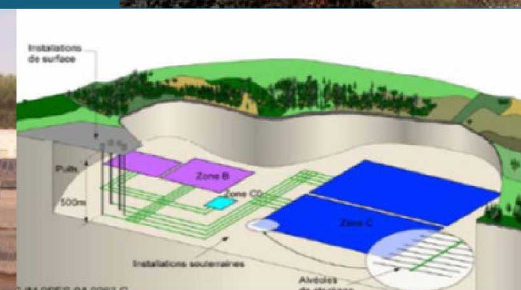
Sandia National Laboratories

SAND2018-13624C

Focus on Deep Geologic Disposal of Radioactive Waste: Status of Radioactive Waste Management in the United States



PRESENTED BY

David Sassani, Distinguished Member of Technical Staff

AGU Fall Meeting 2018

December 13, 2018; Washington, D.C.

Outline

- Status of the US program
- Options for geologic disposal in the US and other nations

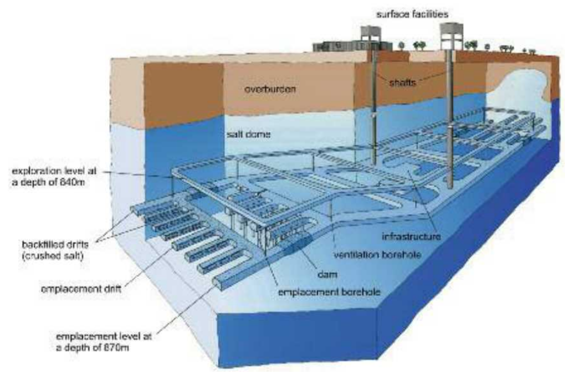
Spent Nuclear Fuel and High-Level Radioactive Waste Disposal: The Goal

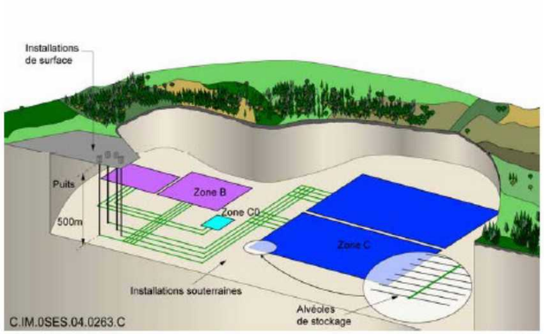
"There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF)."

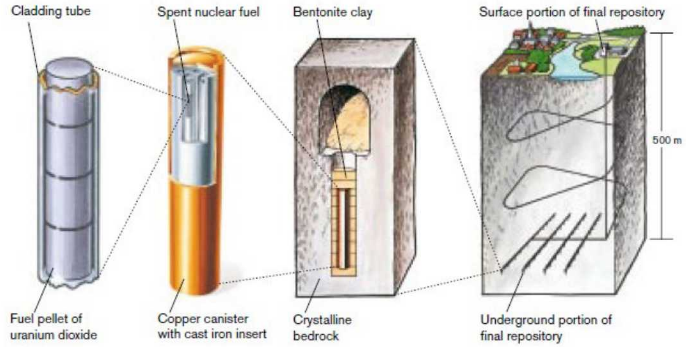
"Geological disposal remains the only long-term solution available."

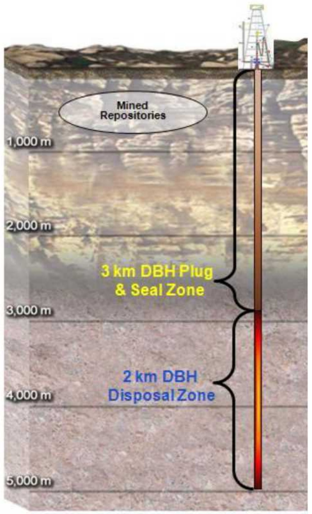
National Research Council, 2001

Deep geologic disposal has been planned since the 1950s





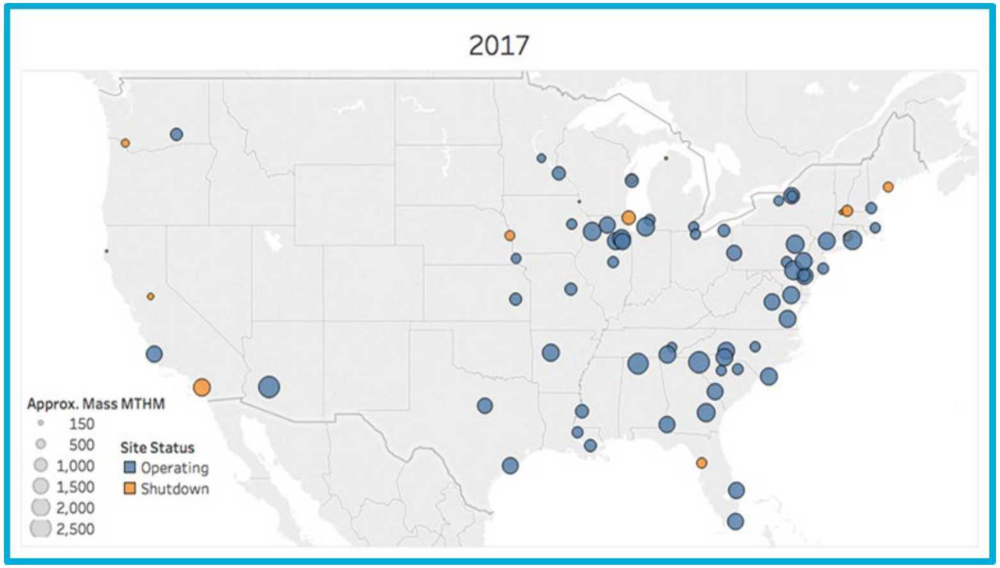




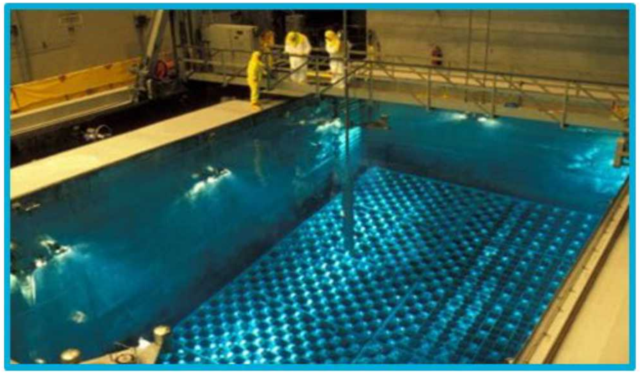
Geologic Disposal in the US: The Reality

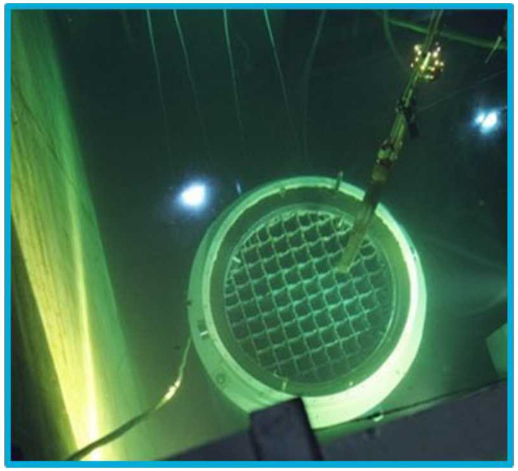
Commercial SNF is in Temporary Storage at 75 Reactor Sites in 33 States

- Pool storage provides cooling and shielding of radiation
  - Primary risks for spent fuel pools are associated with loss of the cooling and shielding water
- US pools have reached capacity limits and utilities have implemented dry storage
- Some facilities have shutdown and all that remains is "stranded" fuel at an independent spent fuel storage installation (ISFSI)



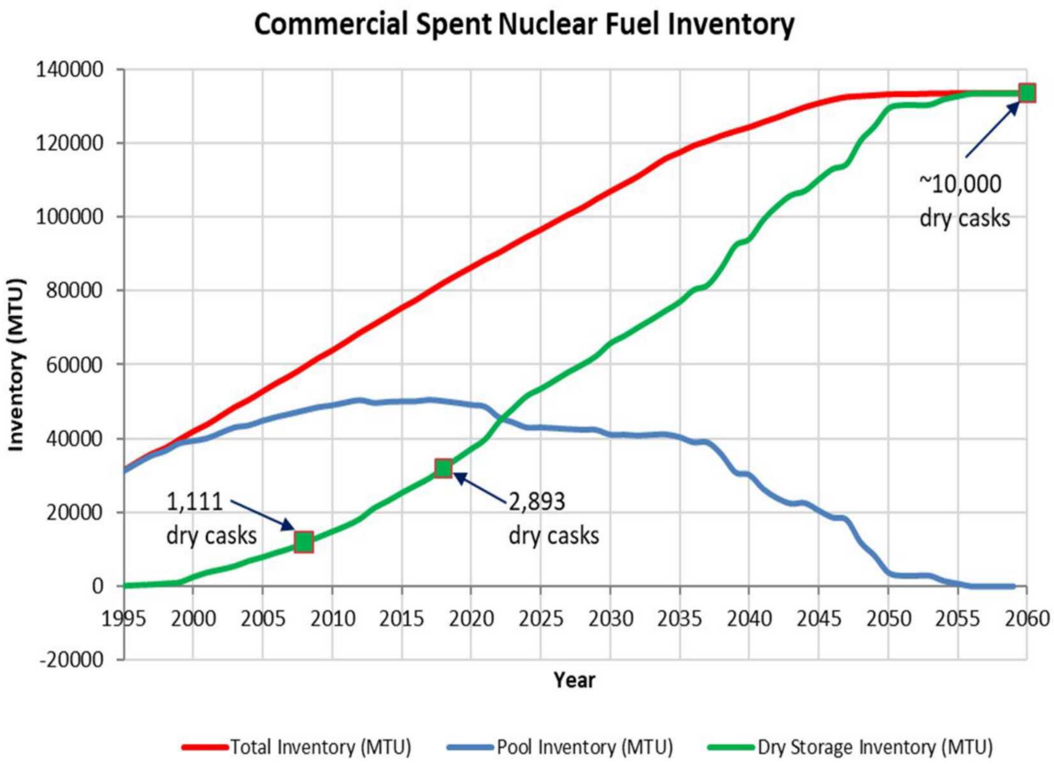
Map of the US commercial SNF storage from Bonano et al. 2018



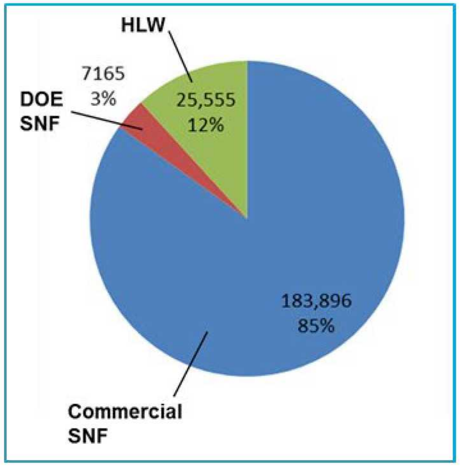


US Projections of SNF and HLW

Projection assumes full license renewals and no new reactor construction or disposal (Bonano et al., 2018)



Projected Volumes of SNF and HLW in 2048



Volumes shown in m³ assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters.

Approx. 80,000 MTHM (metric tons heavy metal) of commercial SNF in storage in the US as of Dec. 2017

Approx. 30,000 MTHM in dry storage at reactor sites, in approximately 2,800 cask/canister systems as of Dec. 2017

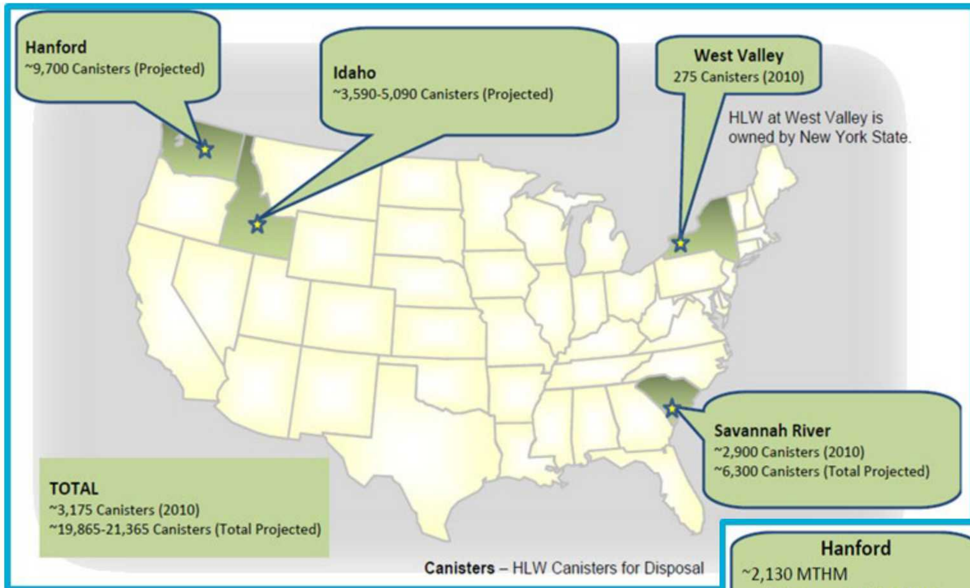
- Balance in pools, mainly at reactors

Approx. 2200 MTHM of SNF generated nationwide each year

- Approximately 160 new dry storage canisters are loaded each year in the US

Geologic Disposal in the US: The Reality (cont.)

DOE-managed SNF and HLW is in Temporary Storage at 5 Sites in 5 States

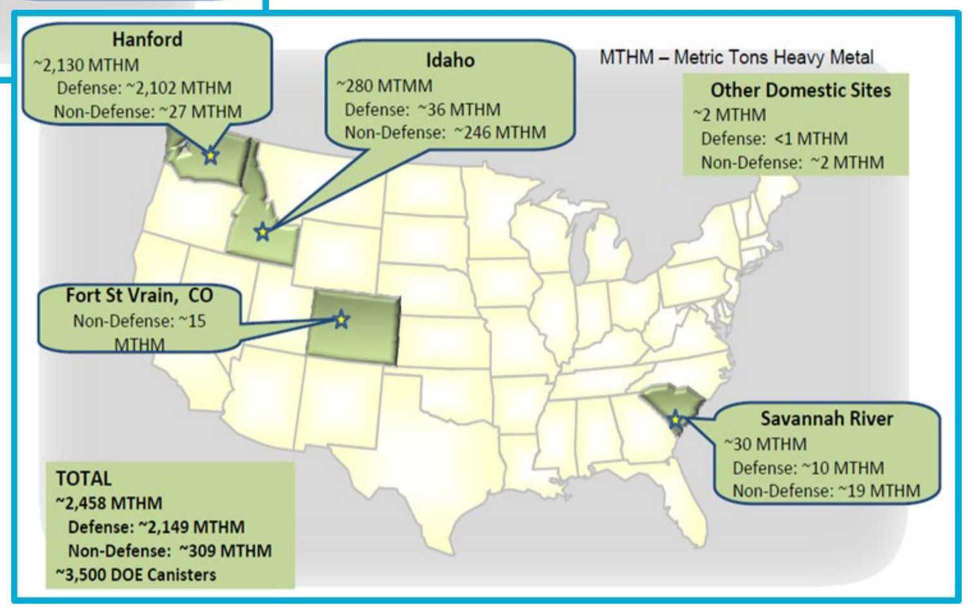


DOE-Managed HLW

~20,000 total canisters (projected)

DOE-Managed SNF

~2,458 Metric Tons



Source: Marcinowski, F., "Overview of DOE's Spent Nuclear Fuel and High-Level Waste," presentation to the Blue Ribbon Commission on America's Nuclear Future, March, 25, 2010, Washington, DC.

Observations on Current Practice

- Current practice is safe and secure
  - Extending current practice raises data needs; e.g., canister integrity, fuel integrity, aging management practices
- Current practice is optimized for reactor site operations
  - Occupational dose
  - Operational efficiency of the reactor
  - Cost-effective on-site safety
- Current practice is not optimized for transportation or disposal
  - Thermal load, package size, and package design

Placing spent fuel in dry storage in dual purpose canisters (DPCs) commits the US to some combination of three options

1) Repackaging spent fuel in the future

2) Constructing one or more repositories that can accommodate DPCs

3) Storing spent fuel at surface facilities indefinitely, repackaging as needed

Each option is technically feasible, but none is what was originally planned

Spent Nuclear Fuel and High-Level Radioactive Waste Disposal: The Goal

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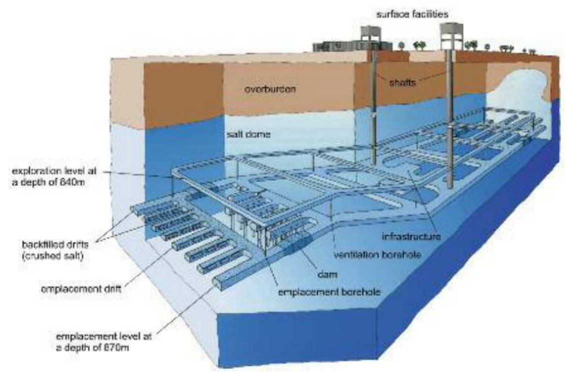
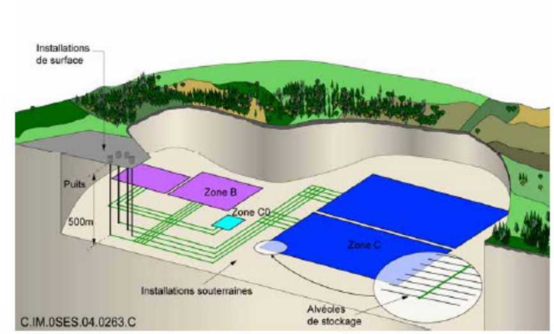
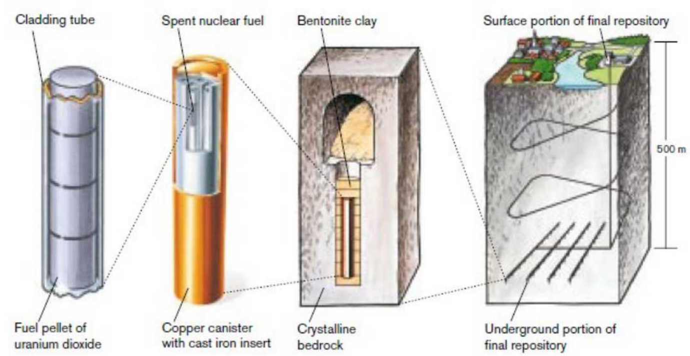
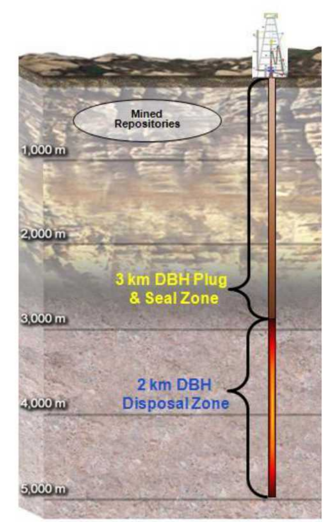








Status of Deep Geologic Disposal Programs World-Wide

Nation	Host Rock	Status
Finland	Granitic Gneiss	Construction license granted 2015. Operations application to be submitted in 2020
Sweden	Granite	License application submitted 2011
France	Argillite	Disposal operations planned for 2025
Canada	Granite, sedimentary rock	Candidate sites being identified
China	Granite	Repository proposed in 2050
Russia	Granite, gneiss	Licensing planned for 2029
Germany	Salt, other	Uncertain
USA	Salt (transuranic waste at the Waste Isolation Pilot Plant) Volcanic Tuff (Yucca Mountain)	WIPP: operating Yucca Mountain: suspended
Others: Belgium (clay), Korea (granite), Japan (sedimentary rock, granite), UK (uncertain), Spain (uncertain), Switzerland (clay), Czech Republic (granitic rock), all nations with nuclear power.		

Source: Information from Faybishenko et al., 2016

After Decades of Repository Science and Engineering, What Do We Have?

- Repository programs in multiple nations
  - Belgium, Canada, China, Czech Republic, Finland, France, Germany, Japan, Korea, Russia, Spain, Sweden, Switzerland, United Kingdom, United States …
- Detailed safety assessments have been published for multiple disposal concepts, e.g.,
  - Switzerland: Opalinus Clay, 2002
  - France; Dossier 2005 Argile, 2005
  - USA: Yucca Mountain License Application for a repository in tuff, 2008
  - Sweden: Forsmark site in granite, 2011
  - Finland: Safety Case for Olkiluoto site in gneiss, 2012
  - Canada: Hypothetical repository in carbonate, 2013
- One deep mined repository has been in operation for transuranic waste (the Waste Isolation Pilot Plant in the US) since 1999

First order conclusions about geologic disposal

- **There are multiple approaches to achieving safe geologic isolation**
- **Estimated long-term doses are very low for each of the disposal concepts that have been analyzed in detail**
- **Safe isolation can be achieved for both SNF and HLW**

How Repositories Work

Natural barriers prevent or delay water from reaching waste form

Engineered barriers prevent or delay water from reaching waste form

Slow degradation of waste form limits exposure to water

Near Field: water chemistry limits aqueous concentrations

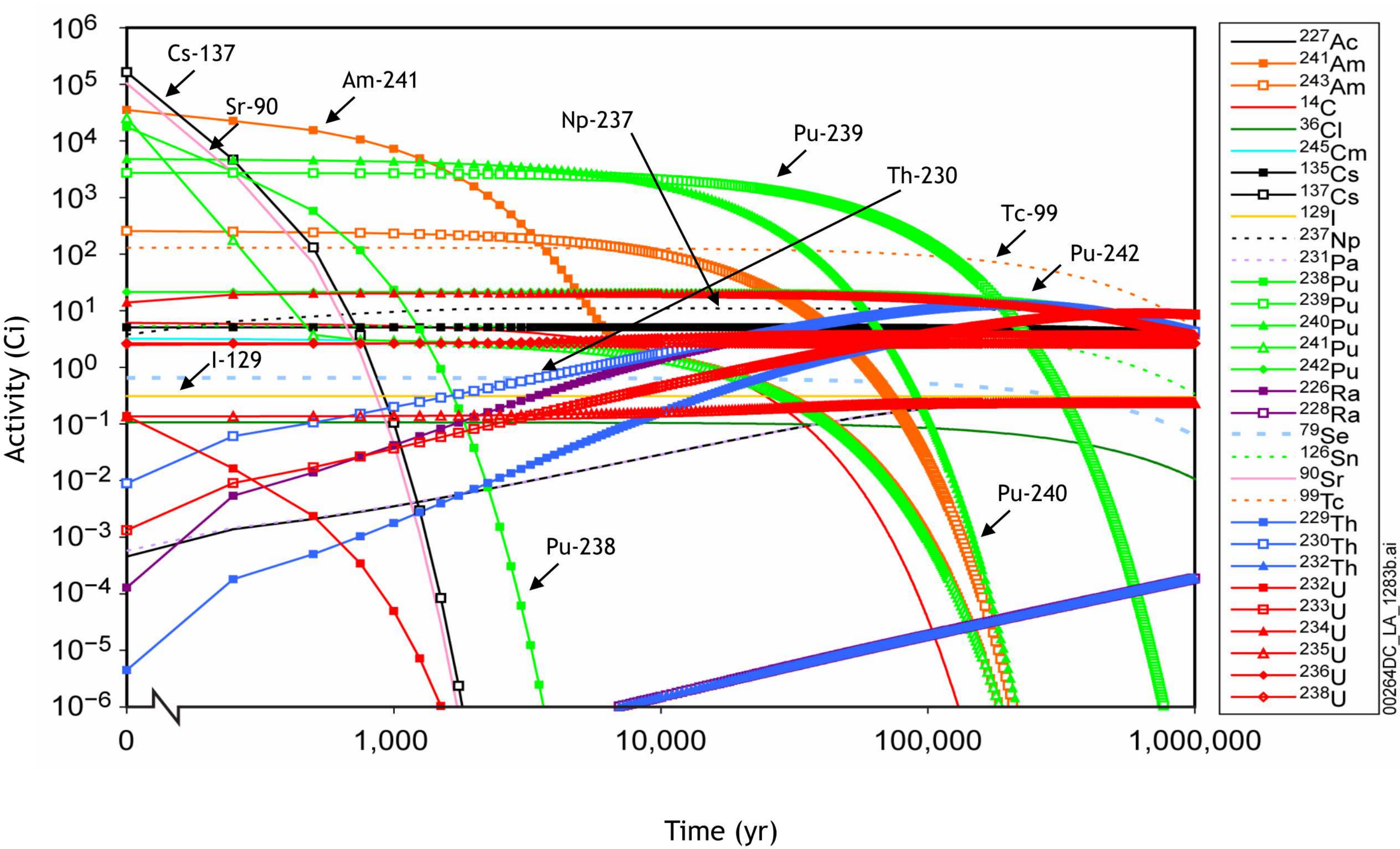
Natural and engineered barriers prevent or delay transport of radionuclides to the human environment

Time (radioactive decay)

Overall performance relies on multiple components; different disposal concepts emphasize different barriers

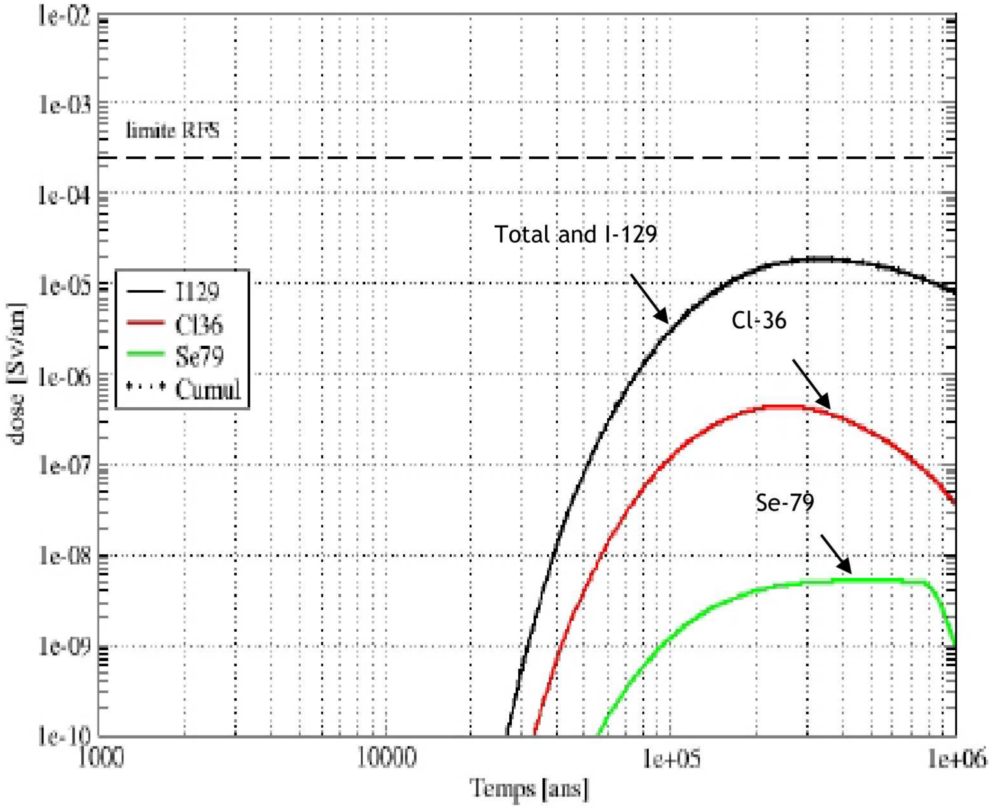
Isolation mechanisms may differ for different nuclides in different disposal concepts

Commercial Spent Nuclear Fuel Decay



DOE/RW-0573 Rev 0, Figure 2.3.7-11, inventory decay shown for an single representative Yucca Mountain spent fuel waste package, as used in the Yucca Mountain License Application, time shown in years after 2117.

Contributors to Total Dose: Meuse / Haute Marne Site (France)

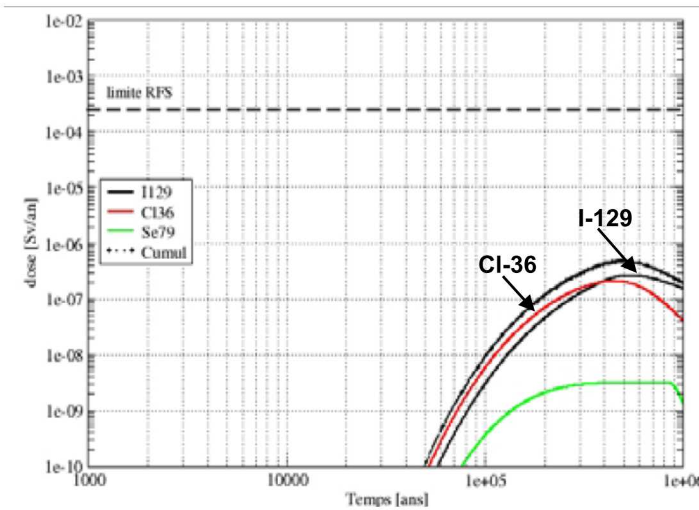


ANDRA 2005, *Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation*, Figure 5.5-18, SEN million year model, CU1 spent nuclear fuel and Figure 5.5-22, SEN million year model, C1+C2 vitrified waste

Diffusion-dominated disposal concept: Argillite

I-129 is the dominant contributor at peak dose

Examples shown for direct disposal of spent fuel (left) and vitrified waste (below)



Contributors to Total Dose: Forsmark site (Sweden)

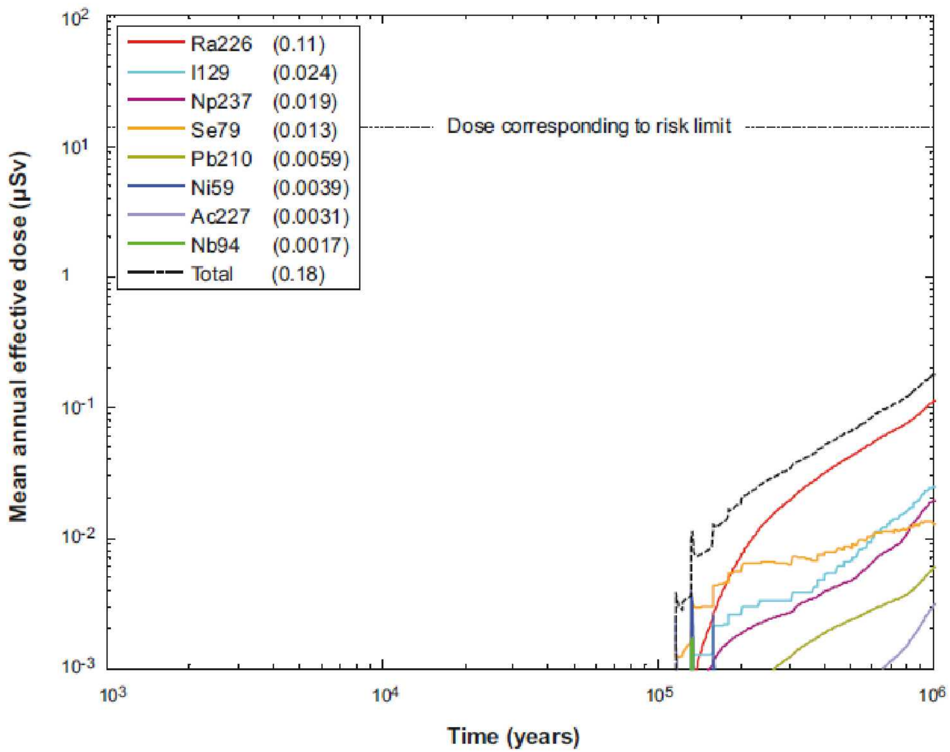


Figure 13-18. Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in µSv).

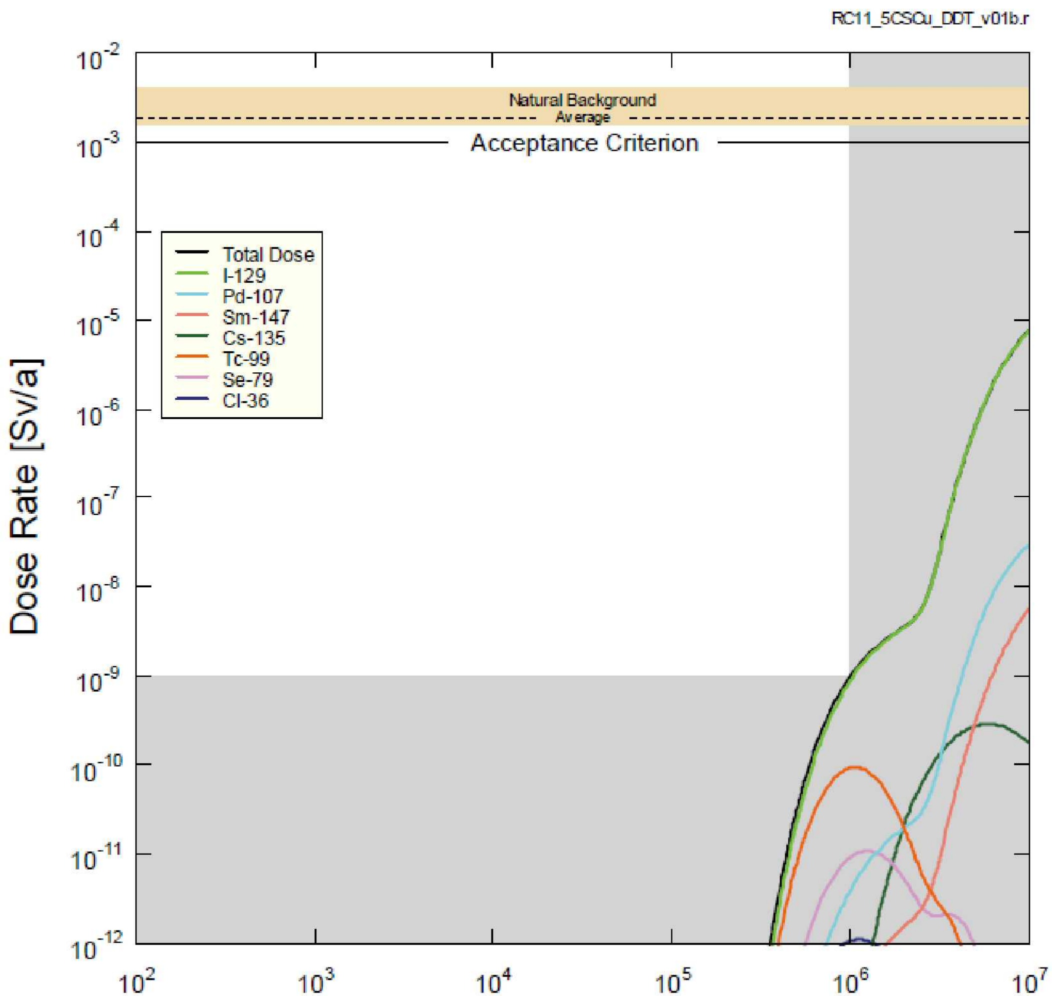
SKB 2011, Long-term safety for the final repository for spent nuclear fuel at Forsmark, Technical Report TR-11-01

Disposal concept with advective transport in the far-field: Fractured Granite

Long-term peak dose dominated by Ra-226

Once corrosion failure occurs, dose is primarily controlled by fuel dissolution and diffusion through buffer rather than far-field retardation

Contributors to Total Dose: Hypothetical Site (Canada)



NWMO 2013, Adaptive Phased Management: Postclosure Safety Assessment of a Used Fuel Repository in Sedimentary Rock, NWMO TR-2013-07, Figure 7-96.

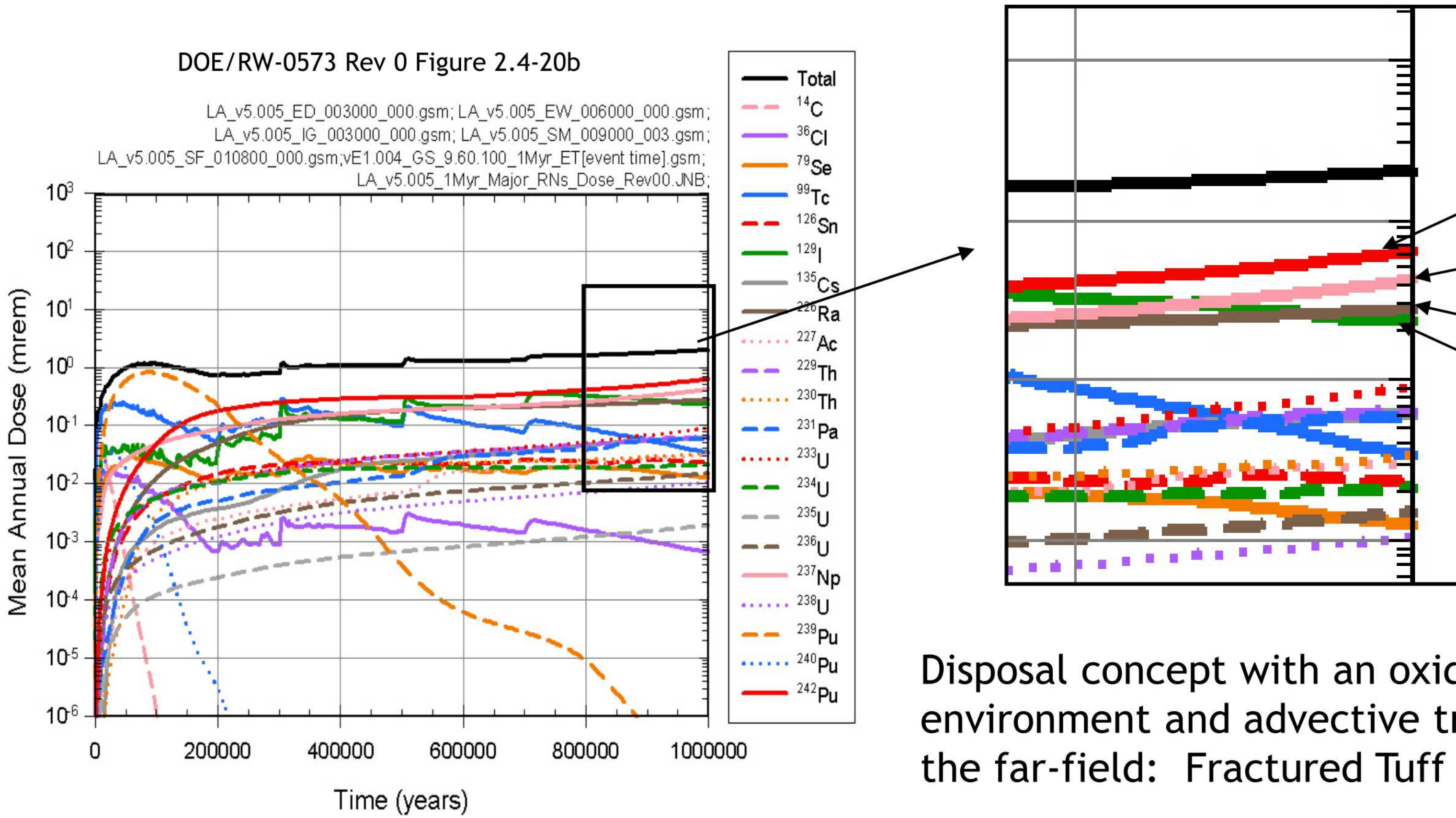
Diffusion-dominated disposal concept: spent fuel disposal in unfractured carbonate host rock

Long-lived copper waste packages and long diffusive transport path

All waste packages assumed to fail at 60,000 years for this simulation; primary barriers are slow dissolution of SNF and long diffusion paths

Major contributor to peak dose is I-129

Contributors to Total Dose: Yucca Mountain (USA)



Disposal concept with an oxidizing environment and advective transport in the far-field: Fractured Tuff

Actinides are significant contributors to dose; I-129 is approx. 1/10th of total

Conclusions

Deep geologic disposal remains the preferred approach for permanent isolation of SNF and HLW

Interim storage of commercial SNF occurs in the US at all operating reactor sites

- The existing inventory of SNF exceeds the legal capacity of the proposed Yucca Mountain repository
- Interim storage will continue for decades longer than originally envisioned

Interim storage of DOE -managed SNF and HLW in the US continues at multiple sites

Multiple geologic disposal options are technically feasible, including the proposed site at Yucca Mountain, Nevada

- Different disposal concepts rely on different combinations of engineered and natural barriers to achieve isolation

BACKUP MATERIAL

References

ANDRA (Agence nationale pour la gestion des déchets radioactifs), 2005. Dossier 2005: *Argile. Tome: Safety Evaluation of a Geological Repository* (English translation: original documentation written in French remains ultimately the reference documentation).

Bonano, E., Kalinina, E., and Swift, P., 2018, "The Need for Integrating the Back End of the Nuclear Fuel Cycle in the United States of America." *MRS Advances*, 1-13. doi:10.1557/adv.2018.231

Faybishenko, B., Birkholzer, J., Sassani, D., and Swift, P., 2016. *International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation, Fifth Worldwide Review*, LBNL-1006984, Lawrence Berkeley National Laboratory.

NAGRA (Nationale Genossenschaft für die Lagerung Radioactiver Abfälle [National Cooperative for the Disposal of Radioactive Waste]), 2002, *Project Opalinus Clay Safety Report: Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate-level waste (Entsorgungsnachweis),* Technical Report 02-05.

National Research Council / National Academies, 2001. *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges*, Washington, DC, National Academy Press.

NWMO (Nuclear Waste Management Organization), 2013. *Adaptive Phased Management: Postclosure Safety Assessment of a Used Fuel Repository in Sedimentary Rock*, NWMO TR-2013-07.

Posiva Oy, 2012, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto—Synthesis 2012*, POSIVA 2012-12.

SKB (Svensk Kämbränslehantering AB [Swedish Nuclear Fuel and Waste Management Co.]), 2011. *Long-Term Safety for the Final Repository for Spent Nuclear Fuel at Forsmark: Main Report of the SR-Site Project*, Technical Report TR-11-01.

Swift, P.N., and W.M. Nutt, 2010. "Applying Insights from Repository Safety Assessments to Evaluating Impacts of Partitioning and Transmutation," *Proceedings of the 11th OECD-NEA Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation*, San Francisco, CA, November 1-4, 2010.

Swift, P.N., and E.J.Bonano, 2016, "Geological Disposal of Nuclear Waste in Tuff: Yucca Mountain (USA)," *Elements,* volume 12, p. 263-268.

US DOE (United States Department of Energy) 2008. *Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 1.

Timeline of the U.S. Repository Program

Nuclear Waste Policy Act of 1982

1987

Nuclear Waste Policy Amendments Act selects Yucca Mountain as sole site for further characterization

January 31, 1998

DOE fails to open a repository by the statutory deadline

February 2002

Yucca Mountain Site Recommendation
Site is designated by DOE and President G.W. Bush as suitable for repository development and licensing

June 3, 2008

Yucca Mountain Repository License Application submitted to the NRC

2010

Obama Administration decides Yucca Mountain is not workable;
Project suspended

Spent nuclear fuel continues to be generated at ~2,200 MTHM/yr

Present Day
Repository program remains suspended, but law is unchanged

SNF continues to accumulate in dry storage at commercial reactor sites; HLW remains in storage at DOE sites

Today

Current Status of the US Program

- **2008**: Yucca Mountain Repository License Application submitted
- **2009**: Department of Energy (DOE) determines Yucca Mountain to be unworkable
- **2010**: Last year of funding for Yucca Mountain project
- **2012**: Blue Ribbon Commission on America's Nuclear Future completes its recommendations, including a call for a consent-based process to identify alternative storage and disposal sites
- **2013**: Federal Court of Appeals orders Nuclear Regulatory Commission (NRC) to complete its staff review of the Yucca Mountain application with remaining funds
- **2015**: NRC staff completes Yucca Mountain review, finds that "the DOE has demonstrated compliance with the NRC regulatory requirements" for both preclosure and postclosure safety
- **2015**: DOE begins consideration of a separate repository for defense high-level wastes and initiates first phase of public interactions planning for a consent-based siting process for both storage and disposal facilities. (Both activities terminated 2017.)
- **2016-17**: Private sector applications to the NRC for consolidated interim storage (Waste Control Specialists in Andrews, TX and Holtec in Eddy/Lea Counties, NM)
- **2018**: Yucca Mountain licensing process remains suspended, and approximately 300 technical contentions remain to be heard before a licensing board can reach a decision

Dry Storage Systems for Spent Nuclear Fuel

Dual purpose canister (DPC)

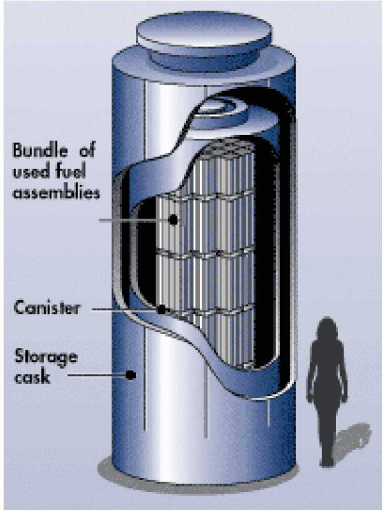
- A canister that is certified for both storage and transportation of spent nuclear fuel

Dry cask/canister storage systems

- The most common type of dry storage cask system is the vertical cask/canister system shown above, in which the inner stainless steel canister is removed from the storage overpack before being placed in a shielded transportation cask for transport
  - Can be constructed both above and below grade
- Horizontal bunker-type systems and vaults are also in use

Some older fuel is also stored as "bare fuel" in casks with bolted lids; few sites continue to load these systems

Multiple vendors provide NRC-certified dry storage systems to utilities



Current Storage and Transportation R&D

Spent fuel integrity

- Current tests and analyses indicate that spent fuel is more robust than was previously thought
- The *DOE/EPRI High Burnup Confirmatory Data Project* will obtain data after 10 years of dry storage to confirm current test and analysis results from parallel hot cell testing of "sister rods"

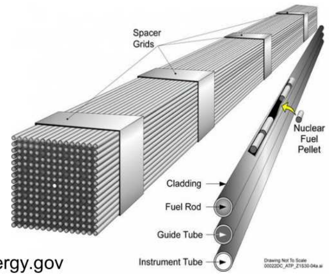


Photo: energy.gov

Storage system integrity

- *Stress corrosion cracking of canisters may be a concern in some parts of the country, and more work is needed in analysis and detection*
- *Monitoring and Aging Management practices at storage sites will be important to confirm storage system performance during extended service*

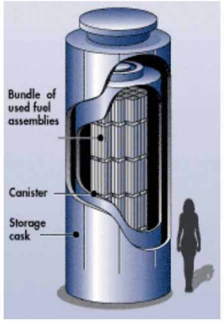
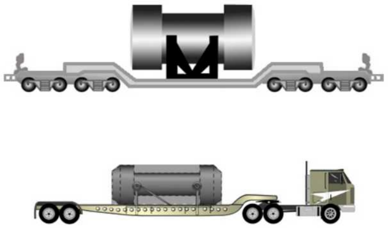


Photo: nrc.gov

Spent fuel transportability following extended storage

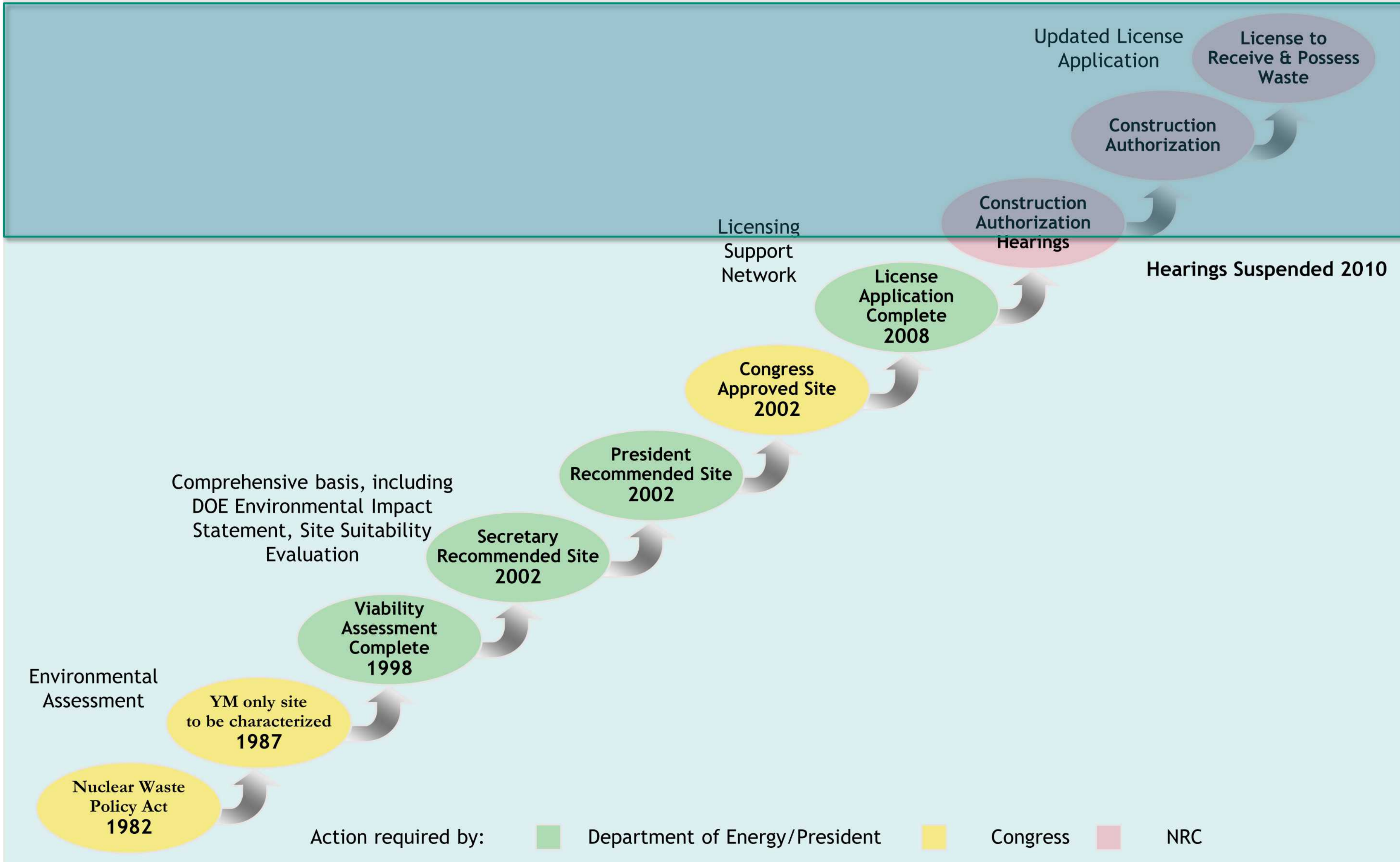
- *The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding*



Energy.gov/pictures

What it may take to License a Repository

Short History of Yucca Mountain



What does a Repository License Application Look Like?

The 2008 Yucca Mountain License Application (LA) included

- 17 volumes; 8,646 pages
- 198 supporting documents (~38,000 pages) submitted with the application

Nuclear Regulatory Commission (NRC) staff issued approximately 673 formal requests for additional information

Approximately 305 contentions admitted for adjudication by the NRC Atomic Licensing and Safety Board

- (nearly all remain unresolved)

NRC Licensing process originally anticipated to take 3-4 years for a decision on construction authorization

The DOE's 1996 Compliance Certification Application to the Environmental Protection Agency (EPA) for the Waste Isolation Pilot Plant (WIPP) was ~72,000 pages, including appendices and supporting references

What is in a License Application?

- **General Information**
  - General Description
  - Proposed Schedules for Construction, Receipt and Emplacement of Waste
  - Physical Protection Plan
  - Material Control and Accounting Program
  - Site Characterization
- **Safety Analysis Report**
  - Repository Safety Before Permanent Closure
  - Repository Safety After Permanent Closure
  - Research and Development Program to Resolve Safety Questions
  - Performance Confirmation Program
  - Management Systems

Repository Safety after Permanent Closure is addressed in 3,456 of the 8,646 pages in the 2008 Yucca Mountain License Application

Postclosure Safety Requirements

For Yucca Mountain, EPA standards and NRC regulations define:

- A requirement for a probabilistic "performance assessment"
- Compliance limits for estimated mean annual dose and groundwater concentrations for
  - Individual protection
  - Individual protection following human intrusion
  - Groundwater protection
- The scope of the total system performance assessment (TSPA) model
  - Criteria for identifying the features, events, and processes (FEPs) that must be considered in the TSPA
  - Characteristics of the "Reasonably Maximally Exposed Individual" (RMEI)
- A requirement for the identification and description of multiple barriers that contribute to waste isolation

Defining the Scope of the Performance Assessment

The EPA defines "Performance Assessment" (40 CFR 197.12; restated by the NRC at 10 CFR 63.2)

'*Performance assessment* means an analysis that:

(1) Identifies the features, events, processes, (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring;

(2) Examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system; and

(3) Estimates the annual committed effective dose equivalent incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence."

Defining the Scope of the Performance Assessment

The EPA defines "Probability" and "Consequence" criteria that determine what must be included in performance assessment (40 CFR 197.36, restated by the NRC at 10 CFR 63.342)

> "The DOE's performance assessments…shall not include consideration of very unlikely features, events, or processes, i.e., those that are estimated to have less than one chance in 100,000,000 per year of occurring"
>
> …
>
> "DOE's performance assessments need not evaluate the impacts resulting from features, events, and processes or sequences of events and processes with a higher chance of occurring if the results of the performance assessments would not be changed significantly in the initial 10,000-year period after disposal."

How Much Can a Performance Assessment Reasonably Include?

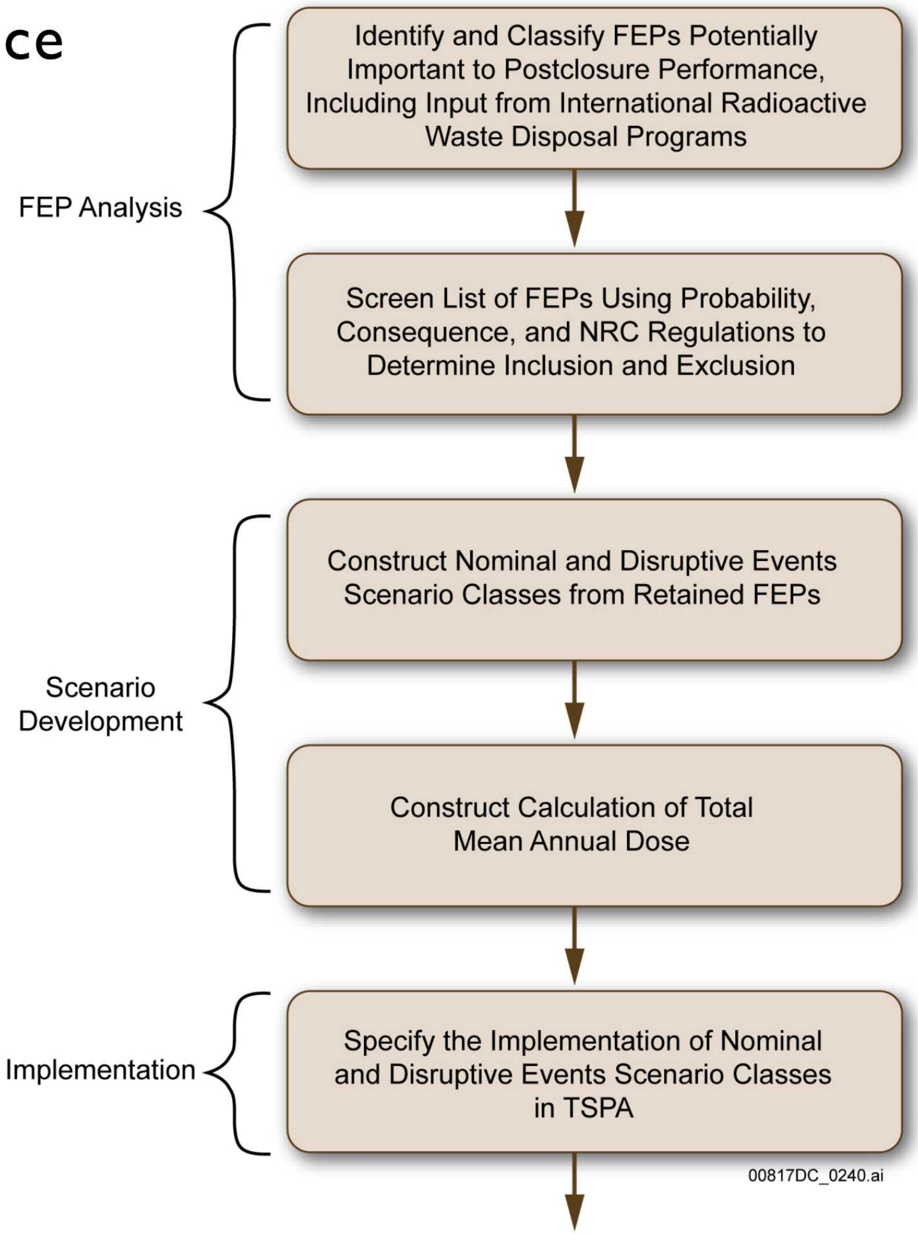
374 FEPs evaluated for the YM LA (SNL 2008a,b)

- 222 excluded from the TSPA
- 152 included in the TSPA
- Full documentation provided with the LA

Four scenario classes defined for TSPA analysis

Formal proof of completeness is not possible for an analysis of the future

Rigorous and iterative review can provide confidence that the chosen scenarios are representative and include the necessary FEPs



TSPA-LA Scenarios

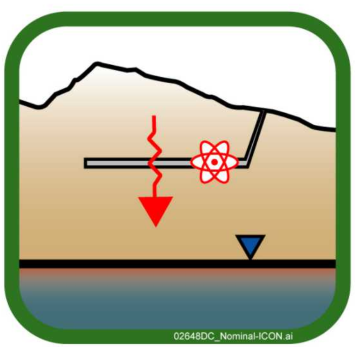
Four scenario classes divided into seven modeling cases

<u>Nominal Scenario Class</u>

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

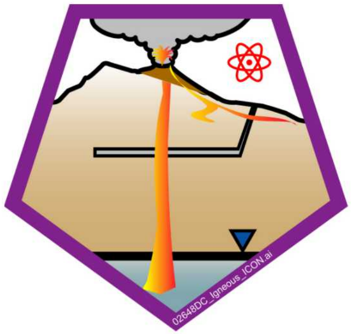
<u>Early Failure Scenario Class</u>

- Waste Package Modeling Case
- Drip Shield Modeling Case



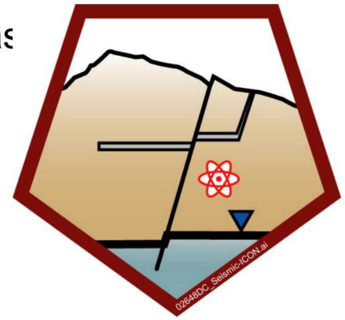
<u>Igneous Scenario Class</u>

- Intrusion Modeling Case
- Eruption Modeling Case



<u>Seismic Scenario Class</u>

- Ground Motion Modeling Case
- Fault Displacement Modeling Cas



Regulatory Basis for Uncertainty Analysis

"The NRC will determine compliance, based upon the arithmetic mean of the projected doses from DOE's performance assessments for the period within 1 million years after disposal" (EPA 40 CFR 197.13(a), restated by the NRC at 10 CFR 63.303)

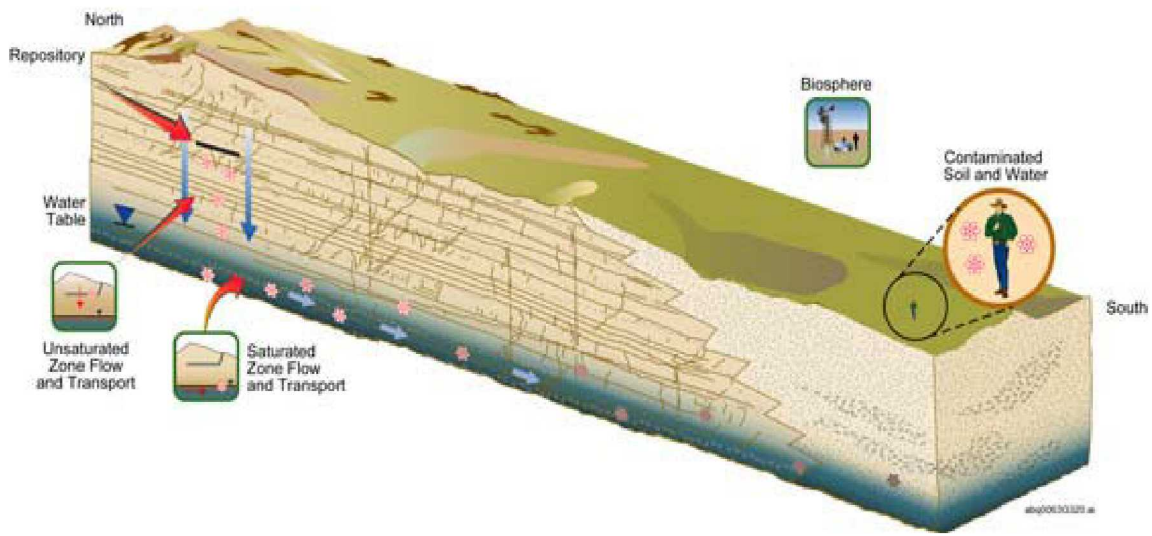
"The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that … " [estimated doses will be below specified limits] (EPA 40 CFR 197.20(a), restated by the NRC at 10 CFR 63.111(a))

"Reasonable expectation means that NRC is satisfied that compliance will be achieved based upon the full record before it. Characteristics of reasonable expectation include that it:

- (a) Requires less than absolute proof because absolute proof is impossible to attain for disposal due to the uncertainty of projecting long-term performance;
- (b) Accounts for the inherently greater uncertainties in making long-term projections of the performance of the Yucca Mountain disposal system;
- (c) Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify to a high degree of confidence; and
- (d) Focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values." (EPA 40 CFR 197.14, restated by the NRC at 10 CFR 63.304)

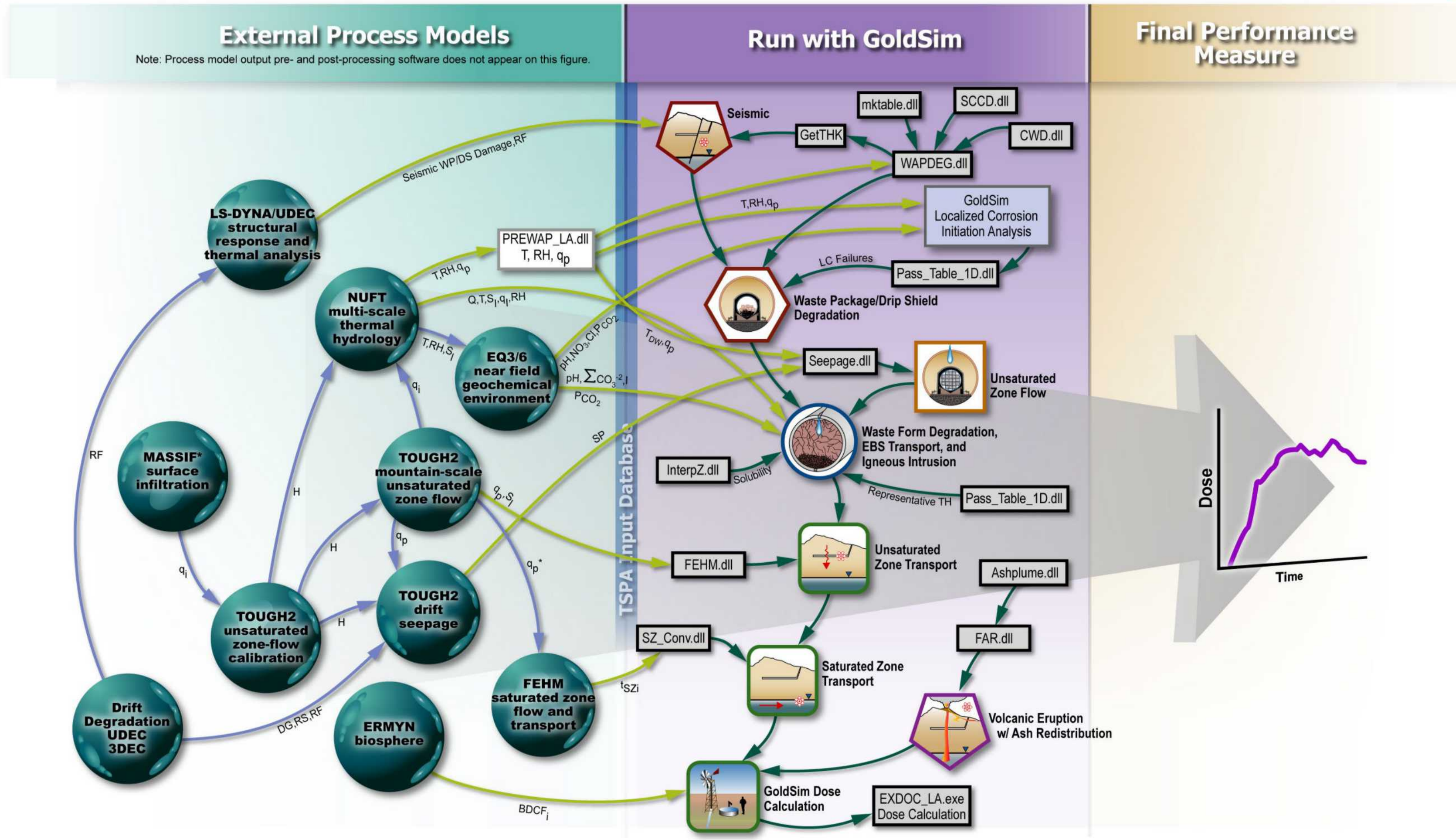
Major Long-Term Processes Active at Yucca Mountain

- Precipitation infiltrates and percolates downward through the unsaturated zone
- Multiple 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
- Seismicity and volcanism may disrupt the system over geologic time

Total System Performance Assessment Architecture



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		
P_{CO_2}	Partial Pressure of CO_2	q_l	Liquid Flux	q_g	Gas Flux		

*Note: q_p derived from INFIL model

Legend

- Response Surface between Process Models
- Response Surface from Process Model to GoldSim
- Connection in GoldSim
- Preprocessor
- TSPA Model DLL

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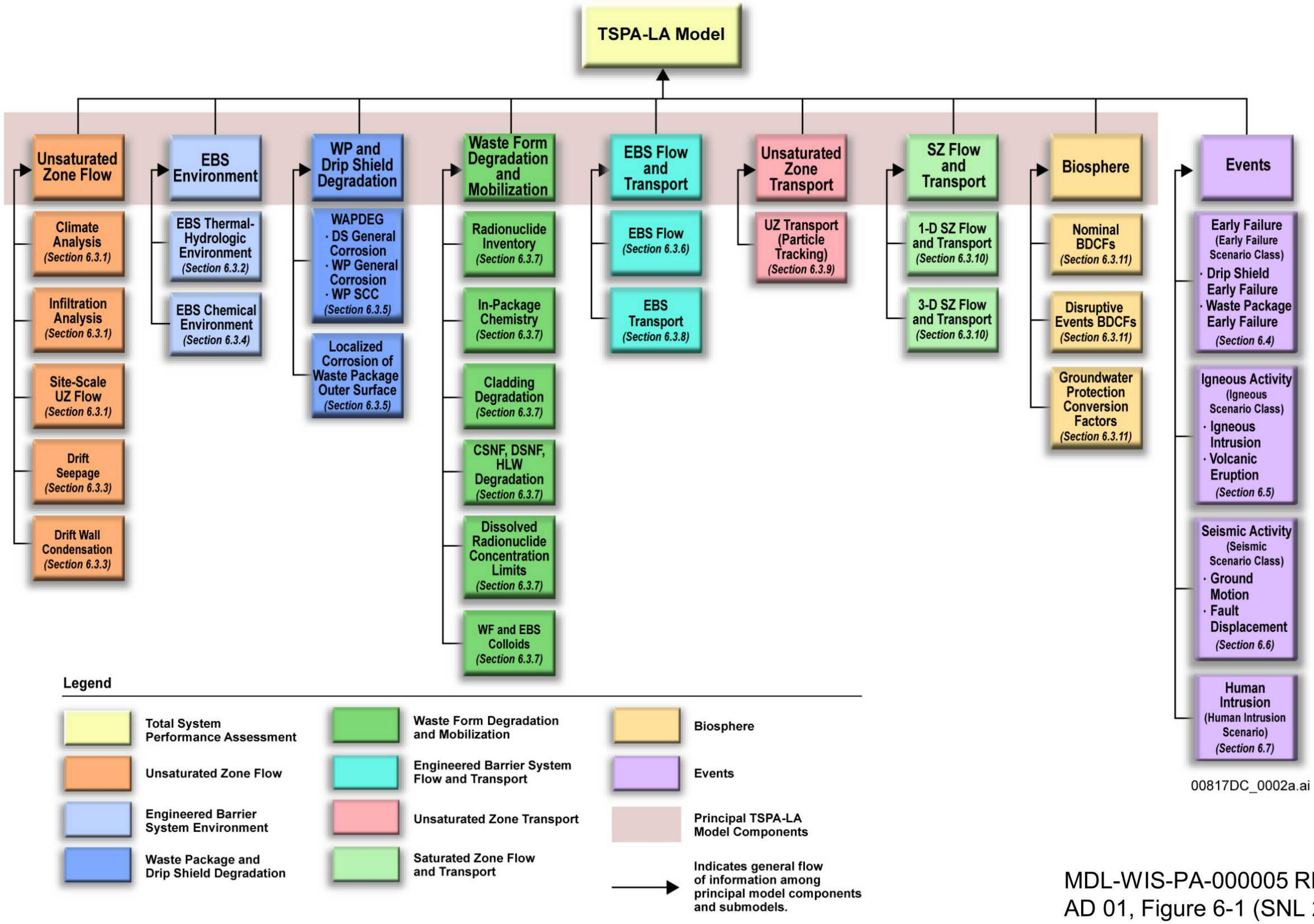
Postclosure Science Supporting the TSPA



MDL-WIS-PA-000005 REV 00 AD 01, Figure 6-1 (SNL 2008c)

Uncertainty in Yucca Mountain TSPA

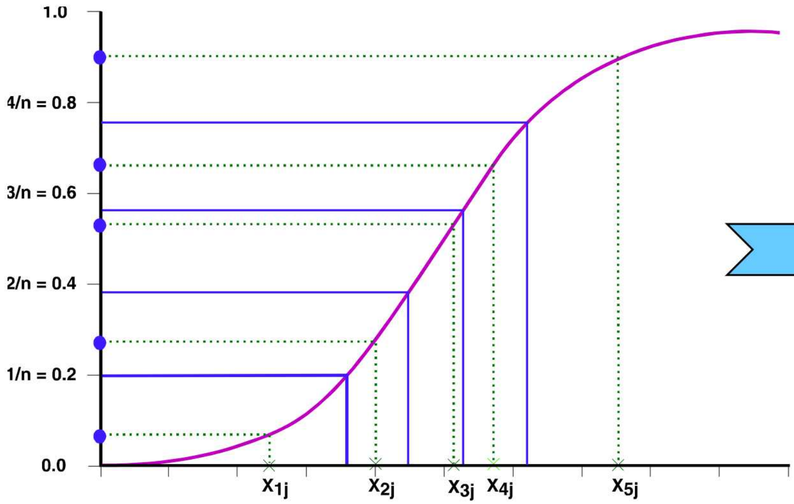
Aleatory Uncertainty
− Inherent randomness in events that could occur in the future
− Alternative descriptors: irreducible, stochastic, intrinsic, type A
− Examples:
➢ *Time and size of an igneous event*
➢ *Time and size of a seismic event*

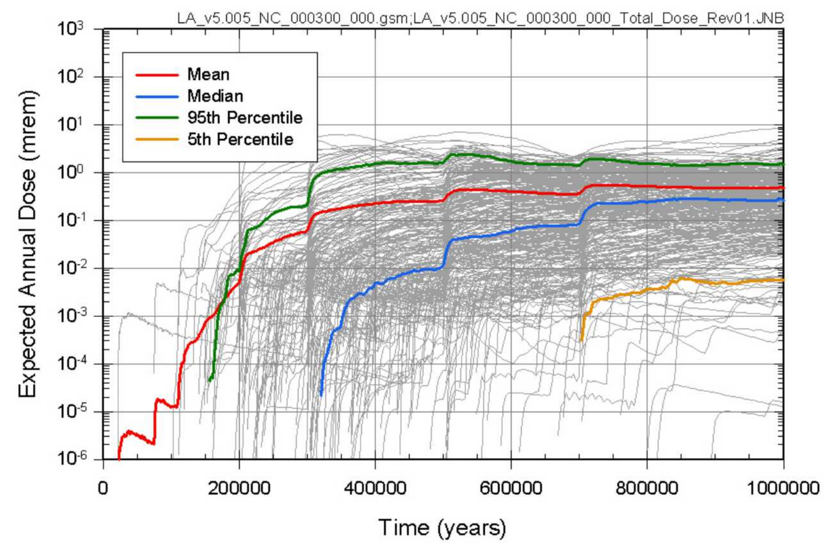
Epistemic uncertainty
− Lack of knowledge about appropriate value to use for a quantity assumed to have a fixed value
− Alternative descriptors: reducible, subjective, state of knowledge, type B
− Examples:
➢ *Spatially averaged permeabilities, porosities, sorption coefficients, …*
➢ *Rates defining Poisson processes*

Uncertainty in YM TSPA (cont.)

Epistemic uncertainty incorporated through Latin hypercube sampling of cumulative distribution functions and Monte Carlo simulation with multiple realizations

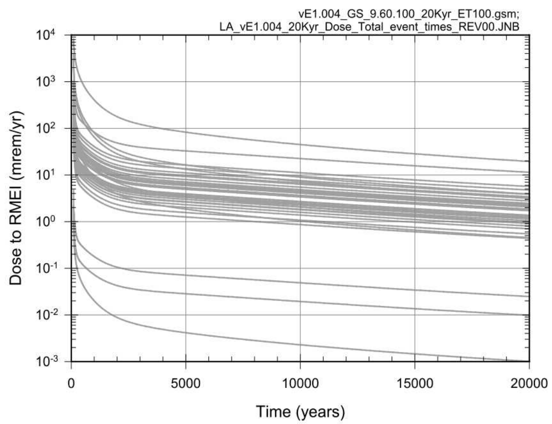
(approx. 400 uncertain epistemic parameters in TSPA-LA)



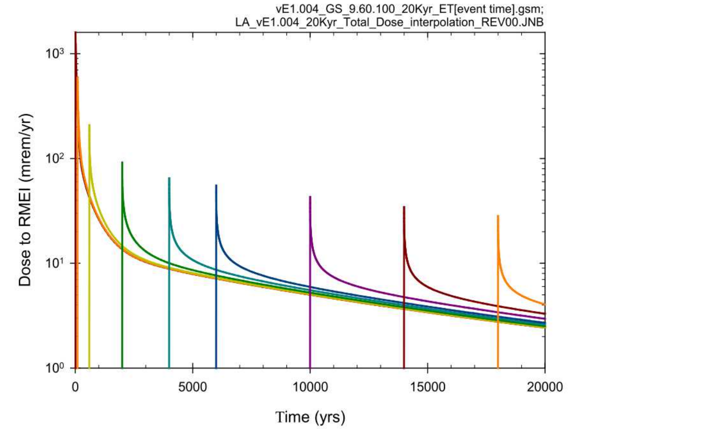


Aleatory uncertainty incorporated through the design of the analysis

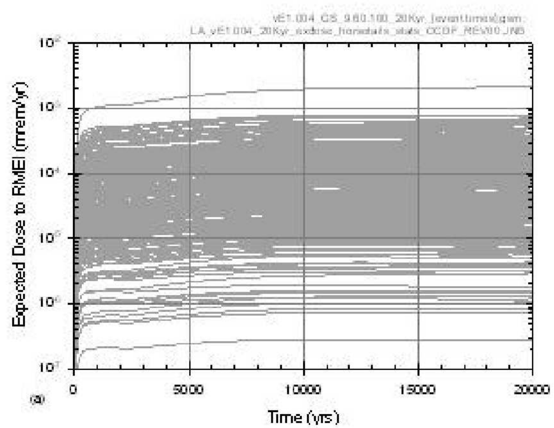
Example: Calculation of Expected Eruptive Dose



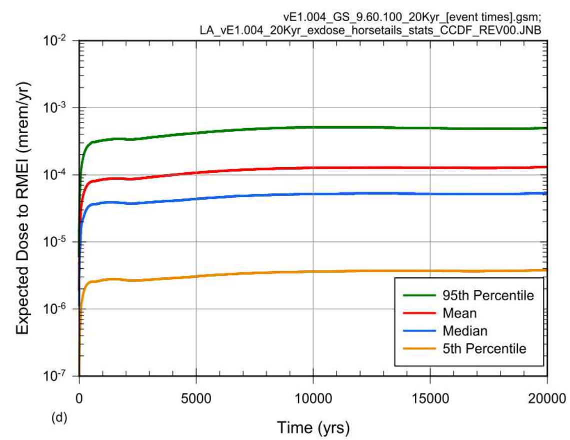
Eruptive dose: 40 realizations of aleatory uncertainty conditional on a single eruption of 1 waste package at time zero



Eruptive dose averaged over aleatory uncertainty associated with a single eruption of 1 waste package, eruptions at multiple times



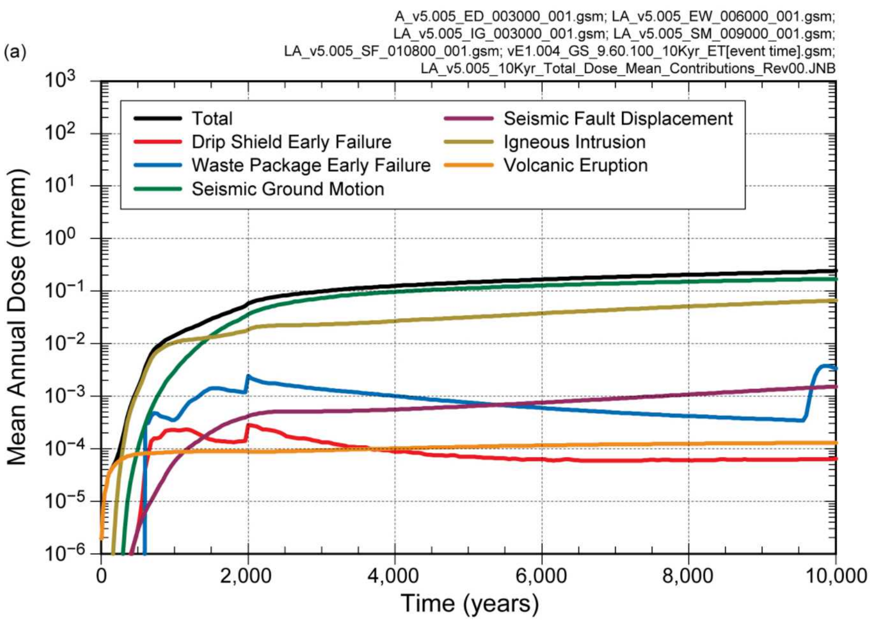
Expected eruptive dose; 300 realizations, each showing expected dose from a single sampling of epistemic uncertainty with events at all times



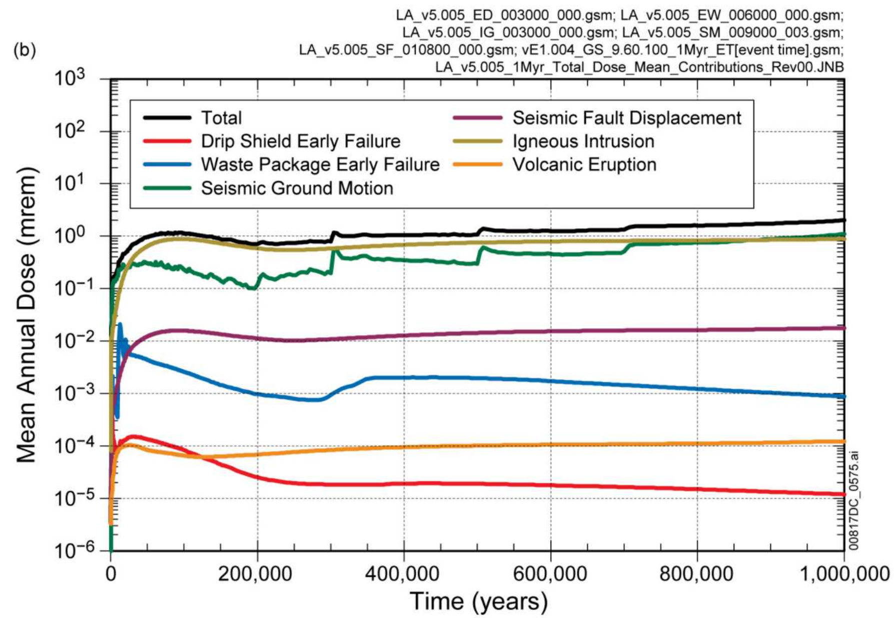
Summary curves showing overall mean dose from eruption

MDL-WIS-PA-000005 Rev 00, Figures J7.3-1, 2,&4 (SNL 2008c)

Modeling Cases Contributing to Total Mean Annual Dose



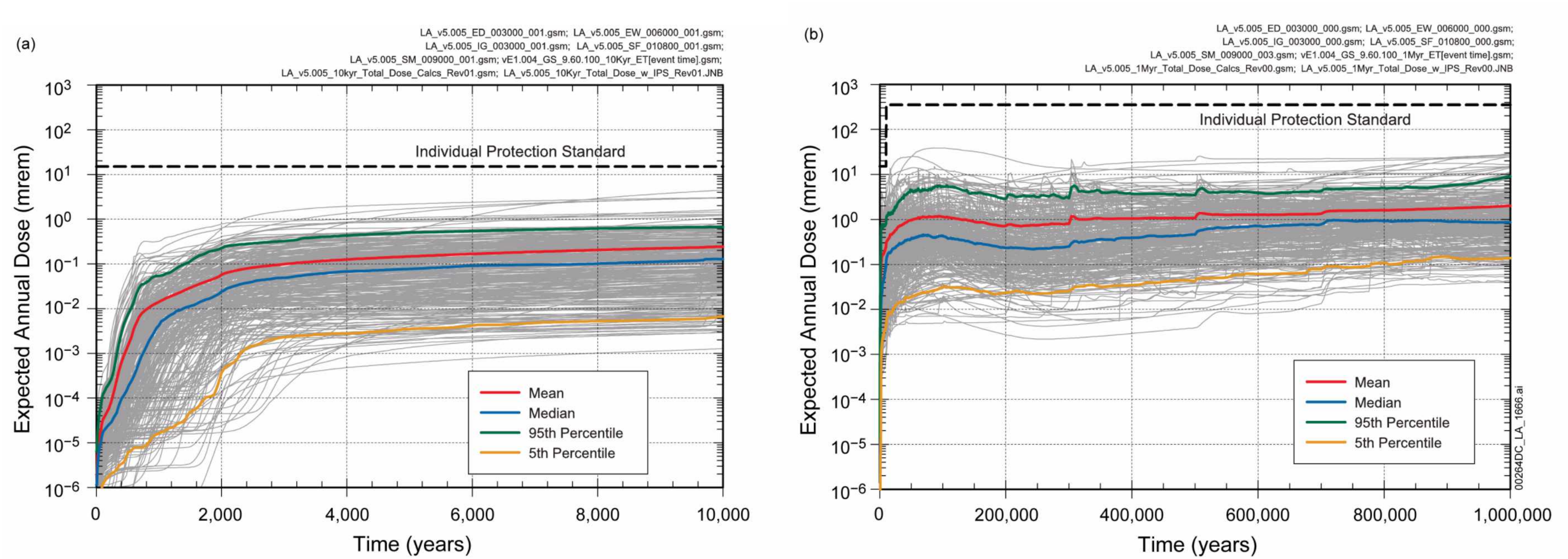
10,000 years



1,000,000 years

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-3[a] (SNL 2008c)

Long-Term Performance of Yucca Mountain



DOE/RW-0573 Rev 1 Figure 2.4-10
(DOE 2008)

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)

Closing thoughts regarding Repository Licensing

40 CFR 191 (EPA 1985)

"Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with §191.13 (a) will be achieved." (40 CFR 191.13(b)) *[emphasis added]*

"Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well." (40 CFR 191 Appendix B (now Appendix C))

There is much more to licensing a repository than quantitative postclosure safety assessment

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Key Websites for Yucca Mountain and WIPP: http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html; http://www.wipp.energy.gov/library/caolib.htm