Interdisciplinary Science and Nuclear Waste: A Risk-Informed Performance-Based Approach Applied to Yucca Mountain, Nevada

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The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geologic repository at Yucca Mountain.

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Regulatory Work Versus Scientific Work

"The vision is that you have got to be nimble, you have got to be flexible, you have got to bring the crosscutting mix of scientific talents to bear on projects as they are needed in real time, not in geologic time." Chip Groat, former Director, United States Geologic Survey

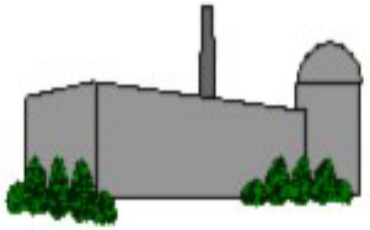
"Policy-making is about rapid, timely decisions made in the face of constantly inadequate information. Science is about tentative conclusions made only after thorough examination of well-researched data."

Melody Brown Burskins, former Congressional Science Fellow

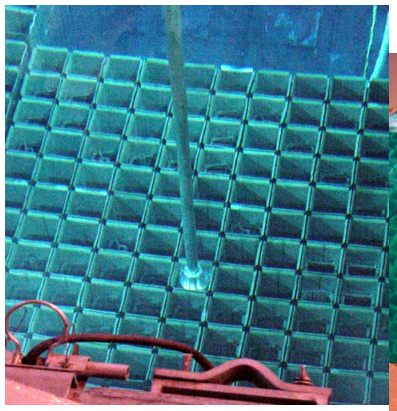
Outline

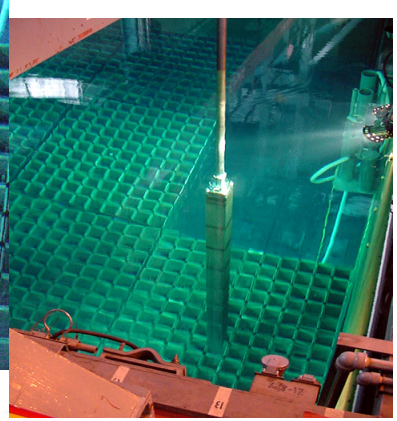
- Introduction to nuclear waste
- Who is who and what are their responsibilities?
- U.S. Nuclear Regulatory Commission (NRC) approach
- Yucca Mountain site
- A risk-informed example
- Conclusions

Nuclear Waste



Light Water
Power Reactors

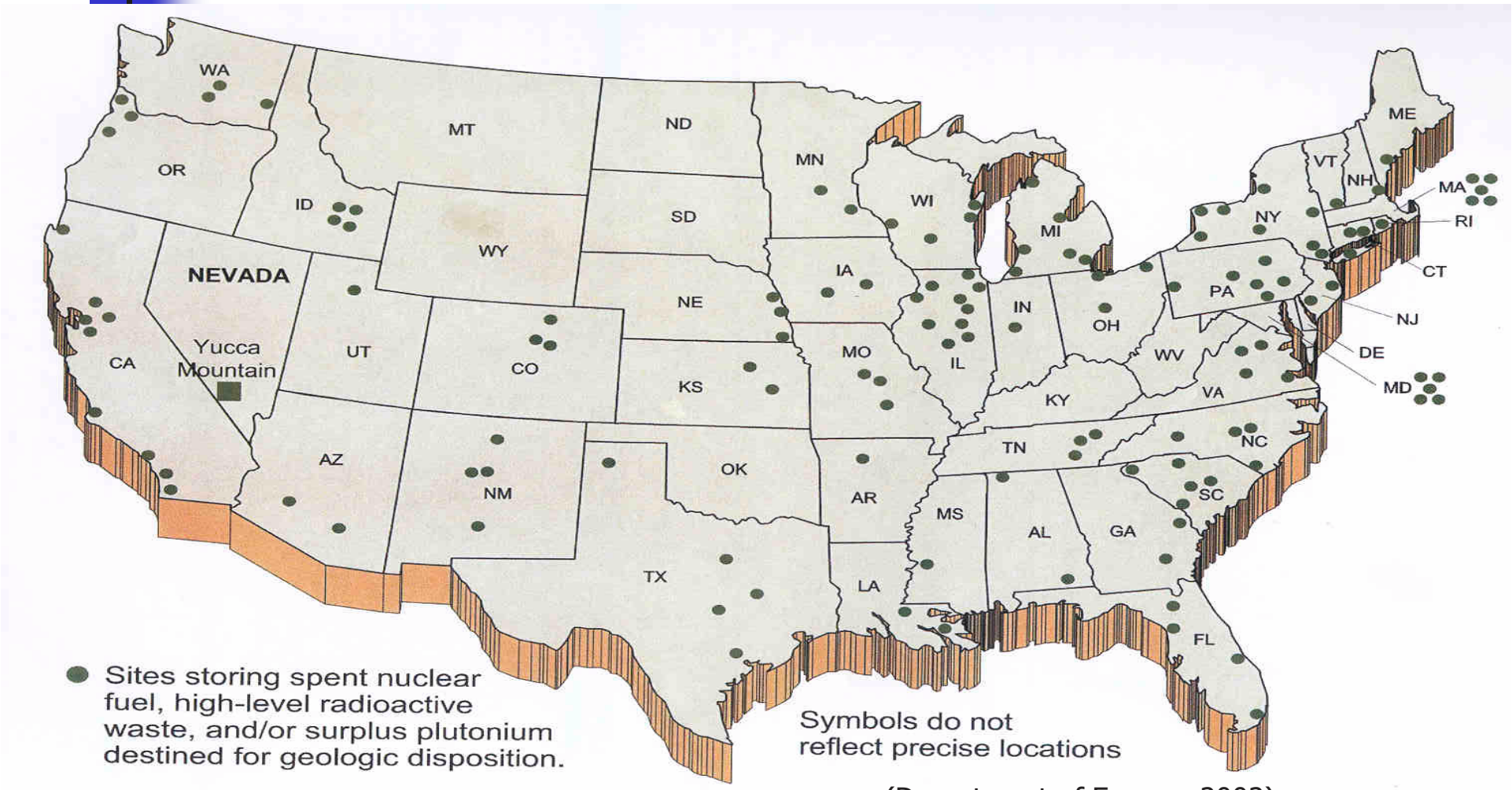




Interim Storage

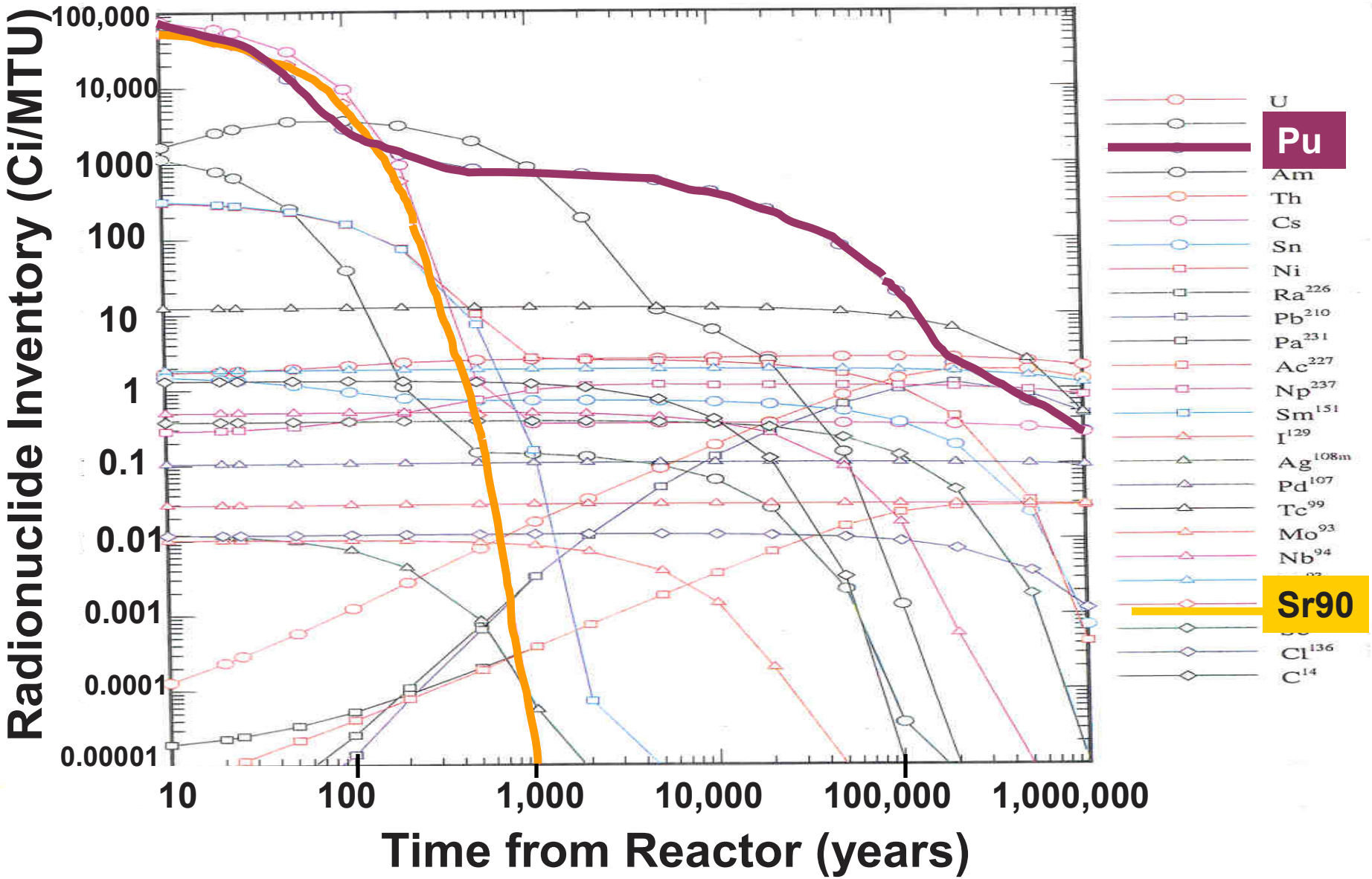
Federal
Waste
Repository

Where is the Waste?



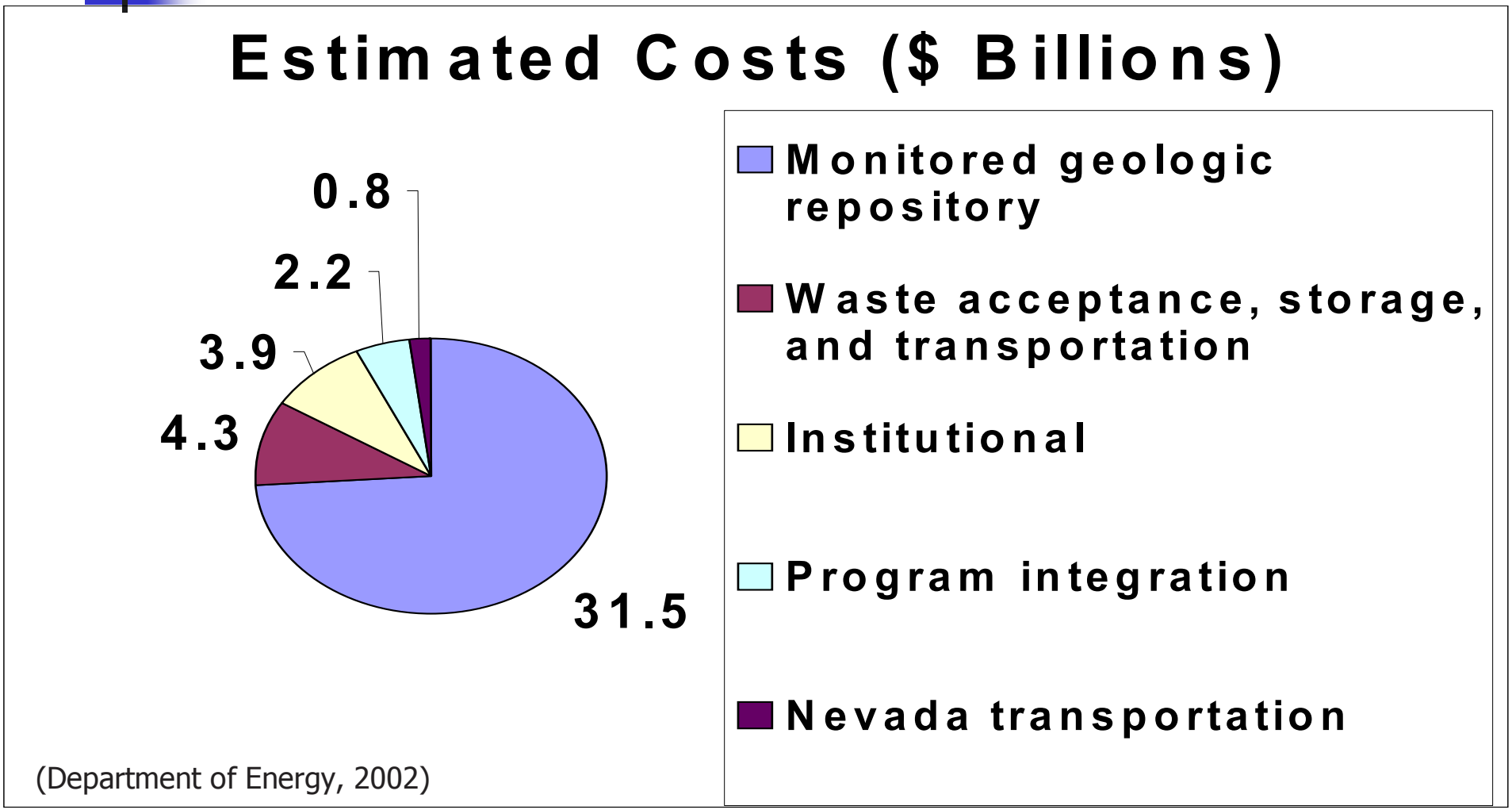
(Department of Energy, 2002)

How much and how long?



(after CNWRA, 1995)

What are the Costs?



(Department of Energy, 2002)

Regulatory Framework

- **Nuclear Waste Policy Act of 1982**
  - **Defined high-level radioactive waste**
  - **Established permanent disposal as national policy**
- **Nuclear Waste Policy Amendments Act of 1987 - Yucca Mountain, Nevada**
- **Energy Policy Act of 1992 – National Academy of Sciences provide technical bases for safety standard**

Who is Who?

- **U.S. Department of Energy (DOE) – characterizes site, license applicant, and potentially constructs and operates repository**
- **U.S. Environmental Protection Agency (EPA) – establishes safety standards for potential repository**
- **NRC – issues technical criteria and requirements for implementing EPA standards, and grants or denies construction authorization and license for repository**

Where are we?

- 2002
  - DOE submitted Site Recommendation
  - President recommended site to Congress
  - State of Nevada disapproved
  - Joint Congressional resolution endorsed site recommendation
- 2003 - 2004
  - DOE addressed NRC issue resolution topics and began preparing license application

Where are we? (continued)

- July 2004
  - U.S. Court of Appeals for the District of Columbia Circuit vacated EPA 10,000 year compliance period
- Fall 2005
  - EPA and NRC proposed rules addressing longer compliance period

NRC's Licensing Criteria

- **Requirements include:**
  - **Pre-closure safety, site security, radioactive material control, post-closure safety, and performance confirmation**
- **Post-closure safety (prior to July 2004)**
  - **Performance objective – releases do not result in an expected annual dose of > 15 mrem for 10,000 years**
  - **Demonstration – requires performance assessment and multiple barriers**

NRC Approach - Licensing

- Legal proceeding – expert witness, testimony, finding of safety
- Three years for NRC decision
- Three decisions can be made
  - Deny the construction authorization
  - Approve the construction authorization
  - Approve the construction authorization with conditions

NRC's Regulatory Approach

- **The licensee has the primary responsibility to conduct licensed activities safely.**
- **NRC's oversight of licensee activities includes inspections, investigations and audits.**
- **Risk-informed and performance-based**

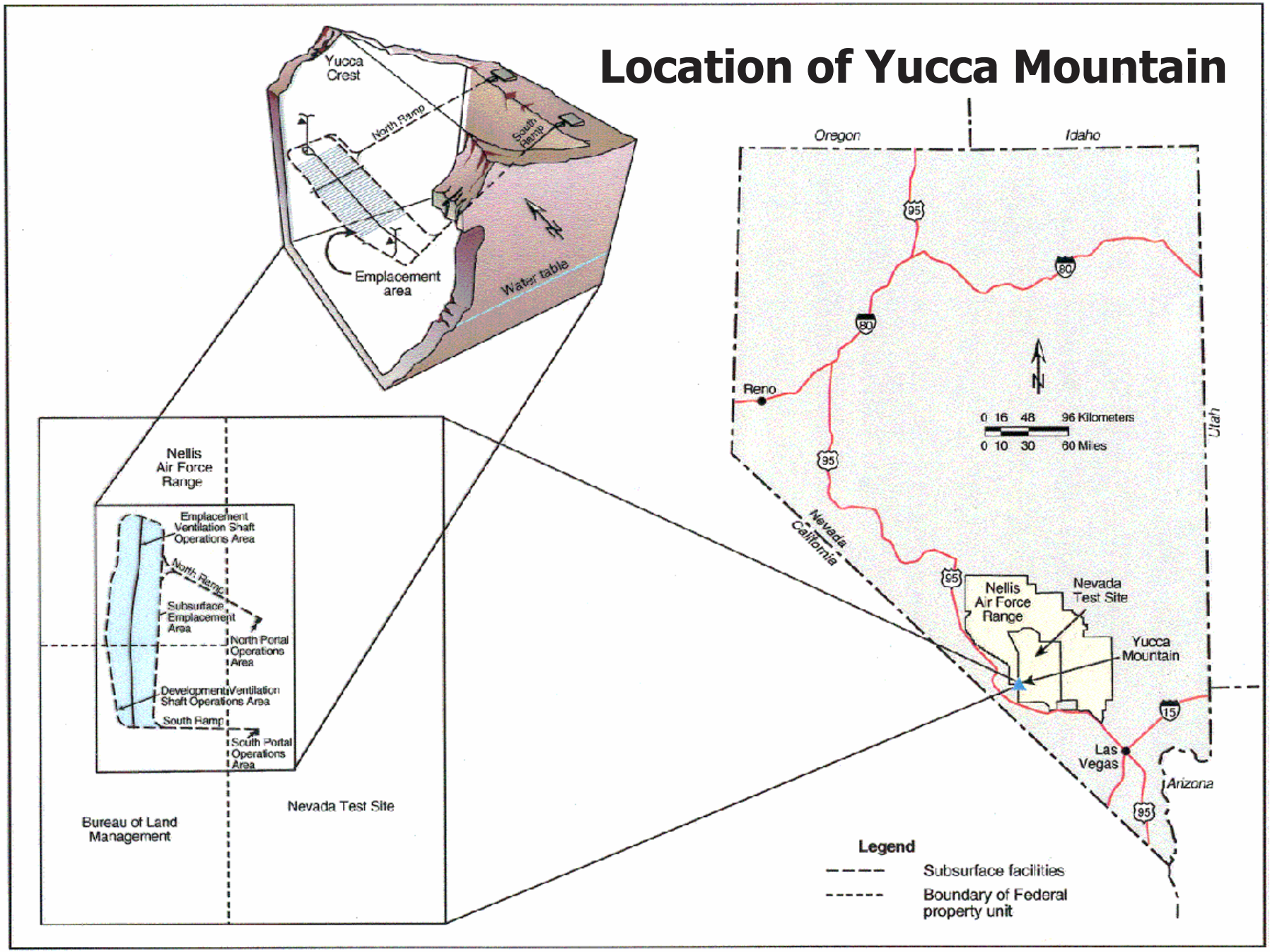
Risk and Risk Assessment

- **What is the risk?**
  - **What can happen?**
  - **How likely is it?**
  - **What can result?**
- **Risk assessment**
  - **Systematically addresses the risk triplet**
  - **Risk insights – a basis for decision-making**

An Example of a Risk-Informed Regulatory Requirement 10 CFR 63.114f

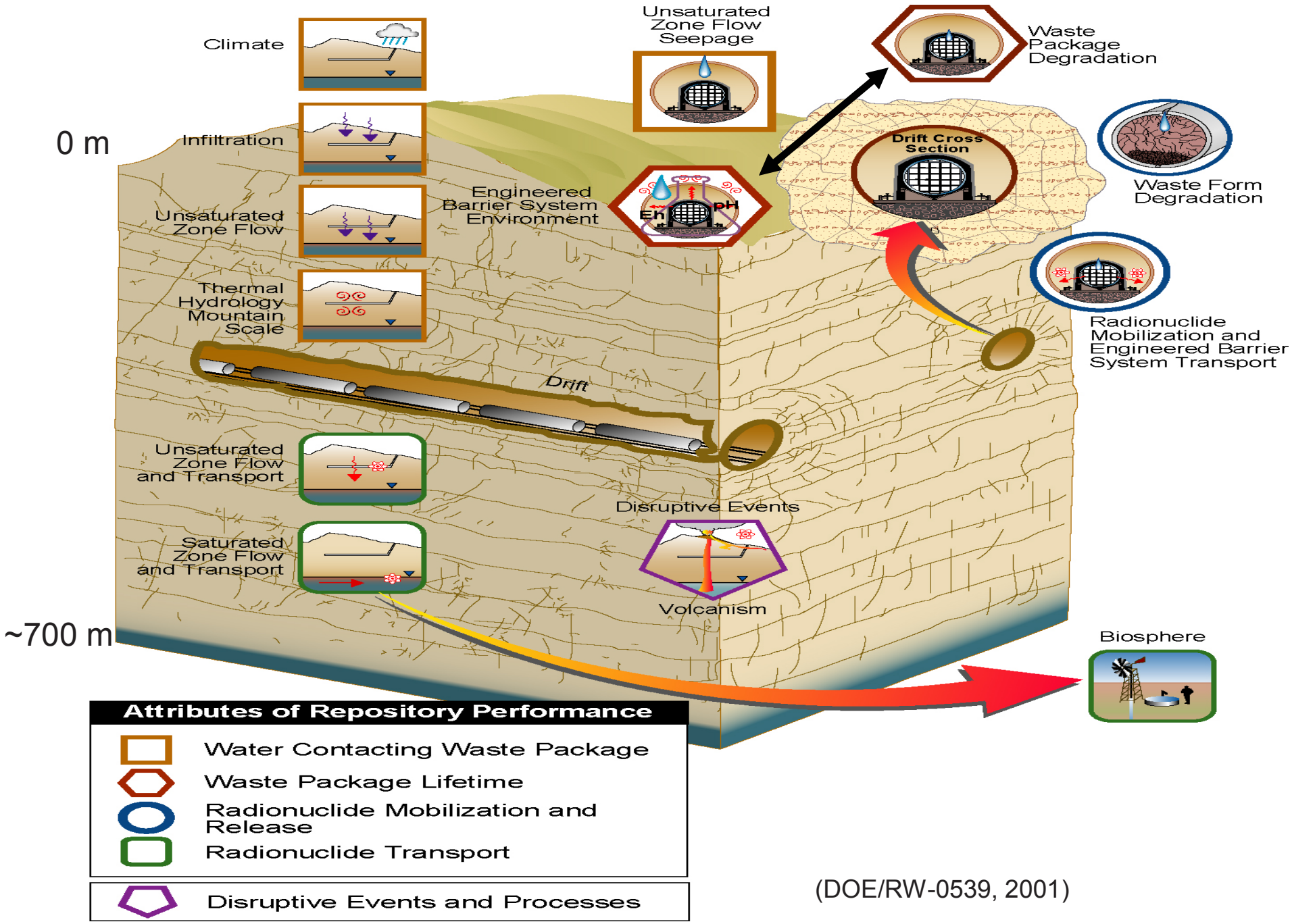
- "*Provide* the *technical basis for either inclusion or exclusion of degradation*, deterioration, or alteration processes *of engineered barriers* in the performance assessment, including those processes that would adversely affect the performance of natural barriers. *Degradation*, deterioration, or alteration processes of engineered barriers *must be evaluated in detail* ***if*** *the magnitude and time of* the resulting radiological *exposures* to the reasonably maximally exposed individual, *or* radionuclide *releases* to the accessible environment, would be *significantly changed by their omission*."

Location of Yucca Mountain



(DOE, 1998, Viability Assessment)

Yucca Mountain Viewed from the Southwest



(DOE/RW-0539, 2001)

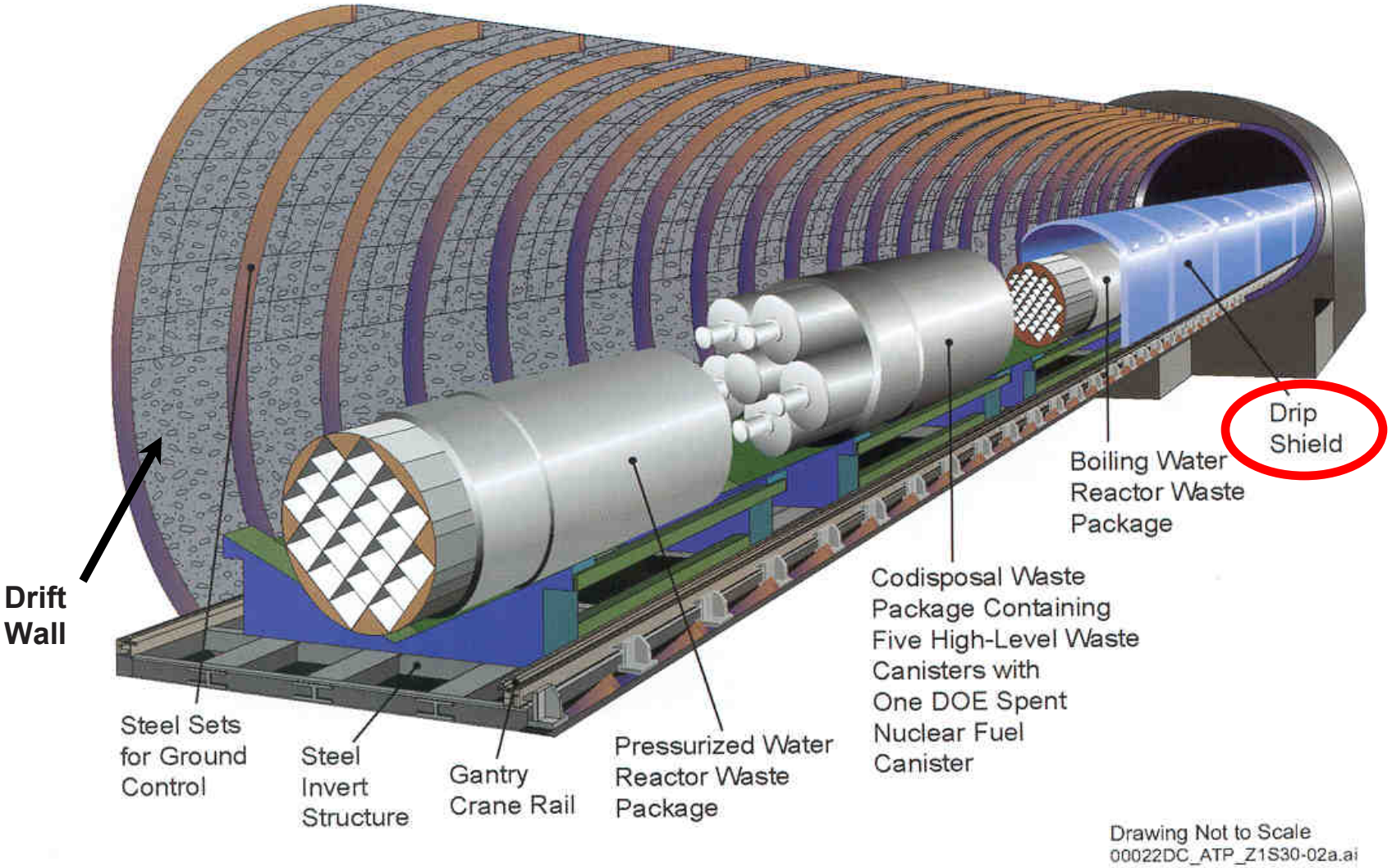


Figure 3-3. Schematic Illustration of the Emplacement Drift with Cutaway Views of Different Waste Packages

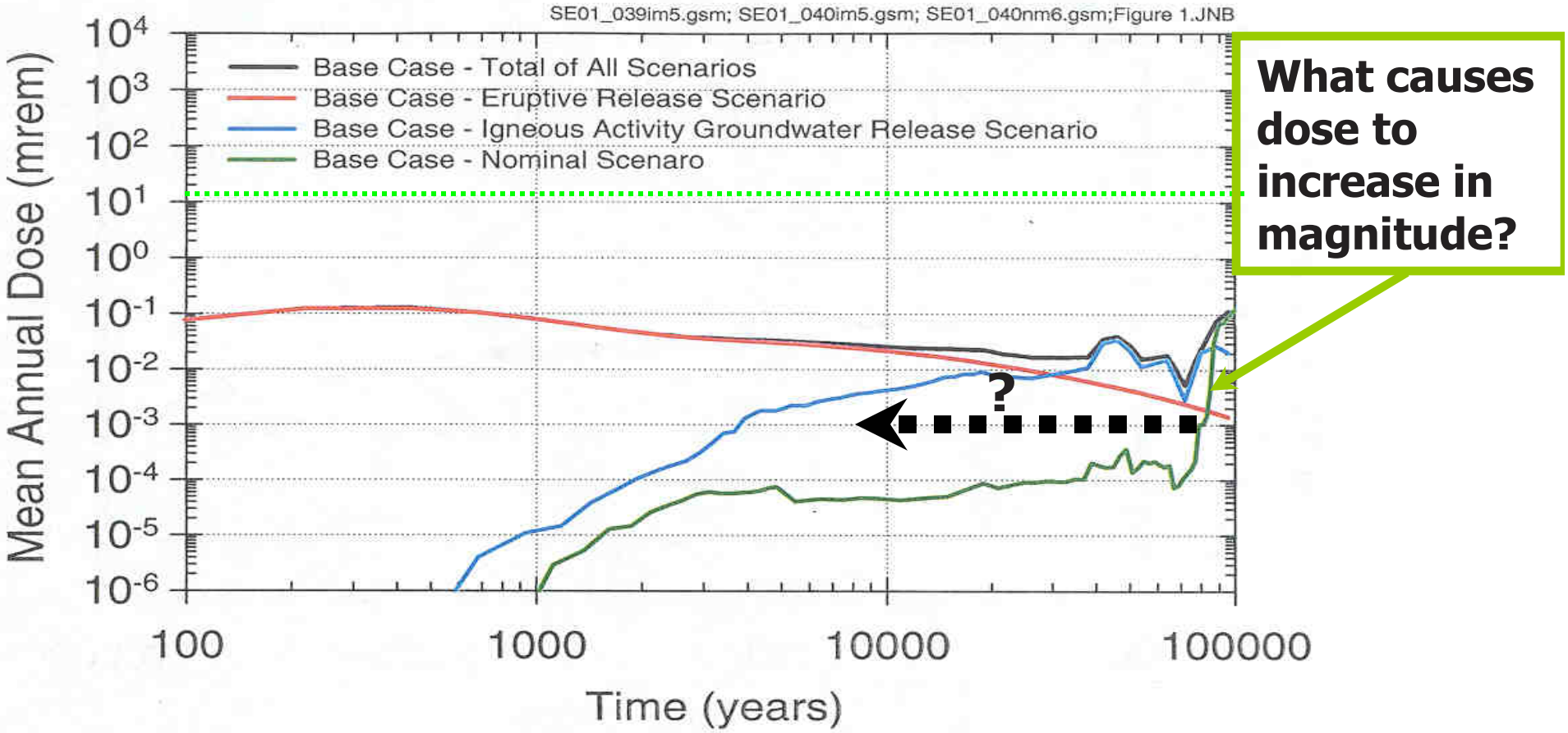
Ground support for emplacement drift walls is illustrated in the figure, which also shows three designs for dual-metal waste packages (representing various waste forms), a protective drip shield, and emplacement pallets supporting the waste package above the drift floor.

(DOE/RW-0539, 2001)

Risk-Informed Example: Fluoride and Ti Drip Shield

- Titanium drip shield cost ~ $4 billion
- Keeps water off waste container
- "Fluoride could lead to corrosion at Yucca, report says"
  - Las Vegas Sun February 4, 2002
- An interdisciplinary risk-informed approach

A DOE Projection of Potential Repository Performance



NOTE: Each mean annual dose curve is a probability-weighted average.

(Bechtel SAIC Company, 2002)

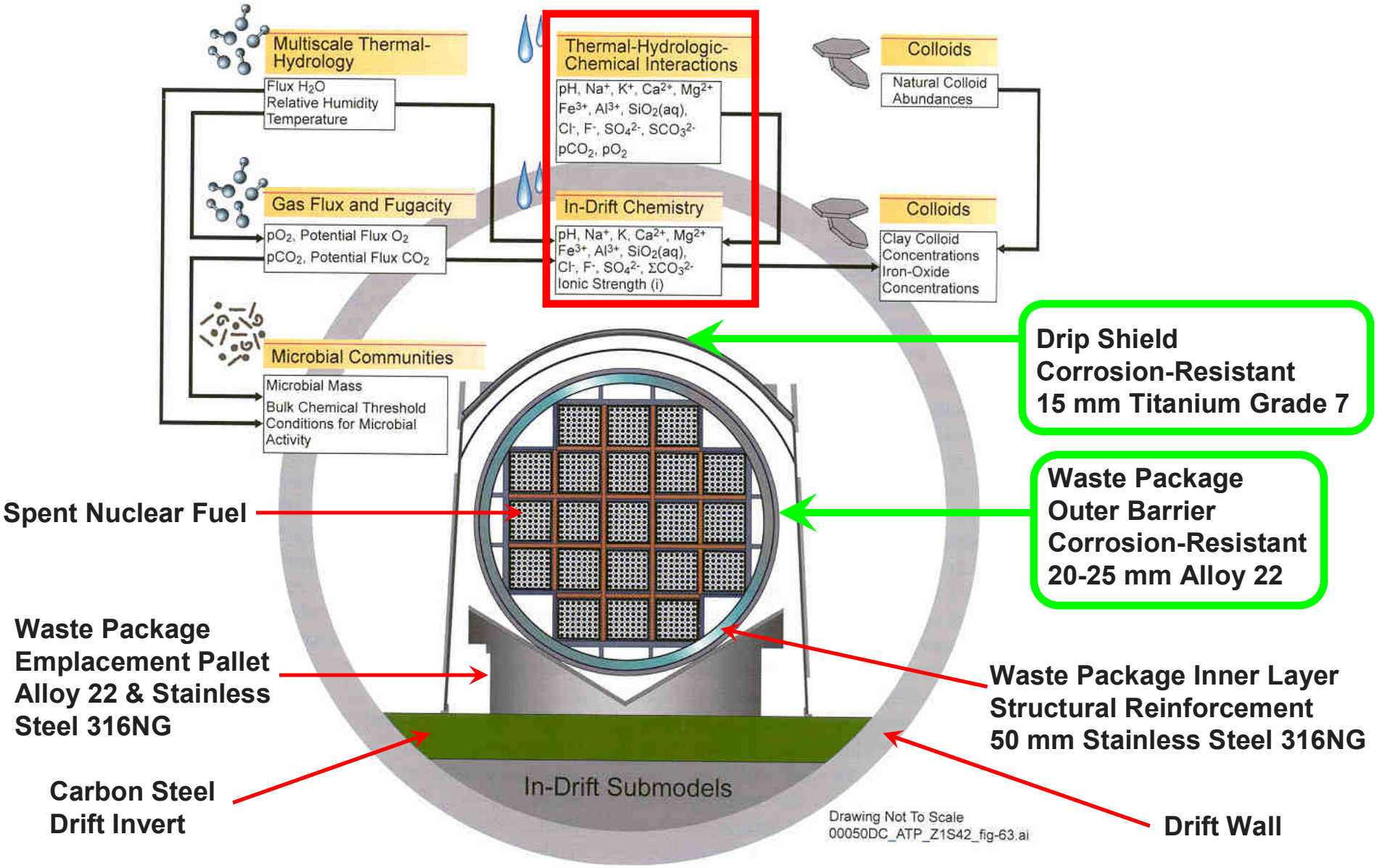


Figure 4-74. Emplacement Drift Cross Section Showing the Processes Considered in the Evolution of the Physical and Chemical Environment, and in the Transport of Radionuclides, within the Emplacement Drifts

Source: Modified from CRWMS M&O 1998g, Chapter 4, Figure 4-1

(DOE/RW-0539, 2001)

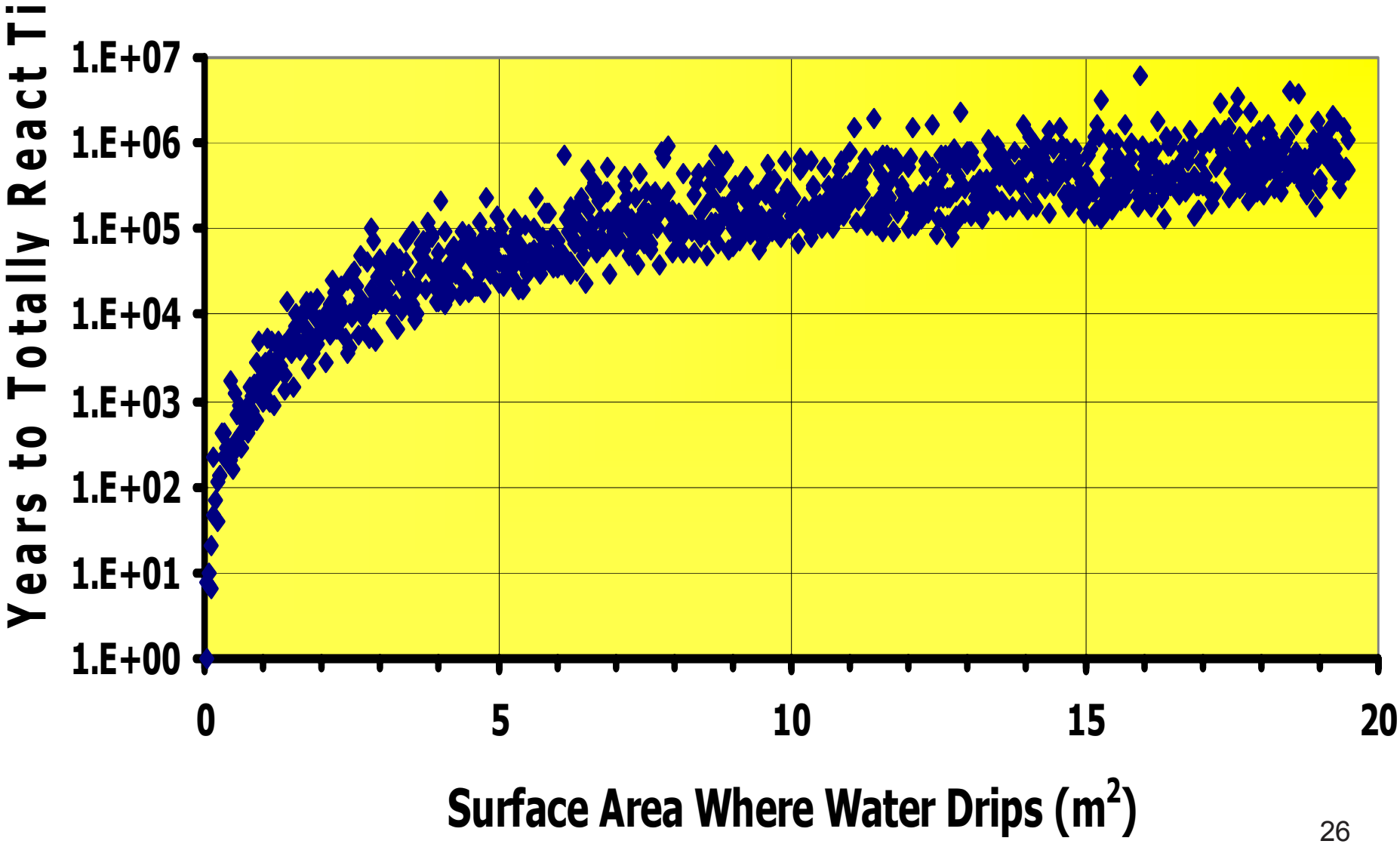
Effects of Geochemistry on Degradation of Barriers

- **Alloy 22 waste package – one failure mode is dependent on chemical environment**
  - **Cl initiates localized corrosion, but only under very specific conditions (T ~> 90 ^{o}C, highly oxidizing, Cl ~> 4M)**
  - **Cl penetrates passive film**
- **Ti drip shield – one failure mode is dependent on chemical environment**
  - **Fluoride causes fast uniform corrosion**
  - **Fluoride (F) is a reactant**

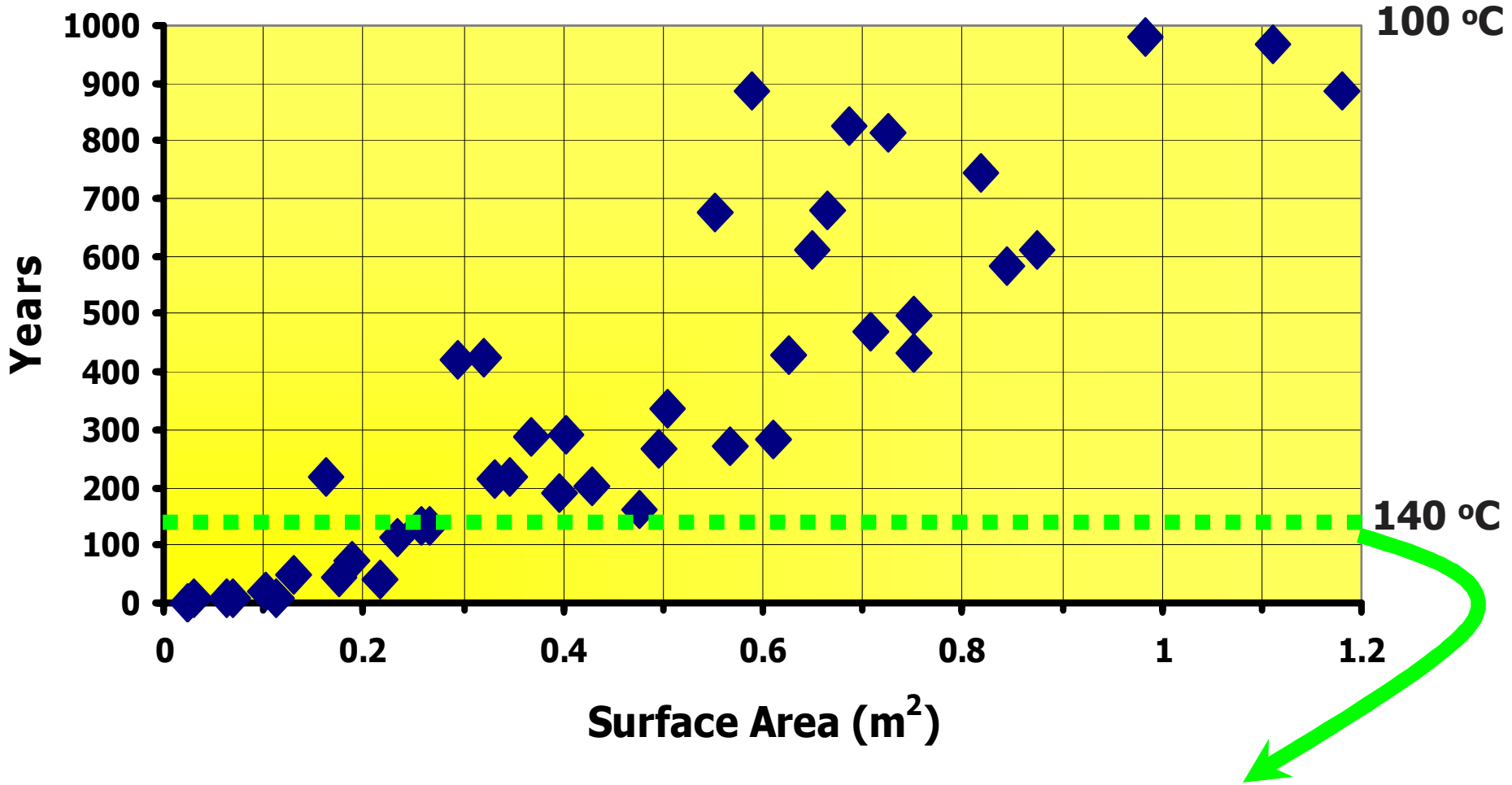
Fluoride-Induced Drip Shield Degradation Model

- Mass balance between the amount of F in potential dripping water and Ti in drip shield
- Assumes water doesn't run off, instantaneous reaction between Ti and F, and (1Ti:1F)
- F concentration, amount of dripping water, and area over which dripping occurs are variables
- Probabilistic approach, where variables sampled using Monte Carlo approach

Estimated Extent of Reaction



Estimated Extent of Reaction



~1.3% probability of occurrence within 130 years when temperatures are above 140 °C. Complete through-wall dissolution could be limited to <1% of the surface area of the drip shield.

Summary

- Disposal at Yucca Mountain is influenced by politics, science, and judicial system
- Regulators are required to be nimble, flexible, and able to make decisions in the face of uncertainty
- Interdisciplinary science is crucial in a risk-informed performance-based approach
- NRC focuses on the most important items necessary to demonstrate that human health and the environment will be protected

Additional information at www.nrc.gov/waste/hlw-disposal.html

THE

END

Additional Information

- Following slides identify topics in geochemistry which have been used in characterizing the site and assessing the performance of a geologic repository at Yucca Mountain.
- Each geochemical topic is presented along with the processes that may be applicable

Applied Geochemistry at Yucca Mt.

- Cosmogenic radionuclides – erosion, fast paths for water in unsaturated zone, and age dating
- Stable isotopes – climatic information, upwelling versus downward flow, water source mapping
- Radiogenic isotopes – age dating, estimating rock characteristics, water source mapping
- Gas composition – microbial processes, control of oxidation, and atmospheric flow thru mountain
- Salt chemistry – dust composition, evaporation, deliquescence, chemical divide, fluid inclusions, and brine composition

Applied Geochemistry (continued)

- Physical chemistry – sorption, colloidal formation, surface properties, and diffusivity
- Thermodynamics – solubility, speciation, sorption modeling, mineral stability, co-precipitation and solid solutions, molar volume changes
- Kinetics – dissolution of fuel, corrosion of metal, precipitation of minerals, colloid formation and stability
- Reactive transport modeling – coupled thermal-geochemical-hydrologic effects
- Oxidation and reduction – controls on solubility, dissolution rates, corrosion rates, speciation, microbial processes