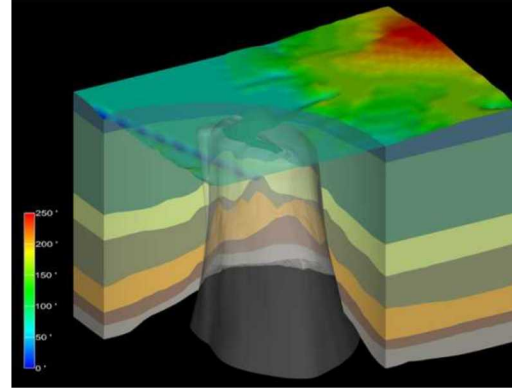


Exceptional service in the national interest



National Case Study: Mature Program without Active Siting

Robert J. MacKinnon

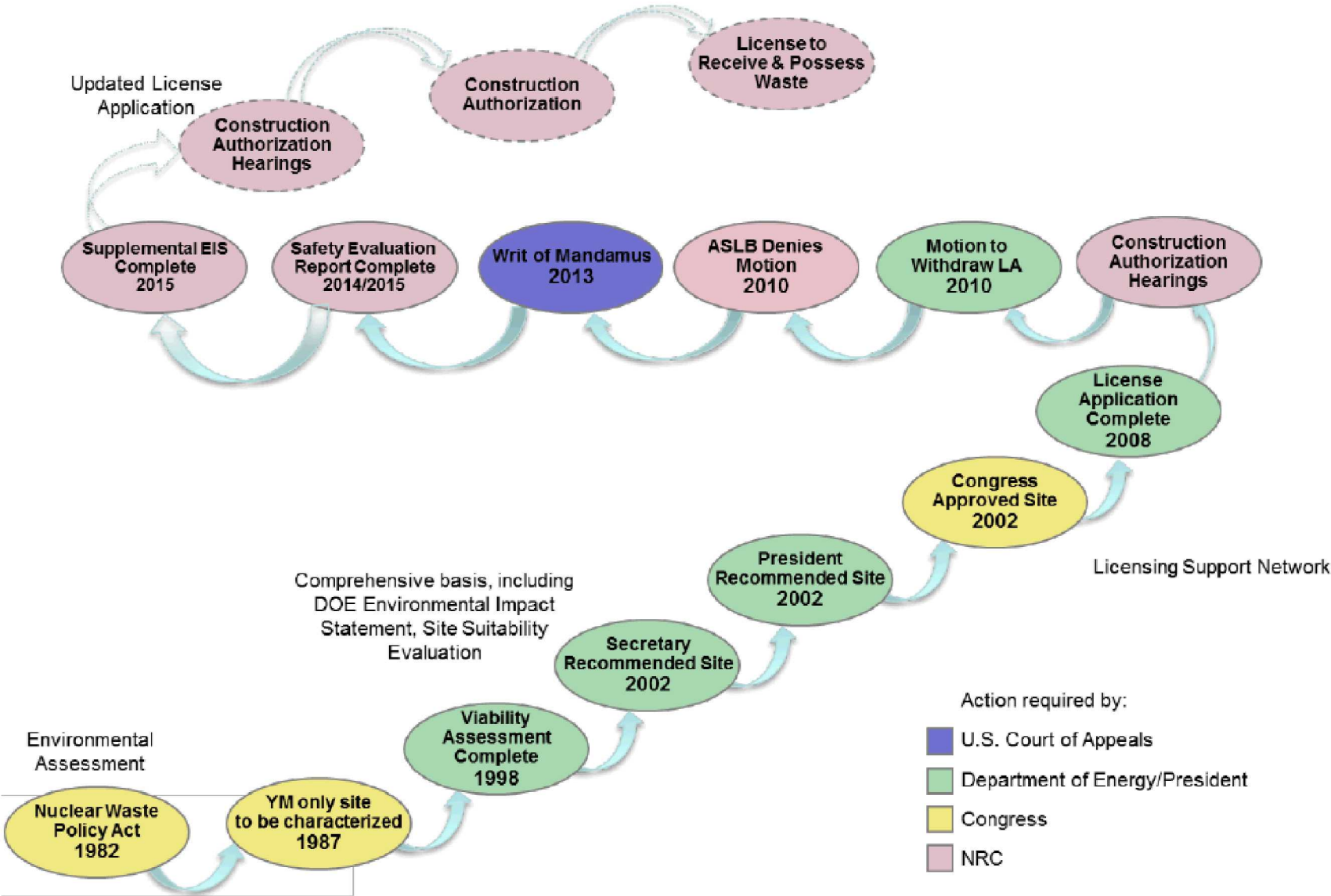
12 – 16 September 2016

JRC Ispra (Italy)

Outline

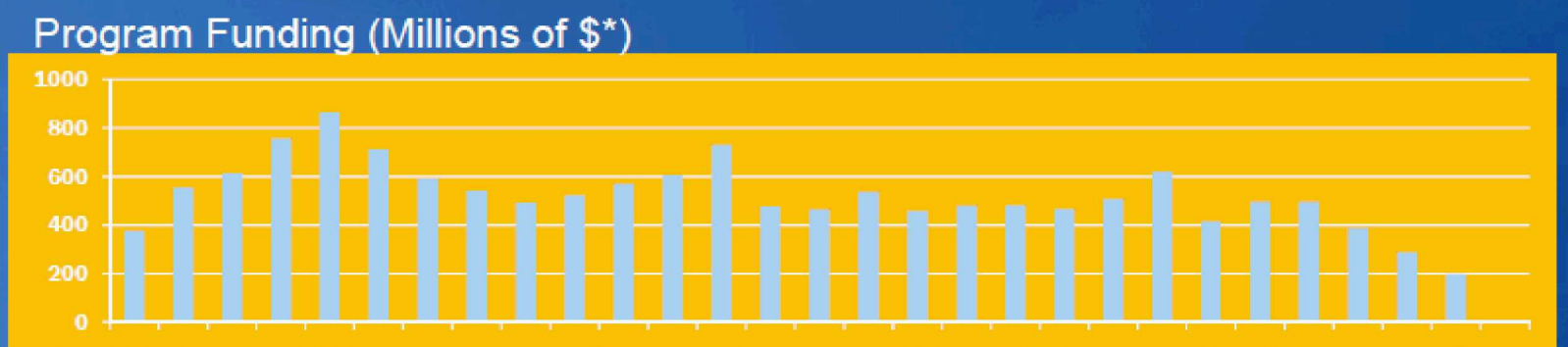
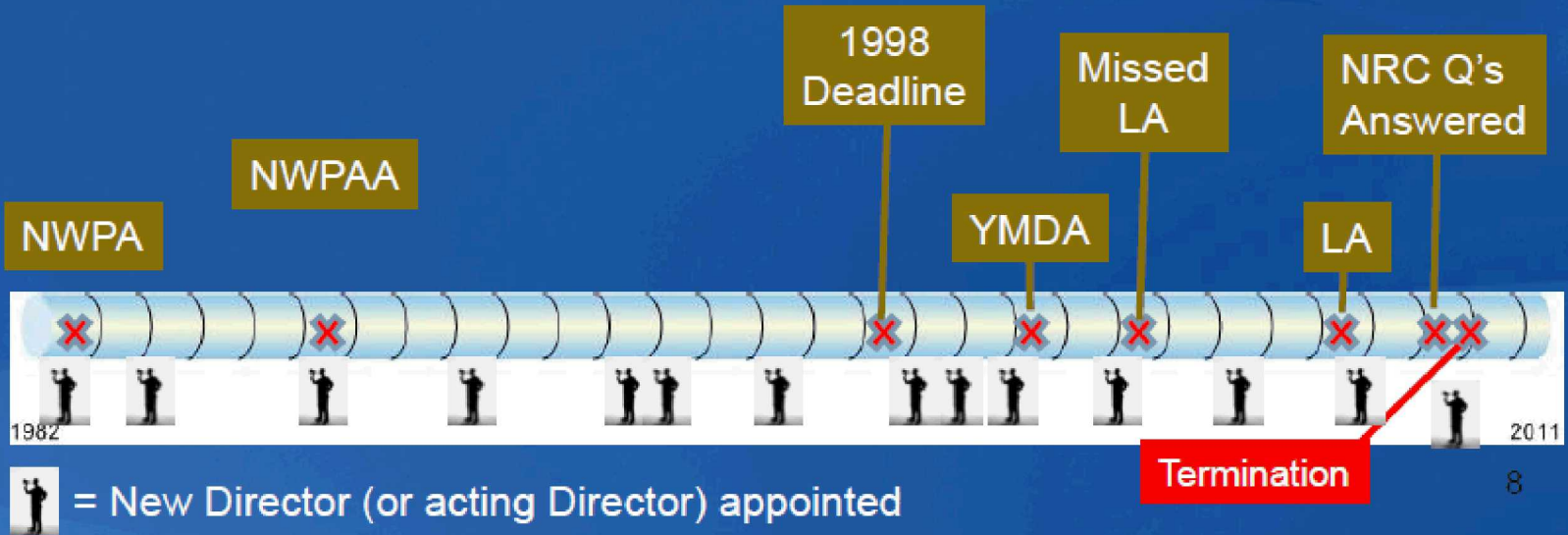
- **Yucca Mountain Timelines**
- **Regulatory Framework for Yucca Mountain**
- **Yucca Mountain Repository Concept and Long-Term Performance**
- **Safety Analysis Report and License Application**
- **Knowledge Preservation**
- **Key Lesson Learned – Site Characterization, Performance Assessment, and Design activities should be integrated**
- **Current US Nuclear Waste Management Strategy and Disposal R&D Program**
- **Conclusions**

Yucca Mountain Project Timeline



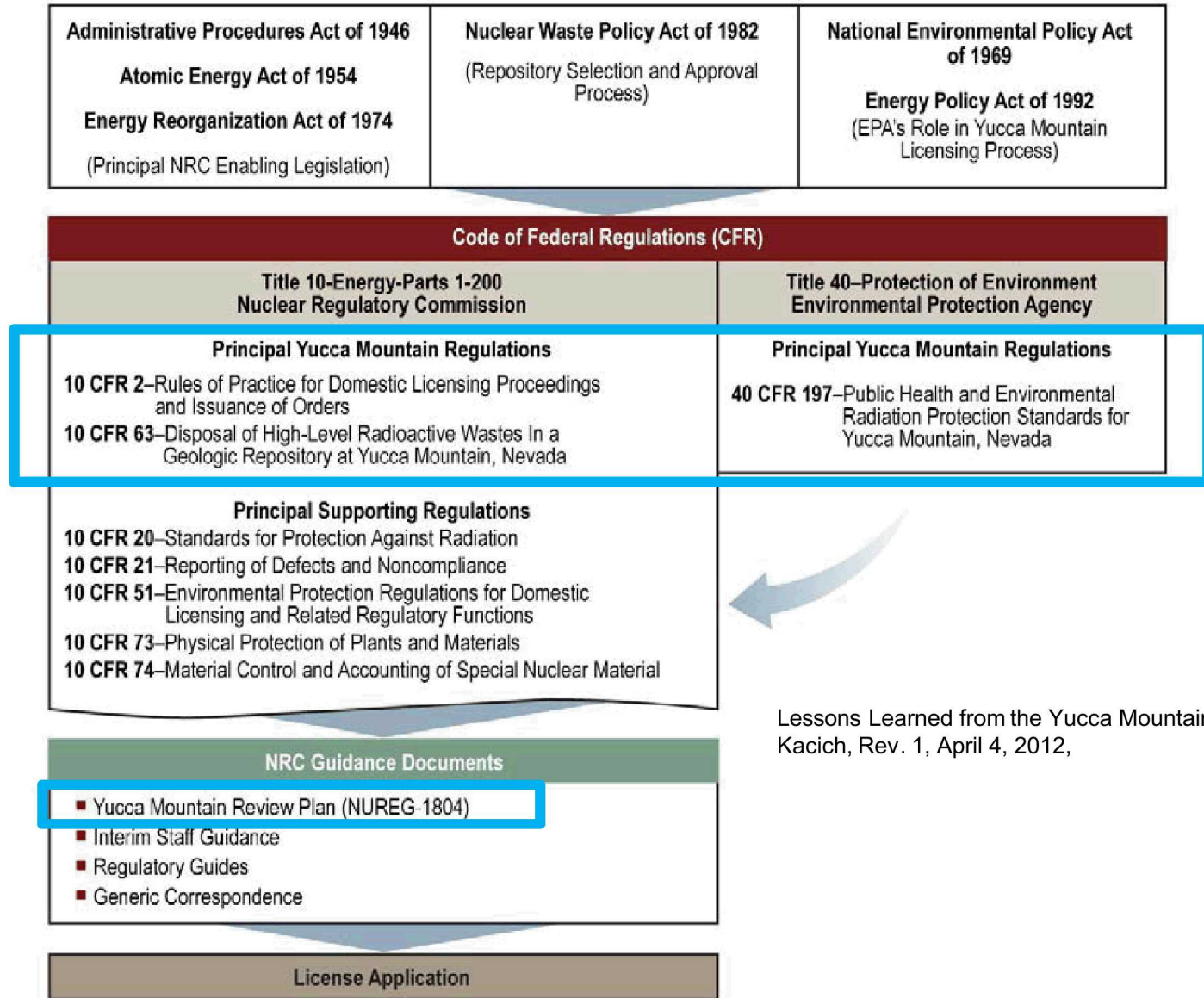
Yucca Mountain

Funding and Governance Timeline



* Constant 2007 \$ until 2007, actual \$ thereafter

Regulatory Framework for Yucca Mountain



Lessons Learned from the Yucca Mountain Project, Richard M. Kacich, Rev. 1, April 4, 2012,

Major Elements of the Yucca Mountain Repository Concept

- The waste:
 - HLW and SNF from defense and commercial activities
- The repository design
 - Waste packages emplaced in open tunnels in unsaturated rock
- The site
 - Arid climate, topography, and geology limit water flow reaching the engineered barriers and provide a long transport path before radionuclides can reach the human environment
- Long-term performance of the repository relies on natural and engineered barriers working together to isolate the waste

Waste for Yucca Mountain



Commercial Spent Nuclear Fuel:
63,000 MTHM (~7500 waste packages)



DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(~400 naval waste packages)
(DSNF packaged with HLW)



DOE & Commercial High-Level Waste:
4,667 MTHM
(~3000 waste packages of co-disposed DSNF and HLW)



DSNF: Defense Spent Nuclear Fuel
HLW: High Level Radioactive Waste
MTHM: Metric Tons Heavy Metal

Yucca Mountain Subsurface Design

Emplacement drifts

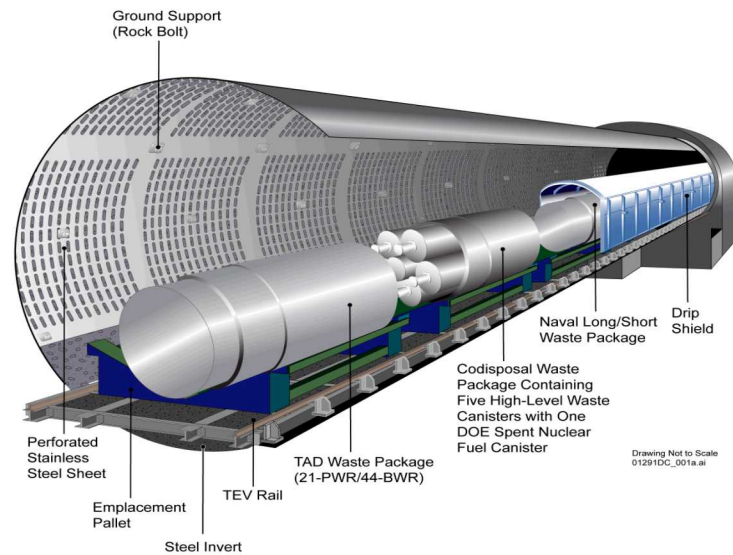
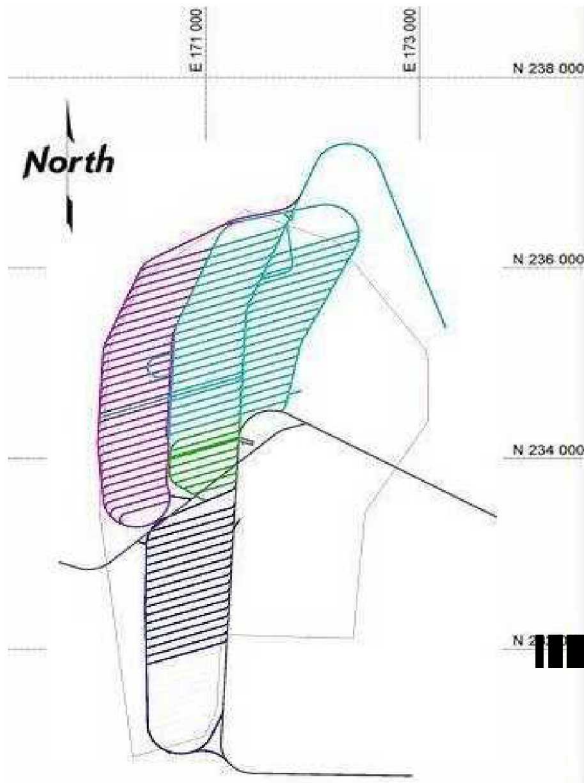
5.5 m diameter
approx. 100 drifts, 600-800 m long

Waste packages

~11,000 packages
~ 5 m long, 2 m diameter
outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)
inner layer 5 cm stainless steel
Internal TAD (transportation, aging, and disposal) canisters
for commercial spent fuel, 2.5 cm stainless steel

Drip shields

free-standing 1.5 cm Ti shell

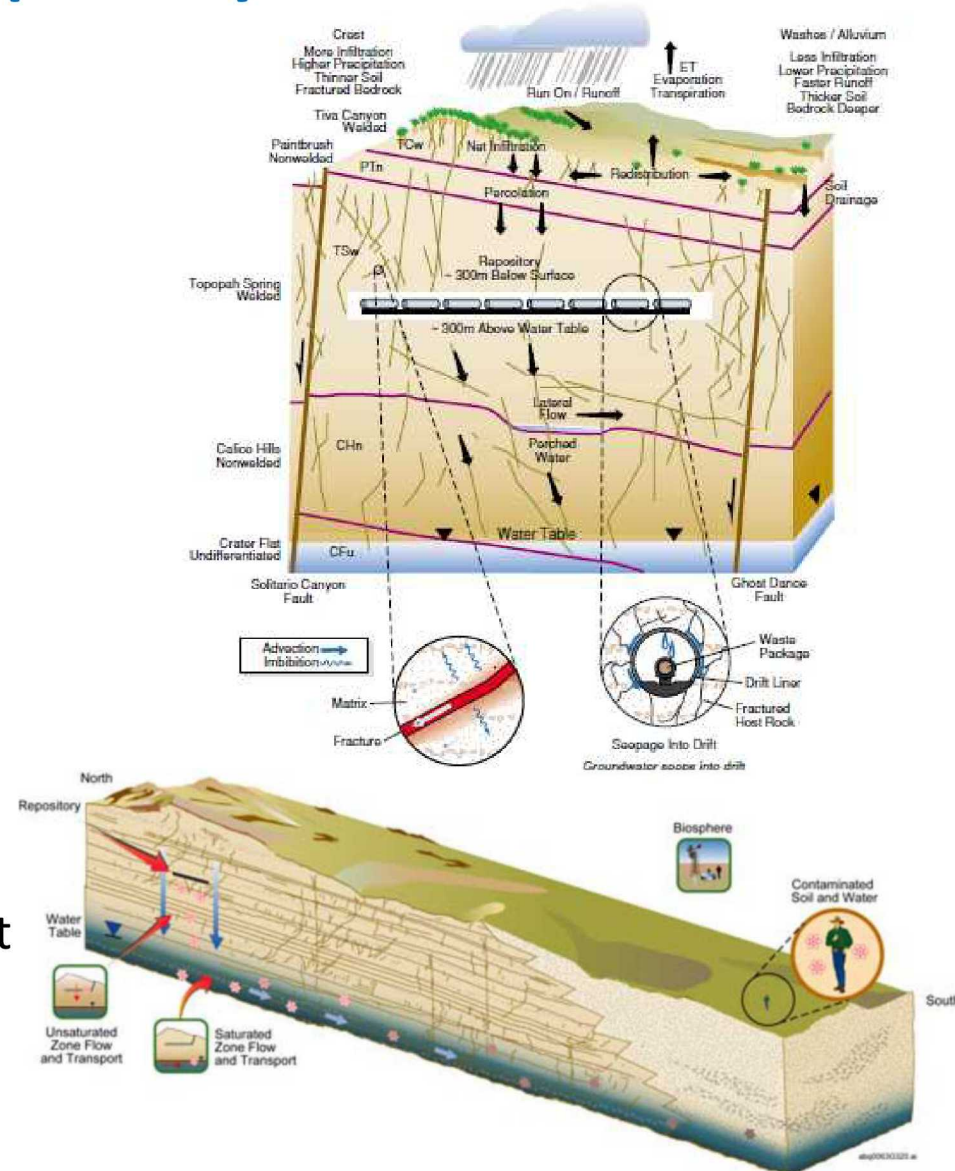


Yucca Mountain Exploratory Studies Facility Sandia National Laboratories

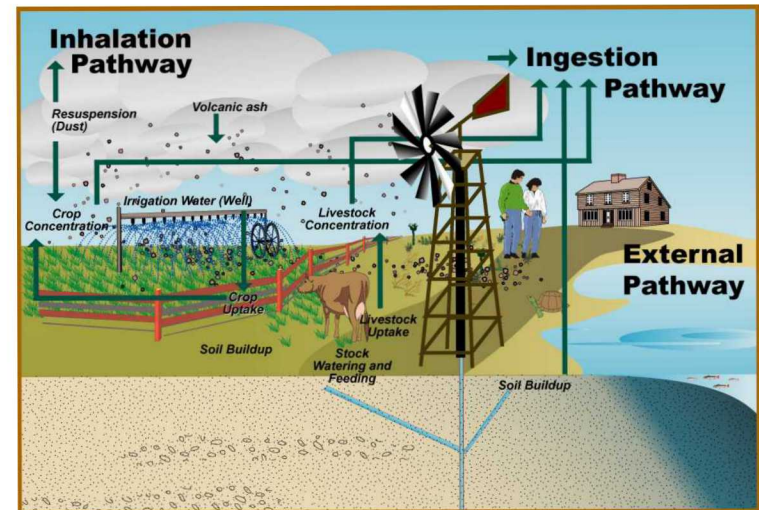
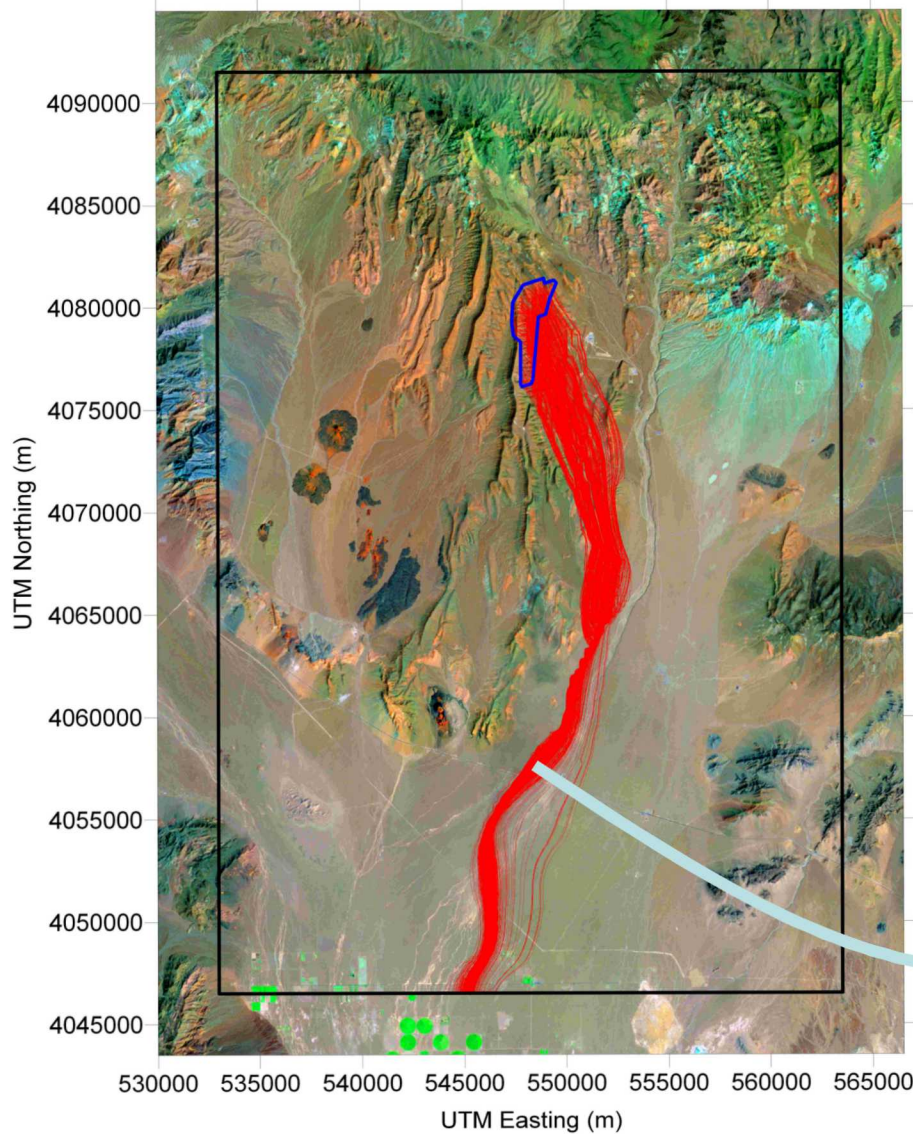


Long-term Performance of the Proposed Yucca Mountain Repository

- Water provides the primary release mechanism
 - Precipitation infiltrates and percolates downward through the unsaturated zone
 - Corrosion processes degrade engineered barriers, including the waste form
 - Radionuclides are mobilized by seepage water and percolate downward to the water table
 - Lateral transport in the saturated zone leads to biosphere exposure at springs or withdrawal wells



Estimating Dose to Hypothetical Future Humans



Modeled groundwater flow paths and hypothetical exposure pathways

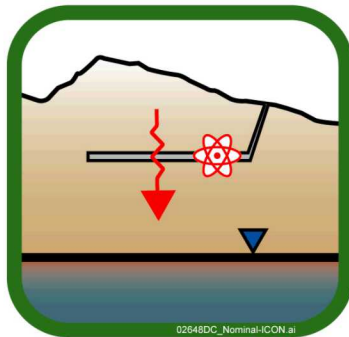
Four scenario classes divided into seven modeling cases

Nominal Scenario Class

- Nominal Modeling Case (included with Seismic Ground Motion for 1,000,000-yr analyses)

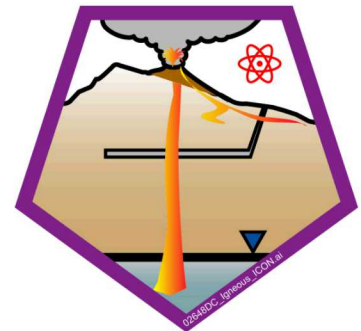
Early Failure Scenario Class

- Waste Package Modeling Case
- Drip Shield Modeling Case



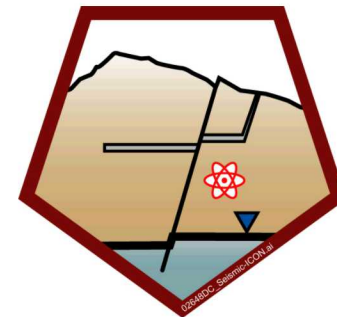
Igneous Scenario Class

- Intrusion Modeling Case
- Eruption Modeling Case

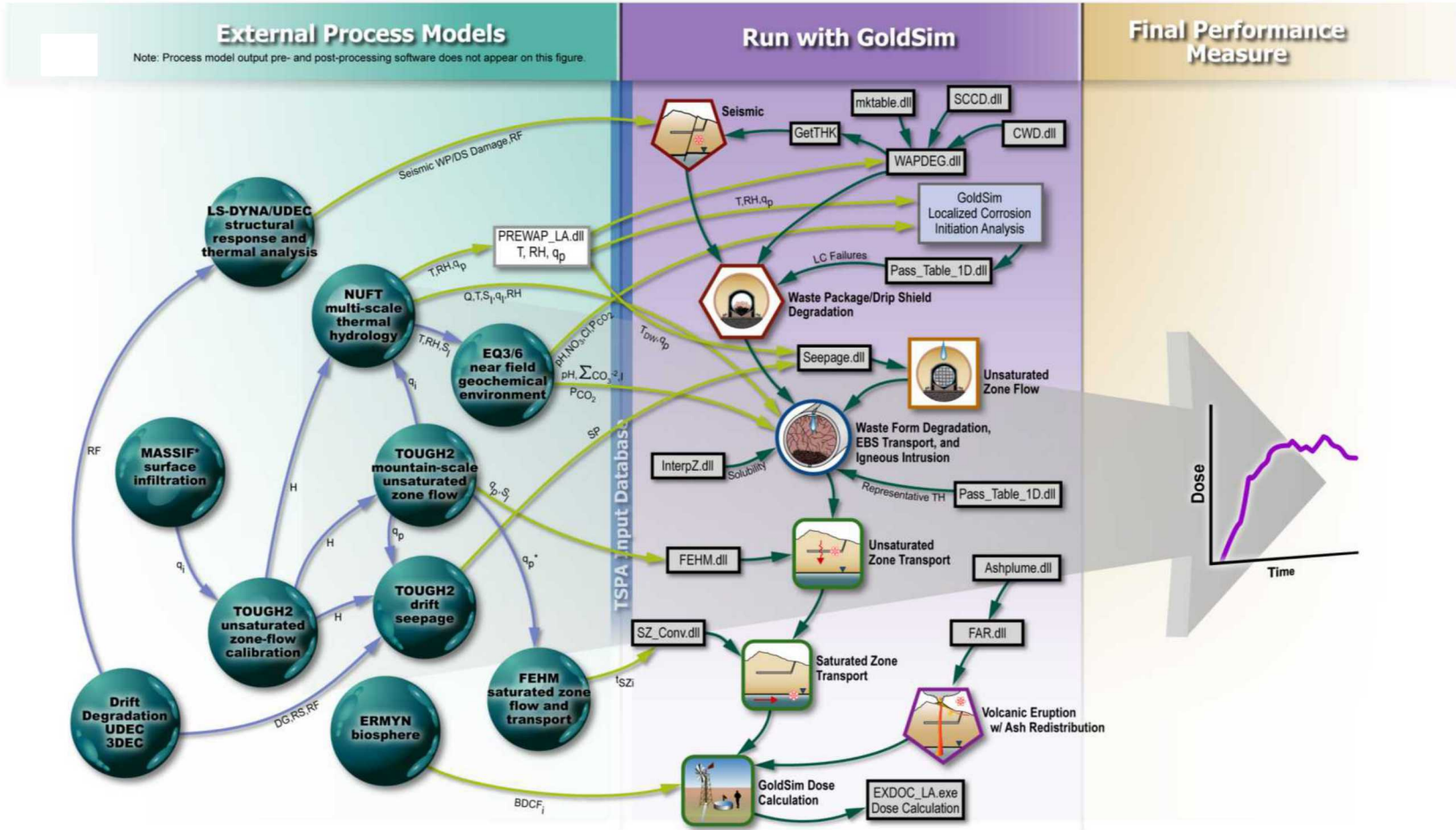


Seismic Scenario Class

- Ground Motion Modeling Case
- Fault Displacement Modeling Case



Yucca Mountain Total System Performance Assessment

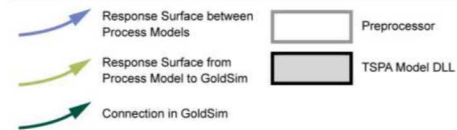


Output Parameters

f_S	Fraction of WPs with Seeps	q_p	Percolation Flux	q_i	Infiltration Flux	H	Hydrologic Properties
EBS	Engineered Barrier System	NO_3	Nitrate Concentration	DG	Drift Geometry	SP	Seepage Parameters
Q_S	Seep Flow Rate	T	Temperature	Cl	Chloride Concentration	RS	Rock Strength
Q	Evaporation Rate	RH	Relative Humidity	I	Ionic Strength	RF	Rockfall Size and Number
pH	pH	S_l	Liquid Saturation	t_{SZI}	Saturated Zone Transport Time		
ΣCO_3^{-2}	Carbonate Concentration	X_a	Air Mass Fraction	$BDCF_i$	Biosphere Dose Conversion Factor		
PCO_2	Partial Pressure of CO_2	q_l	Liquid Flux	q_g	Gas Flux		

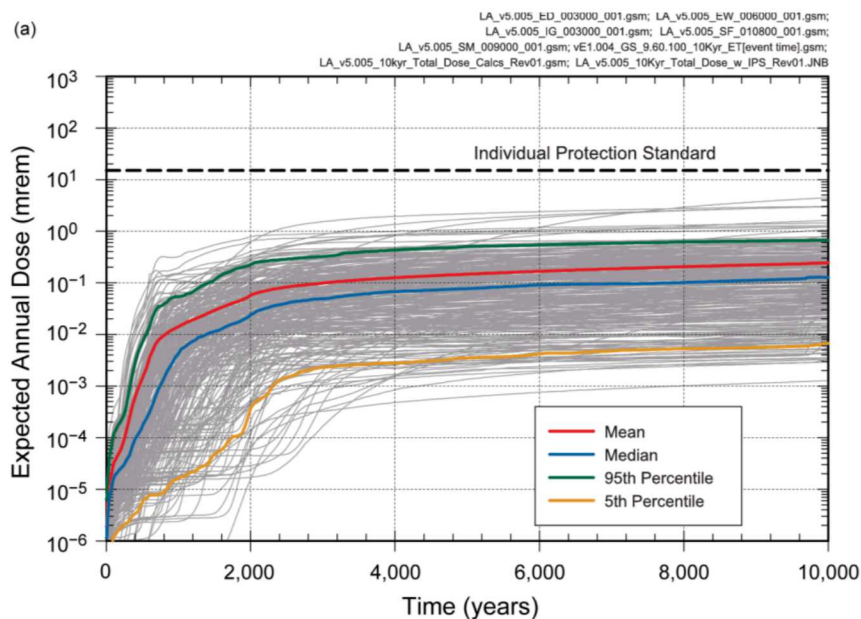
*Note: q_p derived from INFIL model

Legend



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Long-Term Performance of Yucca Mountain

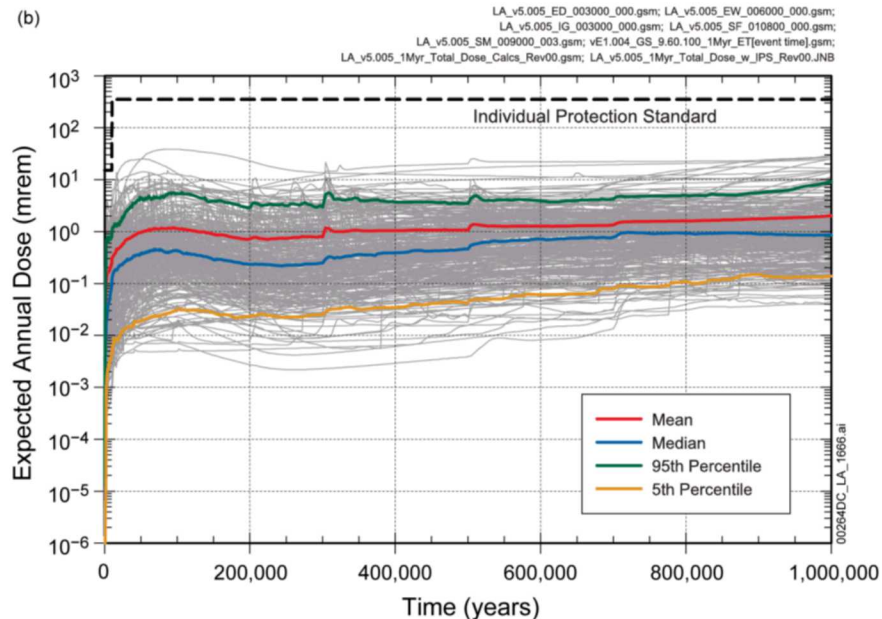


DOE/RW-0573 Rev 1 Figure 2.4-10

10,000 years

10,000-year Standard:
 Mean annual dose no more than
 0.15 mSv (15 mrem)

TSPA-LA estimated 10,000 yr maximum mean
 annual dose: 0.0024 mSv (0.24 mrem)

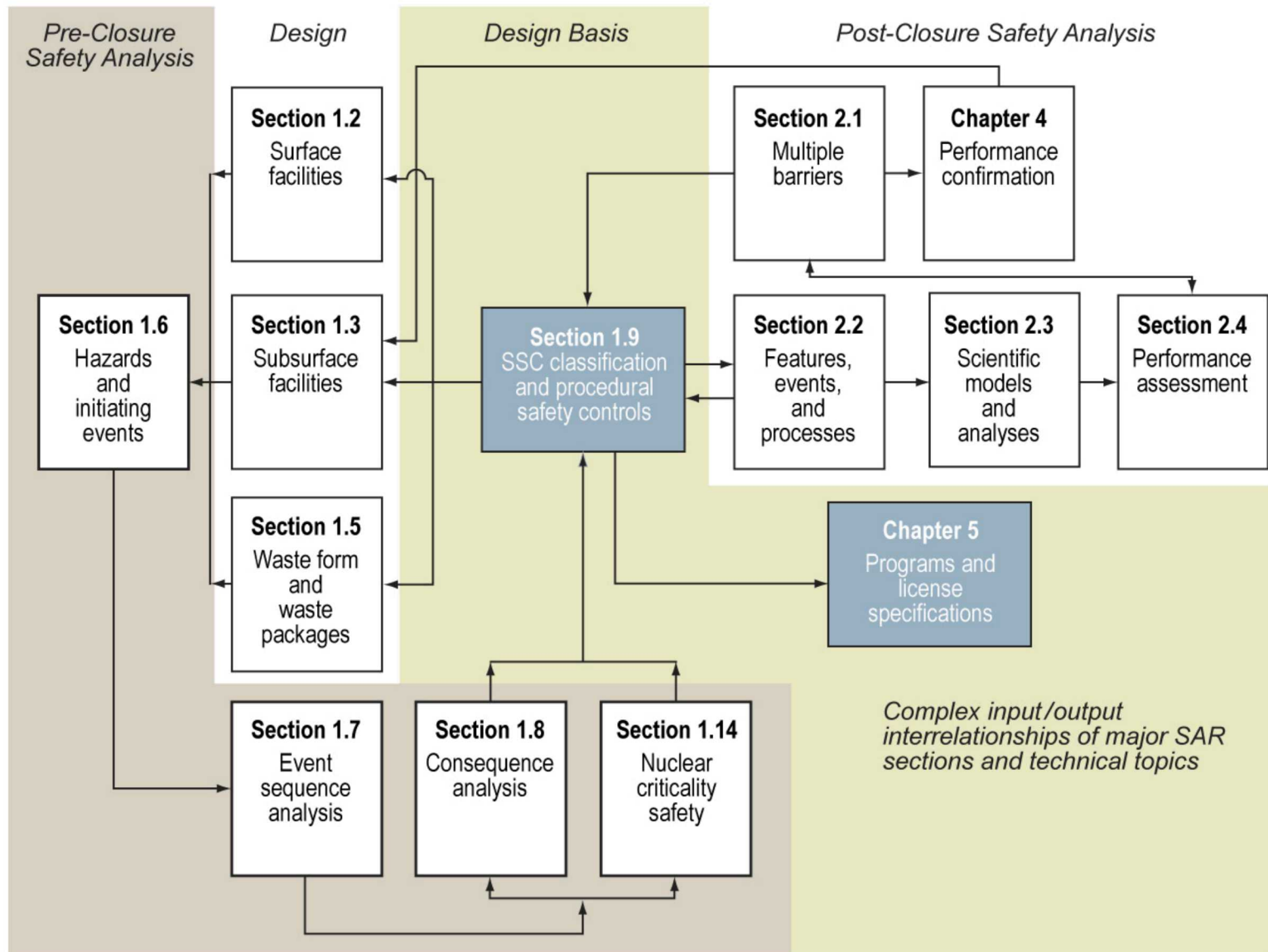


1,000,000 years

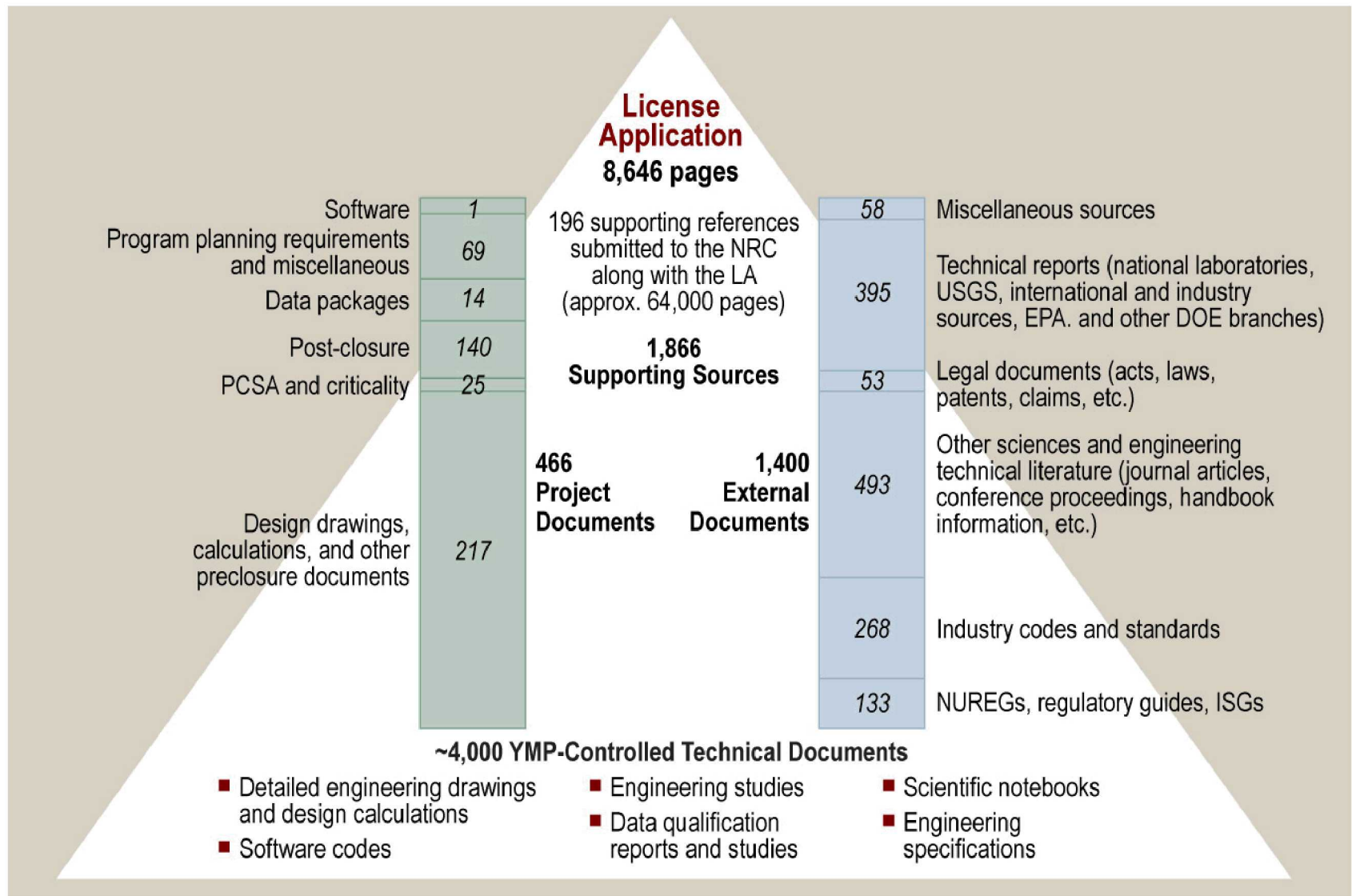
1,000,000-year Standard:
 Mean annual dose no more than 1
 mSv (100 mrem)

TSPA-LA estimated 1,000,000-yr maximum
 mean annual dose: 0.02 mSv (2.0 mrem)

Safety Analysis Report



Yucca Mountain License Application



■ **Current Status**

- Licensing Proceeding is not concluded... future uncertain
- SNL, DOE, and NRC preserved scientific, technical and procedural information from the project

■ **Knowledge from Yucca Mountain Project is preserved** in the following systems:

- USNRC ADAMS (Agency Document and Management System) Collection
- USNRC ASLAB LSN (Licensing Support Network) Collection
- USDOE Legacy Management Collection
- Yucca Mountain Project Lead Laboratory Archive (SNL)
- Other Proceeding Participant Collections (e.g., State of Nevada)

Yucca Mountain Knowledge Preservation Sandia National Laboratories

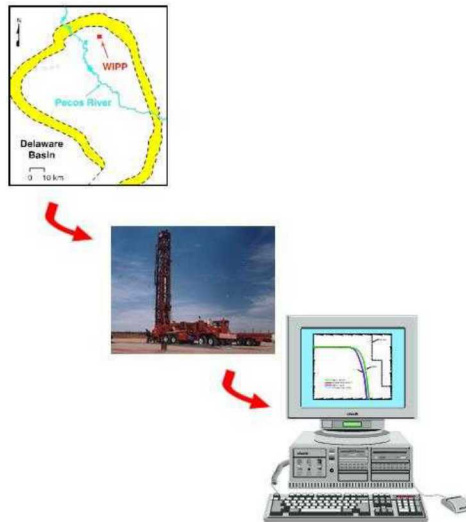
- DOE's Legacy Management office has most comprehensive YMP collection
 - More than 62 million records, including:
 - over 3.6 million project documents in the LSN collection:
 - other artifacts (computer programs, etc.) related to research conducted in USDOE's Waste Management program over 30 years
- USNRC 'Licensing Support Network' (LSN)
 - Electronic system, established by the NRC and operated by the NRC's Atomic Safety and Licensing Board (ASLAB) to provide internet access to documents that may be used as evidence in the licensing proceedings
 - 3.6 million documents at the time of the license submittal
 - Public access to the LSN was terminated in August, 2011
 - USNRC committed to transfer this document collection to a publicly accessible library FY15

Key Lesson Learned

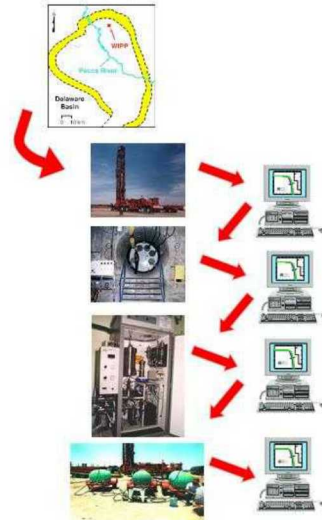
The Yucca Mountain Project could have been more efficient if the project had adopted a total integrated systems approach to performing the necessary science and engineering

- Early in the Yucca Mountain program performance assessment methodology and models were developed in parallel with site-characterization activities rather than integral with them
- During the latter stage of the Yucca Mountain program probabilistic performance assessment methodology and models were used to identify and prioritize site characterization activities
- Repository programs should use probabilistic performance assessments throughout the life of a program to help set priorities among site-characterization activities.
- Management attention, funding, and manpower resources should be allocated to those variables and processes identified by performance assessment to be important to reducing uncertainty and demonstrating compliance

Classical Approach



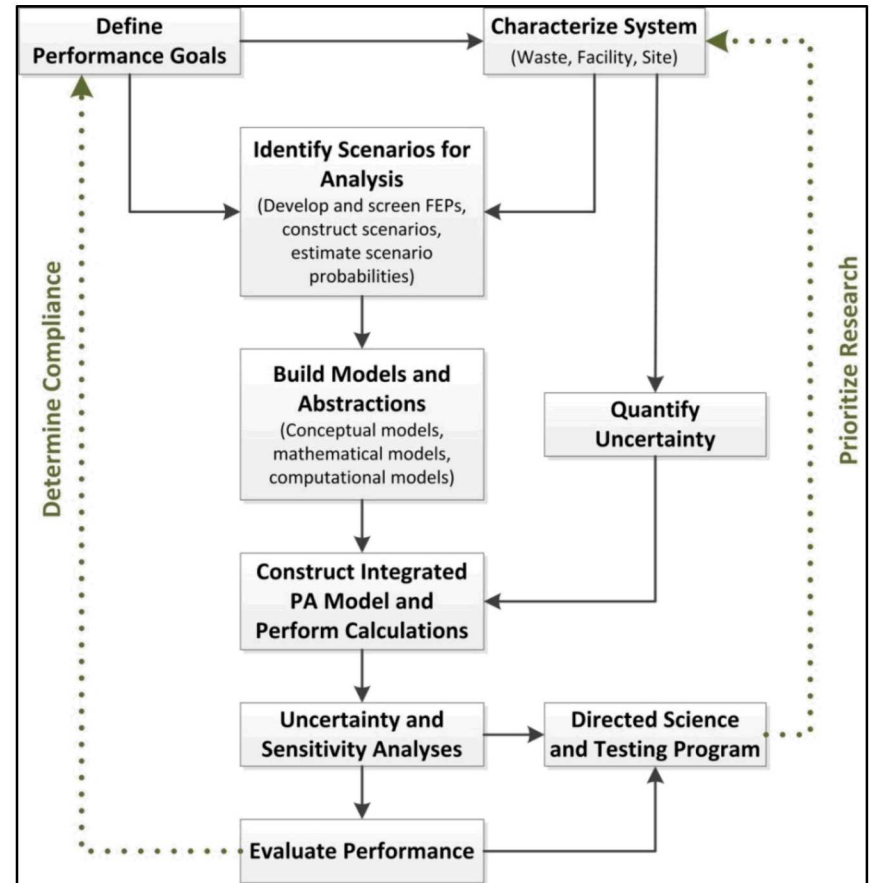
Iterative Approach



Site Characterization

Primary challenges of early site characterization

- Making decisions about where to focus and how to prioritize multiple site characterization activities
- Making decisions about what data and models will ultimately be required to assess the performance of the total repository system
- Making decisions about how much information is enough



Site Characterization: Key Point

- Recognize *Compliance* rather than *Science* is the primary purpose of characterization
 - Focus program on uncertainties that matter
 - Document decisions and rationale

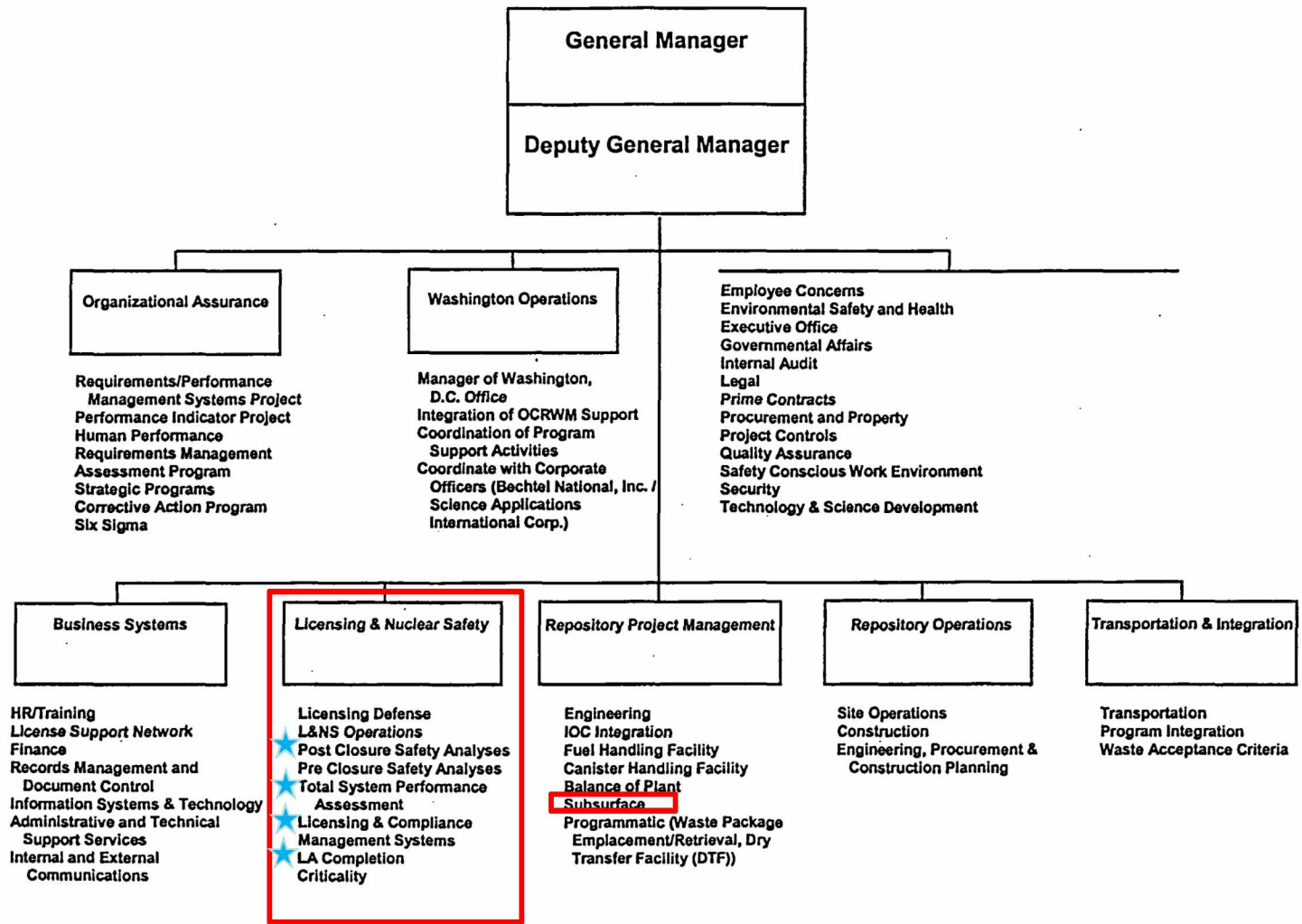
Site Characterization and Performance Assessment

- Site characterization should be cautious about focusing attention on assumed dominant processes or pathways before performance assessment modeling is performed
- Caution should also be exercised when interpreting early performance assessments as they are only as good as the data and models that support them
- Perform experiments and develop detailed models to understand processes are essential for demonstrating adequacy of performance assessment models
- For experimental guidance, performance assessment should use reasonable estimates of parameter and conceptual uncertainty and not conservative assumptions that may bias results towards preconceived ideas
- Neither site characterization nor performance assessment should completely dominate iterative interactions

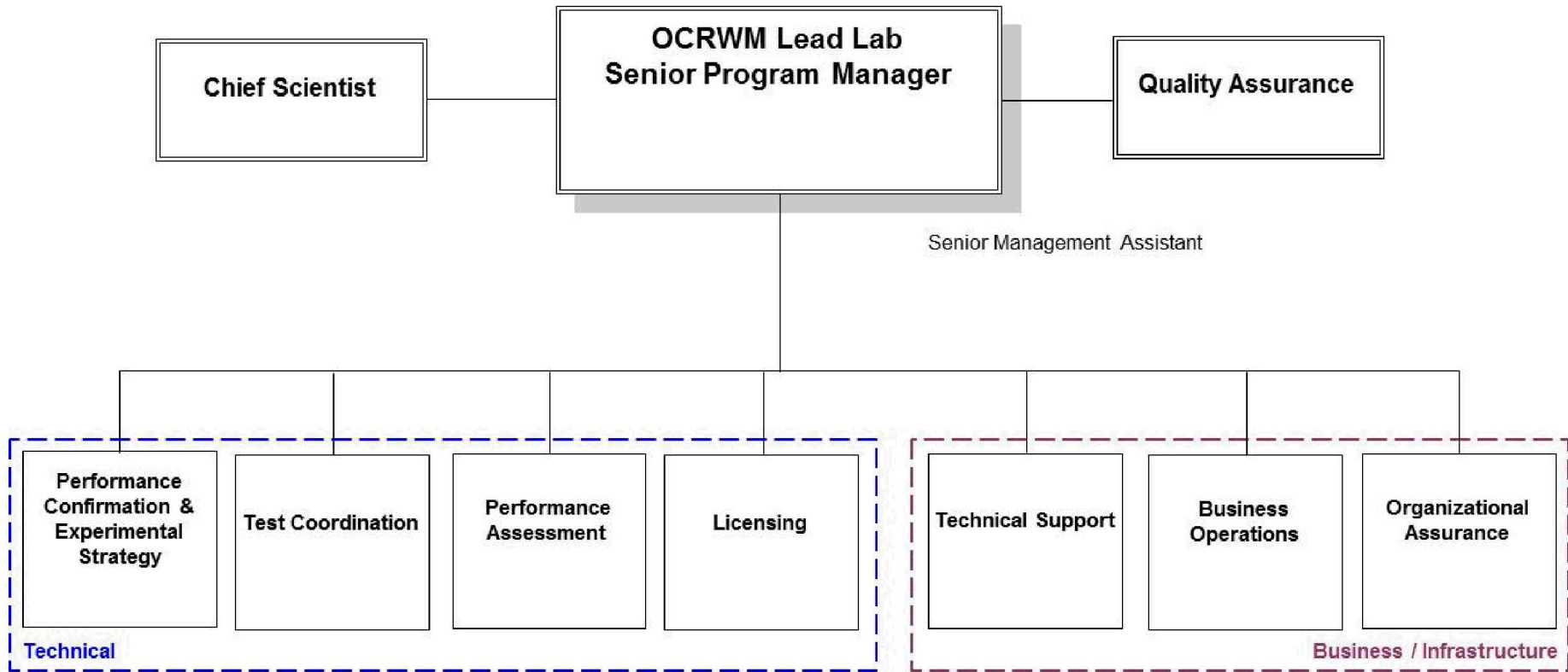
Interactions Between Site Characterization, Repository Design, and PA Staff

- Site characterization, repository design, and performance assessment groups have important contributions to make to understanding uncertainty
- Formalized integration between site characterization, repository design, and performance assessment groups can be facilitated through workshops on major system components
- Integration can be enhanced by encouraging collaboration between individual staff members from site characterization, repository design, and performance assessment groups
- Mutual technical review of project documentation by site characterization, repository design, and performance assessment groups contributes to information exchange and consistency

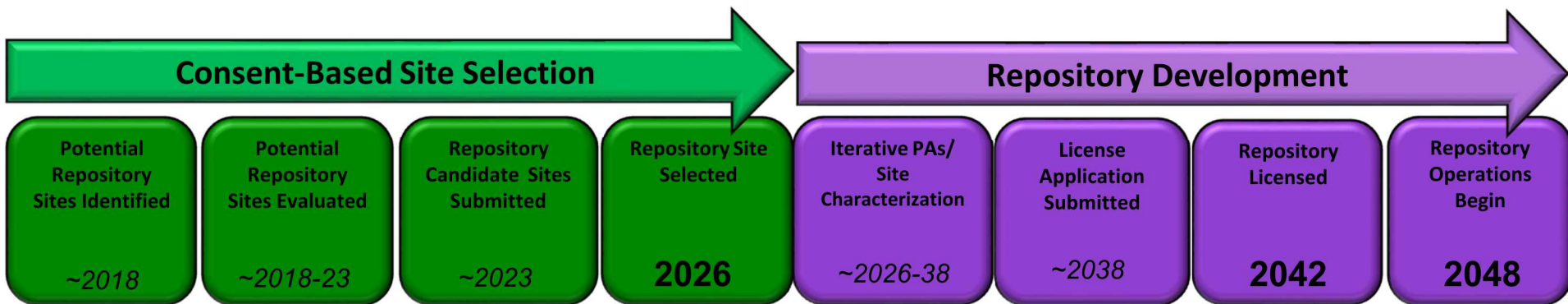
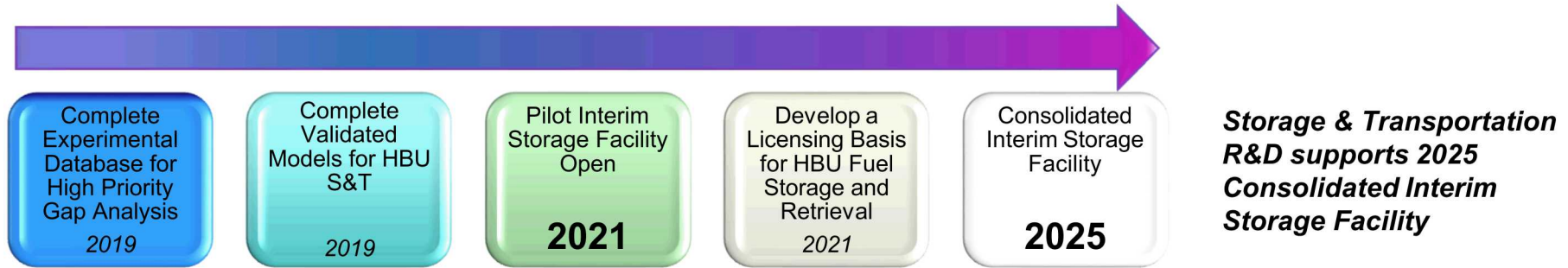
Yucca Mountain Implementer Organization



Post-Closure Safety Case Organizations



R&D Mission to Support Current US DOE Waste Management Strategy

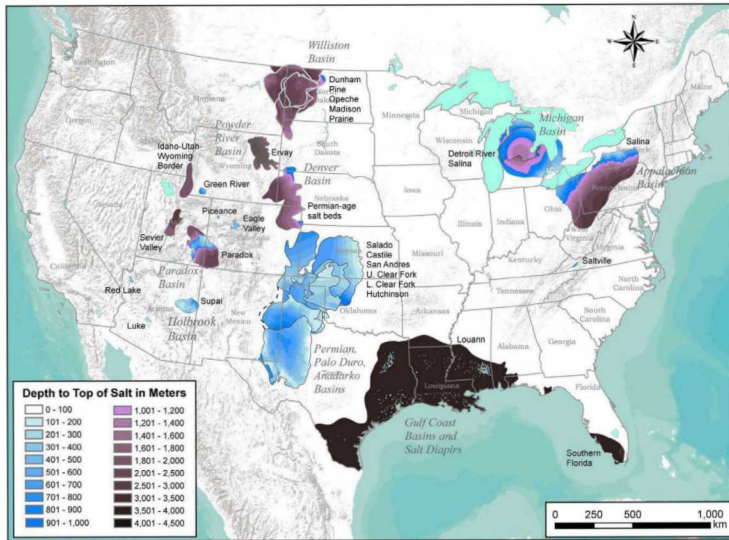


Approximate target dates (in *italics*) needed to meet milestones (in **bold**) set out in the 2013 DOE Strategy

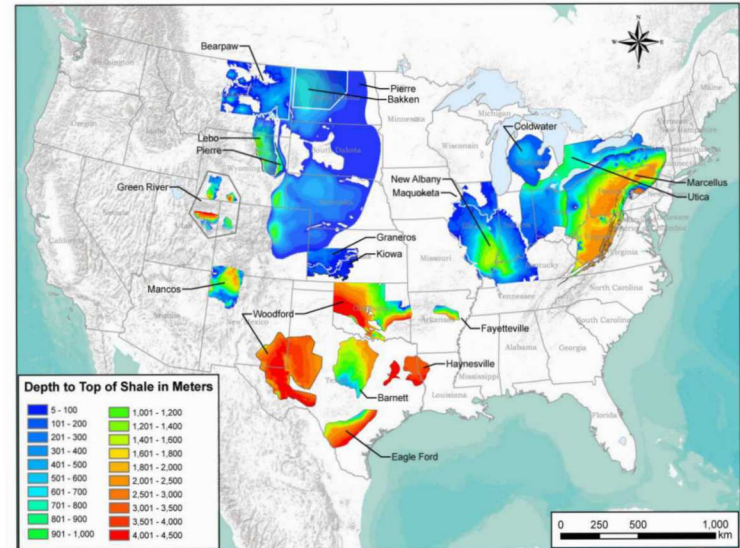
Disposal R&D supports 2026 Repository Site Selection and 2042 Repository Licensing

- The Nuclear Waste Policy Act precludes site-specific repository investigations at locations other than Yucca Mountain
- All disposal research must be generic
- What can generic R&D accomplish?
 - Provide technical basis supporting multiple viable US disposal options available when national policy is ready
 - Identify and research the generic uncertainty sources that can challenge disposal concept viability
 - Increase confidence in robustness of generic disposal concepts to reduce the impact of site-specific complexity
 - Develop tools in science and engineering to address other goals

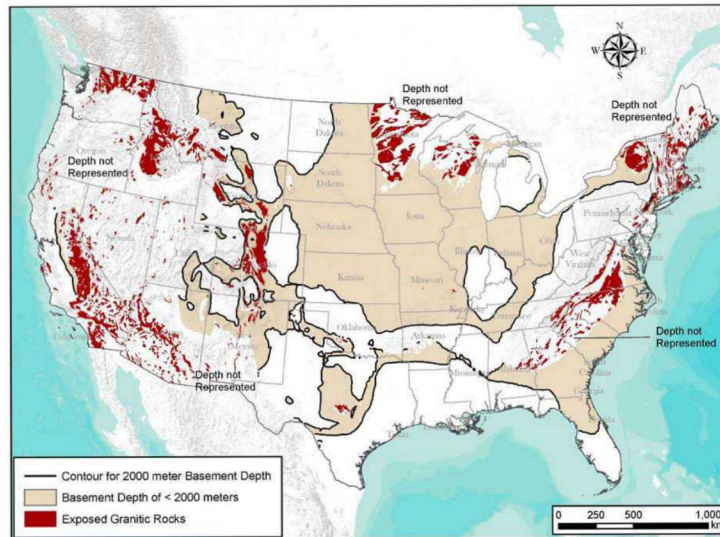
Alternative Host Rock Formations



Salt Formations



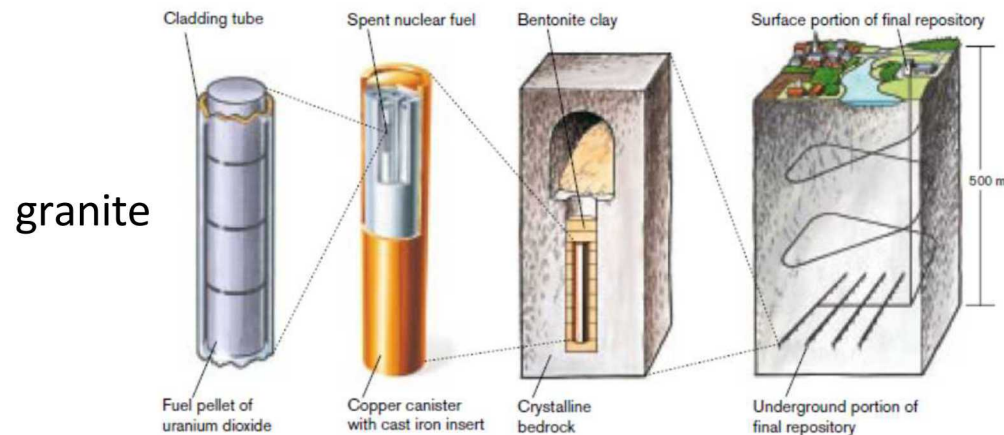
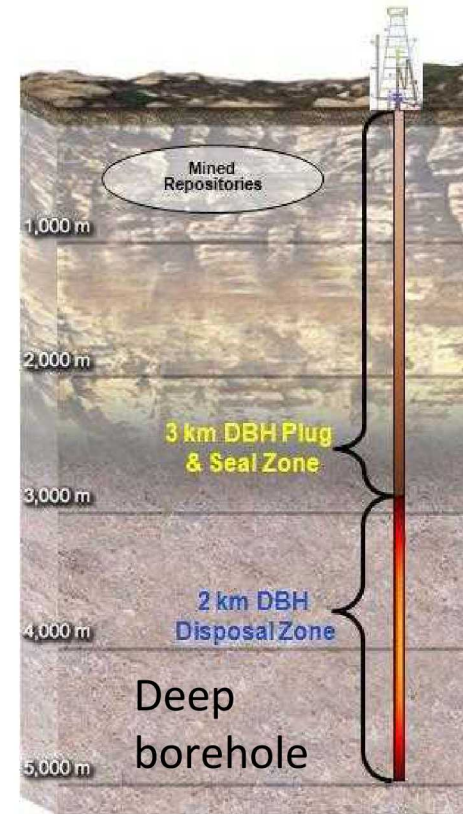
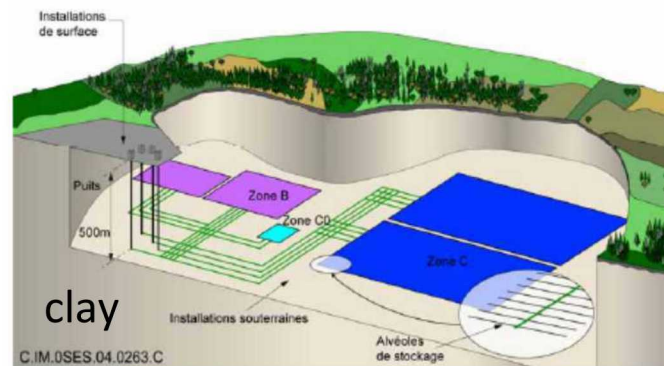
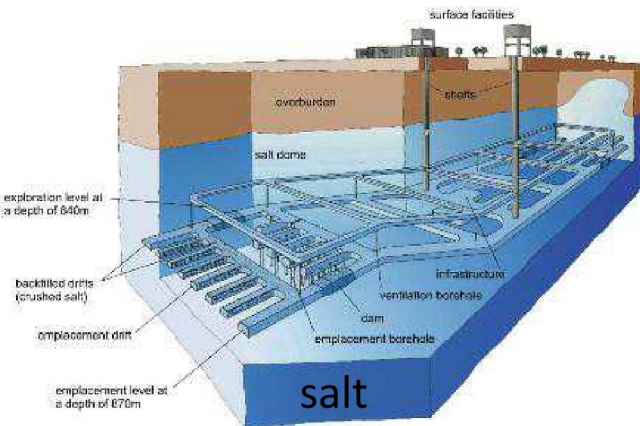
Shale Formations



Crystalline Formations

U.S. Disposal R&D Focuses on Four Options

- Three mined repository options (granitic rocks, clay/shale, and salt)
- One geologic disposal alternative: deep boreholes in crystalline rocks



Overview and Status of International Collaboration

- Promising international opportunities for “active” collaboration were identified, evaluated, and selected
- DOE has joined formal collaborative R&D agreements with multinational collaborative initiatives as well as bilateral agreements with selected international programs in Europe and Asia
- Several UFD funded collaborative R&D projects have been initiated within these R&D agreements

Multinational Initiatives

- ❑ **Mont Terri Project**
 - *Participate in experiments at Mont Terri clay URL in Switzerland*
- ❑ **DECOVALEX Project**
 - *Participate in model comparison initiative for several URL related tasks in different host rocks*
- ❑ **Colloid Formation and Migration Project**
 - *Participate in colloid research at Grimsel granite URL in Switzerland*
- ❑ **SKB Task Forces**
 - *Participate in crystalline rock research centered around Äspö HRL in Sweden*
- ❑ **FEBEX DP**
 - *Participate in FEBEX dismantling project, which will analyze bentonite-rock behavior after 17 years of heating*

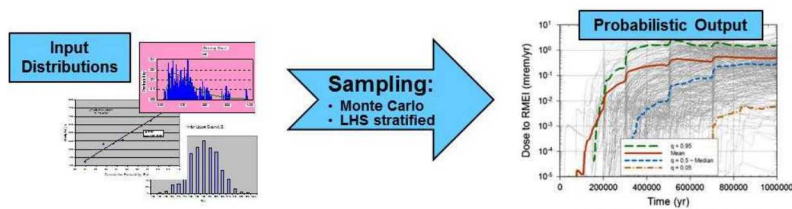
Bilateral Agreements

- ❑ **KAERI Underground Research Tunnel (KURT)**
 - *Participate in collaborative US/ROK experiments in crystalline rock*
- ❑ **US-German benchmarking study for salt**
 - *Participate in model comparison for TM behavior of domal and bedded salt*
- ❑ **Other**
 - *Other opportunities may be pursued, as bilateral agreements exist with France, Japan, Belgium, etc.*

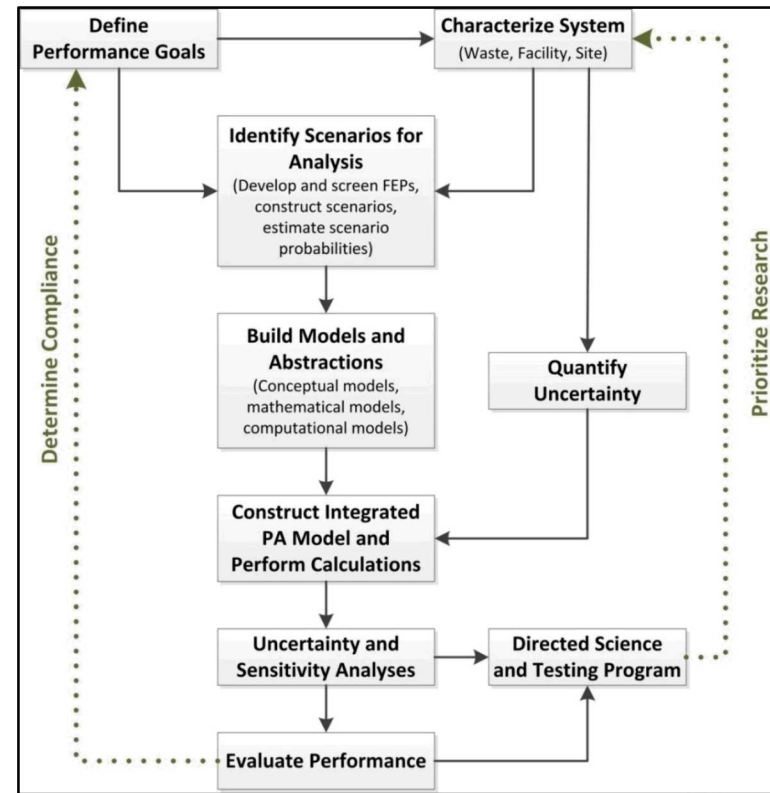
Also NEA Salt Club, Clay Club, Thermochemical Database Project

PA Model/Code Development Philosophy Sandia National Laboratories

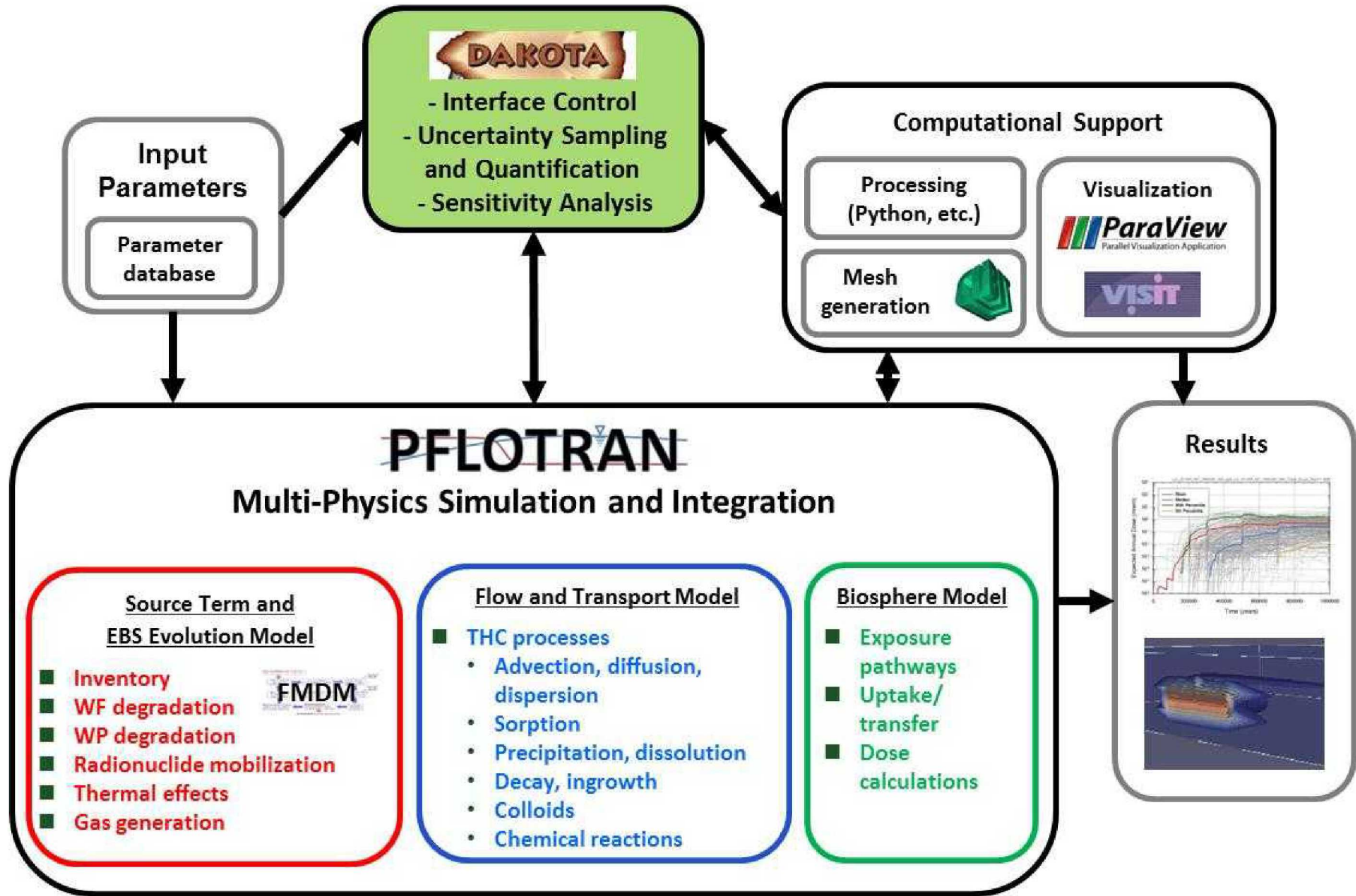
- **Objective:** More accurate solution to the coupled continuum field equations (mass, momentum, energy) over a large heterogeneous domain, including
 - Quantification and propagation of uncertainties, both aleatory and epistemic
 - Direct representation in PA model of significant coupled multi-physics processes in three dimensions (3-D)
 - Realistic spatial resolution of features and processes
 - *Explicit representation of all waste packages*
- **Key points:**
 - Less reliance on assumptions, simplifications, and process abstractions
 - Adopt a numerical solution and code architecture that can evolve throughout the repository lifecycle (decades!) and is able from the outset to use the most advanced hardware and numerical solvers available



* Fig. 1. J.C. Helton et al. / Reliability Engineering and System Safety 122 (2014) 267–271.



Enhanced PA Computational Model Architecture



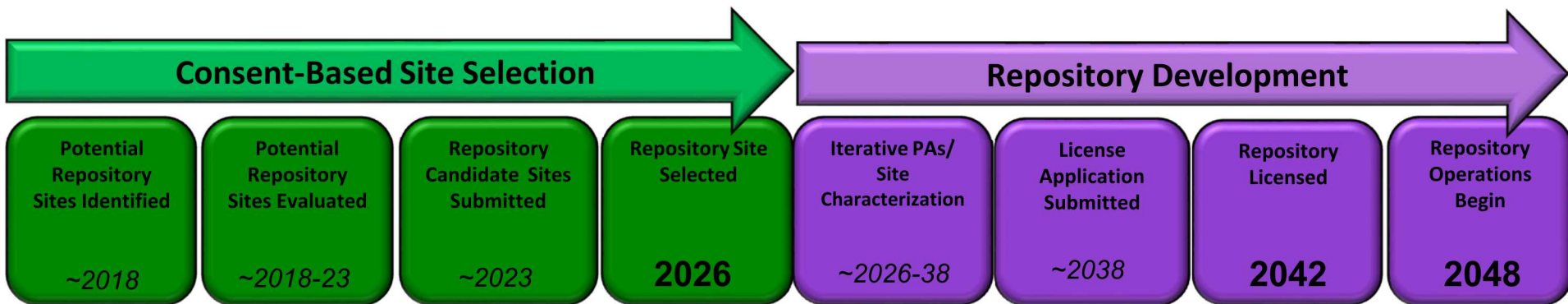
Goals/Uses of the Enhanced PA Capability

■ Goals:

- Enhance confidence and transparency in disposal system safety case
- Enable better decisions (technical, political, fiscal)

■ Uses:

- Evaluate potential disposal concepts and sites in various host rock media
- Help prioritize Site Characterization and RD&D activities (initially *generic*; later *site-specific*)
- Support safety case development during all phases of lifecycle



Approximate target dates (in *italics*) needed to meet milestones (in **bold**) set out in the 2013 DOE *Strategy*

*Disposal R&D supports
2026 Repository Site
Selection and 2042
Repository Licensing* 33

Conclusions

- **Siting, site characterization, and licensing can take decades**
- **Repository programs should use probabilistic performance assessments throughout the life of a program to help set priorities among site-characterization and design activities**
- **Performance assessment, Site Characterization, and Design groups should be organized to facilitate integration and iterative development of the Safety Case and License Application**
- **Performance assessment, Site Characterization, and Design groups should be involved in identifying and characterizing uncertainties**
- **Maintaining and managing project knowledge are important**
- **An effective Quality Assurance Program should emphasize best scientific practices**

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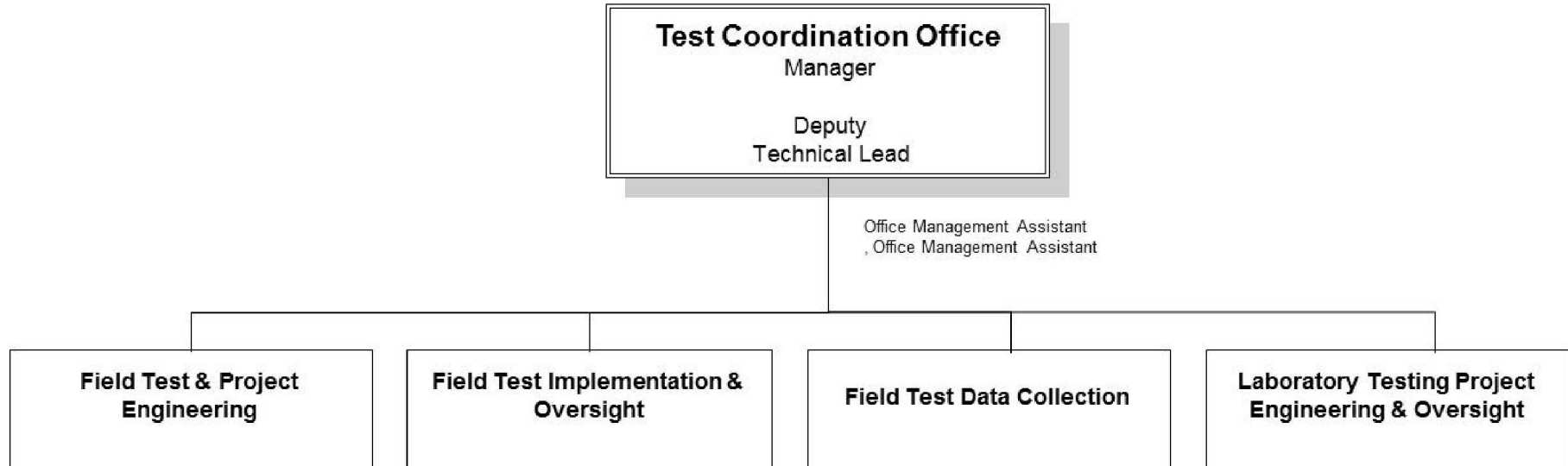
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Key Website: <http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html>

Post-Closure Safety Case Organizations



Post-Closure Safety Case Organizations

