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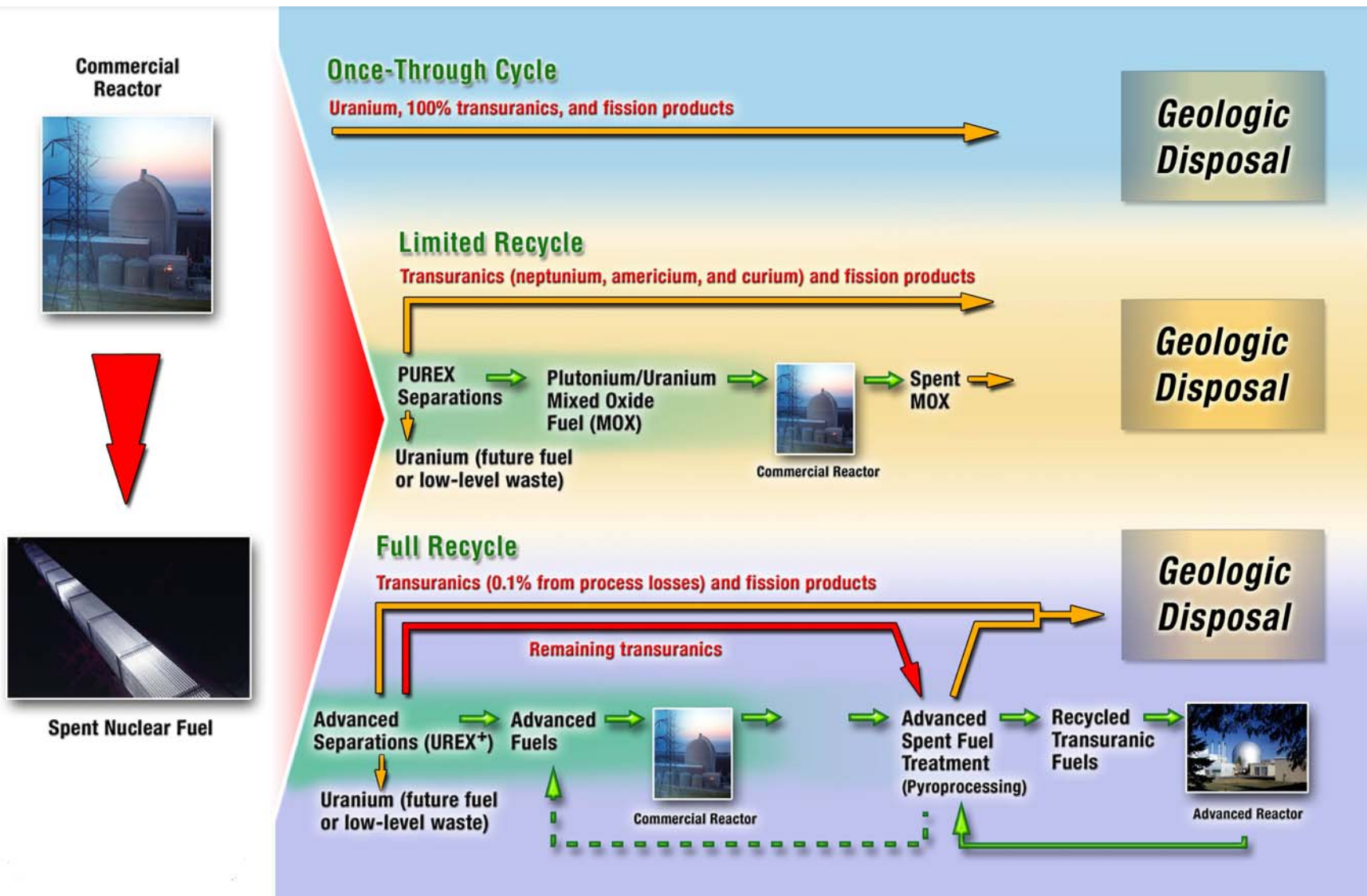


Geoscience Needs for Subsurface Disposal

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Spent Nuclear Fuel Management Options



Geologic Disposal

- **There is scientific consensus that the disposal of spent nuclear fuel and high-level radioactive waste in deep geologic formations is potentially safe and feasible**
 - Provided that sites are chosen and characterized well, and
 - Provided that the combination of engineered and natural barriers is designed appropriately

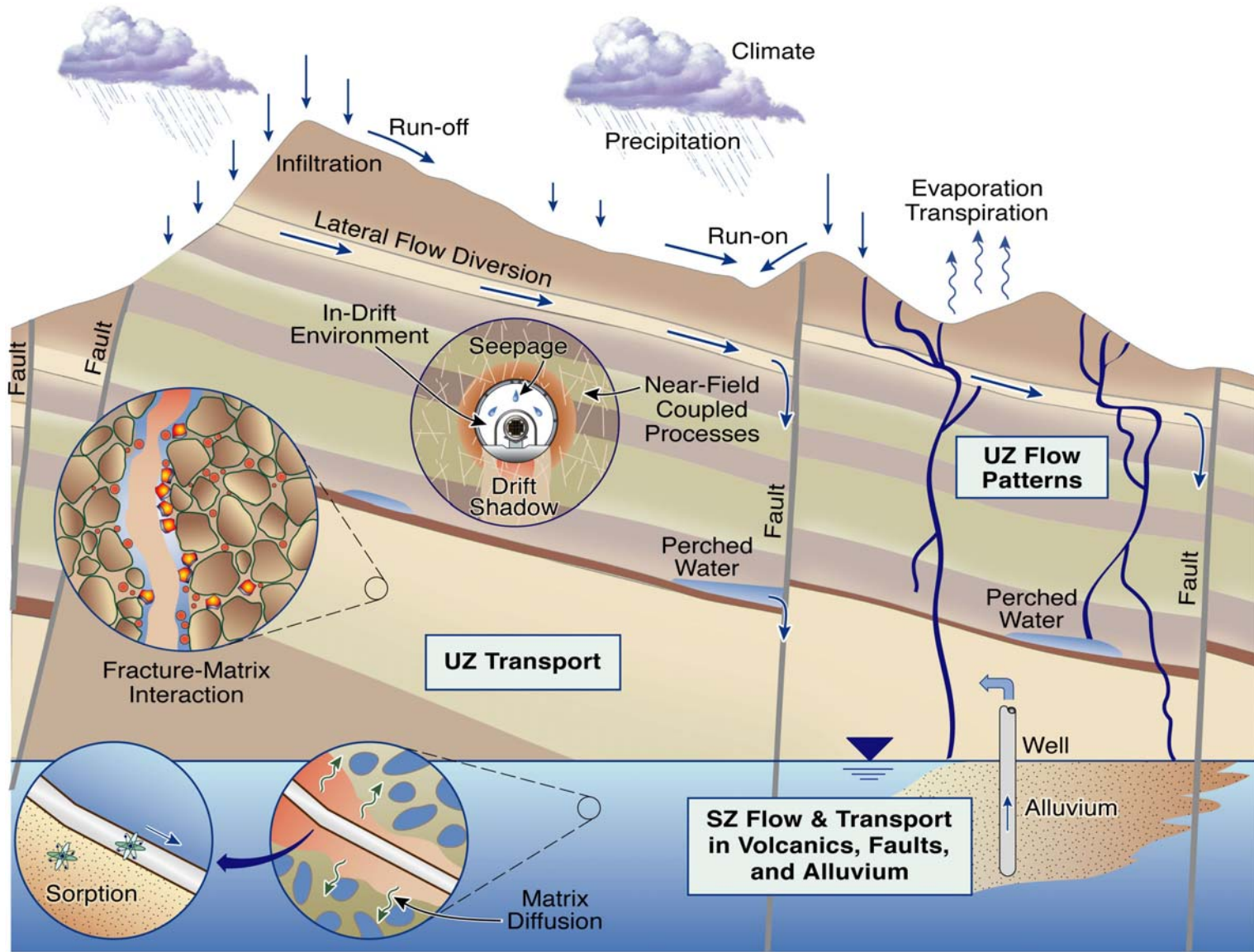
- **Geologic systems are considered suitable for radioactive waste disposal because of:**
 - Their stability over long time periods,
 - Their ability to physically and chemically isolate the waste canisters,
 - Their property to limit or significantly retard the release of radionuclides, and
 - Their relative inaccessibility, preventing unintentional or malevolent interventions

Barriers Important to Waste Isolation

- **Natural barriers contribute to waste isolation by:**
 - Limiting the amount of water entering emplacement drifts, and
 - Limiting the transport of radionuclides through the natural system
 - In addition, the natural system provides an environment that would contribute to the longevity of the engineered components (disposal canisters and waste forms)

- **Engineered barriers are designed specifically to complement the natural system in prolonging radionuclide isolation within the disposal system and limiting their potential release**

Natural Barriers

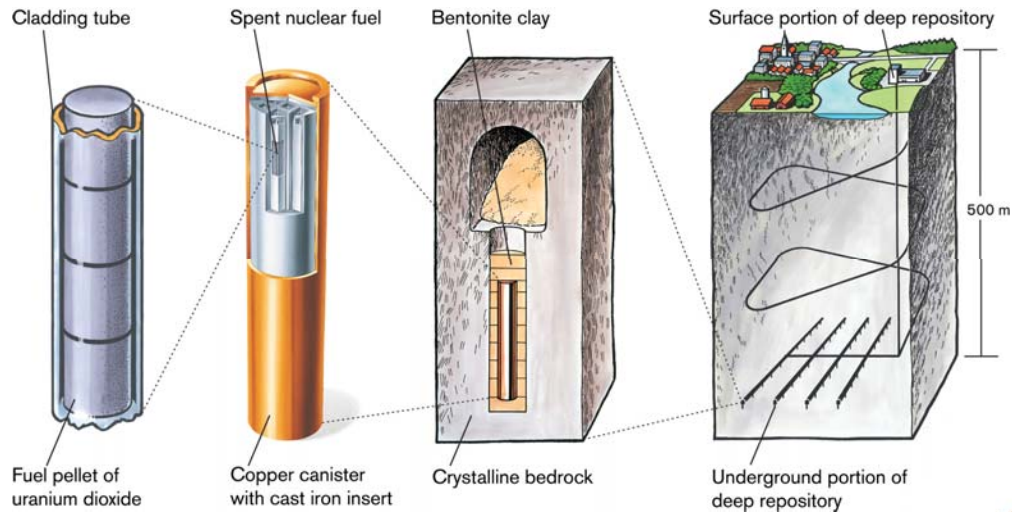


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Potential World-Wide Geologic Repository Environments

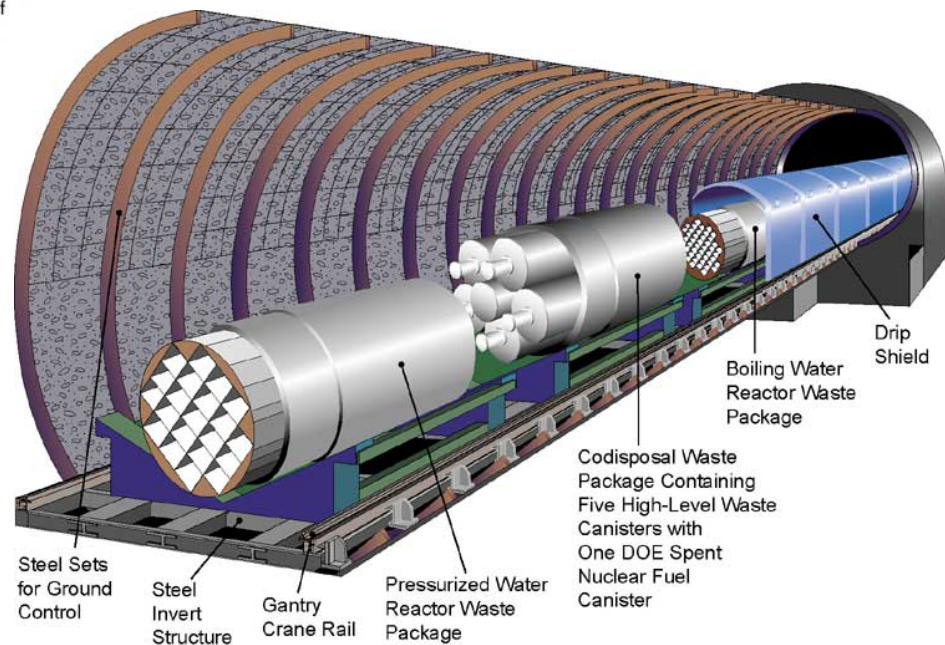
Hydrologic Environment	Rock Type	Key Features	Countries Considering this Option
Unsaturated	Ash-flow tuff	Limited seepage, fluid flow predominantly in fractures, zeolitic units have high sorptivity, oxidizing environment	USA
Saturated	Crystalline rock	Low porosity and permeability, fluid flow predominantly in fractures, reducing environment	Canada, Finland, France, Germany, Hungary, Russia, Sweden, S. Korea, Spain, Switzerland,
	Clay	Low permeability, high sorptivity, reducing environment	Belgium, France, Germany, Hungary, Russia, Spain, Switzerland
	Salt	Low-permeability, self-sealing, reducing environment	Germany, USA

Engineered Barriers



Swedish Concept (after Lundqvist, 2006)

United States Concept



Drawing Not To Scale
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The Grand Challenge for Nuclear Waste Disposal

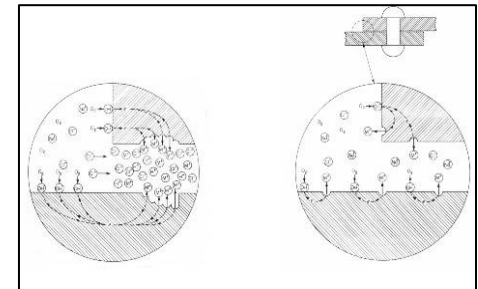
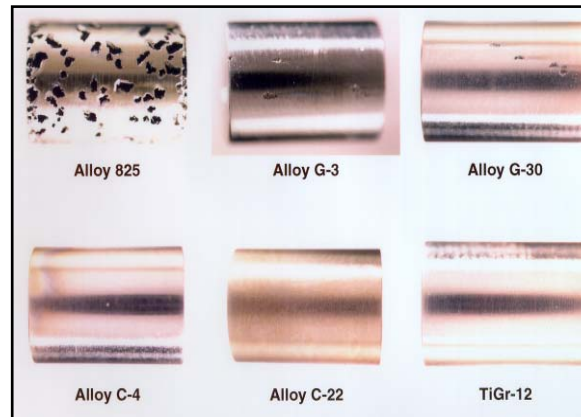
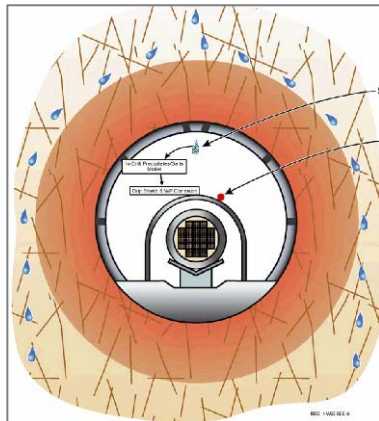
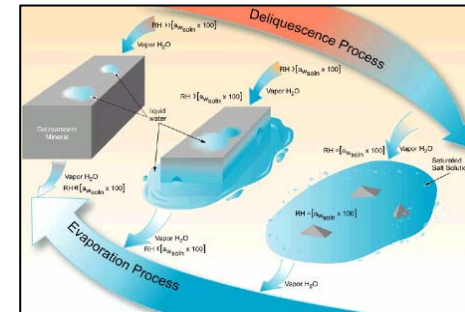
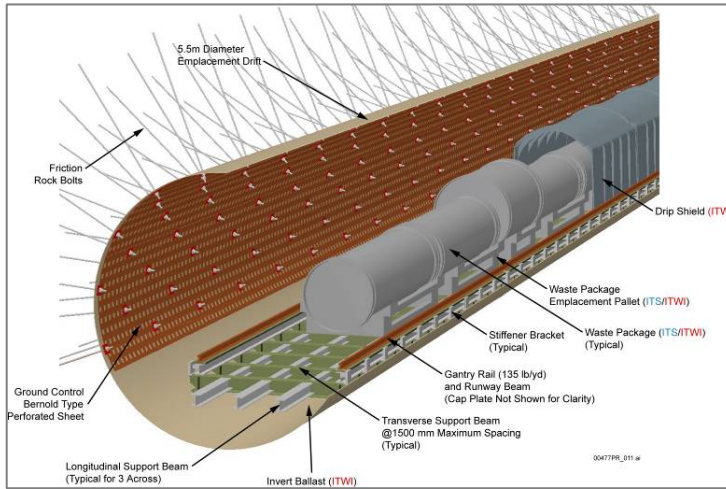
- **Need to understand and predict with sufficient confidence flow and transport processes and performance of materials (engineered and geologic) over geological time scales (at least to a million years), with long-term climate changes and the impact of extreme (disruptive) events (e.g., seismic and volcanic events) taken into account**
 - The longevity of engineered barrier components depends on the quantity and chemistry of fluids in the surrounding natural system
- **Finally, there is a need to establish a sound foundation for model abstraction and stochastic approaches used for performance assessment**

Research Needs – Engineered Materials Performance

- **A major component of the long-term strategy for safe disposal of nuclear waste is, first, to completely isolate the radionuclides in waste packages for long times, and then, to greatly retard the egress and transport of radionuclides from breached packages**
- **Corrosion is a primary determinant of waste package performance in any disposal environment and will control the delay time for radionuclide release and transport from the waste package**
- **Areas of enhanced understanding include: a) long-term behavior of protective, passive films; b) composition and properties of moisture in contact with metal surfaces; c) rate of penetration and extent of corrosion damage over extremely long times**

Engineered Materials Performance

Technical basis: corrosion science, electrochemistry, materials science, physical chemistry, geochemistry



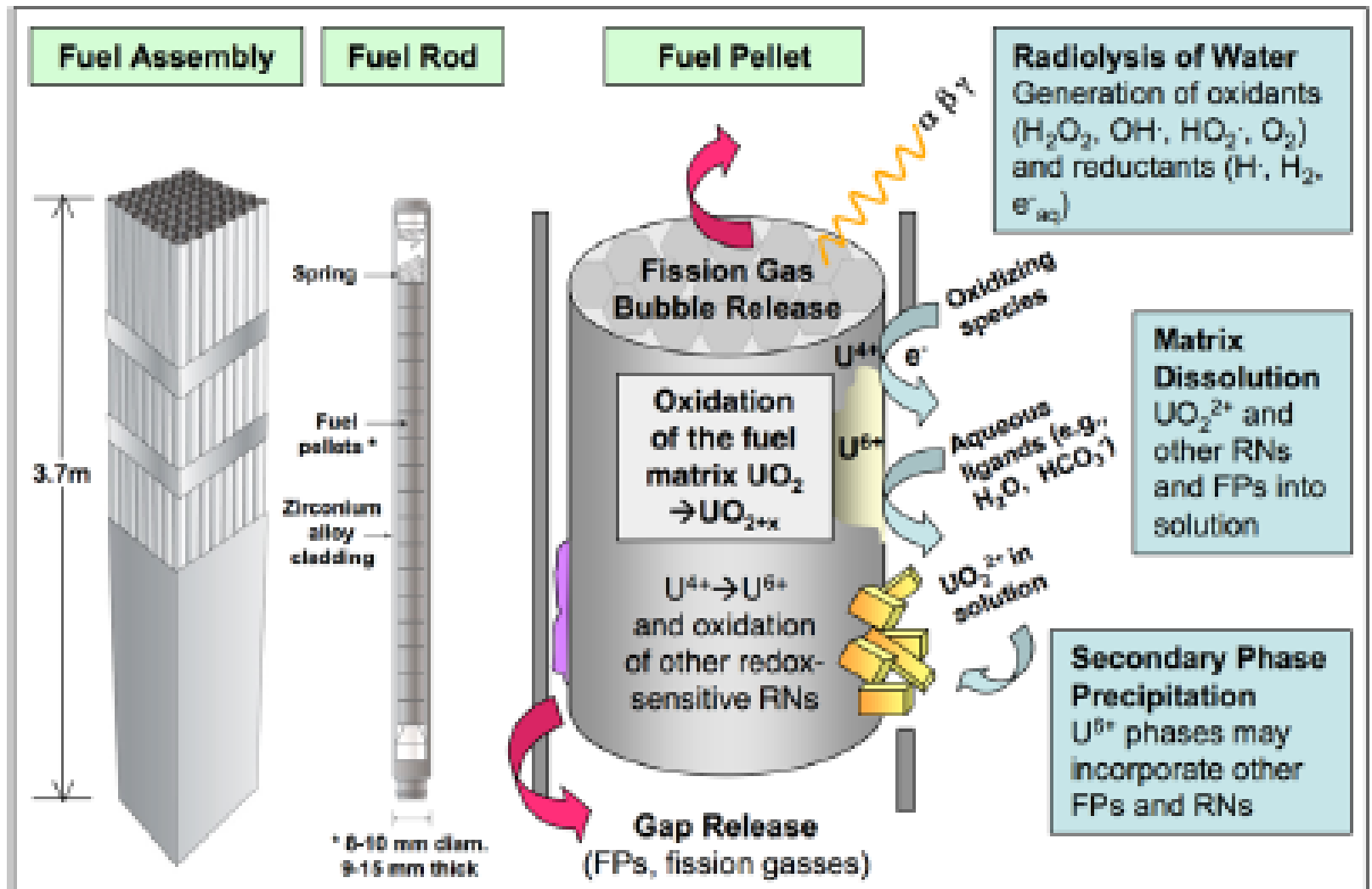
Research Needs – Source Term

- **Enhance the understanding of the performance and evolution of nuclear waste forms (spent nuclear fuel, nuclear waste glass, and other advanced waste forms) and to quantify the release of radionuclides in the evolving near-field environment expected in the repository**

- **A basic understanding of the fundamental mechanisms of radionuclide release and a quantification of the release as repository conditions evolve over time, particularly at longer times ($>10^5$ years), must be developed**

- **Among the important processes that can control radionuclide release are:**
 - Kinetics of waste form corrosion
 - Formation of secondary, alteration phases
 - Reduction and sorption onto the surfaces of near-field materials
 - Biogeochemical processes and microbial activity
 - *May influence the geochemical environment and promote colloid formation with resultant impacts on waste form stability and radionuclide transport.*

Source Term



after Bruno and Ewing (2006)

Research Needs – Natural Systems

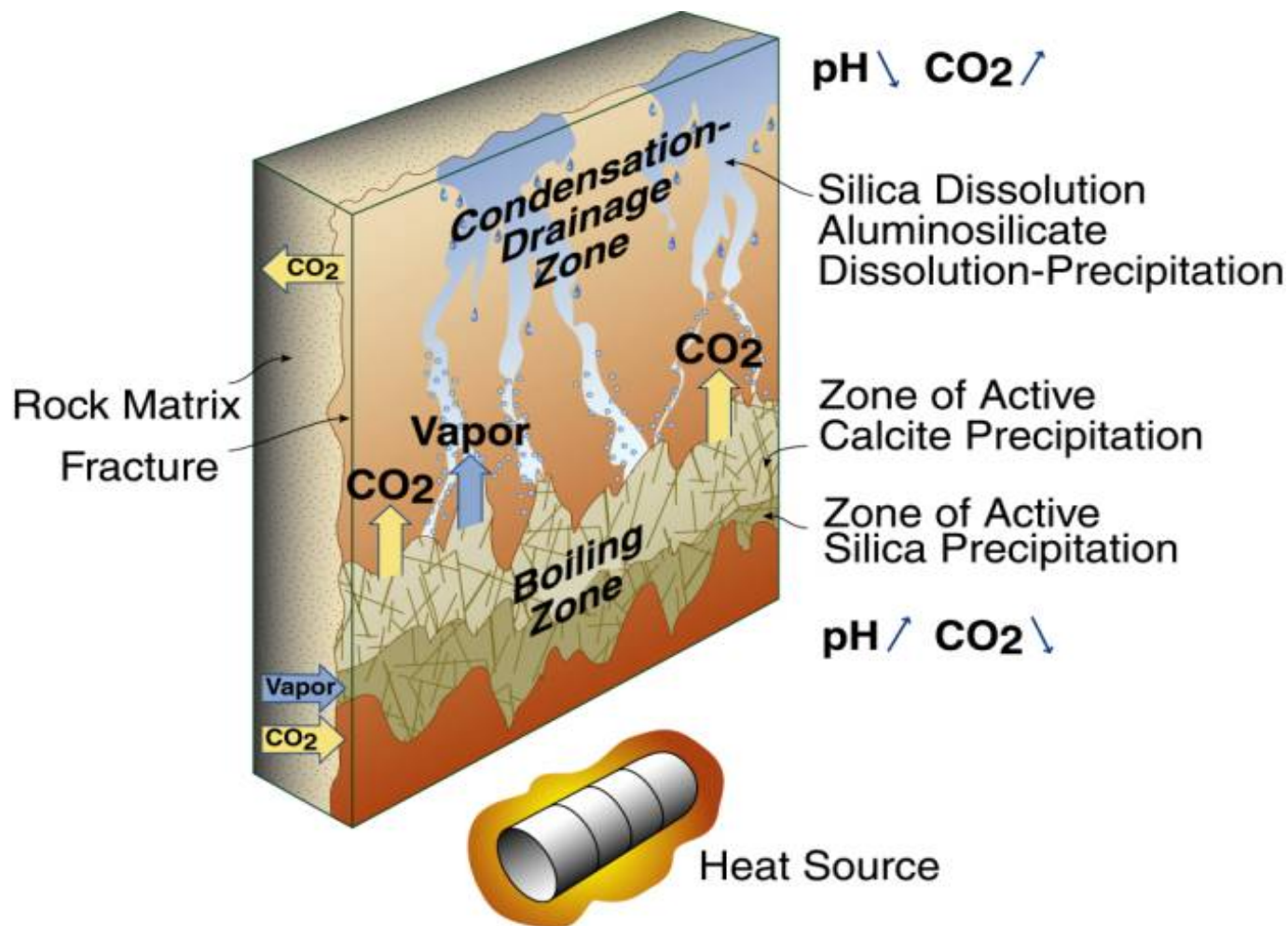
■ Requires:

- An understanding of the features, events, and processes that could transport radionuclides from the repository to the accessible environment;
- Laboratory experiments and field observations and tests to appropriately characterize the relevant properties at a potential repository site;
- Conceptual, mathematical, and numerical models that predict the behavior and performance of the repository system given its site-specific characteristics and properties; and
- Natural analogs, which help build confidence that the model predictions can be reliably extrapolated to the long time scales required for waste isolation.

Specific Research Needs – Natural Systems

- **Long-term climate change**
- **Groundwater recharge and discharge**
- **Percolation processes and definition of groundwater flow fields**
- **Near-field effects and thermally coupled processes**
- **Radionuclide transport**
- **Low probability disruptive events (such as volcanic and seismic events)**

Coupled Processes



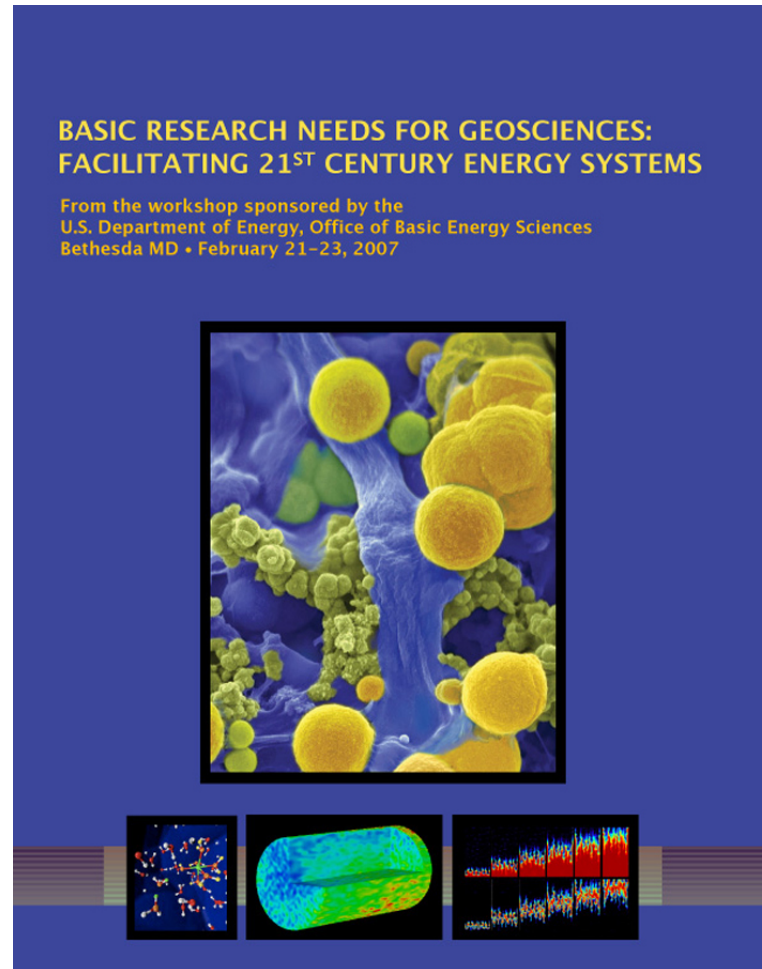
Crosscutting Needs

- **Advanced Repository Concepts/Designs for Advanced Fuel Cycles**
- **Monitoring and Performance Confirmation**
- **Reversibility and Retrievability**
- **Natural Analogues**
- **Advanced Modeling and Simulation**

DOE BES Workshop – “Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems”

■ Grand Challenges

- Computational Thermodynamics of Complex Fluids and Solids
 - Dynamical methods at the atomic time scale and upscaling
 - Equations of state for complex systems
- Simulation of Multiscale Systems for Ultra-long Times
 - Coupling methods used for different scales
 - Methodology concept and computational
 - Mathematical theory
 - Data integration

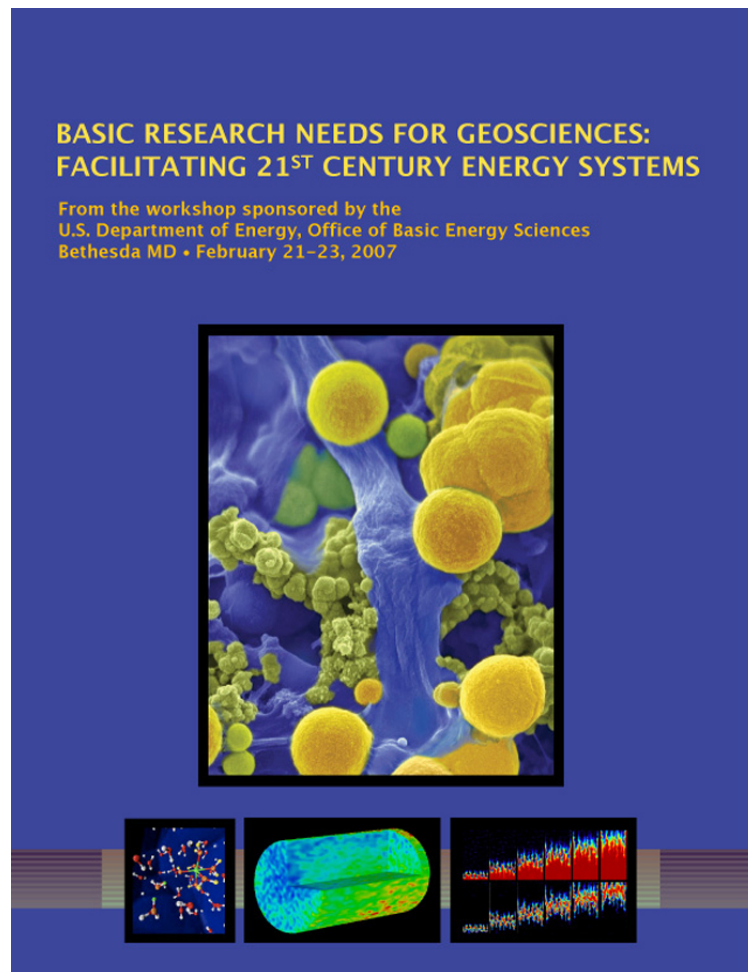


http://www.sc.doe.gov/bes/reports/files/GEO_rpt.pdf

DOE BES Workshop – “Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems” (cont.)

■ Grand Challenges (cont.)

- Integrated Characterization, Modeling, and Monitoring of Geologic Systems
 - Optimal detail in geological modeling
 - Incorporating large and diverse datasets into models
 - Relating geophysical measurements to in situ properties/processes
 - Coupled monitoring and modeling approaches
 - Early identification and quantification of anomalous behavior

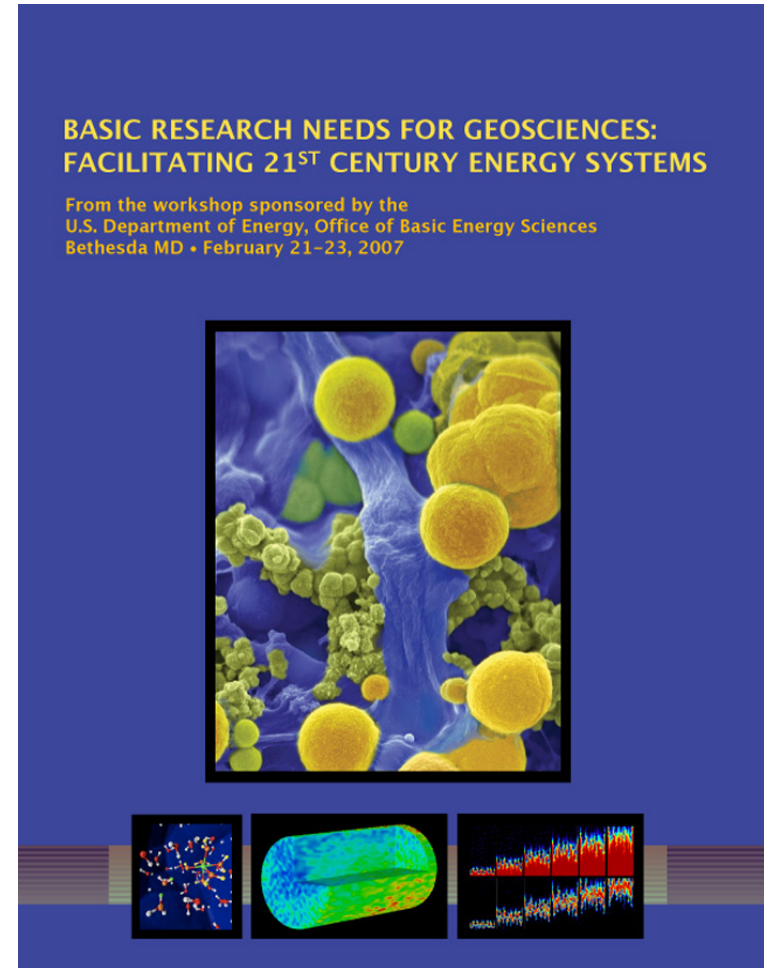


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DOE BES Workshop – “Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems” (cont.)

■ Priority Research Directions Relevant to Nuclear Waste Disposal

- Mineral-Water Interface Complexity and Dynamics
- Nanoparticulate and Colloid Physics and Chemistry
- Dynamic Imaging of Flow and Transport
- Transport Properties and *In Situ* Characterization of Fluid Trapping, Isolation, and Immobilization
- Biogeochemistry in Extreme Subsurface Environments

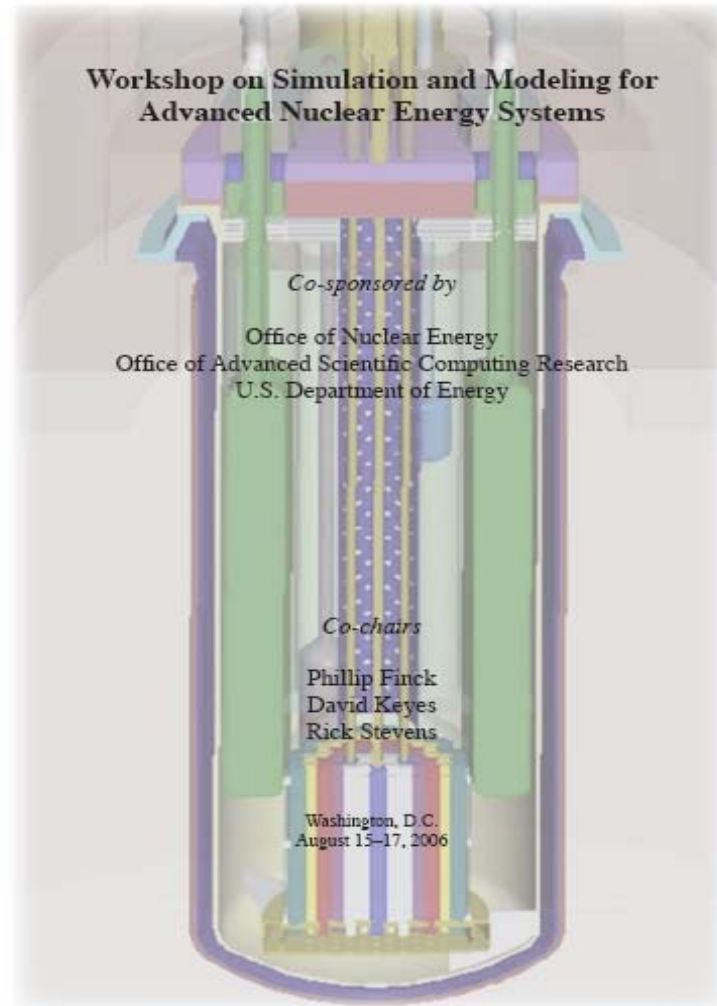


http://www.sc.doe.gov/bes/reports/files/GEO_rpt.pdf

DOE 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



<http://www-fp.mcs.anl.gov/anes/>

Closed Fuel Cycle Requirements

- **The objective of increasing energy production, while reducing the global proliferation risk and environmental impacts, could be achieved with a combination of Light Water Reactors (LWR) and Fast Reactors**

- **Technology choices must be made for:**
 - LWR fuels and LWR fuel separations technologies (if LWR recycle is contemplated)
 - Fast reactor technologies, fast reactor fuels, and fast reactor fuel separations technologies

- **The fuel cycle must be designed as a system, taking into account the following constraints:**
 - Compatibility between technologies
 - Safety of each component
 - Feasibility of each component
 - Proliferation resistance
 - Suitability of waste forms for geologic disposal
 - Cost reduction
 - Infrastructure distribution

A Science-Based Approach to Understanding Waste Form Durability and Repository Performance

- **A closed fuel cycle could allow for an evolution in the designs and operational concepts of geologic repositories**
 - Such a change could simplify the demonstration of repository safety and the requirements for engineered barrier system materials

- **Future Directions**
 - Development of advanced, more durable, tailored waste forms
 - Enhanced understanding of geologic repository performance
 - Systems optimization of repository design
 - Systems-level optimization of closed fuel cycle
 - Development of advanced geologic disposal concepts in a range of geologic settings and geochemical environments