved Cladding Properties**
- Clad fracture
- Geometric stability
- Thermal shock resistance
- Melting of the cladding

**Enhanced Retention of Fission Products**
- Gaseous fission products
- Solid/liquid fission products
Feasibility studies on advanced fuel and clad concepts
-- bench-scale fabrication
-- irradiation tests
-- steam reactions
-- mechanical properties
-- furnace tests
-- modeling

Assessment of new concepts
-- impact on economics
-- impact on fuel cycle
-- impact on operations
-- impact on safety envelope
-- environmental impact

Industry led projects (Phase 1a)

Phase 1
Feasibility
Workshops

Phase 2
Development/Qualification

Fuel Selection/Prioritization
Steady State Tests
Transient Irradiation Tests
LOCA/Furnace Tests
Fuel Performance Code
Fuel Safety Basis
LFA/LFR Ready

Industry led project(s) (Phase 2)

Phase 3
Commercialization

Industry led projects (Phase 1b)

RD&D Strategy For Enhanced Accident Tolerant Fuels – 10 Year Goal

Industry led projects (Phase 1b)

Fuel Selection/Prioritization
Steady State Tests
Transient Irradiation Tests
LOCA/Furnace Tests
Fuel Performance Code
Fuel Safety Basis
LFA/LFR Ready

Industry led project(s) (Phase 2)

Phase 3
Commercialization

Industry led projects (Phase 1b)
**AREVA**
- Develop coated Zr-alloy cladding for improved accident performance
- Increased fuel pellet conductivity: Fuel with reduced stored energy that must be accommodated during DBE
- Additives achieved:
  - SiC powder or whiskers
  - Diamond
  - Chromia dopant

**GE**
- Develop advanced ferritic/martensitic steel alloys (e.g., Fe-Cr-Al) for fuel cladding to improve behavior under severe accident scenarios
- Objectives:
  - Characterize candidate steels
  - Study tube fabrication methods, neutronics, fuel economy, thermo-hydraulic calcs, reg approval path
  - Initiate ATR testing with UO₂ and two cladding materials.

**Westinghouse**
- Develop and test cladding concepts: SiC and SiC ceramic matrix composites; coated Zr alloys
- High density/high thermal conductivity fuel pellets (e.g., uranium nitride/silicides)
- First batch of U₃Si₂ pellets were sintered using finely ground powder
- Pellets were pressed using pressures of 6,000-10,000 psi and sintered at temperatures of 1400°C
Small Modular Reactors

Potential Benefits

• Enhanced safety and security
• Reduced capital cost makes nuclear power feasible for more utilities
• Shorter construction schedules due to modular construction
• Improved quality due to replication in factory-setting
• Meets electric demand growth incrementally
• Regain technical leadership and advance innovative reactor technologies and concepts

Potential Markets

• Domestic and international utility markets
• Non-electrical (process heat/desalination) customers

SMRs: reactor units with less than 300 MWe and are able to have large components or modules fabricated remotely and transported to the site for assembly.
Size Comparison of Conventional Large LWR and SMR

Representative Westinghouse Nuclear Steam Supply System

Westinghouse SMR Integral Nuclear Steam Supply System

25 Westinghouse SMR Containment Vessels fit into single AP1000 Containment Vessel
Major challenge for commercialization is completing the NRC licensing process

In 2012, DOE initiated the SMR Licensing Technical Support program – Currently a 6 year/$452 M program

Accelerate commercial SMR development through public/private arrangements
  - Deployment as early as 2022

Exploring additional mechanisms for SMR fleet deployment

“I believe small modular reactors could represent the next generation of nuclear energy technology, providing a strong opportunity for America to lead this emerging global industry.”

-- Secretary of Energy, Dr. Ernest Moniz
Status of SMR Licensing
Technical Support Program

**B&W mPower America**
- Cooperative Agreement established with team consisting of B&W, Bechtel, and TVA in April 2013
- Initial DOE commitment of $115 M through Nov 2014
- DOE is working with B&W to establish a path forward for the mPower project

**NuScale Power**
- Selection of NuScale announced on December 12, 2013
- Cooperative Agreement signed May 27, 2014
- DOE to fund up to $217 M for NuScale SMR development
- DCA submittal currently planned for 2nd half of 2016

The U.S. Government wants to support the safest, most robust SMR designs that minimize the probability of any radioactivity release
Overview of Reactor Developments

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

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

**Generation III / III+**
- 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-405 PWR
  - VVER-1200 (Gidropress PWR)

**Generation IV**
- 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

Timeline:
- 1950
- 1970
- 1990
- 2010
- 2030
- 2050
- 2070
- 2090

Arriving ~ 2030

(U.S. Department of Energy)
Sodium Fast Reactor Development

### Experimental Breeder Reactor - II
- 62.5 MWt, pool-type, sodium-cooled fast reactor
- Successfully operated over 30 years from 1964 to 1994

### Fast Flux Test Facility
- 400 MWth sodium-cooled fast test reactor, located at Hanford, WA
- World class testing capabilities, operated from 1982-1992

### Clinch River Breeder Reactor
- 1000 MWth commercial prototype SFR
- Project started early 1970s
- Terminated in 1983 by Congress
High Temperature Gas Cooled Reactor Technology Development

Graphite Characterization, Irradiation Testing, Modeling and Codification

Fuel Fabrication, Irradiation, and Safety Testing

Design and Safety Methods Development and Validation

High Temperature Materials Characterization, Testing and Codification
Space and Defense Power Systems

Programmatic Goals

- Design, develop, build and deliver radioisotope power systems for space exploration and national security applications
- Support research, development and design of fission power systems for space exploration and national security needs

Benefits

- Enable NASA and national security missions in locations and environments where other power systems such as chemical batteries and solar power systems do not work

Long history of use in space

- First launched in 1961, used safely and reliably on 28 missions for over 50 years
- And since August of 2012, we have been exploring interstellar space with the Voyager 1 spacecraft launched 37 years ago
Radioisotope Power Systems

Basic Features

- General Purpose Heat Source Module
  - Plutonium-238 – heat from alpha decay, easily shielded
  - High-strength cladding to encase the fuel
  - Layers of graphite components for insulation and impact protection
  - Each module provides ~250 Wth
- Convertor – heat to electricity
  - All systems flown to date have used thermoelectric conversion
  - Also exploring dynamic conversion for higher efficiency

Multi-Mission Radioisotope Thermoelectric Generator

- Current design - operates in vacuum of space and Mars atmosphere
- Uses eight GPHS modules to produce ~115 W e
- First used on Mars Curiosity Rover in 2011
Mars Science Laboratory
National Laboratory Support to Nuclear Energy
• Nuclear Energy in the U.S.
  – 1940’s and 1950’s from concept to prototype
  – 1960’s from prototype to commercialization
  – 1970’s an industry is launched
  – 1980’s ensuring safety
  – 1990’s laying the foundation for a new generation of nuclear power plants
  – 2000 & beyond a new generation of nuclear power and advanced fuel cycle technologies
Nuclear Energy Leadership –
A Key Component in A Robust Clean Energy Future

<table>
<thead>
<tr>
<th>Optimized Use of LWRs</th>
<th>Optimization of Nuclear Systems in The Modern Context</th>
<th>Rapid Translation of Innovation to Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Plant Sustainability</td>
<td>• Improved economics, safety, security and non-proliferation</td>
<td>• Engineering-scale High-performance Computing</td>
</tr>
<tr>
<td>• Used Fuel Disposition</td>
<td>• Advanced Designs, Fuels, and Fuel Cycles</td>
<td>• User Facilities</td>
</tr>
<tr>
<td>• Accident Tolerant LWR Fuels</td>
<td>• Process Heat Applications</td>
<td>• Knowledge Centers</td>
</tr>
<tr>
<td></td>
<td>• Hybrid Energy Systems/Load Following</td>
<td>• Risk-informed Safety Approaches</td>
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ATR  TREAT  HFEF  IMCL  HSSL  RELAP  MaCS  MOOSE
Argonne’s Nuclear Program Builds on its Pioneering Achievements

- First controlled chain reaction: CP-1 (U. of Chicago)
- First electricity generation from nuclear energy
- First use of plutonium as fuel
- First demonstration of breeding

- First prototype BWR power plant: EBWR
- First close coupling of reactor operation and fuel recycling
- First demonstration of fast reactor inherent safety

- Development of metallic fast reactor fuel
- Development of pyroprocessing for nuclear fuel recycle

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**Argonne’s Pyroprocessing Technology**

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**Chicago Pile 1 (CP-1)**

**Experimental Breeder Reactor No. 1 (EBR-I)**

**Experimental Breeder Reactor No. 2 (EBR-II)**

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**Experimental Boiling Water Reactor**
Oak Ridge National Laboratory was founded in 1943 to Develop and Pilot World’s First Nuclear Fuel Cycle

X-10 Manhattan Project Mission:
- Pilot reactor-based plutonium production
- Pilot Pu separation from irradiated fuel
- Training Hanford staff
- Fission, reactor, separations R&D

Success led to an expanded mission of basic and applied research:
- Science and engineering for nuclear power
  - Materials and fuels
  - Separations chemistry
  - Reactor safety and technology
- Development of neutron scattering
  - Nobel Prize in Physics
- Development, production, and distribution of radioisotopes for medicine and research
  - Birth of a billion dollar industry

The Clinton Pile was the world’s first continuously operated nuclear reactor

Chemical processing techniques were developed to separate plutonium from irradiated fuel
Oak Ridge National Laboratory’s Key Contributions
to Nuclear Energy Development

**ORNL’s Thirteen Innovative Nuclear Reactors**

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Power</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite Reactor</td>
<td>3.5MW</td>
<td>1943-63</td>
</tr>
<tr>
<td>Homogeneous Reactor Exp.</td>
<td>1.6MW</td>
<td>1952-64</td>
</tr>
<tr>
<td>Homogeneous Reactor Test</td>
<td>5.0MW</td>
<td>1957-61</td>
</tr>
<tr>
<td>Aircraft Reactor Exp.</td>
<td>2.5MW</td>
<td>1954-55</td>
</tr>
<tr>
<td>Molten Salt Reactor Exp.</td>
<td>4MW</td>
<td>1965-69</td>
</tr>
<tr>
<td>Health Physics Research Reactor Pulsed</td>
<td></td>
<td>1963-91</td>
</tr>
<tr>
<td>Low Intensity Test Reactor</td>
<td>3.0MW</td>
<td>1950-68</td>
</tr>
<tr>
<td>Bulk Shielding Reactor</td>
<td>20MW</td>
<td>1950-91</td>
</tr>
<tr>
<td>Geneva Reactor</td>
<td>0.1MW</td>
<td>1955</td>
</tr>
<tr>
<td>Oak Ridge Res. Reactor</td>
<td>30 MW</td>
<td>1958-87</td>
</tr>
<tr>
<td>High Flux Isotope Reactor</td>
<td>85MW</td>
<td>1966-</td>
</tr>
</tbody>
</table>

**Reactor Technology**
- Lab Director Weinberg patented LWR
- First proof of electricity generation (1948)
- First zero-power LWR (LITR)
- First Molten Salt Reactor (1954)
- First use of U-233
- Advanced Reactors (gas-cooled reactor, fast breeder reactor development)

**Separations**
- Development of Purex process
- Development of Thorex process
- Fluorination processing

**Reactor Safety**
- Criteria for avoiding vessel pressurized thermal shock
- Understanding zirconium-alloy clad behavior in accidents
- Investigation of BWR severe accident phenomena

**Radioisotopes**
- HFIR and REDC developed to produce heavy elements (Cf and above)
- Medical isotopes
- Stable isotopes

Landmark Reactor Projects at the Hanford Site

B Reactor- 1st large scale nuclear reactor

Fast Flux Test Facility
Unique Testing Capability

Impact Testing

Fire Testing and Modeling

F4 Crash Test

1/4-Scale Prestressed Concrete Containment Vessel Failure Test

Nuclear Safety

Modeling and Analysis of Severe Accidents in Nuclear Power Plants

Severe accident codes are the “Repository” of phenomenological understanding gained through NRC and International research performed since the TMI-2 accident in 1979

Integrated models required for self-consistent analysis

Important Severe Accident Phenomena

- Accident initiation
- Reactor coolant thermal hydraulics
- Loss of core coolant
- Core meltdown and fission product release
- Reactor vessel failure
- Transport of fission products in RCS and Containment
- Fission product aerosol dynamics
- Molten core/basemat interactions
- Containment thermal hydraulics
- Fission product removal processes
- Release of fission products to environment
- Engineered safety systems - sprays, fan coolers, etc
- Iodine chemistry, and more
Summary of the Administration’s UNF and HLW Strategy

Response to the final report and recommendations made by the Blue Ribbon Commission on America’s Nuclear Future

• 10-year program of work that:
  • Sites, designs, licenses, constructs and begins operations of a pilot interim storage facility
  • Advances toward the siting and licensing of a larger interim storage facility
  • Uses a consent-based siting process
  • Geologic repository operational by 2048

Advanced Modeling and Simulation

Building a Virtual Reactor to Address Industry Defined Challenge Problems

Advanced predictive capability

- mechanistic descriptions of key phenomena
- Simulating phenomena at the appropriate resolution and fidelity
- Coupling multiple phenomena where they compete in real world conditions
Nuclear Energy University Programs

- Competitive process for awarding R&D, infrastructure and scholarships/fellowships

- Integrated Research Projects
  - Multi-University teams
  - Significant scope/budget

- Since FY09, we have awarded $343M to 97 schools in 38 States

- Awards to Purdue University total $5,822,912
  - R&D projects $3,761,100
  - Infrastructure $1,576,812
  - Scholarships/Fellowships $485,000
International Cooperation

DOE supports technical collaborations through bilateral Action Plans, Working Groups, and the International Nuclear Energy Research Initiative

Bilateral:
- Peaceful Uses of Nuclear Energy Agreements (123 Agreements)
- R&D Agreements
- International Nuclear Energy Research Initiatives (I-NERIs)
- Memoranda of Understanding (MOUs)

Multilateral:
- International Framework for Nuclear Energy Cooperation (IFNEC)
- Generation IV International Forum (GIF)
- International Atomic Energy Agency (IAEA)
- International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)
- Nuclear Energy Agency (NEA)
Conclusion

Nuclear Energy

- Nuclear power is an essential element of our energy mix
- Several factors can inhibit the future growth of nuclear energy
- DOE is working with the NRC, industry, academia and international partners to overcome these challenges
- Expanding nuclear energy can help achieve the Administration's clean energy goals

“President Obama has made clear that nuclear energy is an important part of our all-of-the-above energy strategy.”

“In partnership with our nuclear industry, the U.S. Government is supporting the deployment of passively safe reactors both in the United States and around the world.”

U.S. Secretary of Energy, Dr. Ernest Moniz
September 2014 Vienna, Austria
Useful Websites for Additional Information on Nuclear Energy

DOE Home Page - http://energy.gov
American Nuclear Society (ANS) - http://www.ans.org/
International Atomic Energy Agency (IAEA) - http://www.iaea.org
Nuclear Energy Institute - http://www.nei.org
Backups
## FY 2015 Congressional Request Funding Summary

(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program</th>
<th>FY 2014 Enacted</th>
<th>FY 2015 Request</th>
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<tr>
<td>Integrated University Program</td>
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<tr>
<td>SMR Licensing Technical Support</td>
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<td>Supercritical Transformational Electric Power Generation</td>
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<td>Reactor Concepts RD&amp;D</td>
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<td>Fuel Cycle R&amp;D</td>
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<td>Nuclear Energy Enabling Technologies</td>
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<td>Radiological Facilities Management</td>
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<td>International Nuclear Energy Cooperation</td>
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<tr>
<td>Idaho Facilities Management</td>
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<td>Idaho Safeguards and Security</td>
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<td>Program Direction</td>
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<td>Adjustments</td>
<td>-5,000</td>
<td>b) -</td>
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<tr>
<td><strong>Total, Nuclear Energy</strong></td>
<td><strong>888,376</strong></td>
<td><strong>863,386</strong></td>
</tr>
</tbody>
</table>

a) Reflects application of $814,100 rescission as identified within section 317 of Public Law 113-76.
b) Use of Prior Year Balances.
Nuclear Energy Plays an Important Role in US Energy Supply

- **Nuclear power is a clean, reliable base load energy source**
  - Provides 19% of U.S. electricity generation mix
  - Provides 61% of U.S. emission-free electricity
  - Avoids about 700 MMTCO2 each year
  - Helps reduces overall NOx and SOx levels

- **U.S. electricity demand projected to increase ~28% by 2040 from 2011 levels**

- **99 GWe nuclear capacity - 100 operating reactors**
  - Fleet maintaining close to 90% average capacity factors
  - Most expected to apply for license renewal for 60 years of operation

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**Electricity Production, 2012**

- Nuclear 19%
- Total: 4,054,485 GWh

**Net Non-Carbon Emitting Sources of Electricity, 2012**

- Nuclear 61%
- Conven. Hydro 22%
- Wind 11%
- Solar <1%
- Biomass 5%
- Geothermal 1%

Source: Energy Information Administration
U.S. Nuclear Power Plants in Operation

Key
- Period of Extended Operation
- Recently shut-down plants

2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.

3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.

4. Prompt efforts to develop one or more geologic disposal facilities.

5. Prompt efforts to develop one or more consolidated storage facilities.

6. Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available.

7. Support for continued U.S. innovation in nuclear energy technology and for workforce development.

8. Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.
Public Support Increases

Nuclear Energy Institute-commissioned national public opinion surveys from 1983 to 2013
Generation IV Reactor Concepts

Nuclear Energy

Sodium Fast Reactor

Lead Fast Reactor

Very High Temperature Reactor

Gas Cooled Fast Reactor

Supercritical Water Cooled Reactor

Molten Salt Cooled Reactor
Fuel Cycle Research and Development: an Integrated Approach

Front End
- Uranium Resources
  - Conventional production
  - Innovative approaches
    - U Seawater
- Fuel Fabrication
  - Safety enhanced LWR fuel
    - Accident tolerance
  - Higher performance
    - Improved burnup
- Reactors
- Interim Storage
  - Evaluating extended time frames
  - Transport after storage
- Recycle
  - Separations
  - Recycled fuel
  - Secondary waste treatment
- Disposal
  - Alternative geologies
  - Alternative waste forms

Optimize through Systems Analysis, Engineering, and Integration

Safeguards and Security By Design

September 24, 2014