U.S. DEPARTMENT OF ENERGY | Nuclear Energy

The Advanced Fuel Cycle Initiative

Science Based Fuel Cycle Research and Development

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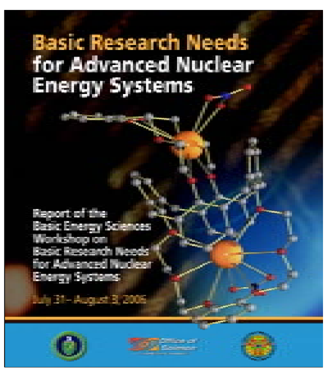
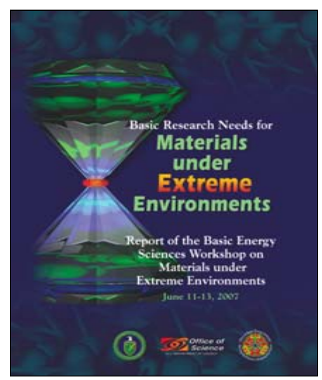
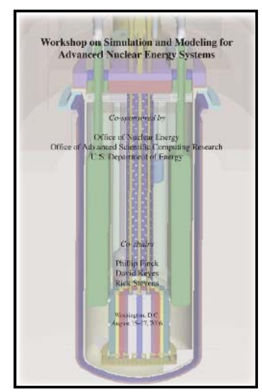
Former Programmatic Approach

- **Incremental improvement of existing technologies to allow for short-term (~20 years) deployment, driven by better utilization of Yucca Mountain**
  - Specific choice of technologies and integrated system (dictated by time frame and Yucca Mountain characteristics)
  - Challenges were well identified
  - Engineering approaches were chosen to address these challenges
  - Fundamental challenges had also been identified (2006 workshops), but were marginally acted upon (e.g., modeling and simulation)
- **The industrial approach resulted in very limited investment in the tools needed to develop a better understanding of the fundamentals**

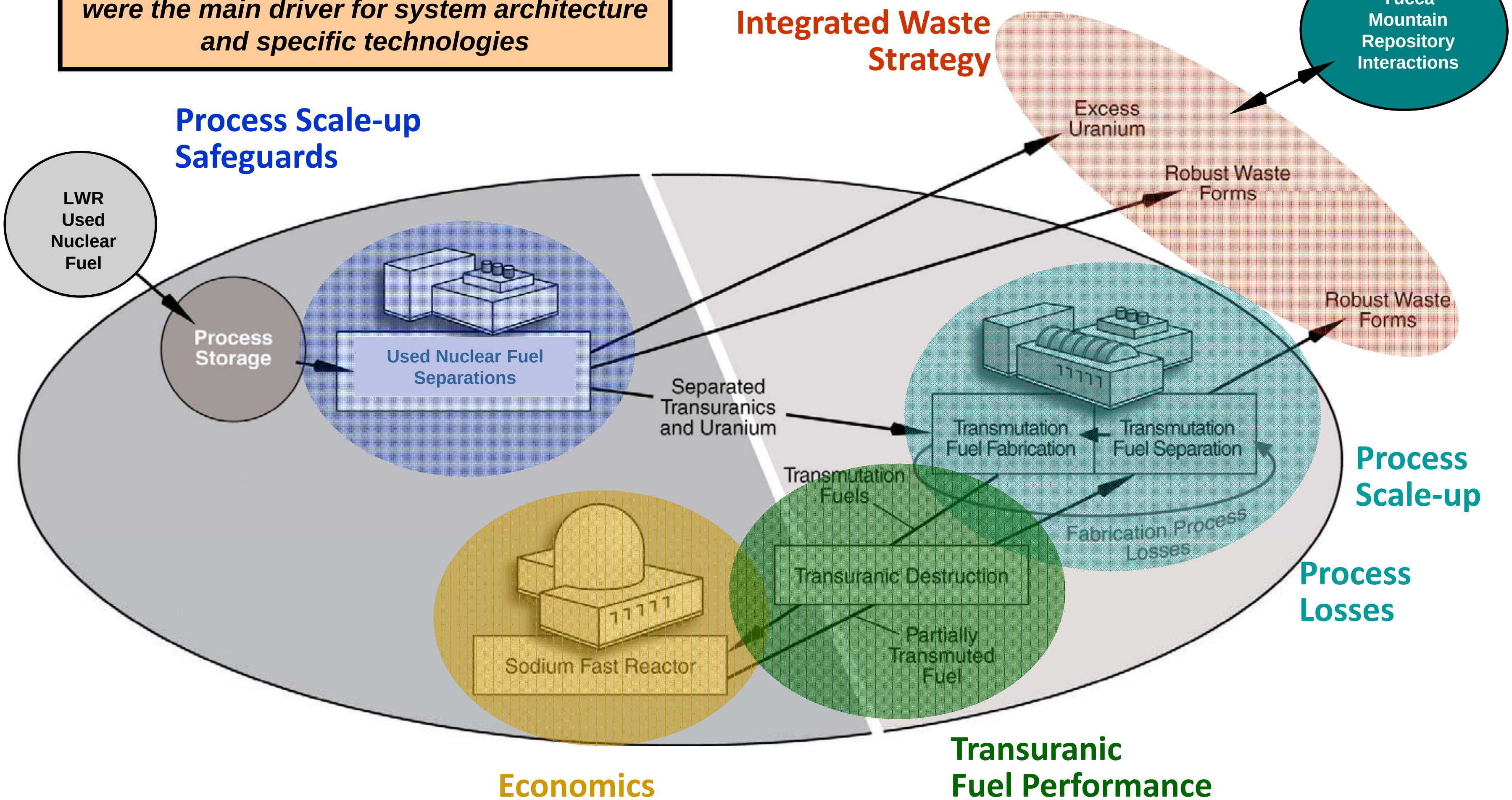






Past Definition of Technical Challenges

Yucca Mountain repository characteristics were the main driver for system architecture and specific technologies

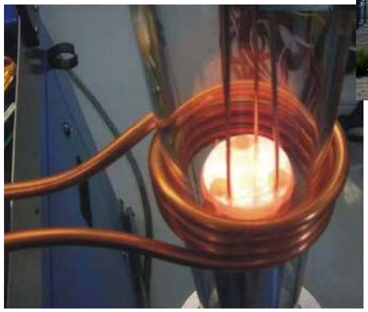


Proposed New Approach

1. **Long term deployment of fuel cycle technologies**

2. **Based on an initial analysis of a broad set of options**

3. **Based on the use of modern science tools and approaches designed to solve challenges and develop better performing technologies**



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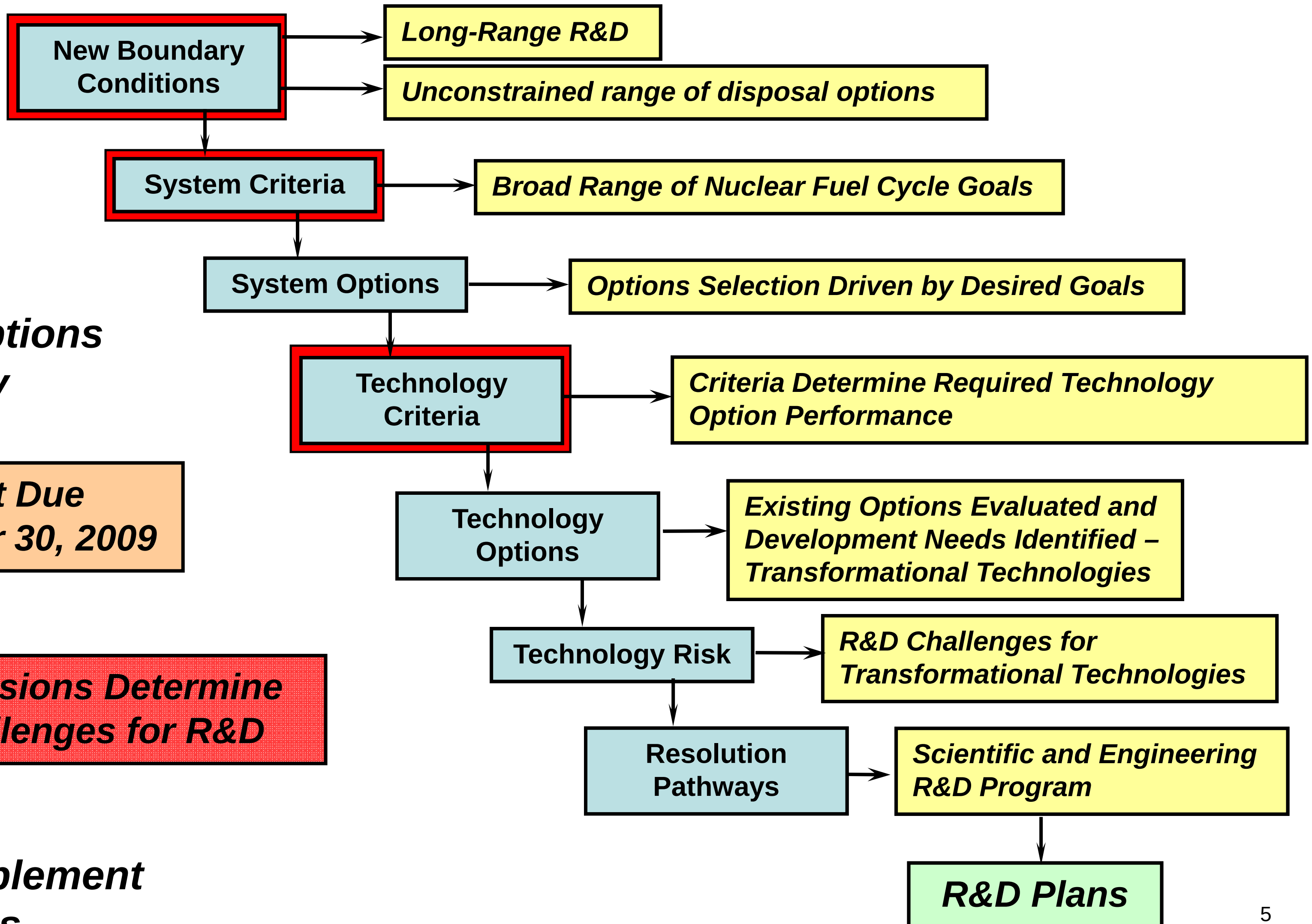
Proposed New Approach (2)

Step 1: Options Study

Report Due September 30, 2009

Policy Decisions Determine Grand Challenges for R&D

Step 2: Implement Plans



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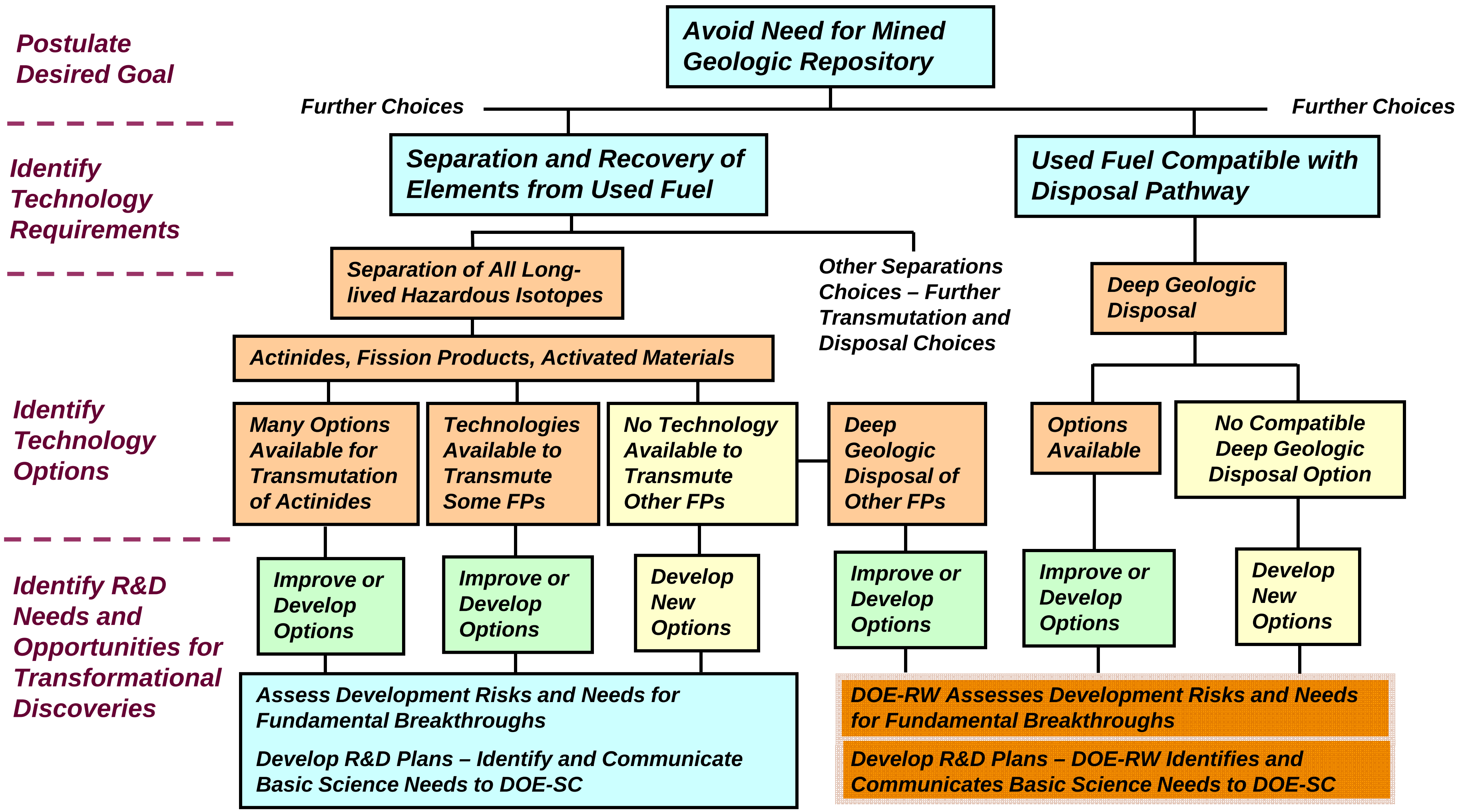
Example of System Development from Postulated System Goal



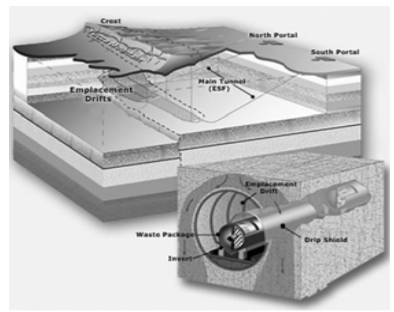
Deep Geologic Disposal

- **There are many options for deep geologic disposal**

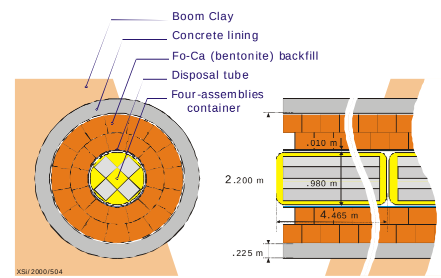
Mined geologic repositories –
Saturated rock
Hard rock – granite, basalt, …
Soft rock – shale, sedimentary rocks, …
Unsaturated rock
Volcanic tuff
Clay (saturated)
Salt (dry)

Isolation is provided by engineered systems, chemical environment, geologic stability, …

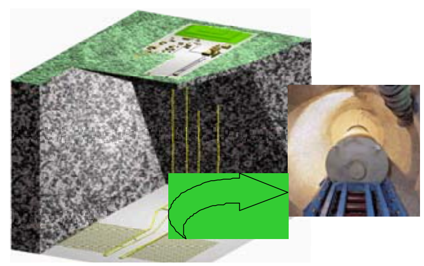
Deep boreholes
Isolation is provided by depth



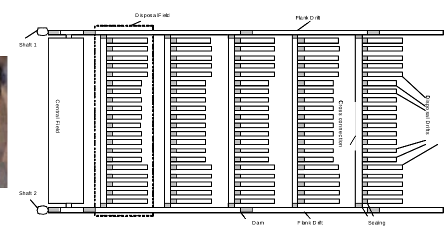
Yucca Mountain



Saturated Clay Layer



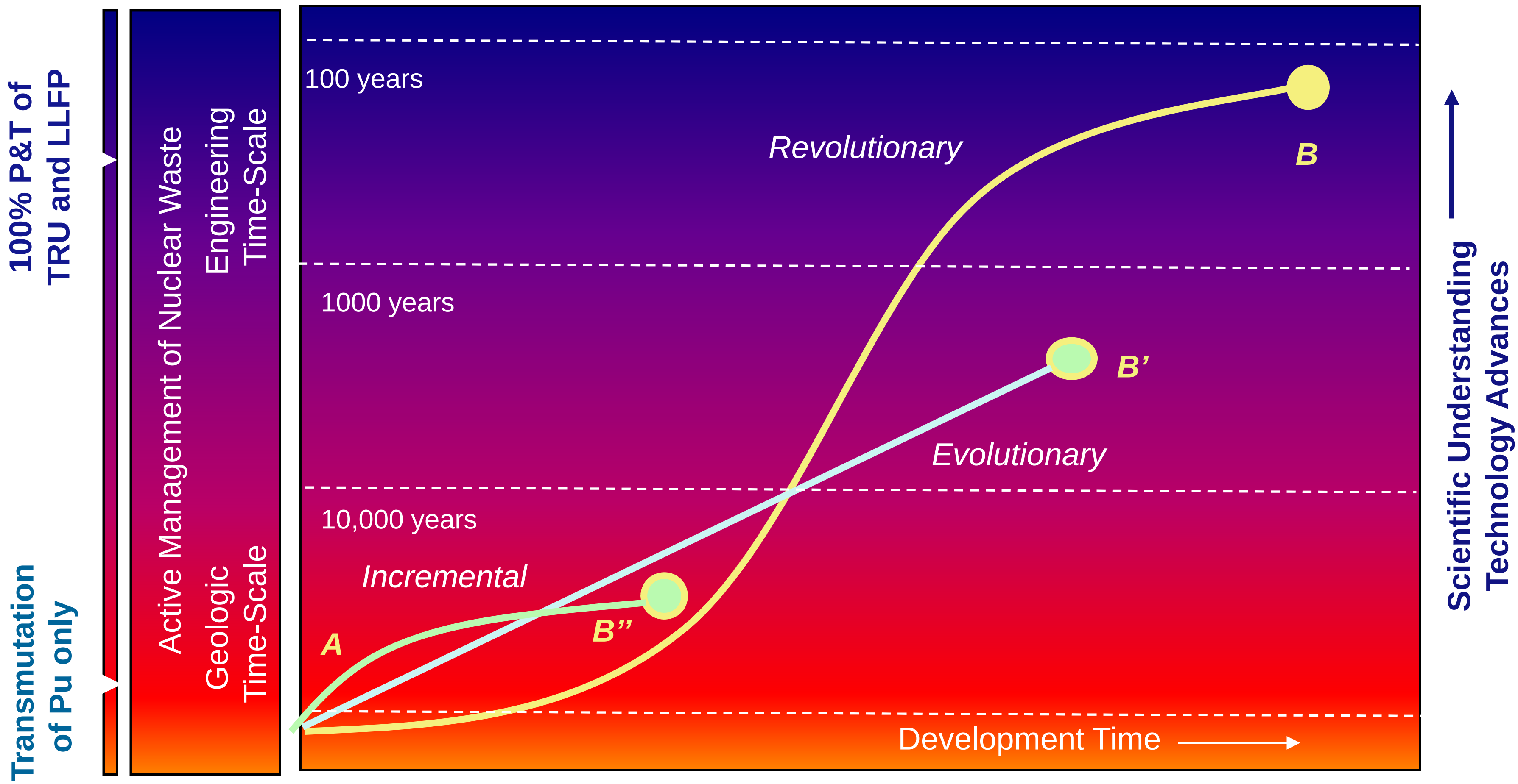
Granite



Salt

Seabed/sub-seabed, Subduction Zone, Rock melt, Island (intentional dilution in ocean), Ice sheet, Space, … Many issues - isolation potential, international law, geology, …

Need For Creativity



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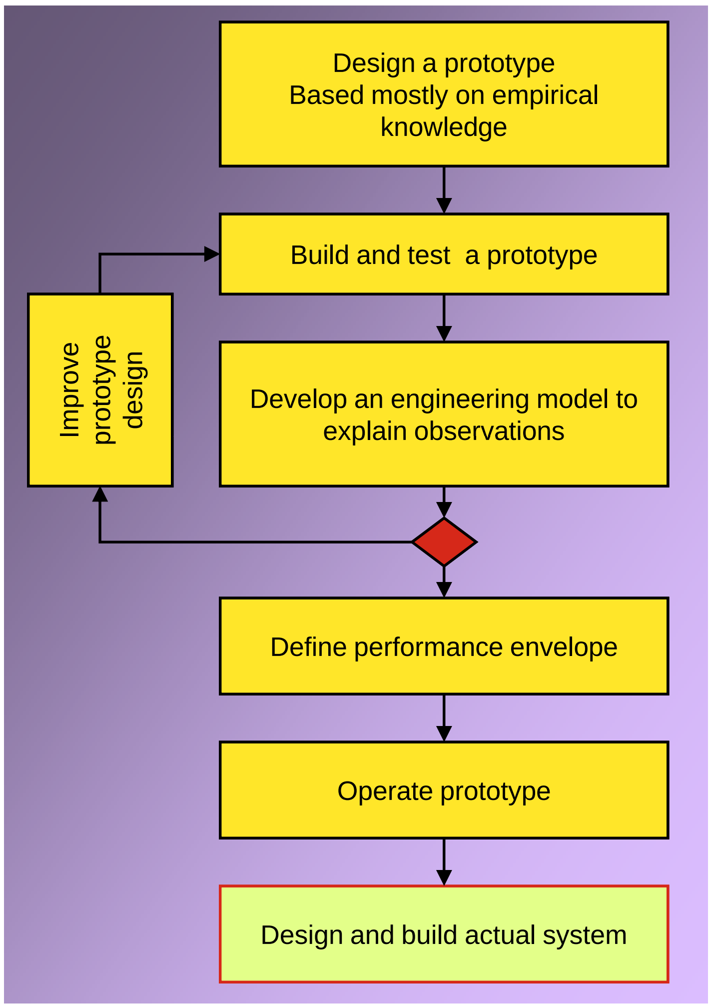
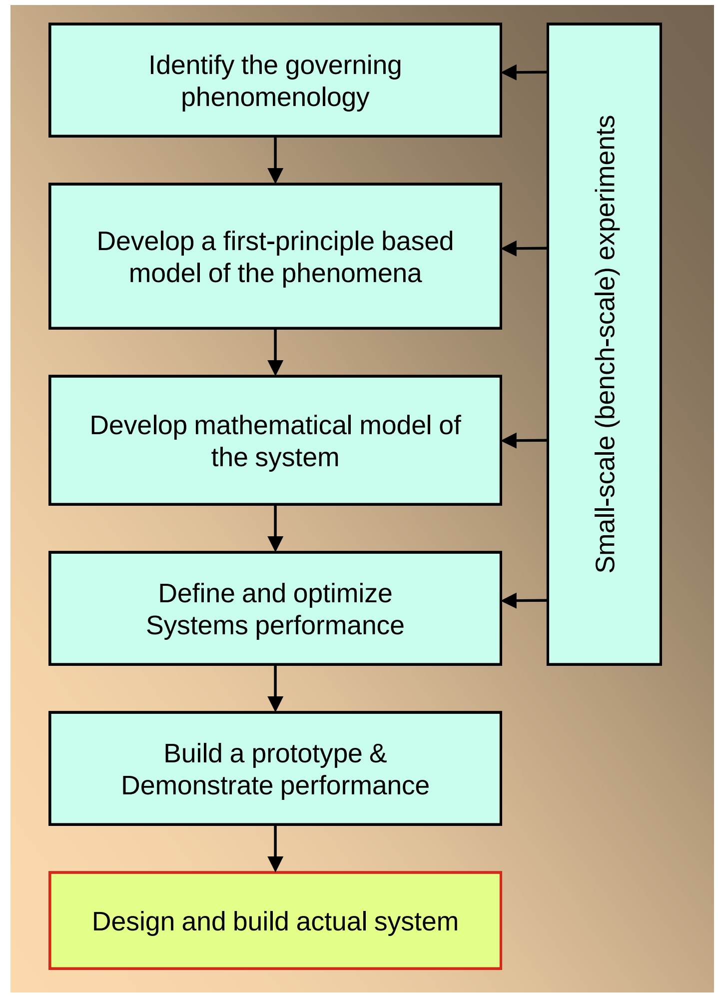
Observational vs Predictive Approaches

Engineering Approach Empirical - Observational



"Science-Based" Approach - Predictive



Transformational Nuclear Fuels Scientific Research and Development

Today's Technology Challenges

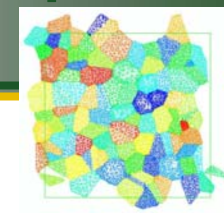
For fuels with variable compositions

- Understanding and predicting fuel behavior and performance
- Reliably fabricating fuel with zero defects and with zero losses

Grand Challenge

- Zero loss and zero defect fuel fabrication
- Ultra-high burnup fuel operation with zero clad-breach

Development Path



Develop a μ-structural understanding of fuels and materials

- Closure of combined transport and phase-field equations
- Separate effect testing and properties measurement at sub-grain scale
- Effect of nano-scale implantations
- Innovative clean and reliable fabrication techniques with tightly controlled microstructures tailored to desired performance

Transformational Result

- Predictive capability for fuel process and in-pile behavior for a variety of initial and boundary conditions
- Novel fuel forms

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Waste Storage and Disposal Scientific Research and Development

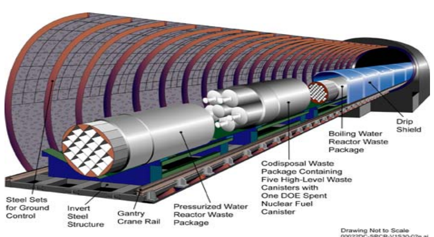
Today's Technology Challenges

Storing and disposing spent fuel, HLW, GTCC, and LLW from a range of fuel cycles

- Understanding and predicting geologic repository performance
- Safe, secure, and cost effective storage and disposal

Grand Challenge

Integrated waste management with near zero radionuclide release from storage and disposal system



Development Path

Develop an understanding of geologic repository performance

- Review extensive technical basis developed in the U.S. and internationally over the past several decades
- Explore range of geologic settings, including granite, salt, clay, and tuff, and range of disposal concepts, including shaft-room, ramp-drift, borehole, and shallow land burial
- Investigate storage concepts for a range of waste streams
- Develop an integrated waste management strategy applicable to a range of fuel cycle options

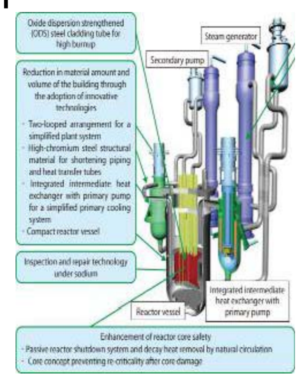
Transformational Result

Predictive capability for performance of storage and disposal options for a range of fuel cycles

Transmutation Systems Scientific Research and Development

Today's Technology Challenges

- Fast reactors have not been commercially deployed – perception of higher system cost of electricity
- Licensing regime is based on light water reactor technology
- Ability to design and assess other systems



Grand Challenge

- Risk to public health and safety prohibited by inherent safety
- Cost of fast spectrum systems less than current ALWR
- Ability to model new systems

Development Path

Develop key cost reduction features

- Modeling and simulation for optimized design and performance, and safety assurance
- Advanced materials for performance, reliability, longevity, and safety
- Energy conversion innovations for improved efficiency and component cost
- R&D facilities for validation of innovative features and exploration of options

Transformational Result

- Revolutionary improvements in fast spectrum system performance (and cost) to enable transmutation and economic fuel cycle closure
- Novel transmutation systems

Separations and Waste Form Scientific Research and Development

Today's Technology Challenges

Recycling used nuclear fuel:

- Meeting current air emission requirements
- Economical recovery of transuranic elements for recycle/transmutation
- Minimal waste generation

Grand Challenge

- Near-zero radioactive off-gas emissions
- Simplified, single-step recovery of transuranic elements
- Significantly less waste produced

Development Path

Develop fundamental understanding of separation process and waste form thermodynamics

- Understand underlying separation driving forces
- Exploit thermodynamic properties to effect separations
- Elucidate microstructural waste form corrosion mechanisms

Transformational Result

- Predictive capability for separation and waste form performance over a broad range of operational conditions
- Novel separations technologies

Materials Protection, Accounting, and Control for Transmutation Scientific Research and Development

Today's Technology Challenges

- Large throughput facilities require shutdown for periodic inventory
- New reactor designs require new nuclear material management approach
- Move from reactive to preventive systems approach

Grand Challenge

Develop online, real-time, continuous, accountability instruments and techniques that permit an order of magnitude improvement in the ability to inventory fissile materials in domestic fuel cycle systems, in order to detect diversion and prevent misuse

Development Path

- **Next generation instrumentation**
  - High sensitivity and specificity
  - Enabled by new physics data
  - New sensor materials
- **Integration of disparate data in quantitative manner**
  - Real time assessments
  - Probability basis with uncertainties
- **Predictive modeling and simulation at atomistic and plant level**

Transformational Result

Real time nuclear materials management with continuous inventory

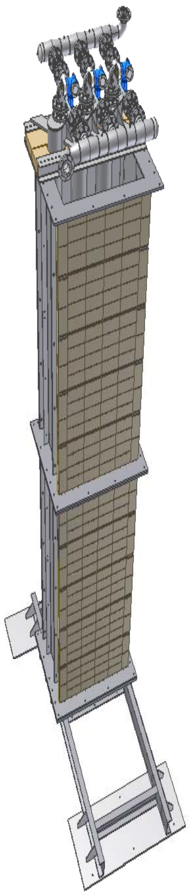
Modeling and Simulation Scientific Research and Development

Today's Technology Challenges

- Theory drives experiment design
- Experiments provide discoveries to drive theory
- Empirically based modeling and simulation heavily dependent on staying close to experimental basis

Grand Challenge

Develop process/methodologies to enable the use of computer simulation in a fundamentally new way for operation, design, and licensing of nuclear systems



Development Path

- Treat simulations as numeric experiments
- Focus on simulating physics vs characterizing specific devices
- Numerically solve governing equations of motion in detailed 3-D grids
- Carry out simulations prior to experiments
- Leverage massive computing power (petascale) + HPC expertise
- Combine single-effects validation to infer behavior of integrated systems

Transformational Result

Modeling and simulation tools that are based on fundamental understanding of physical processes and capable of predicting performance of fuel cycle technologies

Example: Mixing in upper plenum

- **New CFD TH-validation experiment**
- **BG/P simulations supported through separate INCITE award**
- **Comparing LES & RANS results**
  - *First experimental data this summer*