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"Irradiation Related Challenges" Related to Nuclear Energy R & D

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Fermi National Accelerator Laboratory
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Outline

- **Who Are We?**
  - **- How we fit into the NE Roadmap**
  - **- Our view of the future and where we want to be**

- **Fuel Cycle R&D Technologies With Irradiation Needs**
  - **Near Term Needs**
  - **Long Term Needs**

- **Challenges for an Irradiation Facility to get us to where We Want to Be?**
  - Accelerator source?
  - Reactor source?
- **Charge for this Workshop**

Presentation -- Bottom Line

The Office of Nuclear Energy has a diverse set of R&D responsibilities, including:

- **Development of advanced fuels and materials**
- **Advanced instrumentation for safeguards**
- **Separations technologies**
- **Systems Analysis**

Facilities to support this R&D is key to our success, particularly in the area of neutron irradiation testing.

This presentation will provide an overview of some R&D activities with emphasis on neutron irradiation environments.

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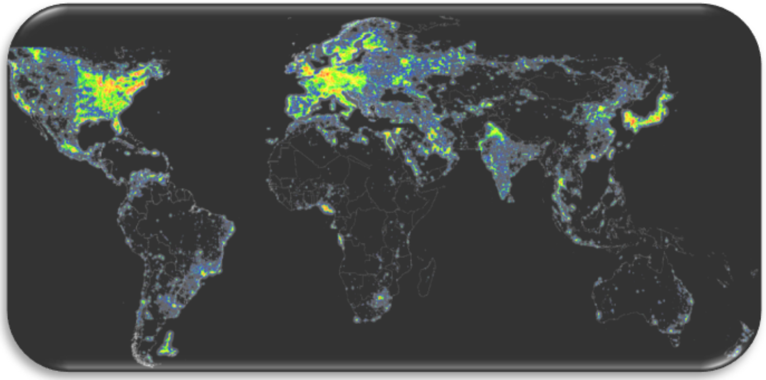
Organization – several offices can benefit from availability of irradiation facilities

- NE-1/2 **Assistant Secretary for Nuclear Energy**
  Dr. Peter B. Lyons - Assistant Secretary
  Dennis Miotla - Acting Principal Deputy Assistant Secretary
  - Nuclear Energy Advisory Committee
  - Senior Advisors
  - **Chief Operating Officer**
    Dennis Miotla
    - NE-21 Office of Human Capital & Business Services
      Deborah Sharpe
    - NE-22 Office of Budget & Planning
      Patrick Edgerton
  - NE-3 **Deputy Assistant Secretary for Nuclear Facility Operations**
    Tracey Bishop, Acting
    - Idaho Operations Office
      Richard Provencher, Manager
    - NE-31 Office of Facilities Management
      Tracey Bishop
  - NE-4 **Deputy Assistant Secretary for Science and Technology Innovation**
    Shane Johnson, Acting
    - NE-41 Office of Advanced Modeling & Simulation
      Trevor Cook, Acting
    - NE-42 Office of Innovative Nuclear Research
      Mike Worley, Acting
  - NE-5 **Deputy Assistant Secretary for Fuel Cycle Technologies**
    Monica Regalbuto
    - NE-51 **Office of Systems Engineering & Integration**
    - NE-52 **Office of Fuel Cycle Research & Development**
      Andy Griffith
    - NE-53 **Office of Used Nuclear Fuel Disposition Research & Development**
      William Boyle
    - NE-54 **Office of Uranium Management and Policy**
      William Szymanski
  - NE-6 **Deputy Assistant Secretary for International Nuclear Energy Policy and Cooperation**
    Ed McGinnis
    - NE-61 Office of International Nuclear Energy Policy
      Michelle Scott, Acting
    - NE-62 Office of International Nuclear Fuel Management
      Alan Brownstein
  - NE-7 **Deputy Assistant Secretary for Nuclear Reactor Technologies**
    John Kelly
    - NE-72 Office of Light Water Reactor Technologies
      Rebecca Smith-Kevern
    - NE-74 Office of Advanced Reactor Technologies
      Tom O'Connor, Acting
    - NE-75 Office of Space & Defense Power Systems
      Owen Lowe

Our Environment (1): Nuclear Energy, America's Future for Energy Security

- **Ensure reliable energy to power our economy, homes, and maintain a standard of living, free from carbon emissions**
  - The only economic large-scale method to generate electricity that is essentially carbon-free
- **Challenges**
  - Managing used nuclear fuel from the current fleet of reactors (near-term)
  - Safely disposition of nuclear fuel (near-term)
  - Nuclear energy sustainability (long-term)
- **Success in meeting the above challenges is essential to ensure energy security, economic security, and environmental security**



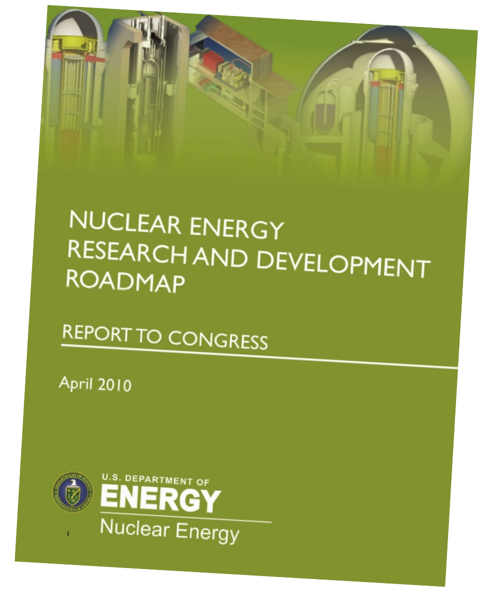
Our world needs more energy

Our Environment (2): DOE Nuclear Energy R&D Roadmap

- **DOE's Nuclear Energy R&D Roadmap**

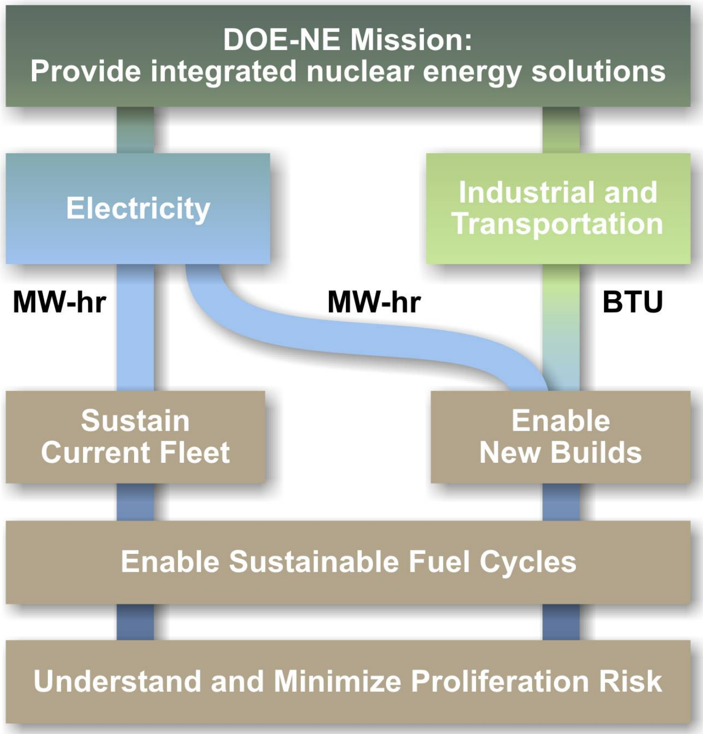
  Nuclear power is a key component of a portfolio of technologies that meets U.S. energy goals

- ***R&D activities are organized along four main objectives* that address challenges to expanding the use of nuclear power**
  - Develop technologies that can improve the reliability, sustain the safety, and extend the life of current reactors
  - Develop improvements in the affordability of new reactors to help meet energy security and climate change goals
  - ***Develop sustainable nuclear fuel cycles***
  - Understand and minimize risks of nuclear proliferation



U.S. Nuclear Energy Objectives

- **Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors**
- **Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals**
- **Develop sustainable nuclear fuel cycles**
- **Understand and minimize the risks of nuclear proliferation and terrorism**



Objective 3. Enable Sustainable Fuel Cycles

- **Near term – Define and analyze fuel cycle technologies to develop options that increase the sustainability of nuclear energy**
- **Medium term – Select preferred fuel cycle option(s) for further development**
- **Long term (2050) – Fuel cycle technologies ready for commercial deployment**

(FCR&D program also supports fuel cycle R&D for Objectives 1 & 2 reactors and safeguards technologies for Objective 4.)

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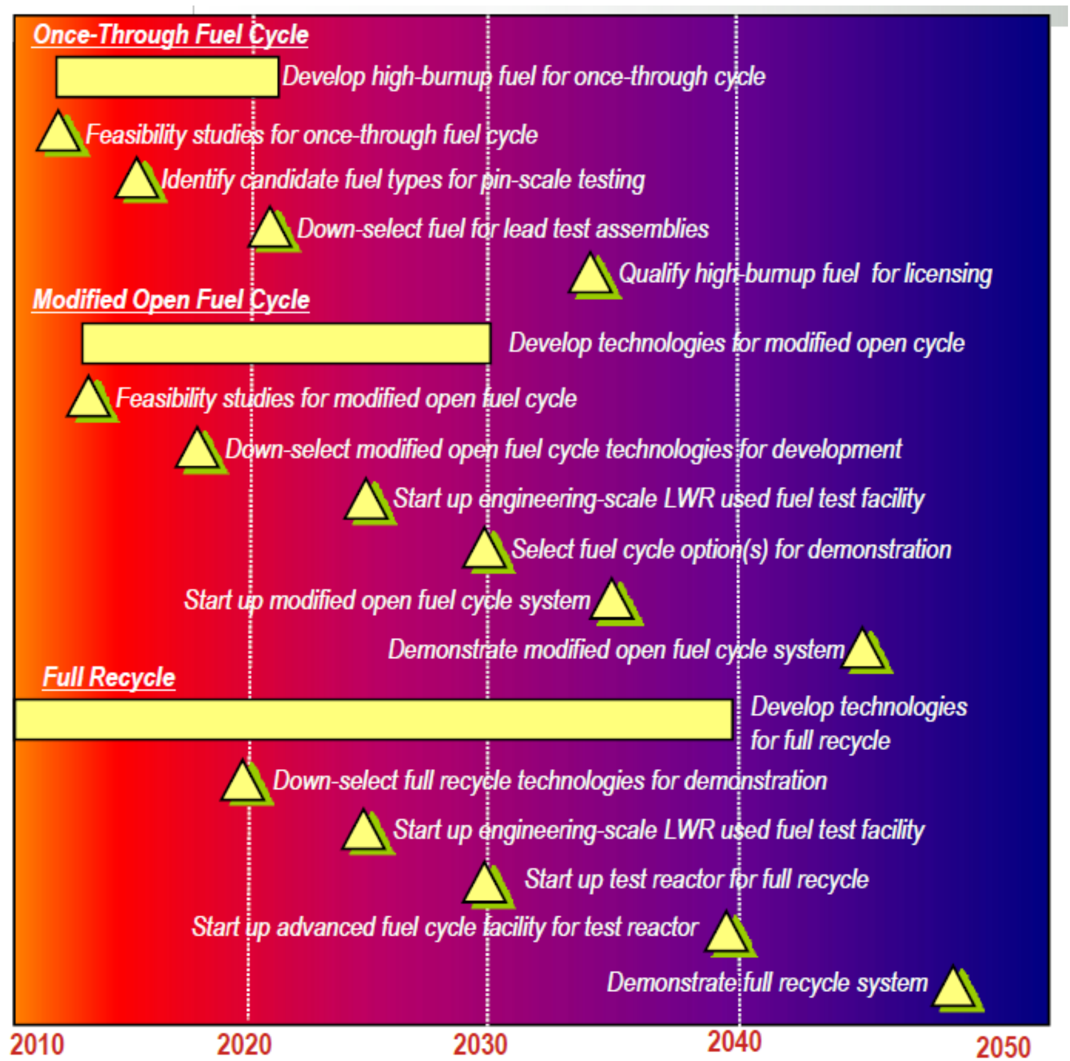
An Example of a 50 year Sustainable Fuel Cycle Implementation Strategy – availability of test facilities are key to it's realization



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Focus For My Responsibility (1): Fuel Cycle Technologies (FCT) – Mission and Guiding Documents

DOE

Ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

Goal 3: Secure Our Nation

- Enhance nuclear security through defense, nonproliferation, and environmental efforts.

NE

Advance nuclear power as a resource capable of making major contributions in meeting the Nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and regulatory issues through research, development, and demonstration.

FCT

Develop sustainable fuel cycles and Used Fuel waste management strategies that improve resource utilization, minimize waste generation, improve safety and limit proliferation risk.

http://energy.gov/sites/prod/files/2011_DOE_Strategic_Plan_.pdf
http://www.ne.doe.gov/pdfFiles/NuclearEnergy_Roadmap_Final.pdf

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Focus of My Responsibility (2): Advanced Fuel Cycle Technology Development - Science-Based, Engineering-Driven

- **Focusing on three overarching fuel cycle options:**
  - ***Once Through***
  - ***Closed or Partially Closed***
- **Defining and considering a broad range of fuel cycle technologies supporting:**
  - ***Fuel stabilization, waste management and national security material recovery***
  - ***Advanced fuels and enhanced accident tolerance LWR fuels***
  - ***Addressing proliferation and terrorism risks***

By the middle of the next decade, engineering scale experiments on a new generation of advanced technologies will enable their deployment by the middle of the century

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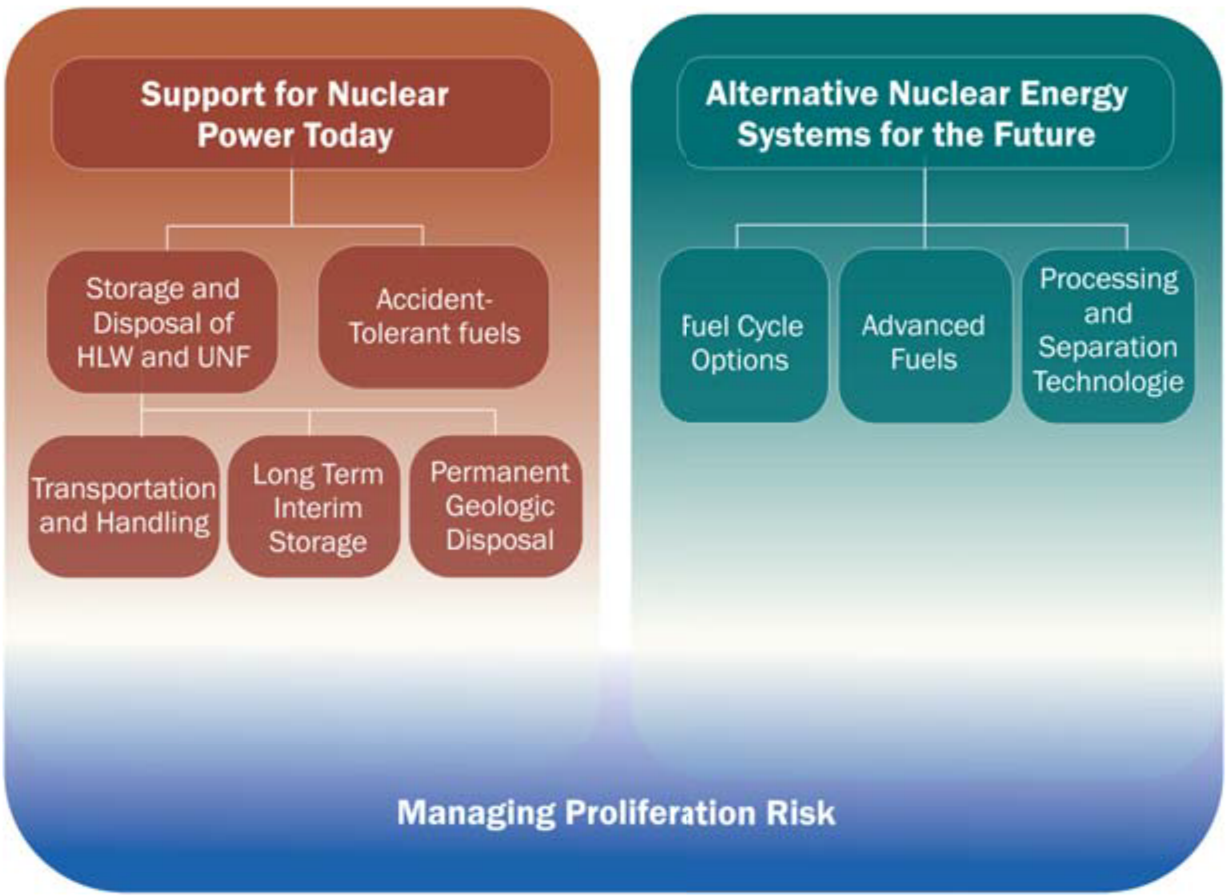
Fuel Cycle Technologies – Objectives -- Our View of the Near Term and the Future

Near-Term **Long-Term**



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Where We Are Today

Global demand for energy and concerns about climate change has accelerated deployment of reactor and fuel cycle facilities worldwide

There is a continuing build up of nuclear waste from commercial nuclear plants and stockpile of DOE wastes stored across the country.

After Fukushima – new awareness as a country of the need for a waste management strategy

- **Interim storage**
- **Fuel cycle alternatives**
- **Disposal options**

The BRC conducted a comprehensive evaluation of policies for managing the back end of the nuclear fuel cycle, including advanced fuel cycle technologies

The Fuel Cycle Technology Program seeks to develop innovative technologies that represent significant advantages in terms of economics, proliferation resistance, resource utilization and waste management

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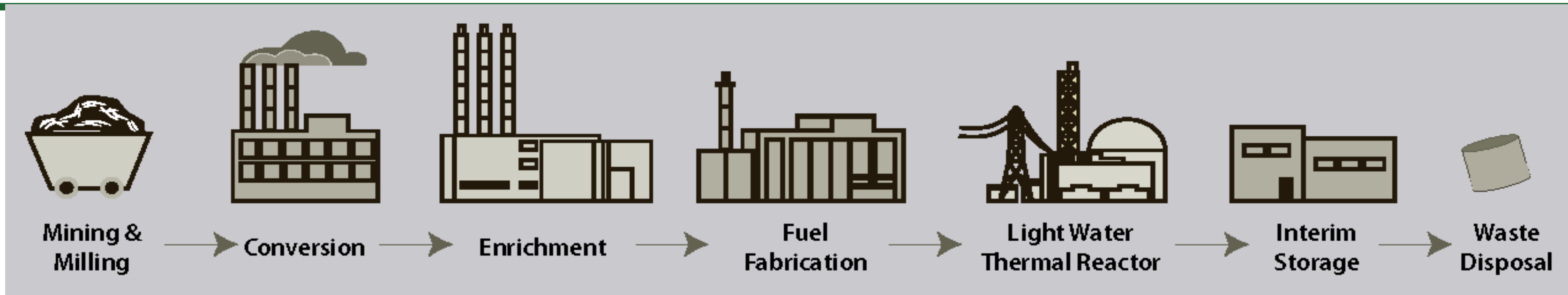
The U.S. Open Fuel Cycle is Still Incomplete – Missing Facilities – affect future R&D Development Requirements



R&D considerations

- Are there ways to isolate the SNF or its constituents for the very long term?
- Are there proliferation issues associated either with long-term accumulation or treatment and recycle of SNF?

Is used fuel a waste or a resource?

Used fuel contains:

- Fissile isotopes that could be recovered and re-used in nuclear fuel
- Isotopes that are radioactive for long time periods that would cause environmental and health impacts if released.

U.S. path forward

- Used fuel can be stored safely for decades
- BRC provided recommendations that help guide management of used nuclear fuel and fuel cycle R&D
- BRC affirms the need for R&D on advanced fuel cycles that represent advantages over today's technologies.

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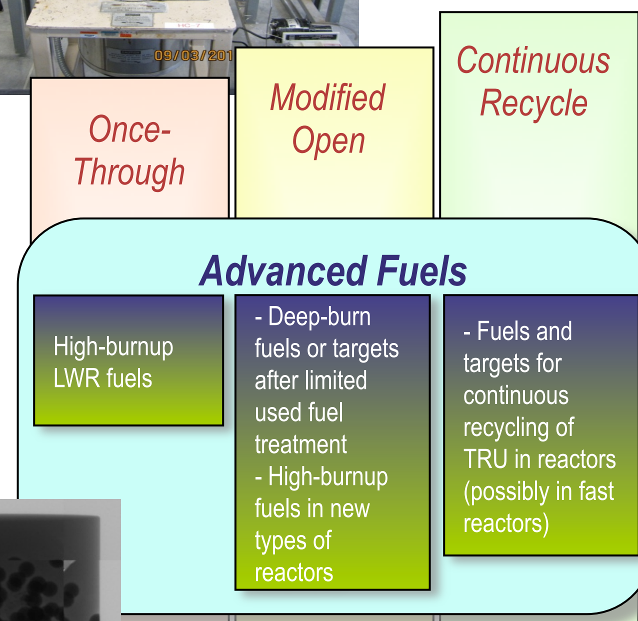
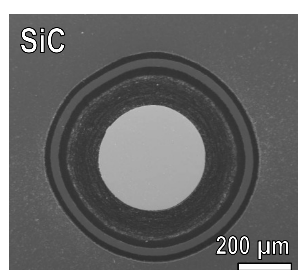
Advanced Fuels and Accident Tolerant LWR Fuels – example of an activity needing significant irradiation related support

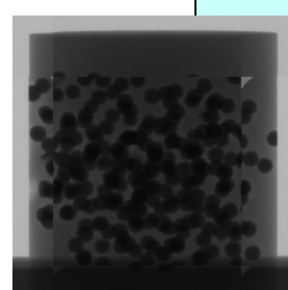
- **Innovative LWR Fuels and Cladding**
  - Better safety performance (e.g. during normal operation, design basis accidents and beyond design basis accidents)
  - Reliability and fuel configurations similar to current fleet
  - Acceptable economics
  - Favorable neutronics and licensing characteristics



- **Advanced fuels in support of closed or partially closed fuel cycles**

- **Advanced fuel fabrication methods with a low degree of losses**





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Where Do We Want to Be?

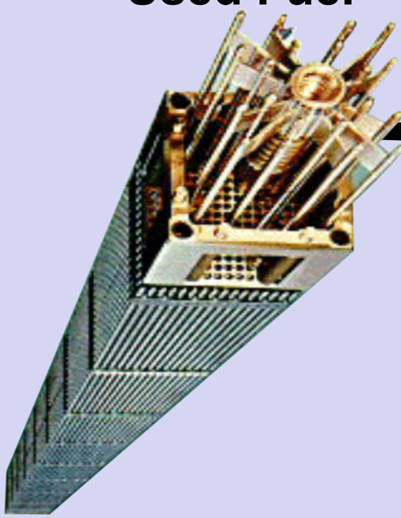
Near term: Improve management of SNF

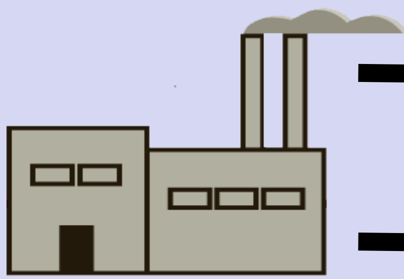
Complete our open fuel cycle

Support Development of Accident Tolerant LWR fuel

Long term – Focus on sustainable fuel cycle

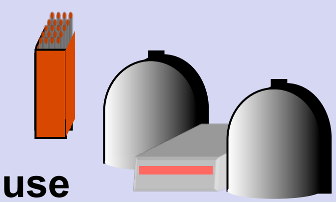
Used Fuel





Recycle

Economically
Safely
Securely



Product
- Ease of reuse
- Retain high U/Pu ratio

Waste
- Reduce secondary streams
- Ease of Management
  - Storage
  - Transportation
  - Disposal

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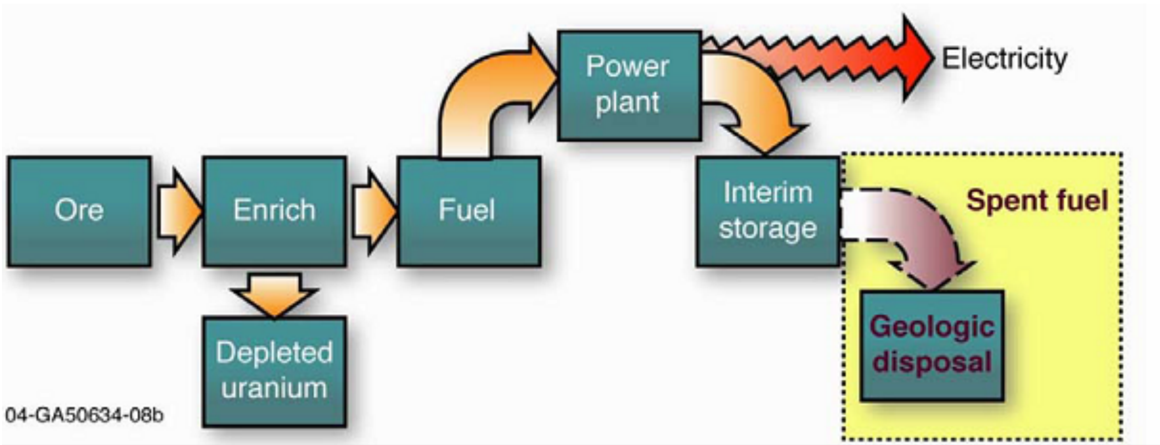
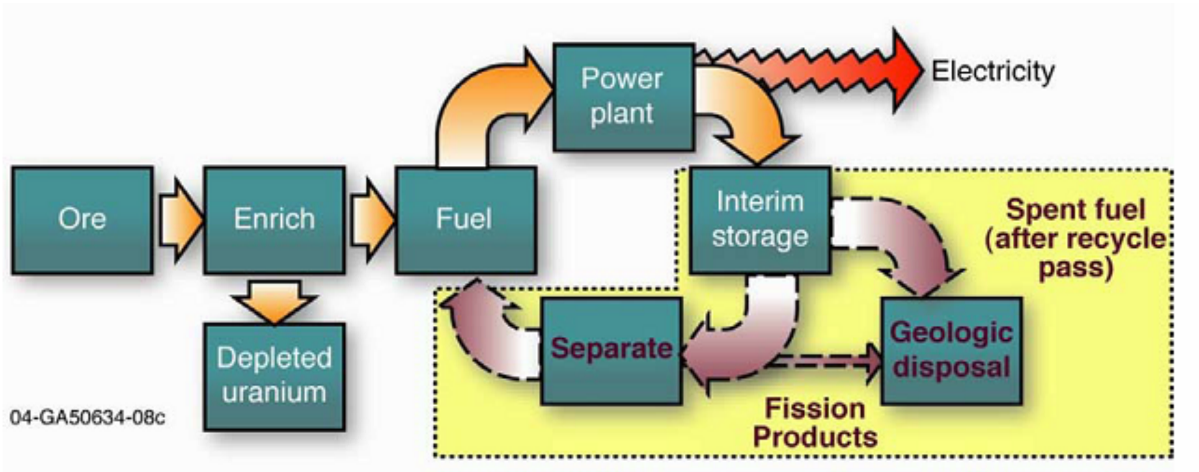
Near Term Reality: Once-Through Nuclear Systems – Includes Current U.S. Fuel Cycle



- **Continuing storage of a growing spent fuel inventory**
- **Interim storage and geologic disposal still needs to be implemented**
  - What is the impact of alternate disposal system environments?
- **Are there “promising” once-through options?**

Future Vision: Closed or Partially Closed Nuclear Systems – Include Recycle



- **What is the benefits for recycle systems?**
  - Does irradiated fuel have “value” that can be recovered by reprocessing?
  - Are there operational and/or storage advantages?
  - Does HLW offer disposal advantages over SNF?
- **Numerous options, including limited or continuous recycle, different reactors and fuels, use of extended storage, disposal, etc.**
  - How do we determine what are the “promising” alternatives?

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What Are the Challenges for Selecting Options for Further Development?

- Complex problems with many complex technologies
- Numerous fuel cycle options possible
- Numerous studies in the past with no clear consensus
- Long time horizon choices
- Multiple interests and stakeholders
- Variations in policy directions over time

It is critical to have adequate testing, characterization, and processing facilities to deal with the challenges and choices

Some Irradiation Related Needs and Challenges

Main Irradiation Challenge:

For an Irradiation Facility To Be Useful to NE and Fuel Cycle R & D Program

What is required:

Stable, well characterized, test spaces, capable of testing fuels & materials from coupon size up to assembly sizes in a neutron environment, characteristic of thermal or fast spectrum nuclear reactors

Key High Level Considerations:

- **Flux Spectrum - model both thermal and fast spectrum reactors**
- **Fuel Pin Coolant environment - water, sodium/lead, gas, molten salt**
- **Flexibility of fuels to be tested - homogeneous/heterogeneous, LEU, plutonium/thorium bearing**
- **Instrumentation – capable of characterizing fuel, clad, coolant temperatures**

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Examples of Technical Irradiation Requirements:
"Useful to NE Advanced Development Needs"

- **Test Volume - coupon size up to 100 liters, well characterized test space**
- **Irradiation Temperature - e.g. ambient up to 300 C – 1000 C**
- **Neutron Energy - thermal to 14 MEV - maximum**
- **Neutron Flux range - peak value of up to 5e15 n/sq cm/sec**
- **Displacement per Atom range - few dpa up to 50 dpa per year**

Associated post irradiation capable facilities must also be planned on for a new irradiation capability

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Some Accelerator Versus Reactor Characteristics Related to Needs

Characteristic		Reactor Source of Neutrons	Accelerator source of neutrons
Well Characterized and controlled Neutron Flux Environment over test volume		Primarily determined by reactor design, fast vs thermal – difficult to cover both needs in one concept	Easier to cover both flux types in one concept, but challenging due to spatial variations in relation to incoming beam orientation
Test Volume		Probably greater in a nuclear reactor	May be limited by need to control uniformity of flux environment
Instrumentation Capability		Capability demonstrated	Probably similar to that of a test reactor
Prototypic geometry Fuel Pin Testing Capability		Easier in a nuclear reactor to test multiple prototypic fuel pins	May be more challenging due to spatial limitations
Technical Requirement capability (flux, energy, temperature, dpa)		Generally designed into reactor	Easier to vary in an accelerator device, but may be more difficult to achieve spatial homogeneity over larger test volumes

Charge to WG: Carefully consider the flux spectra, relative to the incident beam, for applications considered

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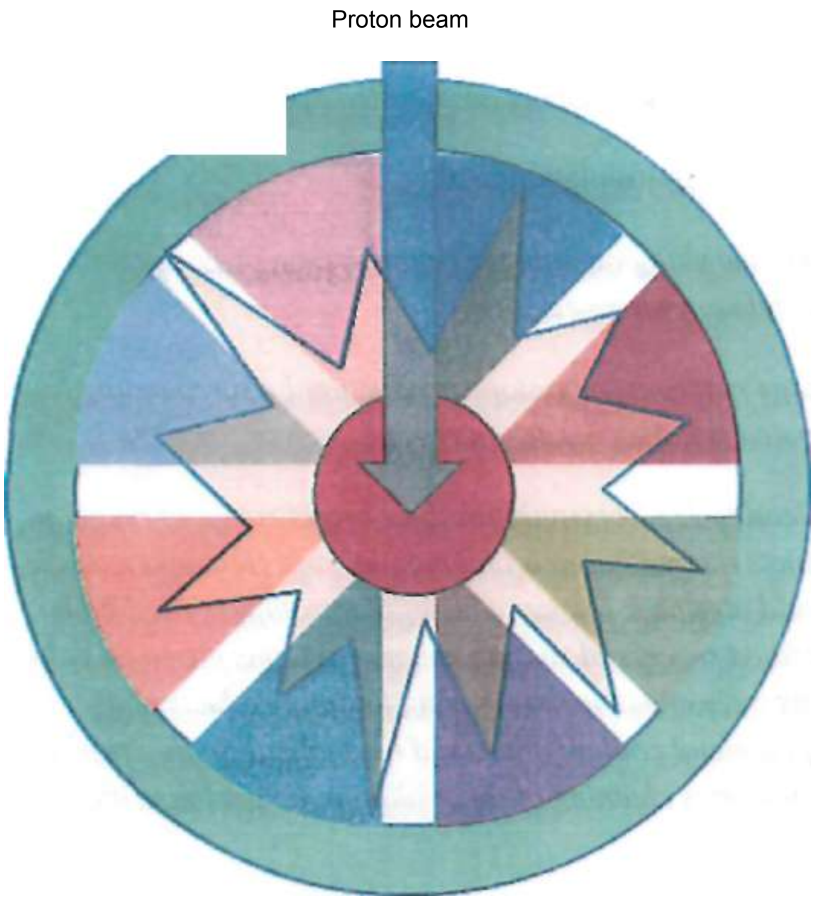

Figure 4.6. Nuclear Energy Station Concept

Stations

Materials - temperature control

ADS- lead orlead-bismuth loop

HTGR - graphite, He loop

SFR - sodium fast reactor loop

LWR - Zr, water loop

MSR - molten salt loop

Fusion- lithium loop

Other- Cold neutron - liquid He