U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Natural Analogs for the YMP

Presented to:
Nuclear Waste Technical Review Board (NWTRB)

Presented by:
Ardyth Simmons
Lawrence Berkeley National Laboratory

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YUCCA
MOUNTAIN
PROJECT

Outline

- **Programmatic role of natural analogs (VA, SR, LA)**
- **FY99 natural analog studies**
- **Current natural analog work to address uncertainties**
- **Summary**

Natural Analog Definition

- **Natural analogs refer to natural or anthropogenic (human-produced) systems in which processes similar to those that would occur in a nuclear waste repository are thought to have occurred over long time periods and large spatial scales usually not accessible to laboratory experiments**
- **Analogs must be carefully selected to exclude those for which initial conditions are poorly known and where important data, such as the source term, are poorly constrained**

Program Use of Natural Analogs

- **TSPA-VA mentioned natural analogs (NAs) as a means of building confidence in certain process models, but made no specific recommendations**
- **NAs are called out as the fourth element of the post-closure safety case of the SR-LA**
- **NRC anticipates the use of NAs as a means of confidence-building in modeling processes**

Role of Factors in Postclosure Safety Case (January 2000)

Key Attributes of the Repository System	Principal Factors in the Viability Assessment	Factors for the Enhanced Repository System
Limited Water Contacting Waste Package	Precipitation and Infiltration into the Mountain	Climate
		Infiltration
	Percolation to Depth	Unsaturated Zone (UZ) Flow above Repository
	Seepage into Drifts	Seepage into Drifts *
	Effects of Heat and Excavation on Flow	Coupled Processes—Effects on UZ Flow
		Coupled Processes—Effects on Seepage
	N/A	Environments on Drip Shield
	N/A	Performance of Drip Shield *
Long Waste Package Lifetime	Dripping onto the Waste Package	Environments on Waste Package
	Humidity and Temperature at the Waste Package	
	Chemistry on the Waste Package	
	Integrity of Outer Waste Package Barrier	Performance of Waste Package Barriers *
	Integrity of Inner Waste Package Barrier	

* Principal factors of the postclosure safety case

Note: Shaded factors may be studied benificially through natural analogs.

Role of Factors in Postclosure Safety Case (January 2000)

Low Rate of Radionuclide Release from the EBS	Seepage into Waste Package	Environments within Waste Package
	Integrity of Commercial Spent Nuclear Fuel (CSNF) Cladding	Commercial Spent Nuclear Fuel (CSNF) Waste Form Performance
	Dissolution of UO_2 and Glass Waste Forms	DOE-Owned Spent Nuclear Fuel (DSNF), Navy Fuel, and Plutonium Disposition Waste Form Performance
		Defense High-Level Waste (DHLW) Waste Form Performance
	Solubility of Neptunium-237	Solubility Limits of Dissolved Radionuclides *
	Formation of Radionuclide Bearing Colloids	Colloid Associated Radionuclide Concentrations
	Transport within and out of the Waste Package	In-Package Radionuclide Transport
	EBS Radionuclide Migration—Transport Through Invert	Transport through Invert
Delay and Dilution of Radionuclide Concentrations During Transport Away from the EBS	Transport through Unsaturated Zone (UZ)	Advective Pathways in the UZ
		Retardation of Radionuclide Migration in the UZ*
		Colloid Facilitated Transport in the UZ
		Coupled Processes—Effects on UZ Transport
	Transport in the Saturated Zone (SZ)	Advective Pathways in the Saturated Zone (SZ)
		Retardation of Radionuclide Migration in the SZ*
		Colloid Facilitated Transport in the SZ
	Dilution from Pumping	Dilution of Radionuclide Concentrations during Migration*
	Biosphere Transport and Uptake	Biosphere Transport and Uptake

* Principal factors of the postclosure safety case

FY99 Analog Studies

- Confidence building in modeling natural and engineered barrier system processes for performance assessment
- Confidence in design
- Verifying that codes represent processes correctly
- Testing databases; e.g., thermal chemical and kinetic rate data
- Public information and education

FY99 Analog Studies

(Continued)

- Synthesis of relevant analog studies from literature and their applicability to YMP: foundation for future work
- Fracture flow analog at Box Canyon, Idaho: confidence-building in UZ flow and transport model
- Dispersion in a tritium plume at Hanford: confidence-building in SZ flow and transport model
- Migration of U-bearing minerals at Peña Blanca, Mexico: confidence-building in UZ flow and transport model, spent fuel dissolution model
- Information gathering relative to Krasnoyarsk, Russia as a YM coupled process analog
- Products: Analysis/Model Report for UZ, Synthesis Report Chapter in Site Description

NA Synthesis Report for the SD

- **Information from past studies of NAs that support SR safety strategy**
- **Document incorporation of NAs into site characterization, model validation, and performance assessment**
- **Recommendations for use of specific NAs for LA and performance confirmation**

Anthropogenic Analog Studies

- **Utilize experience from modeling flow and transport at DOE sites (where flow has occurred along preferential pathways) to build confidence in approaches to modeling YM flow and transport**
- **Use existing data from selected sites at Hanford (tritium plume in saturated zone) and near Idaho National Engineering and Environmental Laboratory (INEEL) (preferential flow in unsaturated, fractured basalt) using YMP modeling approaches and compare results**
- **Explain occurrence of fast radionuclide transport at DOE sites by using YM modeling approaches**

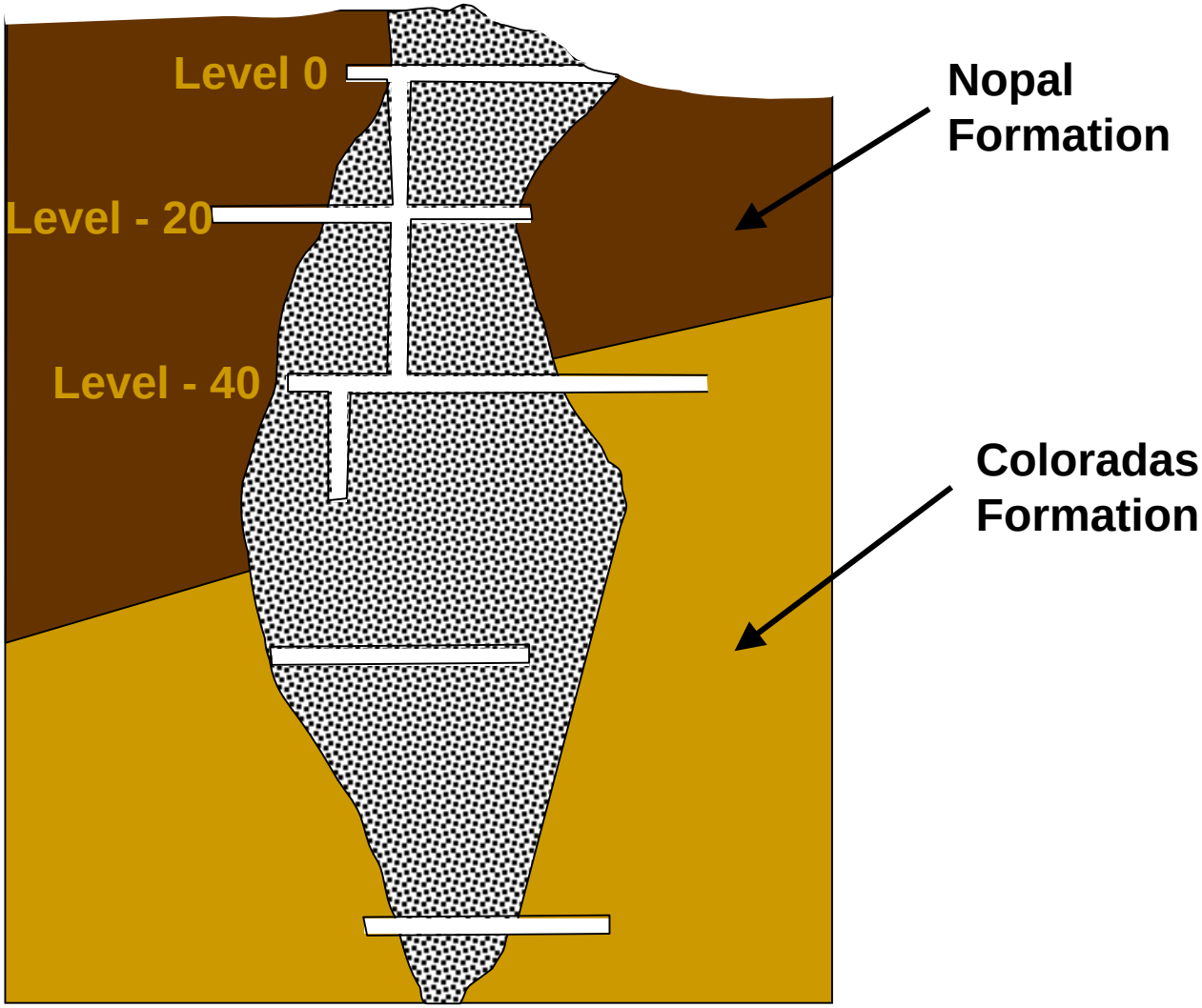
Characteristics of Ideal Transport Analog

- Known source term
- Similar suite of radionuclides
- Well-characterized data set
- Similar geologic conditions
- Observable long-term conditions

Peña Blanca Uranium District

Location:	**Northern Mexico, 50 km north of Ciudad Chihuahua**
Physiography:	**Uplifted block in the Basin and Range Province**
Climate:	**Semi-arid; average rainfall 24 cm/year**
Geology:	**Faulted silicic tuffs 35 to 44 million years old overlie Cretaceous sedimentary rocks**
Hydrology:	**Regional aquifer approximately 200m below the surface; shallow, discontinuous, topographically controlled, perched water table**
Mineralization:	**Numerous uranium deposits of uranyl silicates associated with zones of faulting and hydrothermal alteration**

Nopal I Uranium Deposit



Radionuclide Flow and Transport at Peña Blanca, Mexico

- **Although Nopal I uranium deposit lies in oxidized unsaturated volcanic tuffs, vertical migration of uranium appears to have been minimal**
- **FY- 99 scoping study to determine feasibility of collecting data on vertical transport of uranium**
- **Investigate natural barrier conditions that provide isolation. Assimilate existing data and compare existing data sets; perform scoping calculations; conduct limited outcrop studies; investigate feasibility of future drilling**

Summary of FY99 Peña Blanca Work

- **Geochemical system at Nopal I restricts actinide mobility in an unsaturated environment**
- **U-Th age data, supported by $^{231}Pa/^{235}U$ activity ratios, indicate that the primary transport of U to fractures occurred 300,000 years ago. This should also apply to transuranic and rare earth elements**
- **U-Th ages for opal and caliche suggest enhanced fluxes and local U mobility at 50,000 to 90,000 years ago**
- **Redistribution of radium and minor ^{234}U occurred about 5000 years ago. This should be analogous to Cs and Sr**

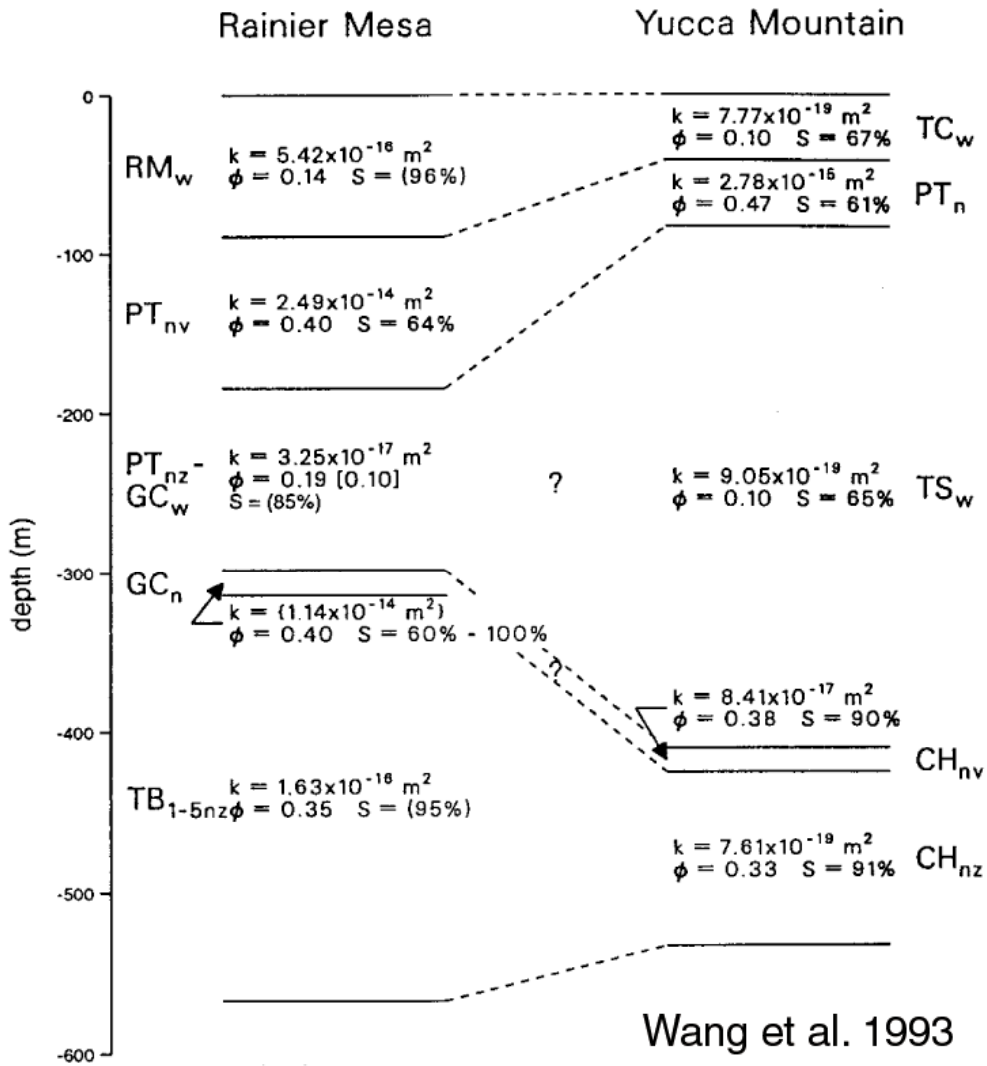
Conclusions from NA Synthesis Report

- **Sequence of uranium alteration paragenesis at Peña Blanca is a very good analog to alteration of uranium oxide spent fuel**
- **Colloid filtration is effective at several analog sites**
- **Advective transport along fractures is a more significant transport mechanism than matrix diffusion at all analog sites investigated**
- **Analogs suggest that fracture sorption enhances radionuclide retardation significantly**

Selected Recommendations from Synthesis Report

- **Rainier Mesa - apply to drift seepage models**
- **Utilize data from fossil hydrothermal systems**
- **Use identified data sets from analog sites to make model predictions (e.g., Alligator Rivers, Oklo)**
- **Use analogs to address issues of public confidence**

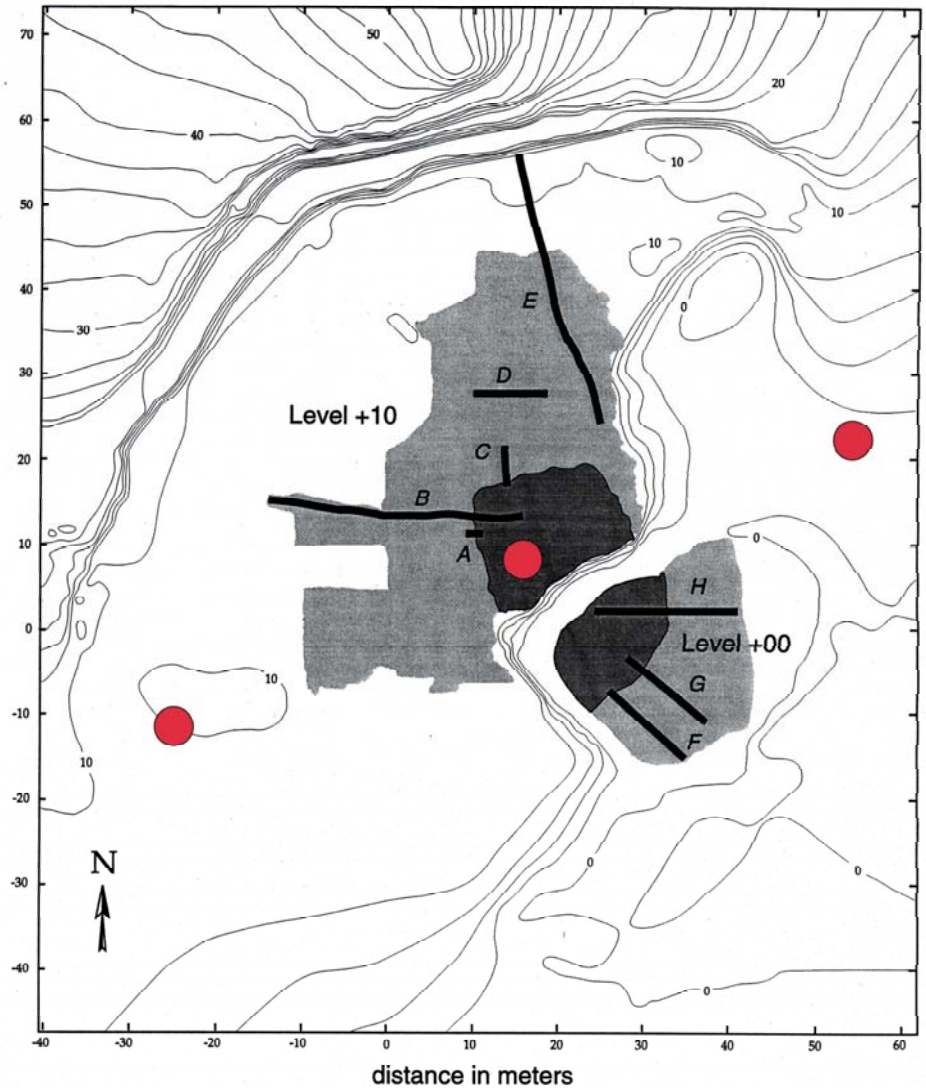
Hydrogeologic Stratigraphic Sections of Rainier Mesa and Yucca Mountain



FY00 Analog Studies

- **Continuation of work at Peña Blanca**
  - **analyses of core and water samples**
  - **preliminary system level analysis**
- **UZ/SZ transport modeling study at INEEL**
- **Modeling of processes at selected active geothermal sites**
- **Field and modeling study of Paiute Ridge intrusive bodies**
- **Potential process modeling with Krasnoyarsk (K-26) data**

Location of Proposed Boreholes at Peña Blanca



K-26: Analog to YM Coupled Processes?

- **Fifty years of data from underground facility, heated by radiation**
- **Coupled thermohydrologic-mechanical-chemical processes**
- **Stability of cement**
- **Radionuclide transport at above-ambient temperatures**
- **Preferential fracture flow and transport**
- **Permeability changes due to thermal processes**
- **Mineral alteration**

Russian Collaboration (K-26)

- **Work with Russians at K-26 to identify potential analog information for YMP**
- **Use selected K-26 data to test YMP coupled process models**
- **Investigate potential use of deep injection data at Krasnoyarsk for confidence building in near-field radionuclide transport models**

Geothermal Analog Needs

- **Relate processes ongoing in geothermal fields to the set of conditions anticipated at a potential YM repository; essential to apply these conditions to YM models to build confidence in UZ mountain-scale TH model**
- **Select data from geothermal fields under relevant conditions (T, P, pH, etc.) for testing thermochemical and kinetic databases**
- **Examine data from fossil hydrothermal systems (e.g., Paiute Ridge) relative to potential mineral alteration and permeability changes at YM**

Coupled Processes in Geothermal Systems

Yucca Mountain Issue	Geothermal Analog	Potential Sites	Possible Approach
Multiphase Flow (liquid, vapor, gas)	Multiphase Flow (liquid, vapor, gas)	All	Numerical Modeling, Conduct and Review Geothermal Post Audits
Hydrologic Properties	Hydrologic Properties	Kamojang (Indonesia), Tianjin (China), Wairakei (New Zealand), Oguni (Japan), Sumikawa (Japan)	Numerical Modeling
Preferential Flow	Preferential Flow	Wairakei (New Zealand), The Geysers (CA), Dixie Valley (NV), East Mesa (CA), Cerro Prieto (Mexico)	Numerical Stochastic Modeling, Evaluate Geothermal Tracer Study Results
Fracture Network Permeability	Fracture Network Permeability	All Modeled Fractured Sites, e.g. Cerro Prieto (Mexico), Krafla (Iceland), Matsukawa (Japan), Sumikawa (Japan), Olkaria (Kenya), Krafla (Iceland), Wairakei (New Zealand), Geysers (CA), Kamojang (Indonesia), Larderello (Italy)	Reservoir Model Calibrations Used
Heat Pipes, Boiling and Condensation	Heat Pipes, Boiling and Condensation	The Geysers (CA), Kamojang (Indonesia), Matsukawa (Japan), Larderello (Italy)	Numerical Modeling to Extend Measurements

Coupled Processes in Geothermal Systems

(Continued)

Mineral Precipitation and Dissolution	Mineral Precipitation and Dissolution	Larderello (Italy), Fenton Hill (NM), Dixie Valley (NV), Wairakei (New Zealand), Broadlands (New Zealand), Long Valley (CA)	Laboratory Experiments, Analog Site Investigation, Numerical Modeling
Self-Sealing	Caprocks	The Geysers (CA), Kamojang (Indonesia), Matsukawa (Japan), Larderello (Italy), Cerro Prieto (Mexico), Reykjanes (Iceland)	Core Sample Evaluation, Water Chemistry Evaluation, Numerical Modeling
Mineral Alteration	Mineral Alteration	Wairakei (New Zealand), Broadlands (New Zealand), Fenton Hill (NM), Dixie Valley (NV)	Core Sample Evaluation, Numerical Modeling
Thermo-Hydro-Mechanical Effects	Subsidence, Flow Changes	Wairakei (New Zealand), Bulalo (Philippines), Krafla (Iceland)	Numerical Modeling
Similarity Factor for comparison to Yucca Mountain: a - similar water chemistry, b - similar geology, c - similar alteration mineralogy		Larderello (Italy)-b, possibly c; Yellowstone (WY)-a,b,c; Fenton Hill (NM)-b; Dixie Valley (NV)-c?; Wairakei (New Zealand)-a,b,c; Broadlands (New Zealand)-a,b,c; Long Valley (CA)-a,b, possibly c.	

Table of Process Models and Natural analog

(Note: Different gray shades for FY99 and FY00 .)

Factors Important to Performance	Process Model	Analog
	Unsaturated Zone Flow & Transport	
1. Climate	Range of climate conditions	Paleoclimate studies in Great Basin (already in TSPA)
2. Infiltration	Range of infiltration values	Negev Desert, Mitchell Caverns
4. Seepage into drifts	Drift seepage model; effect of discrete fractures	Rainier Mesa[1] for wetter conditions; Peña Blanca; INEEL
5. Coupled processes – effects on UZ flow	UZ flow and transport, THC	Magma intrusion (Papoose Lake Sill)
6. Coupled processes – effects on seepage	(1) Rockfall and other thermomechanical effects; (2) dryout, permeability changes	(1) Mined openings; (2) Magma intrusion (Papoose Lake Sill); geothermal fields
7. Moisture, temperature and chemistry on drip shield	Mineral reaction rates	Geothermal fields (e.g., East Mesa, Cerro Prieto), YM as self-analog
9. Moisture, temperature, and chemistry on waste package	Mineral reaction rates	Geothermal fields, YM as self-analog
18. EBS radionuclide migration – transport through invert	Mineral reaction rates, degradation of invert and other EBS materials	Geothermal fields, YM as self-analog
19. UZ flow and transport – advective pathways	(1) UZ flow; effects of transient flow; (2) effect of water table rise	(1) Peña Blanca; Alligator Rivers; INEEL; Apache Leap; Needle's Eye, South Terras; (2) records associated with historical earthquakes in NV
20. UZ flow and transport – sorption and matrix diffusion	UZ flow and transport	Peña Blanca
21. UZ flow and transport – colloid-facilitated transport	UZ flow and transport	INEEL
22. Coupled processes – effects on UZ transport	UZ flow and transport, THC	Oman (alkaline plume)
	Waste Package Degradation	
10. Performance of waste package barriers	Degradation of steel alloys and cladding	Meteorites for Ni-base alloy; eskolaite for Cr_2O_3; Rare earth phosphates as analogue to $GdPO_4$ (neutron absorber); Santorini and Asoka pillar (qualitatively)
	Microbial-induced corrosion	
11. Moisture, temperature, and chemistry within waste package		

Table of Process Models and Natural analog

(Continued)

	Waste Form Degradation	
12. CSNF waste form performance	Secondary mineral formation	Hydrothermal uranium deposits, Oklo[1], Peña Blanca[1]
13. DSNF, Navy fuel, Pu disposition waste form performance	Secondary mineral formation	?
14. HLW glass waste form performance	Stability of glasses	Natural glasses (volcanic), manufactured U-bearing glasses
15. Dissolved radionuclide concentration limits	Solubility of waste form	Hydrothermal uranium deposits
16. Colloid-associated radionuclide concentrations	Colloids in spent fuel, glass, and Pu fuel	
17. In-package radionuclide transport	Radiolysis, sequestration in secondary minerals	Oklo, Peña Blanca
	SZ Flow and Transport	
23. SZ flow and transport – advective pathways	Transverse and longitudinal dispersion	Contaminant plumes at DOE and EPA sites (e.g., Hanford)
24. SZ flow and transport – sorption and matrix diffusion	Sorption coefficient in alluvium	NTS
25. SZ flow and transport – colloid-facilitated transport	Colloidal transport in SZ	NTS, INEEL (?), El Berrocal, Steenskampskraal
	Biosphere	
27. Biosphere transport and uptake	Plant uptake of radionuclides	Poços de Caldas, Peña Blanca
Disturbed Case Factor	**Process Model**	**Analog**
	Volcanism	?NV-CA-AZ eruptive histories of similar basalt fields
	Seismicity	? NV-CA historic earthquakes
	Criticality	Oklo
	Human Intrusion	None
EBS Design Enhancements	**Process Model**	**Analog**
Performance of backfill		
Performance of cements		Maqarin; Krasnoyarsk; New Zealand; Roman concretes
Performance of gettering (sorptive materials in backfill)		Cigar Lake; Dunarobba Forest; Loch Lomond

[1]Strongly recommended by PA

Summary

- **NAs have the potential to increase understanding of some processes that are principal factors in the SR postclosure safety case**
- **NAs have the potential to increase confidence in performance of "other" factors in the SR postclosure safety case**
- **Further work is needed to identify analogs that would increase confidence in waste package materials (e.g., Alloy 22, Ti drip shields)**
- **The illustrative function of NAs in increasing public confidence should not be overlooked**