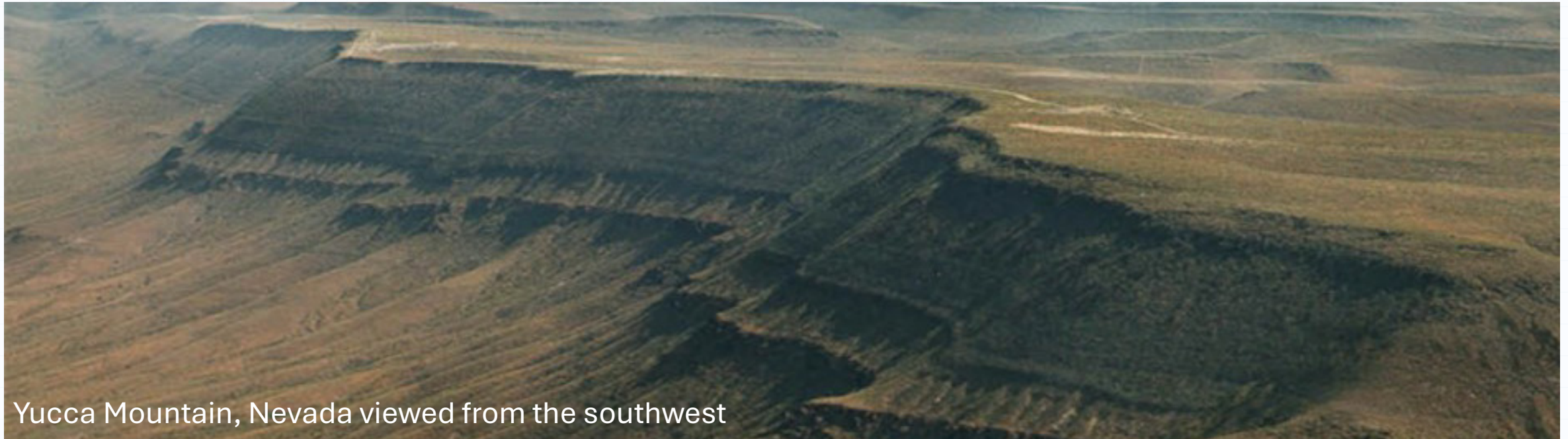


Insights on Safety Cases from Thirty-Five Years in the United States Geologic Repository Program

Knowledge for decisions across decades, generations, and repository timescales



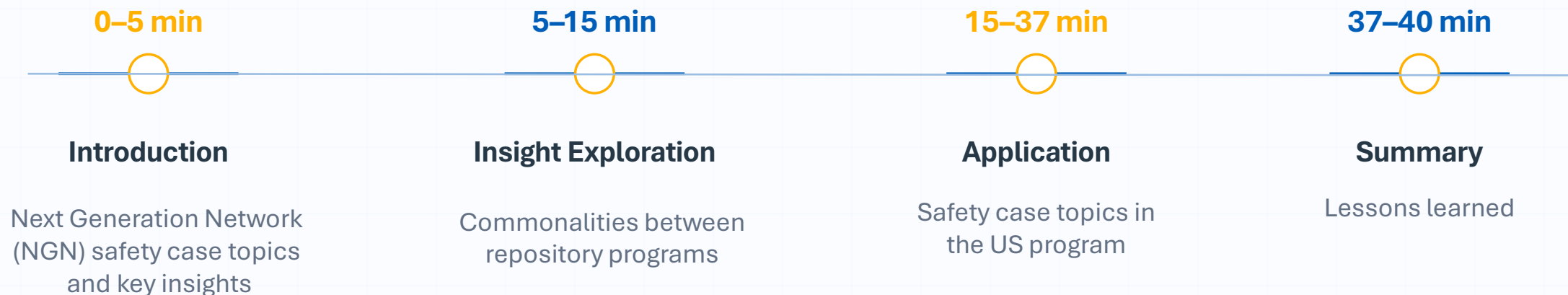
Yucca Mountain, Nevada viewed from the southwest

Bret Leslie, Ph.D. | U.S. Nuclear Waste Technical Review Board | July 1, 2026

The views presented in this talk do not represent those of the U.S. Nuclear Waste Technical Review Board (Board) or the U.S. Nuclear Regulatory Commission (NRC). The Board has no regulatory authority and performs an ongoing and objective peer review of the technical and scientific validity of activities undertaken by the Secretary of Energy [U.S. Department of Energy (DOE); waste management organization] under the Nuclear Waste Policy Act (NWPA).

What this webinar will cover

A 40-minute path from the big picture to specific practical examples.



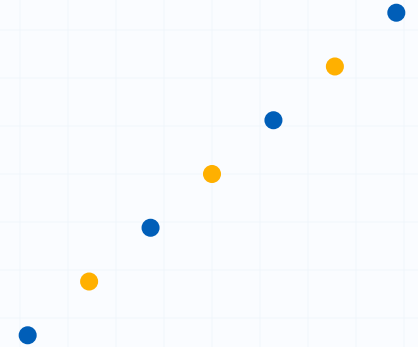
LEARNING OUTCOMES

- Key insights from national radioactive waste disposal programs.
- Understand how the US program addressed some safety case topics.
- Practical suggestions for growing with your disposal program.

01

Introduction

What topics you wanted to learn and what you should know



NGN-identified safety case topics

NGN members provided topics they wanted to be addressed in the webinar series.

Fundamentals of Safety Case

- How to initiate and structure a safety case – insight exploration.
- General understanding of safety case components and their integration – insight exploration.

Safety Case Methodology

- Scenario development: international practices and approaches – application.
- Use of features, events, processes (FEPs) across national programmes – application.
- Model conceptualization: approaches and underlying assumptions – application.
- Performance assessment methods and workflows.
- Data, information, and knowledge management in safety assessment – application.
- Derivation and management of safety requirements – insight exploration.
- Link between design decision and safety case arguments – application.

Regulatory Framework

- Role and application of legal and regulatory frameworks in safety case development – insight exploration.

International Perspectives and Applications

- Differences in safety cases approaches for various host rocks.
- International guidelines and practices in safety case development – insight exploration.
- Safety case considerations for different types waste types – application.
- Experience and lessons learned from other national programs – insight exploration.

Key insights

Principles that affect efforts to develop and maintain safety cases for deep geologic repositories.

Nations Aspire to Site, Licence, Construct, Operate, and Close a Deep Geologic Repository

- Need to keep all future steps in mind when conducting your work.
- A social and technical challenge wherein a society defines acceptability.

Lifecycle Extends Over Decades, Generations, and Potentially Centuries

- Managing knowledge and change are keys to success.

A Systems Engineering Approach is Needed

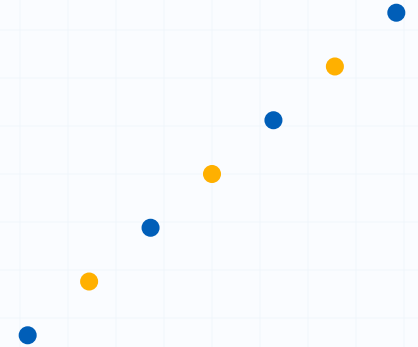
The Safety Case is a Construct

- Neither sufficient for success nor, *sensu stricto*, at least for the US, required.

02

Insight Exploration

Each of the principles explained with examples

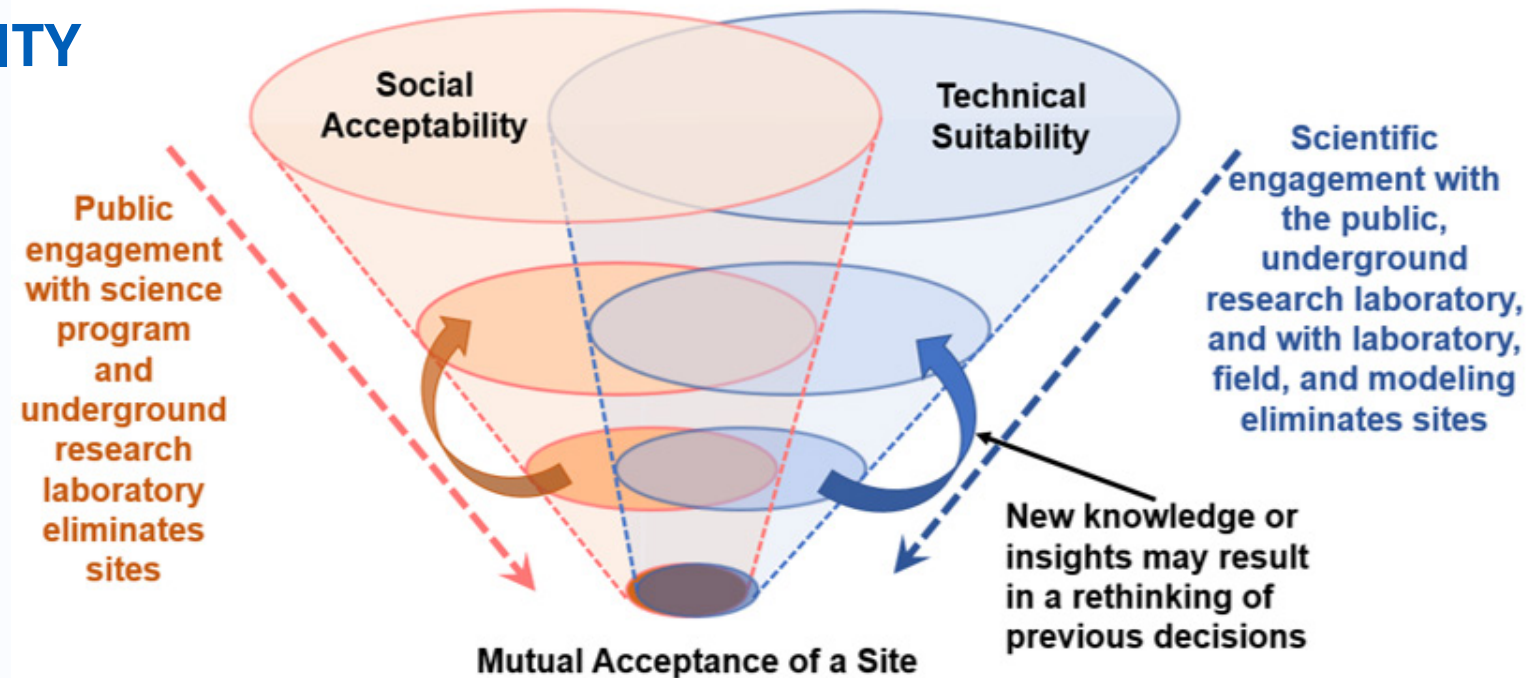


Nations Aspire to Site, Licence, Construct, Operate, and Close a Deep Geologic Repository

A social and technical challenge wherein a society defines acceptability.

SOCIETY DEFINES ACCEPTABILITY

- Decision-making stages, roles, and responsibilities.
- Siting and licensing requirements expressed in law.
- Regulations reflect national norms.
- Regulator and implementer must have and maintain social licence.



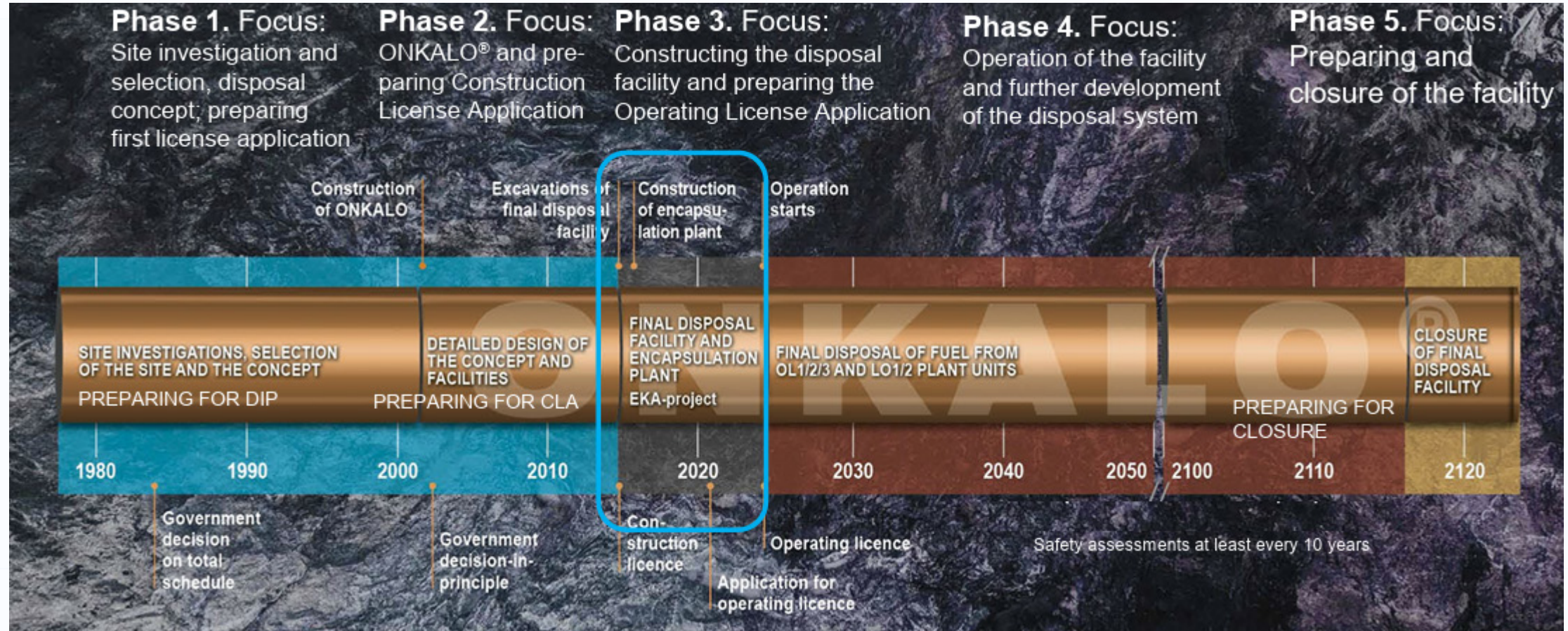
Development of a convergent pathway for siting a geologic repository.

[revised from Figure 4-3 in *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward Report*]

Source: NWTRB 2021

Keep All Future Steps In Mind When Conducting Your Work

Regulator and implementer interactions are important and should start as early as permitted.



- System needs evolve over time (e.g., constructability and optimization).
- Anticipate change; past decision-basis informs future decisions.

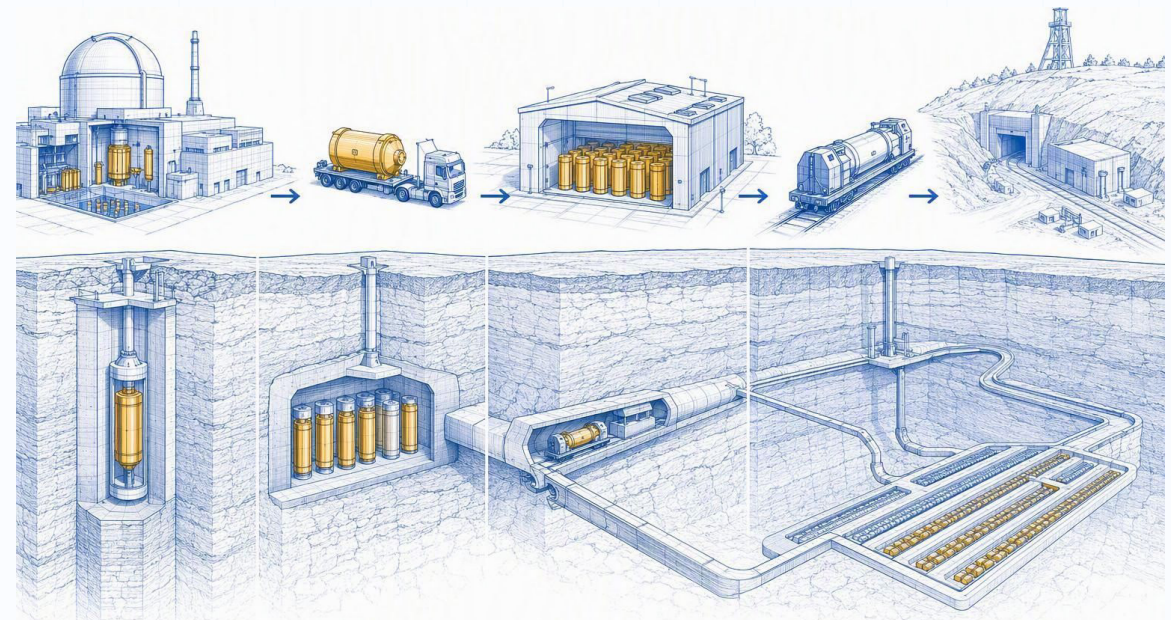
Source: Pastina 2026

Program Extends Over Decades, Generations, and Potentially Centuries

Change is certain and maintaining knowledge is central to success.

CHANGE

- Knowledge, technologies, and designs.
- Optimization.
- Organizations.
- Individuals need to grow and prepare for expected changes as the waste management program evolves from siting to closure.



MANAGING AND MAINTENANCE

- Requirements and configuration management.
- Information, data, and knowledge management.
- Preserve the baseline, the change, and the reason.

Figure source: Microsoft 365 Copilot

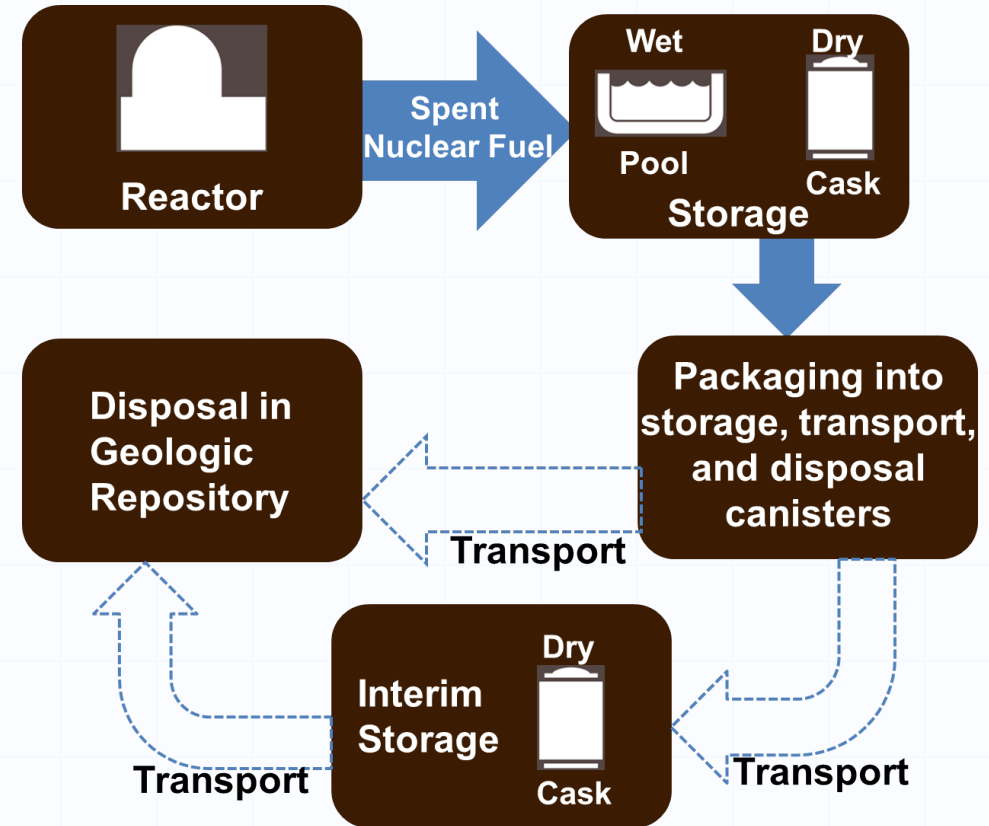
Waste Management System

New waste generation and storage, transportation and disposal of waste needs to be integrated.

- Generation** — waste acceptance and FEPs
- Storage** — monitoring and records
- Packaging** — purpose of container
- Transportation** — Infrastructure: site-transit-site
- Disposal** — licensing, design, operations, closure

Integration: needed between each stage and within each stage.

Needs, requirements, verification, validation across the lifecycle.



U.S. Department of Energy spent nuclear fuel management activities that lead to geologic disposal.

The safety case applies to the disposal facility

IAEA **guidance** treats the safety case and supporting assessment as the basis for licensing and decision-making.

“The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the **safety of a disposal facility**, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the disposal facility.”

Safety case approach is country specific.

US law and regulation established before safety case concept. The license application for construction authorization is the basis for decisions on safety, security, and environmental matters.

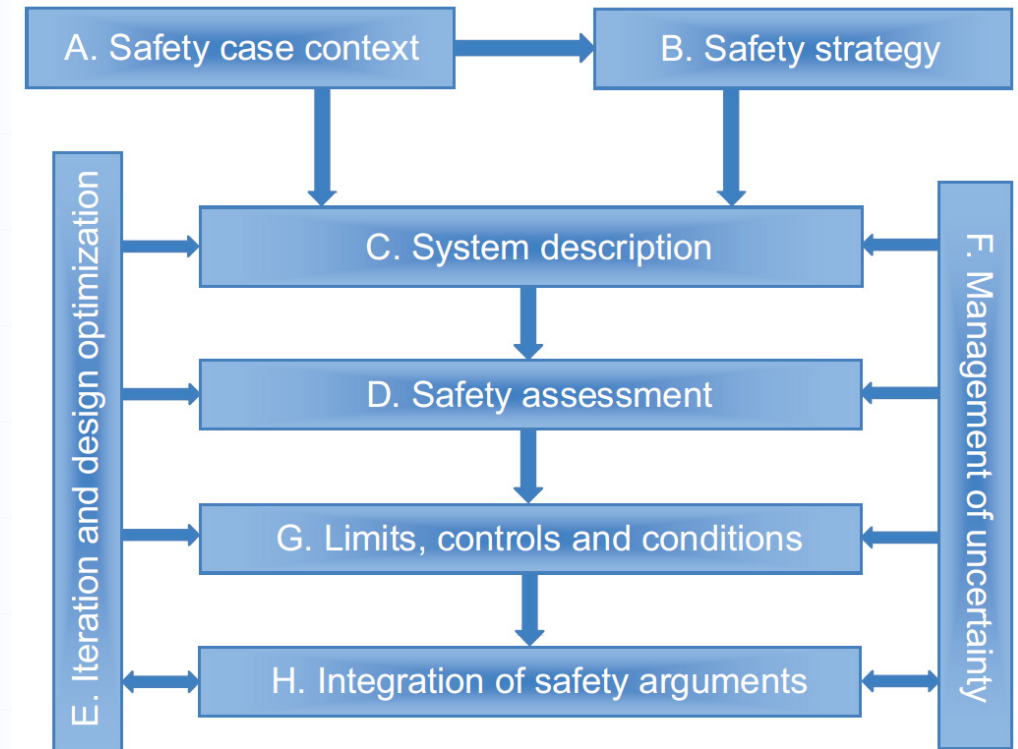
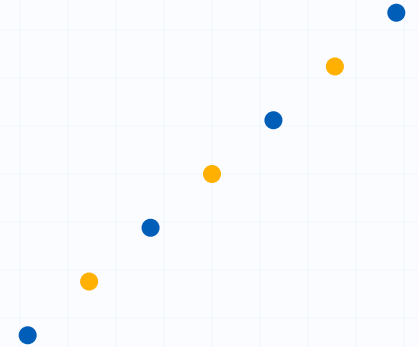


FIG. 2. Components of the safety case.

03

Application

How the US addressed some safety case topics.



Laws and regulations govern the process

US framework reflects societal norms and was in place before safety case guidance was established.

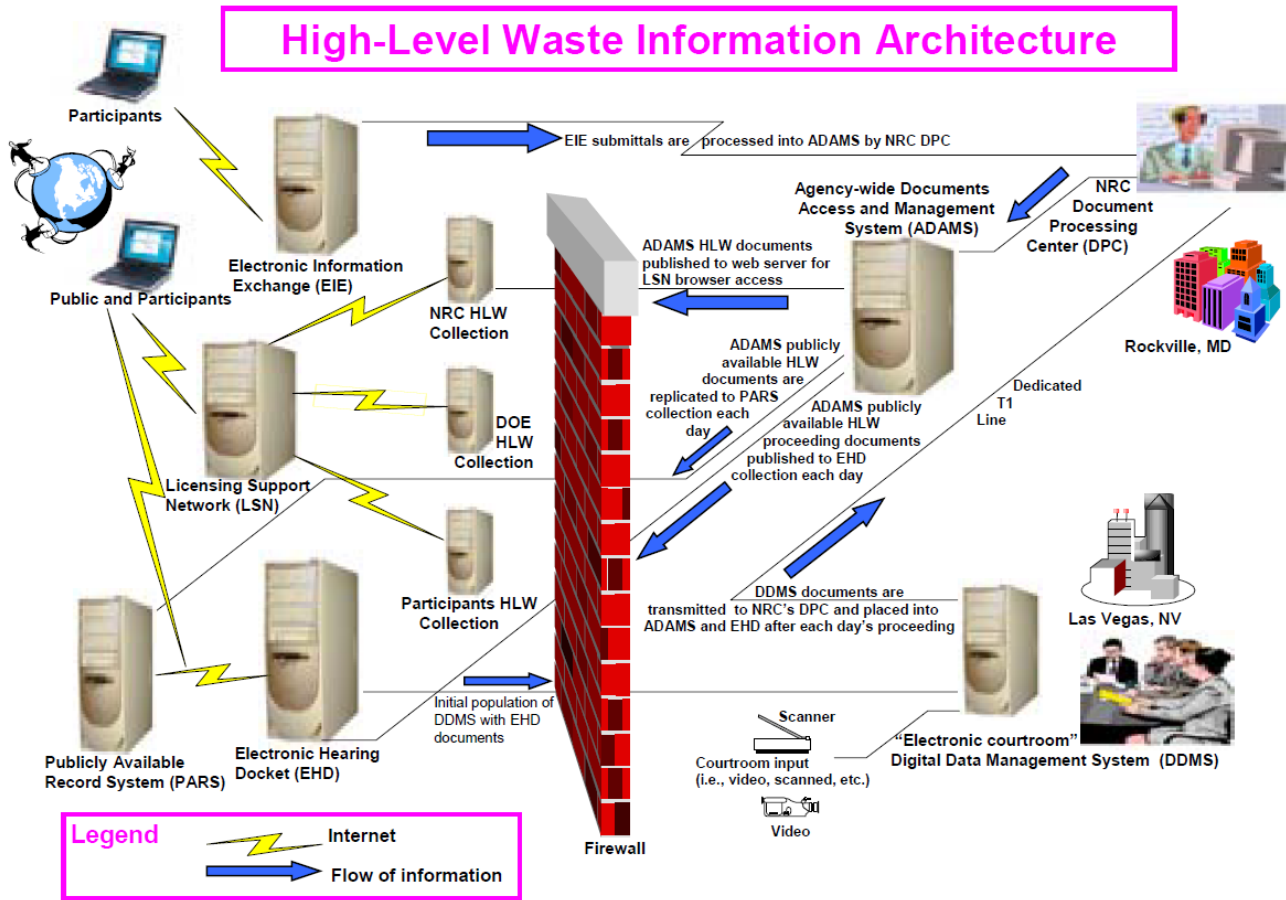


KEY CONCEPTS

- Prescribed roles of civil society, private sector, states, affected units of local government, and affected Indian tribes.
- Intensive pre-licensing interaction between regulator and implementer.
- DOE iterated its design and post-closure safety assessment.

Capture what information is needed to review the licence application

To meet the three-year licence review statutory limit, NRC established a regulation for document management.



KEY FEATURES

- Electronic records managed by NRC
- Each potential participant to the hearing responsible for their document collection; initial submission and updates
- Both supporting and contradicting documents submitted
- Electronic hearing docket
- Agency-wide resource; systems developed decades ago are still in use for other NRC licensing actions

Not a modern digital licence application, but twenty years ago this was the first of its kind in the world.

Source: NRC 1989; Leslie 2004 (Conducting the Review of a License Application for a Repository at Yucca Mountain, Nevada)

Key concepts

Risk-informed and performance-based.

DISPOSAL REQUIREMENTS

- Quality assurance program.
- Performance assessment.
- Multiple barriers.
 - Identify.
 - Describe capability.
 - Provide technical basis.

DISPOSAL GUIDANCE

- Structured review process.
- Acceptance criteria and review methods.
 - Model integration.
 - Data and model justification.
 - Data uncertainty.
 - Model uncertainty.
 - Model support.

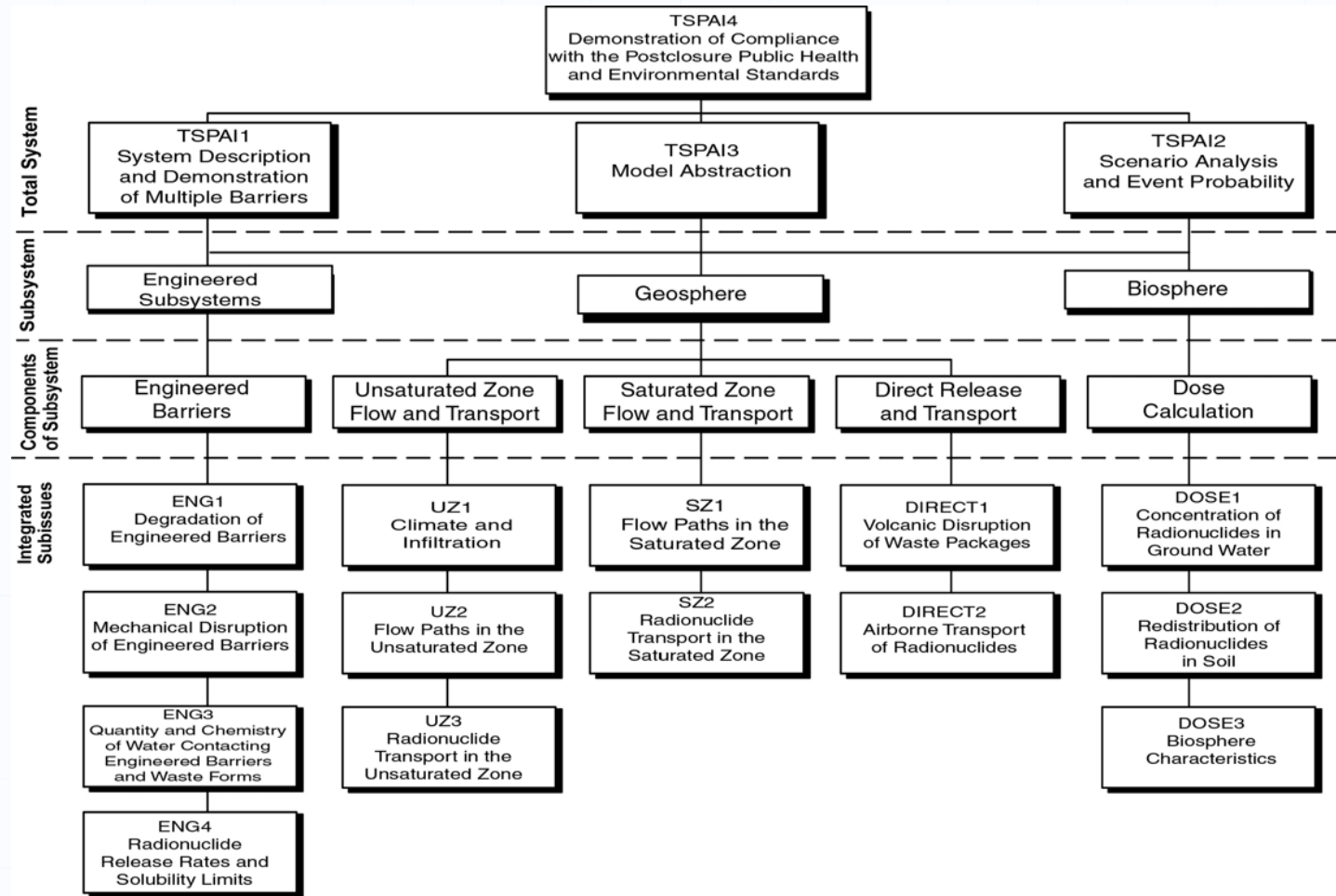


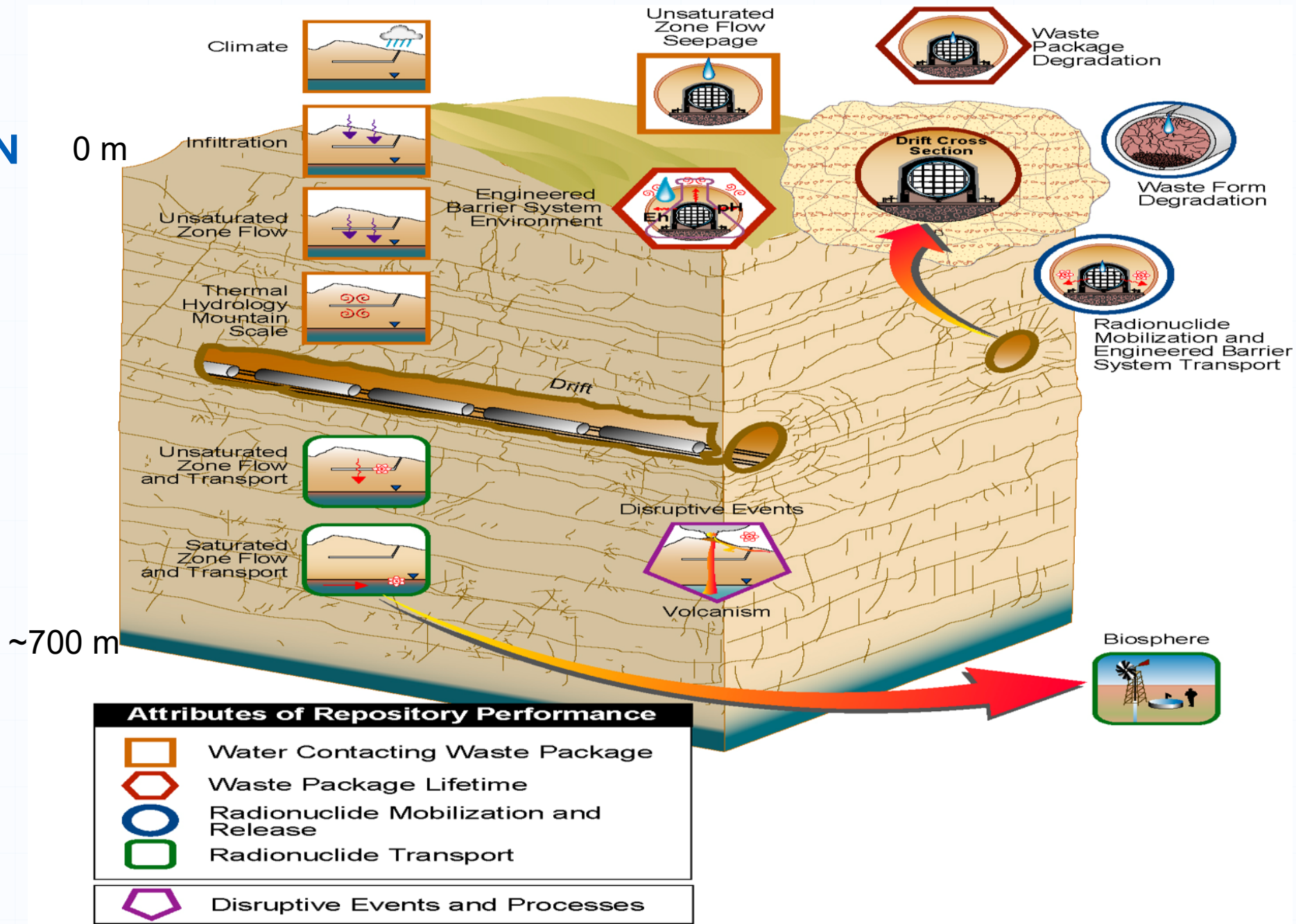
Figure A1-5. Components of performance assessment review.

Sources: NRC 2001; NRC 2003

REPOSITORY CONCEPT

YUCCA MOUNTAIN

- DOE depiction of geologic repository.
- Attributes of performance.
- Scenarios, including volcanism.



Source: DOE 2002

ENGINEERED BARRIER

- Diverse waste forms.
- Large waste packages.
- Thermal power varies by factor of ten.
- Waste package was stainless steel with Alloy-22 outer layer.
- Neutron absorbers in some packages.
- Ventilation during operations.
- Titanium drip shields emplaced prior to closure.

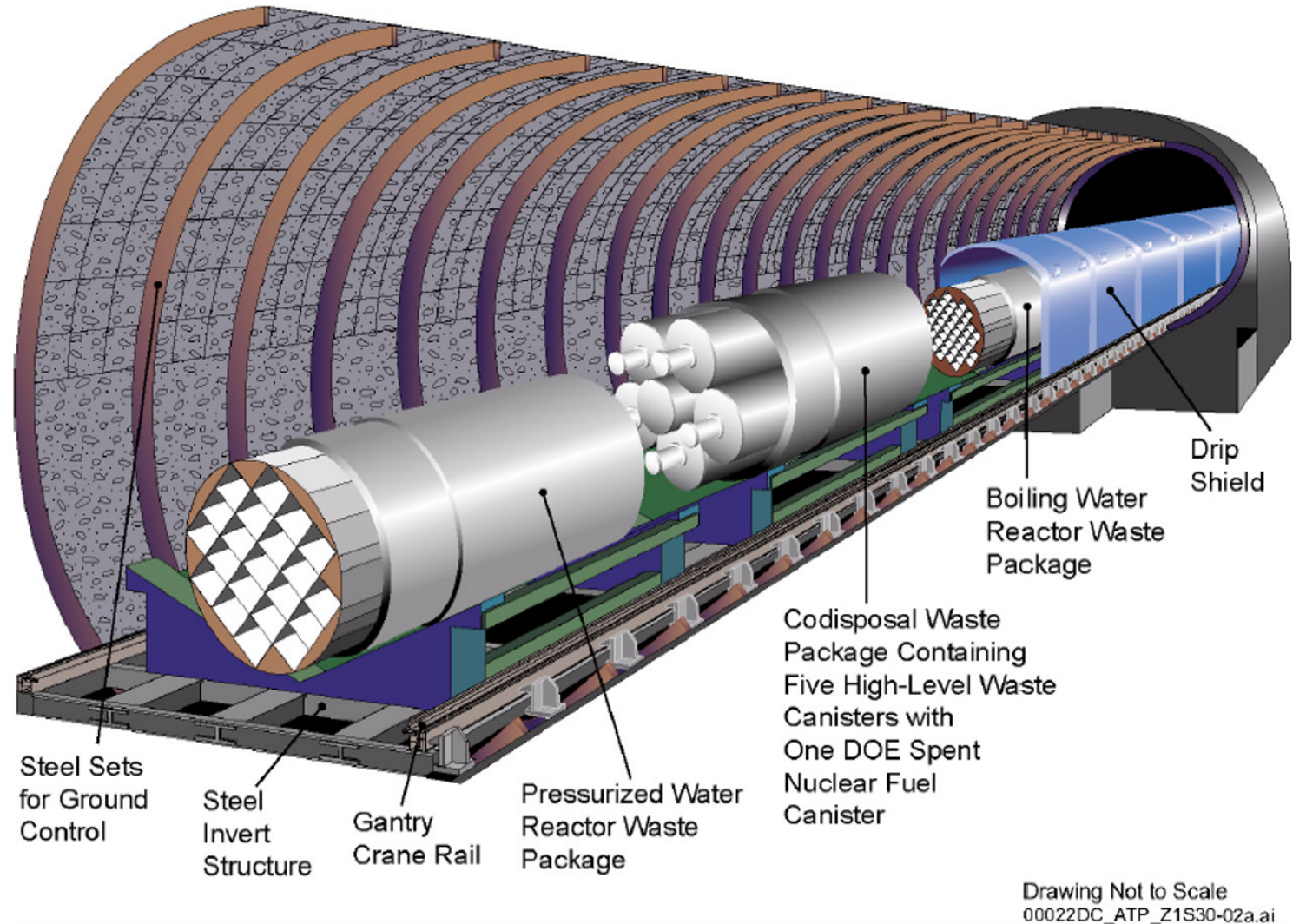
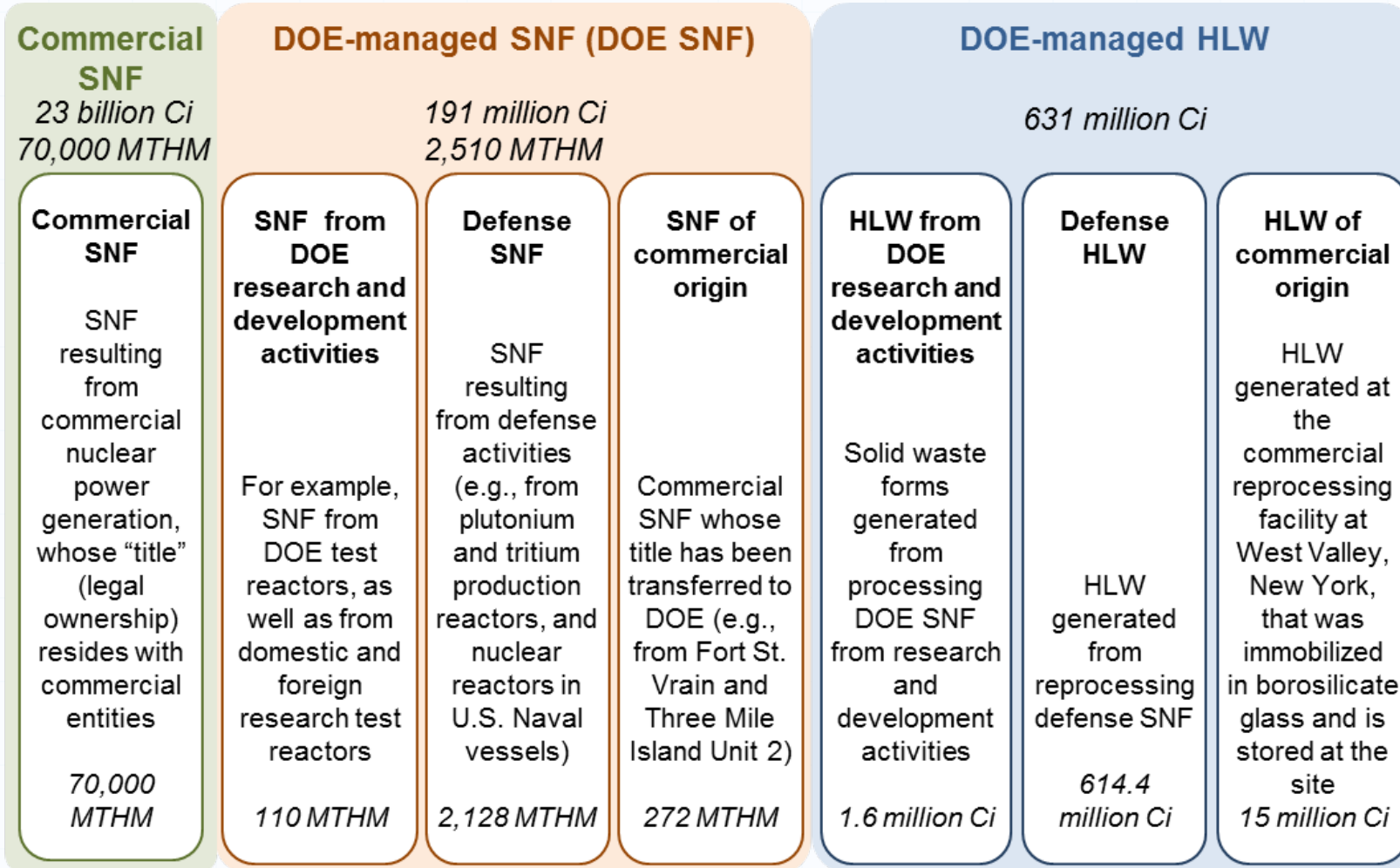


Figure 3. Schematic Illustration of the Emplacement Drift, with Cutaway Views of Different Waste Packages

DOE's concept of engineered barriers include the waste forms, waste packages, and drip shields.

Managing the waste form diversity

DOE grouped the more the 250 types of DOE-managed spent nuclear fuels.



Source: NWTRB 2017

INVENTORY GROUPINGS

- 34 groups based on fuel characteristics used for determining packaging options
- 9 post-closure criticality groups analyzed
- 11 spent fuel degradation groups analyzed

WASTE FORM FEPS

- Criticality required design analyses
- Degradation assumed instantaneous
- Gas generation in unsaturated rock

FEP analysis is host-rock specific.

FEP analysis is inventory specific.

Advanced reactor spent nuclear fuel is comparable to DOE spent nuclear fuel types.

WASTE PACKAGING

Managing the diversity

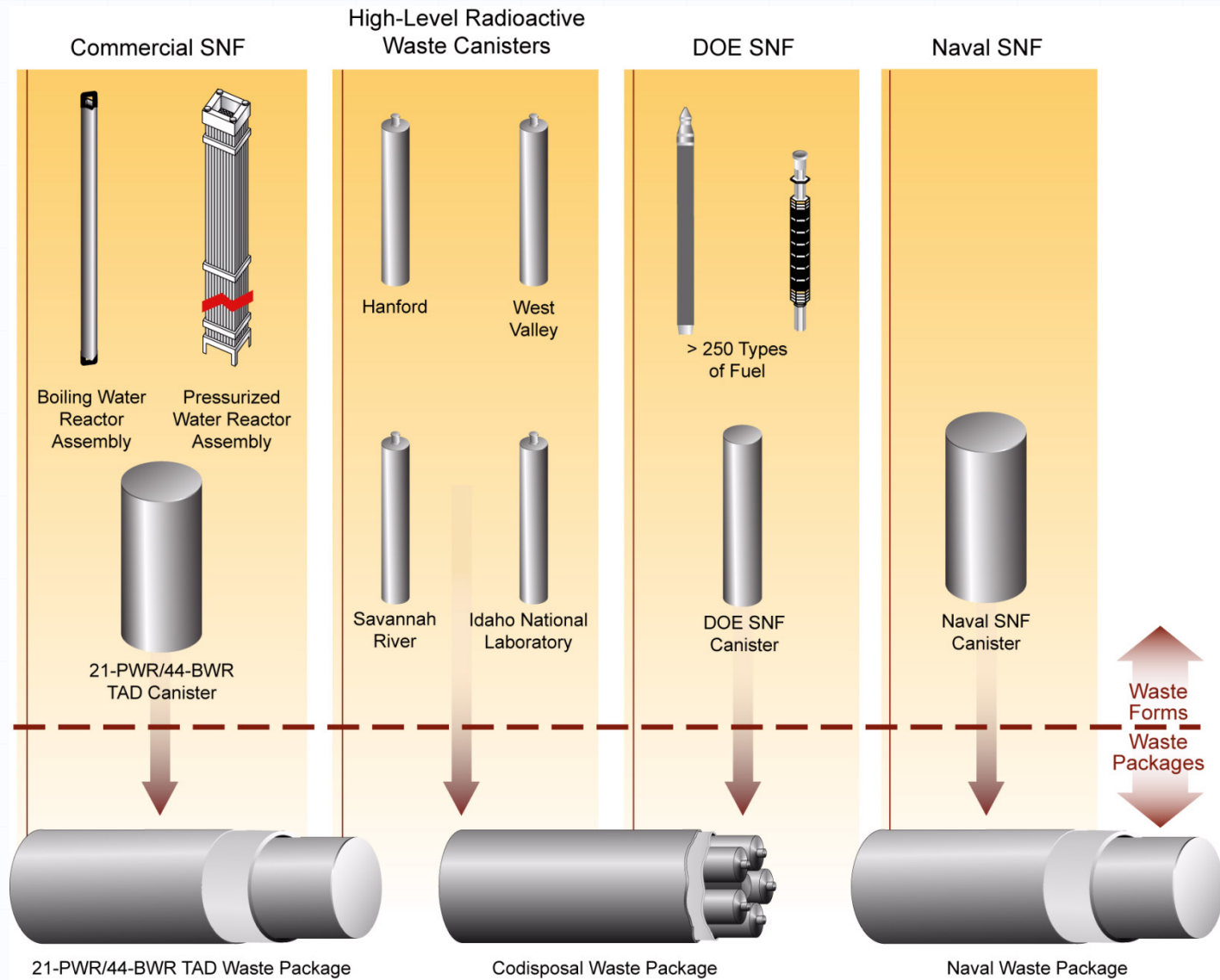
DOE proposed deployment of multiple purpose canisters.

PROPOSED CANISTERS

- DOE spent nuclear fuel canisters (~3,500)
Five canister types with eight basket arrangements
- Transportation, aging, and disposal canister (~7,500)
- Naval spent nuclear fuel canisters (~400)
- High-level radioactive waste canister (~9,500)

WASTE PACKAGE WEIGHT

- Codisposal (~45 tonnes)
- Transportation, aging, and disposal canister (~73 tonnes)
- Naval spent nuclear fuel (~73 tonnes)



Drawing Not To Scale
00240DC_LA_0127f.ai

Only naval canister deployed. Dozens of storage and transportation cask system types deployed for commercial spent nuclear fuel. Tradeoffs between using existing cask systems for disposal elsewhere or repackaging.

Source: NWTRB 2017

Managing the heat

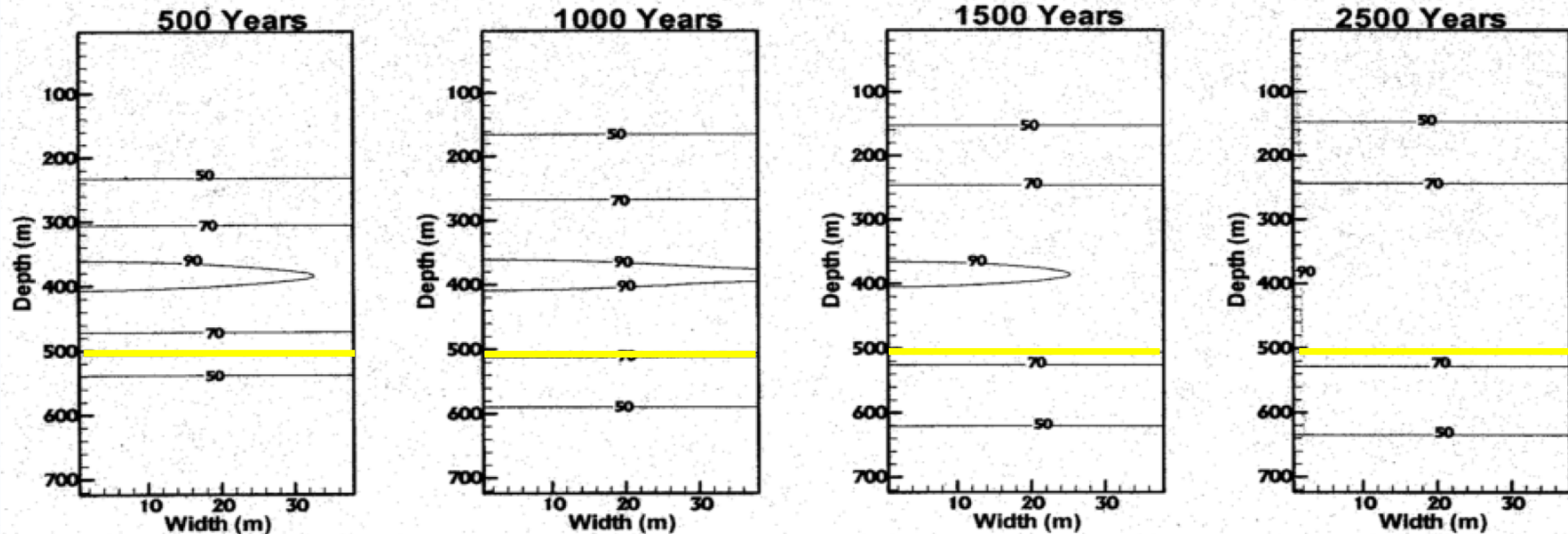
Above boiling repository temperatures created controversy and resulted in extensive design analysis by DOE.

DESIGN ANALYSIS

- Materials (waste package, backfill, drip shield, invert, and ground support)
- Thermal (areal waste loading, drift spacing, and waste package spacing)
- Ventilation rate

NRC TESTED AND EVALUATED

- Flow and transport and performance assessment codes
- Draft acceptance criteria and review methods
- DOE's treatment of FEPs



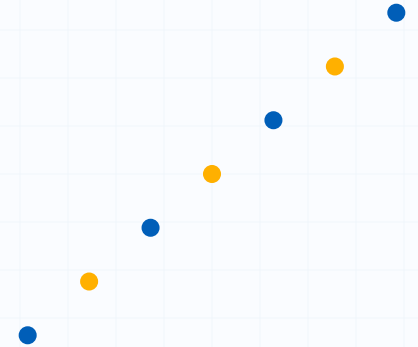
Source: Leslie et al. 2000

 The top of the zeolite-bearing unit (CH1vc) at a depth of 502.3 meters below ground surface.

04

Summary

Lessons learned and key takeaways.



Lesson learned and key takeaways

- 1 ——— Integration is vital and a system engineering approach helps.
- 2 ——— Social acceptability differs between nations; develop and maintain a social licence.
- 3 ——— Managing knowledge and change are keys to success.
- 4 ——— The goal is to site, licence, construct, operate, and close a geologic repository.
- 5 ——— Anticipate change and grow with your program.

Closing prompt: What is the one thing that you will do this year to “grow with your program”?

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QUESTIONS AND DISCUSSION

- 1 — Jay and Hoda will facilitate the questions.
- 2 — Add questions to chat.
- 3 — Provide your email with your question if you want me to get back to you.