The Global Nuclear Energy Partnership (GNEP)

Overview of Systems Analysis and Waste Form Campaigns

Kathryn McCarthy
GNEP Systems Analysis Campaign Director
Mark Peters
GNEP Waste Form Campaign Director

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Outline

- GNEP/AFCI Mission and Requirements
- Overview of Systems Analysis Campaign
- Overview of Waste Form Campaign
- Questions and Discussion

GNEP/AFCI Mission Statement

Conduct a nuclear energy research, development, and demonstration program focused on nuclear fuel recycling and waste management to provide the infrastructure, technologies, and qualified personnel needed to enable the United States to close the nuclear fuel cycle and to support the safe, secure, economic, and sustainable global expansion of nuclear energy in a way that reinforces United States technological leadership.

GNEP/AFCI Program Requirements

Develop and demonstrate technologies to:

1. **Reduce the environmental and financial burden and uncertainty associated with long-term nuclear waste management.**
2. **Optimize nuclear waste management by:**
   - Minimizing the risk of waste that needs to be handled or stored.
   - Producing only solid wastes in robust waste forms.
   - Recycling and reusing materials to the maximum extent possible.
3. Recover the unused energy value of materials separated from spent nuclear fuel for future use.
4. Enhance the ability to safeguard the advanced fuel cycle facilities by developing technologies to more accurately account for, track, and manage nuclear materials.
5. **Support the near-term deployment of fuel cycle technologies (20 years) as well as define longer term deployments of next-generation technologies (50 years).**
6. **Make the closed fuel cycle as economical as possible.**
7. Accelerate deployment of nuclear reactors that are appropriate for regions with limited capacity electricity grids.
8. Permit deployed facilities to be licensable by the appropriate civil regulatory authorities.

GNEP/AFCI Program Requirements (cont.)

9. Develop the research and development infrastructure needed to demonstrate closure of the fuel cycle at an engineering-scale in the United States.
10. **Support the development of programs and processes that will encourage the education and training of the personnel that will be needed to staff industry, regulators, government, universities and national laboratories to allow closure of the fuel cycle in the United States and reinforce United States technological leadership in the world.**

GNEP Program Organizational Structure

PROJECTS

Advanced Burner Reactor
Sal Golub

Consolidated Fuel Treatment Center
Dan Stout

Advanced Fuel Cycle Facility
Andy Griffith

Design Data Needs

Technology

R & D

Advanced Fuel Cycle R & D
Rob Price

Technical Integration
Finck (**INL**)
Cappiello (**LANL**)
Marra (**SRNL**)

Cross Cut Coordination
•Modeling/Simulation (Nowak- **ANL**)
•Safety and Regulatory (Kelly- **SNL**)

Fuels
Pasamehmetoglu (**INL**)

Separations
Todd (**INL**)

Systems Analysis
McCarthy (**INL**)

Safeguards
Miller (**LANL**)

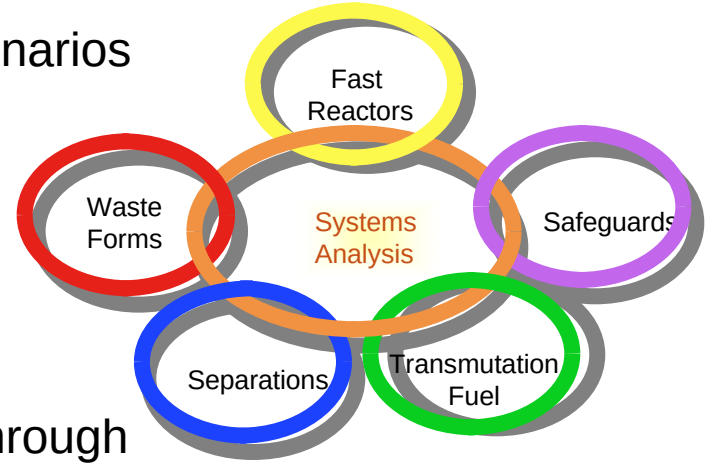
Waste Forms
Peters (**ANL**)

Fast Reactor
Hill (**ANL**)

Grid Appropriate Reactors
Ingersoll (**ORNL**)

Systems Analysis Campaign

- **Mission: Carry out integrating analyses for GNEP development and infrastructure deployment, and enable a requirements-driven process for all technical activities**
- **Objectives:**
  - Integrates information from the diverse technology development and R&D efforts
  - Enables examination of a diverse set of scenarios
    - *Evaluate off-ramps*
    - *Evaluate technology alternatives*
    - *Examine deployment options*
    - *Understand dynamics*
- **Assumptions**
  - Focus on 1-tier and 2-tier relative to once-through
  - All transuranics are recycled

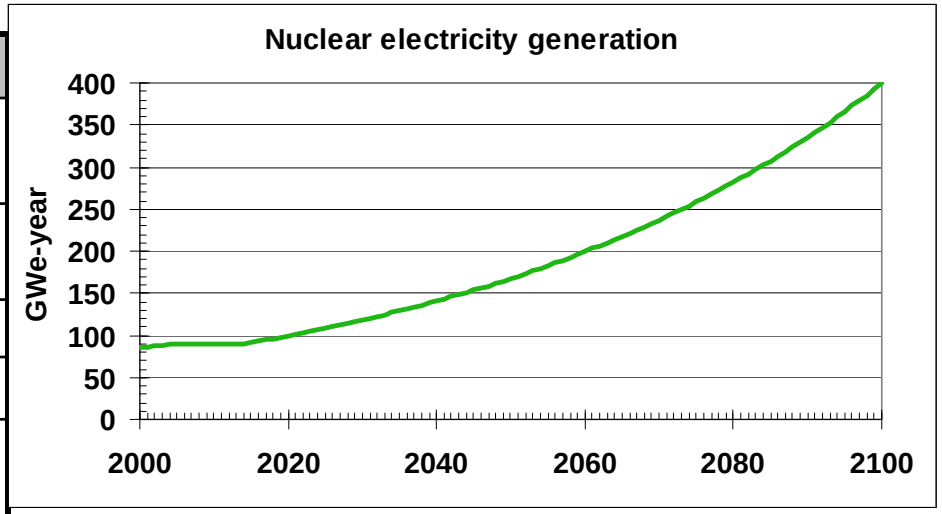


Systems Analysis Increases Understanding of the Fuel Cycle

- **Analyzes the entire fuel cycle to understand trends and relative relationships**
- **Systematically considers multiple objectives and metrics of performance – waste management, TRU reduction, uranium, economics**
- **Clarifies tradeoffs, e.g., 1-tier vs. 2-tier, fast reactor conversion ratio, timing of deployments, FR fuel cooling time, oxide vs. metal fuel**
- **Performs sensitivity analyses to better understand how the system performs**
- **Informs DOE's decision on a path forward, and helps DOE to communicate to stakeholders**

VISION Analyses: Assumptions for Nominal Cases are Based on Technical Feasibility

1-tier	2-tier
Centralized UOX separation starting in 2020 at 0.1% loss/recycle	
Recover TRU, Cs/Sr, etc.	**Recover U-Pu, MA, Cs/Sr, etc.**
1st fast reactor (CR=0.50) in 2022	
	MOX-U-Pu
	Centralized MOX separation starting in 2035 at 0.1% loss/recycle; recover TRU, Cs/Sr, etc.
Fast reactor (CR=0.50) learning period 2032-2041	**Fast reactor (CR=0.50) learning period 2047-2056**
Onsite fast reactor used fuel separation to recover TRU, Cs/Sr, etc. at 0.1% loss/recycle	



- **1st UOX separation plant 800 tonnes/yr**
- **Later UOX separation plants 1600 tonnes/yr, deployed to eliminate used fuel backlog by 2100**
- **MOX separation deployment lags UOX by 15 years, at ~9x lower capacity**
- **FR used fuel separation capacity built as FRs are built (co-location)**

Scenario Studies Summary Findings

- **It is feasible to eliminate excess used fuel storage before 2100 while recycling all separated TRU**
- **Total TRU reduction via recycle must consider both TRU consumed and TRU avoided**
- **Adding a MOX cycle significantly delays and reduces the number of fast reactors**
- **If fast reactor used fuel processing is centralized, more TRU is tied up in cooling used fuel and fewer fast reactors can be supported.**
- **Closed fuel cycles appear to cost 5-6 mils more than once-through, but the uncertainty bounds are large**
- **Examination of cost drivers help show which improvements contribute most to closing the cost gap**

Material Transportation, Storage, & Disposal – Recent Accomplishments

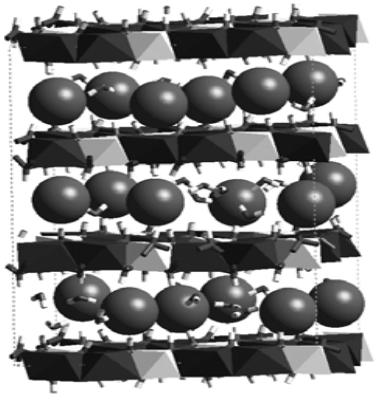
- **Continued repository benefit analyses (Alternative disposal pathways, response to questions)**
- **Material transportation requirements (Assess packaging availability for material shipment, storage)**
- **Technical evaluation of "Institutional Infrastructure" issues (policy, law, regulation, standards, practice, …)**
- **Support for GNEP facilities: (M-TSD strategy consistency, waste stream analyses, disposal alternatives)**

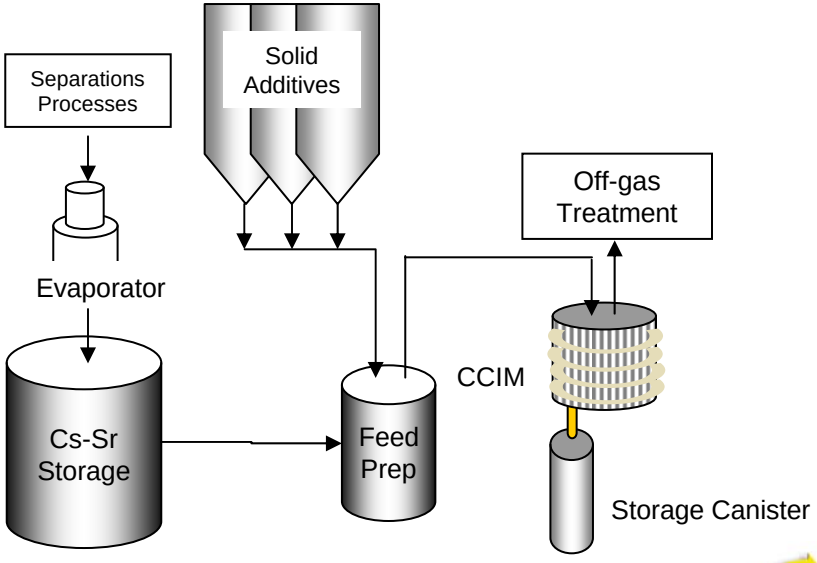
Integrated Waste Management Strategy (IWMS) - Status

- **IWMS identifies all waste streams**
  - Builds on a fuel-cycle using advanced separations
  - Describes potential benefits of a NWPA modification to allow risk-based waste management similar to provisions of 10 CFR 61
  - Could be applied to DOE, NRC, space, defense, medical, and imaging wastes
- **Emphasizes recycle and reuse, but based on economic recovery evaluation factoring in value of material and cost avoidance of disposal**
- **Considers need for industry to have a reliable system to disposition all byproducts/wastes during a phased transition PUREX, UREX+, Echem…**
- **Independent of 1 or 2 tier recycling concepts**
- **Integrates current EM GTCC EIS effort**
- **Anticipates combined oxide and metal waste forms, potential for alternative repository concepts**
- **Suggests a collaborative approach among DOE-NE/EM/RW, NRC/EPA**

Waste Form Campaign

- The mission is to develop and demonstrate durable waste and storage forms for management and disposal
- Fundamental understanding of long-term waste and storage form behavior can only come about through closely coupled theory, modeling, and experimentation
- Waste treatment and disposition must have acceptable cost impacts. The waste form campaign develops and demonstrates cost effective waste processes and durable forms.





Requirements for Waste Forms

- Performance (durability, heat transfer, radiation stability)
- Cost effective (low disposal volumes, low cost processes)
- Flexibility (waste composition, loading, process ranges, etc.)
- Predictable performance (natural analogues, release models)
- Match the waste stream to waste form and disposal environment (e.g., keep noble elements in metal waste form)

Designing Nuclear Waste Forms

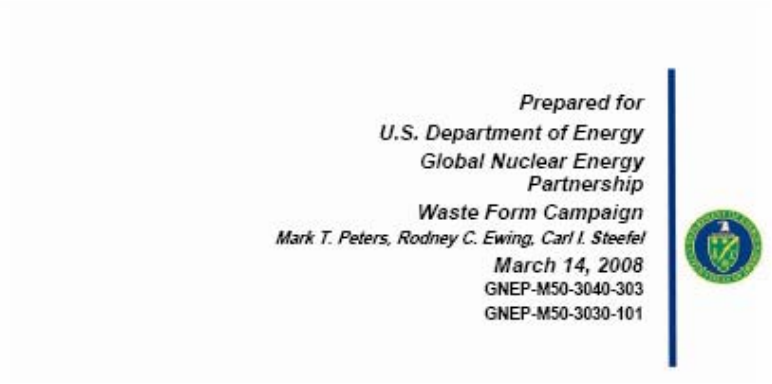
- Waste chemistry, radionuclide(s) to immobilize, and disposal environment guide the selection of waste form
- Let nature guide, particularly when long-term performance is important
- Use *intelligent materials design*
  - Systematic approach rather than “cook and look” approach
- Design material in combination with process
  - Process influences form and vice-versa

Accomplishments to Date
Waste Management Integration/Technology Development

- Support development of IWMS and waste management systems analyses
- Preliminary technology readiness level assessment and evaluate waste and storage form durability testing approaches
- Analyses of waste form performance and development of performance requirements in a range of geologic settings
- Continued work on production and performance of candidate baseline waste and storage forms
  - Cs/Sr, I, Tc, TM, and LN for aqueous and electrochemical processes

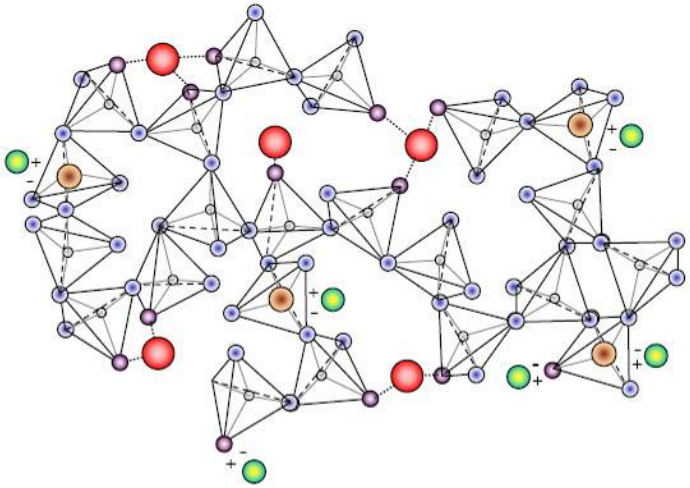
Accomplishments to Date (cont.)
Modeling and Simulation and Long-Term S&T

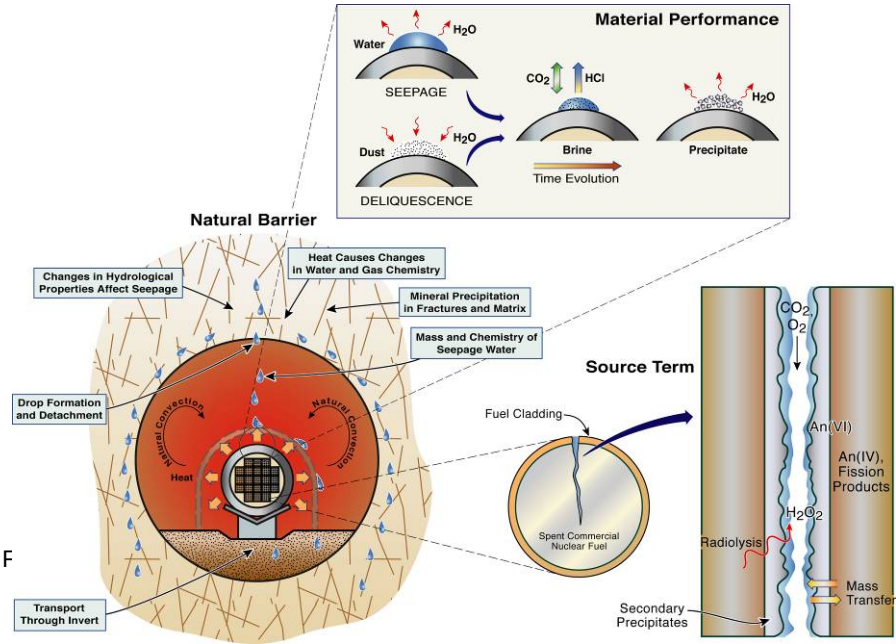
- Conducted workshop and developed Roadmap for M&S and Long-Term S&T
- Future Directions
  - *Development and qualification of advanced, more durable, tailored waste and storage forms*
  - *Development of advanced geologic disposal concepts in a range of geologic settings and geochemical environments*
  - *Enhanced understanding of geologic repository performance*
  - *Systems-level optimization of closed fuel cycle and geologic repository designs*



Waste Form S&T of Specific Materials

- Structure and chemistry
- Phase transitions as a function of temperature and radiation field
- Chemical durability over a range of conditions (thermodynamic and kinetic studies)
- Corrosion mechanisms and rates
- Mechanical properties
- Response to radiation



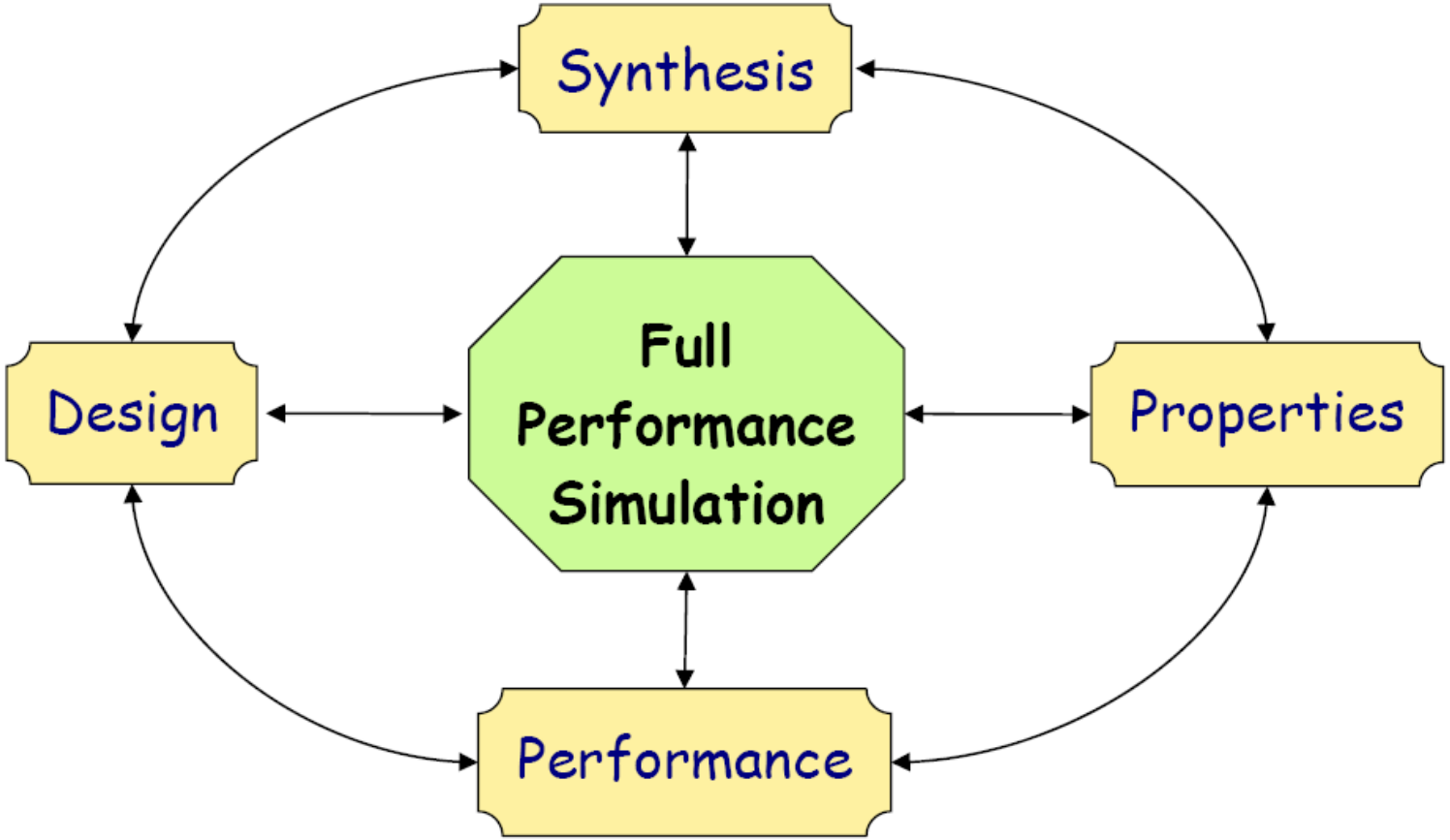


"Integration by Simulation" Waste Form Properties & Performance

- Computational simulation of:
  - Multi-scale simulations of waste form properties (molecular-scale)
  - Modeling/simulation of waste form behavior in the near-field environment (meter-scale)
  - Reference environments (fractured/monolithic, oxidized/reduced, salt/crystalline/clay)
  - Reference waste forms (glass/metal/ceramic phases containing radionuclides)

- Goal: The modeling and simulation effort will identify the controlling mechanisms and processes for different waste form materials in a range of geochemical environments at different spatial and temporal scales
  - **Applied in a general manner to provide a scientifically-defensible basis for waste form development, qualification, and future repository system analysis**

Full Performance Simulation



after Tomas de la Rubia (2007) *Basic Research Needs for Materials in Extreme Environments*

University Involvement and International Collaborations

- **Universities**
  - Key to the success of GNEP waste form campaign
  - Goal is to establish integrated program

- **International Collaborations**
  - France
    - Potential collaborative tasks on waste management and advanced waste form S&T being formulated
  - Japan
    - Action Plan in place
    - Potential collaborative tasks on waste management and advanced waste form S&T being formulated as Part of Phase 1
    - Draft Phase 1 report complete
  - Australia
    - Action Plan in Place
  - Russia
    - Action Plan in place
  - China
    - Action Plan in place

Yucca Mountain Repository Program

- Removal of uranium and transuranics and disposition of fission product storage and waste forms as part of a closed fuel cycle would impact the potential technical capacity of Yucca Mountain (assuming statutory limit is adjusted)

- Many factors potentially control the technical capacity of a repository including:
  - Postclosure repository performance as measured by radiation dose to the public over 10,000+ years
  - Physical area available with suitable geologic and hydrologic characteristics
  - Waste form volume
  - Waste thermal output

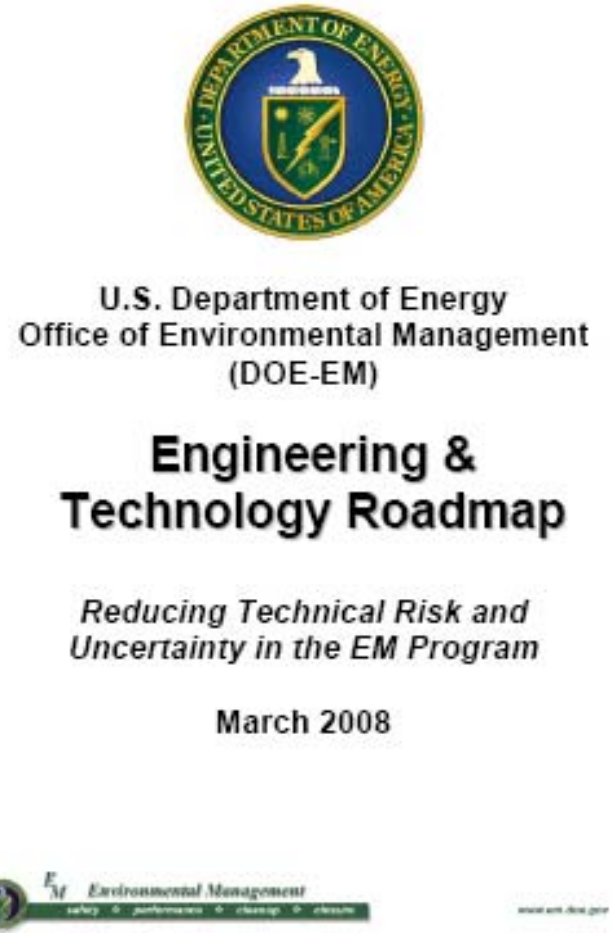
- All of these factors require further analysis before the potential benefits can be clearly understood

- The technical capacity of Yucca Mountain will be capable of accommodating several generations of waste should the technologies being pursued under the GNEP prove successful

Environmental Management Engineering and Technology

- DOE Environmental Management E&T program is evolving and planning additional investment in processing and waste management technology development

- Interface with EM vital to success of GNEP in S&T and development of integrated waste management strategy


U.S. Department of Energy
Office of Environmental Management
(DOE-EM)

Engineering & Technology Roadmap

Reducing Technical Risk and Uncertainty in the EM Program

March 2008

Questions and Discussion

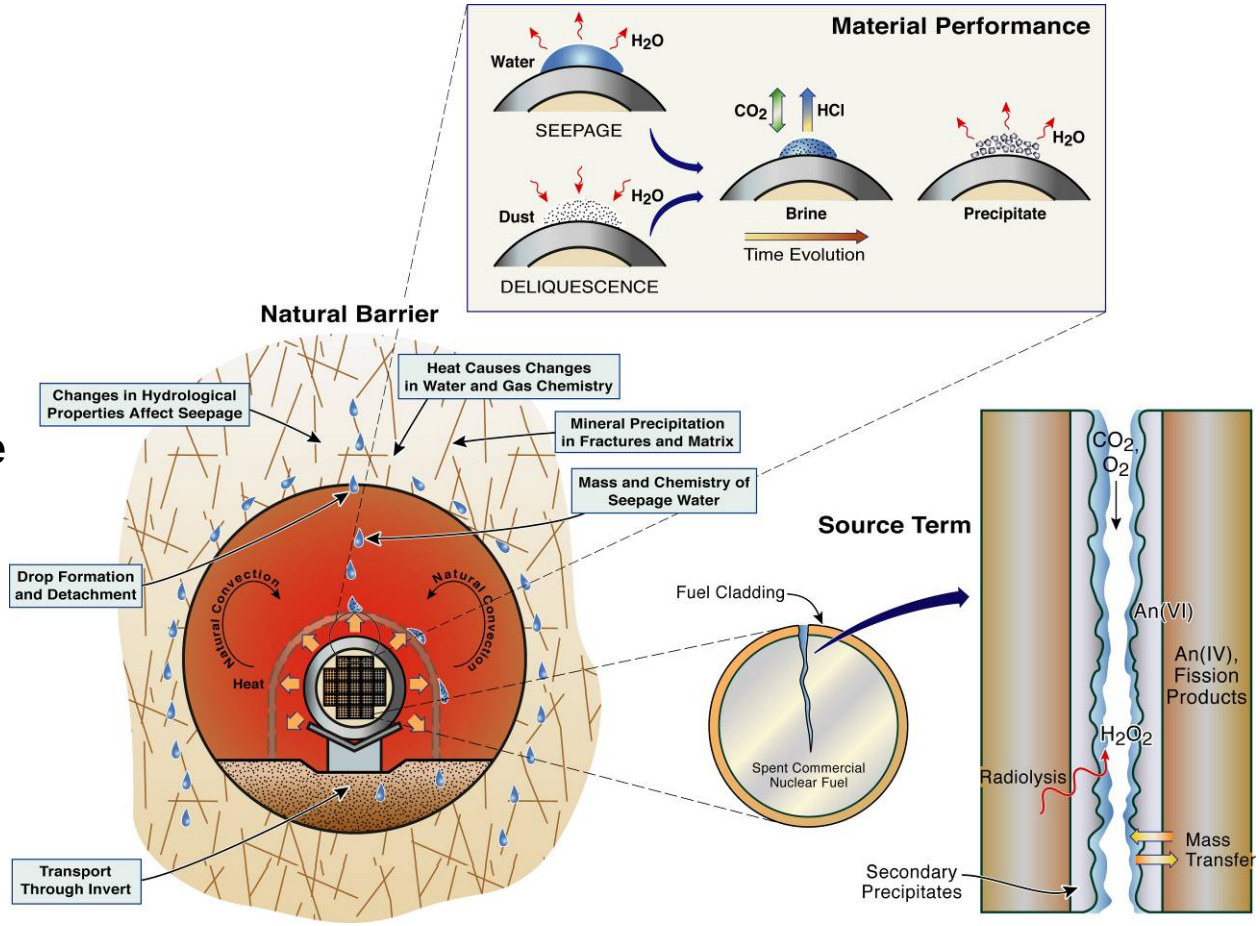
Backup

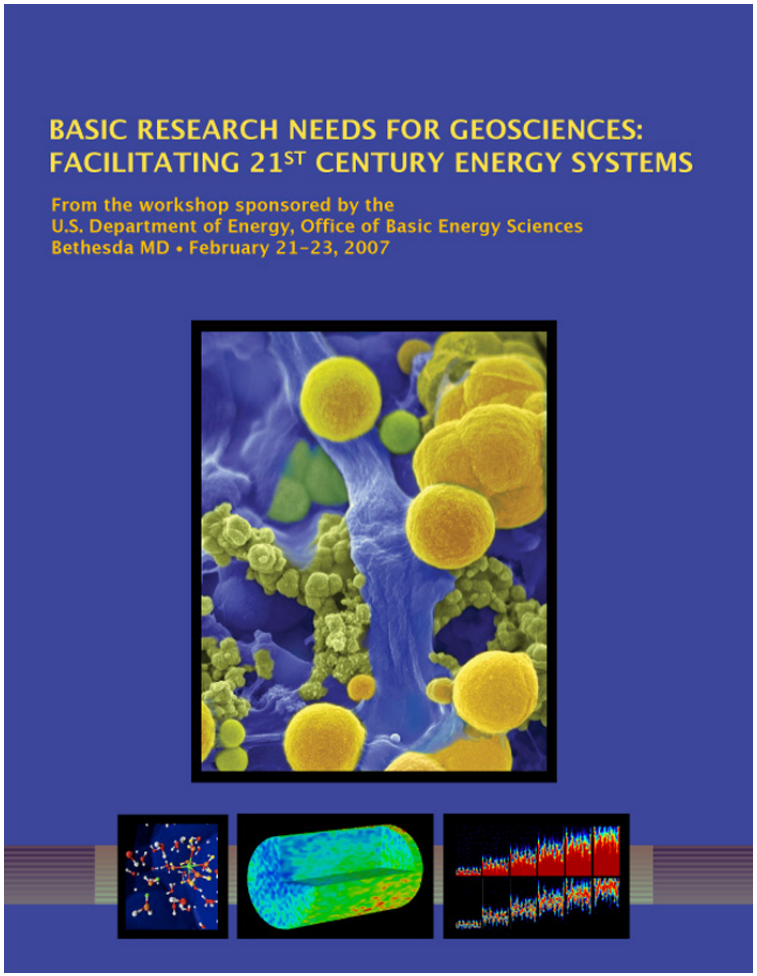
BES Workshop – "Basic Research Needs for Advanced Nuclear Energy Systems"

- Advanced Waste Forms
  - Basic Science Challenges, Opportunities, and Research Needs
    - **Novel materials for advanced waste forms**
    - **Long-term predictions of advanced-waste-form performance in the natural environment**
    - **Thermodynamics for complex systems**
    - **Radiation and radiolysis effects**
    - **Interfaces and nano-scale dynamic behavior**

ASCR/NE Workshop – "Simulation and Modeling for Advanced Nuclear Energy Systems"

- Repository Modeling
  - **Waste Form and Material Degradation**
  - **High Fidelity Assessment of the Geochemical Environment**
  - **Software Infrastructure for Coupled System Performance Assessment**
  - **Uncertainty Propagation**
  - **Visualization**
  - **Modernizing and Parallelizing Existing Legacy Codes**



BES Workshop – "Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems"

- Priority Research Directions
  - Chemistry of mineral surfaces, nanophases, and solutions
  - Subsurface monitoring, imaging, and characterization
  - Physics and chemistry of multiscale systems
  - Biogeochemistry