Sandia National Laboratories

SAND2019-4037C

Re-evaluation of U.S. DOE R&D Efforts for Generic Deep Geologic Repositories – Roadmap Update

Clean. Reliable. Nuclear.

PRESENTED BY

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IHLRWM 2019
Knoxville, TN, USA
April 16, 2019

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SAND2019-XXXXC

Acknowledgements

- <u>Co-authors</u>: **Paul Mariner, Ralph Rogers, Dave Dobson, Bob MacKinnon, Jeralyn Prouty, Laura Connolly**
- **<u>Workshop session chairs and rapporteurs</u>, as well as the <u>Technical Leads</u> for the SFWST Campaign work packages:**

  Dave Dobson, Argillite Session Chair;
  Carlos Jove-Colon, Argillite Session Rapporteur and Argillite Technical Lead;
  Paul Mariner, Crystalline Session Chair;
  Emily Stein, Crystalline Session Rapporteur;
  Yifeng Wang, Crystalline Technical Lead;
  Mark Rigali, Salt Session Chair;
  Kris Kuhlman, Salt Session Co-Rapporteur and Salt Technical Lead;
  Melissa Mills, Salt Session Co-Rapporteur;
  Dave Sassani, EBS Session Chair;
  Ed Matteo, EBS Session Rapporteur and EBS Technical Lead;
  Jens Birkholzer, International Session Chair and International Technical Lead;
  Frank Perry, International Session Rapporteur;
  Ernie Hardin, DPC Session Chair and DPC Technical Lead; and
  Laura Price, DPC Session Rapporteur.
- **Many SFWST and IWM Campaign experts, national lab staff, and DOE staff who took the time to participate in this Roadmap Update Workshop**
- **National Technical Director of the SFWST Campaign, Peter Swift**
- **DOE Federal Manager, Tim Gunter**
- **Mark Tynan, formerly with DOE, now retired, the "motivator"**

Roadmap Update Goals

Consensus of Project experts regarding:

1. **What *<u>has been accomplished</u>* on generic repository R&D in the U.S.**

   ← Work completed since the 2012 UFD R&D Roadmap

2. **What still *<u>needs to be accomplished</u>* on generic repository R&D**

   → updated 2019 R&D Roadmap or Plan

→ **<u>Current Status</u>: snapshot of state-of-the-art in 2019**

2012 UFD R&D Roadmap

- To help prioritize generic R&D for a deep geologic repository in one of three potential host-rock environments: argillite, crystalline, and bedded salt – deep borehole also considered
- Three expert decision analysis workshops conducted
- Generic R&D to be prioritized in the workshops was *quantized* as a set of ~ 354 ***R&D Issues*** :
  - → simply a *standard FEPs* list* used on repository programs worldwide (tailored to the U.S. program)
  - → Three basic metrics used for prioritization:
    1. Importance to the safety case (safety assessment, design/construction/operations, and confidence building)
    2. Current State-of-the-Art knowledge about the Issue
    3. Importance of Issue at various "decision points" in the repository timeline

UFD FEP Number	FEP Description	Associated Processes
2.0.00.00	2. DISPOSAL SYSTEM FACTORS	
2.1.00.00	1. WASTES AND ENGINEERED FEATURES	
2.1.03.00	1.03. WASTE CONTAINER	
2.1.03.02	**General Corrosion of Waste Packages**	- Dry-air oxidation in anoxic condition - Humid-air corrosion in anoxic condition - Aqueous phase corrosion in anoxic condition - Passive film formation and stability - Chemistry of brine contacting WP - Salt deliquescence
2.1.03.03	**Stress Corrosion Cracking (SCC) of Waste Packages**	- Residual stress distribution in WP from fabrication - Stress development and distribution in contact with salt undergoing creep deformation - Crack initiation, growth and propagation
2.1.03.04	**Localized Corrosion of Waste Packages**	- Pitting - Crevice corrosion
2.1.03.05	**Hydride Cracking of Waste Packages**	- Hydrogen diffusion through metal matrix - Crack initiation and growth in metal hydride phases
2.1.09.00	1.09. CHEMICAL PROCESSES - CHEMISTRY	
2.1.09.05	**Chemical Interaction of Water with Corrosion Products - In Waste Packages**	- Corrosion product formation and composition (waste form, waste package internals, waste package) - Evolution of water chemistry in waste packages, in backfill, and in tunnels
2.1.09.11	**Electrochemical Effects in EBS**	- Enhanced metal corrosion
2.1.11.00	1.11. THERMAL PROCESSES	
2.1.11.13	**Thermal Effects on Chemistry and Microbial Activity in EBS**	

Potential R&D "Issues" used in 2012 Roadmap (based on 208 original FEPs)

* Features, Events, and Processes

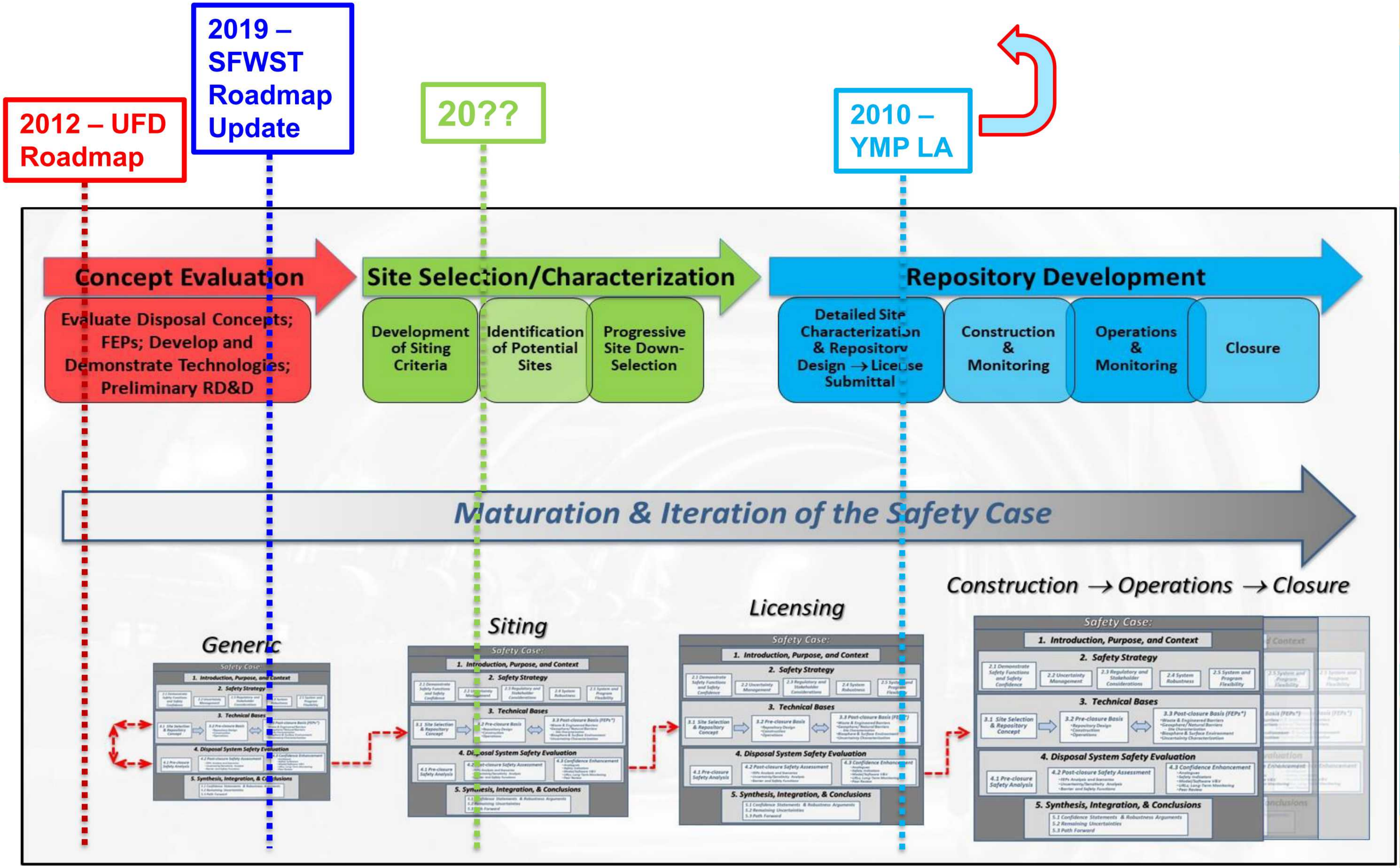
Example Output – 2012 Roadmap

Process (Issue)			Importance of Issue/Process to Safety Case				State of the Art Relative to Issue/Process	
UFD FEP ID	UFD FEP Title	Discussion	Performance (Safety Analysis)	Design, Construction, Operations	Overall Confidence	Discussion *	Status	Discussion
2.1.03.00	1.03. WASTE CONTAINER							
2.1.03.02	General Corrosion of Waste Packages	Also media specific Specific to EBS materials and concept design Applies to waste container and any other "isolation" barriers that could be included in a	High	Medium	High	May be of high importance for performance in certain environments. In addition, the waste container is a key part of a multiple-barrier disposal system concept and must be included in the safety analysis. More Important from a gas generation standpoint in salt and perhaps clay. More Important to granite from a hyrdologic barrier capability	Fundamental Gaps in Method, Fundamental Data Needs	Considerable studies in the corrosion of a variety of metallic materials both in the U.S. and abroad that can be leveraged. Some knowledge gaps exist regarding degradation modes for various alloys under various conditions. Little/no information available regarding new/novel materials Uncertainty in extrapolating short-term laboratory tests to long-time

UFD FEP ID No., Title, and Media	Overall Priority Score
2.2.01.01 - Evolution of EDZ - Clay/Shale	8.00
2.2.08.01 - Flow Through the Host Rock - Salt	7.73
2.2.08.02 - Flow Through the Other Geologic Units - Confining units - Aquifers - Salt	7.73
2.2.08.06 - Flow Through EDZ - Salt	7.73
2.2.08.04 - Effects of Repository Excavation on Flow Through the Host Rock - Salt	7.10
2.2.08.07 - Mineralogic Dehydration - Salt	6.49
2.2.01.01 - Evolution of EDZ - Deep Boreholes	6.13
2.2.09.01 - Chemical Characteristics of Groundwater in Host Rock - Deep Boreholes	5.86
2.2.09.02 - Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units	5.86

* Eight columns deleted regarding "importance to decision points"

Phases of a Repository Project
(and maturation of safety case)



Prioritization Needed in a Multi-Decade R&D Program

- **Constraints on R&D activities:**

  1. **Time**
  2. **Resources**

  } ⇒ **prioritization of R&D is required**

- **General R&D Prioritization Methodology:**

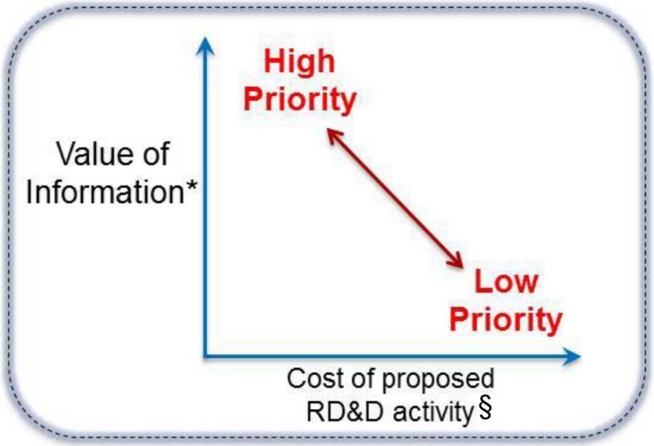
  → **Qualitative with a quantitative (or systematic) basis:**

  - Qualitative: Resources (personnel and funds) apportioned to broad work-package areas based on expert/management judgment, e.g., a work breakdown structure (WBS)
  - Qualitative – Quantitative: Resources further divided based on importance of individual R&D "quanta" or "items," with their "importance" having generally been derived from numerically based rankings developed during decision analysis workshop(s)

Formal Prioritization Process

- **Prioritization process can be formalized (as in 2012 UFD Roadmap)**
  1. Identify a set of items (or "quanta") to be evaluated (e.g., options, activities, or issues, …)
  2. Identify criteria and associated metrics for assessing the set of items:
     - Potential to reduce key *uncertainties*, i.e., to change the SAL (or TRL)*
     - *Importance* to the safety case
     - Other factors, e.g., *cost*, redundancies and/or synergies
  3. Evaluate each R&D item against the metrics
  4. Define a "utility function" (or ranking function) to combine the metric values and produce an overall ranking or score for each R&D item

* SAL = State-of-the-Art Level
* TRL = Technology Readiness Level



* = ***Func*** {sensitivity of performance to the information obtained; uncertainty reduction potential (TRL)}

§ Cost not formally considered in the Update Workshop.

Granularity of R&D "Quanta" or "Items"

***In 2019 Update, use R&D Activities/Tasks*:**

- **Generally, we don't think in terms of FEPs; they are more or less used for a completeness check.**
  - ← They are too "fine-grained" and "discretized" for a high-level "grasp" of how to assign resources and schedule
- **We think more broadly (at a higher grouping level) when designing models and experiments**
  - → i.e., we do our work at the *activity* or task level, each of which usually encompasses several FEPs
  - → WBS scope (PICS-NE) descriptions are generally too broad
- **The 2019 Roadmap Update prioritizes *R&D Activities***
- **Although there is no "right" or "wrong" way to quantize R&D activities, the target level is somewhere *between the fine level of FEPs and the broader level of WBS scope (annual scope descriptions for the Project's WBS elements)***

Generic R&D "Completion" State

Two criteria for "ending" or transitioning to next phase:

1. Change in State-of-the-Art Level (or Knowledge)

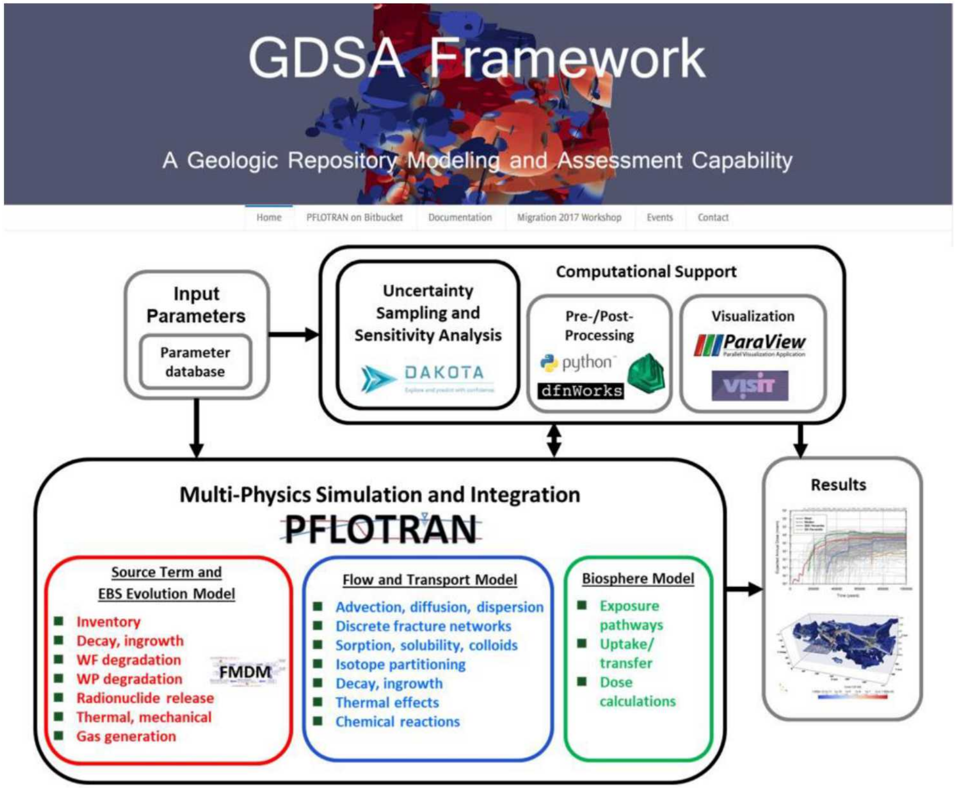
→ R&D necessary to move the <u>state-of-the-art</u> to the next level (defined later in SAL table) for the given R&D item (i.e., activity) – analogous to a change in TRL*

* Sevougian and MacKinnon 2017. "Technology Readiness Assessment Process Adapted to Geologic Disposal of HLW/SNF" IHLRWM 2017, Charlotte, NC.

2. Time constraint:

→ <u>PA "baseline" capability:</u> Process models and their implementation in the PA system model (*GDSA Framework*) will have a certain "fidelity" that allows for a full PA calculation, i.e., a PA simulation that includes important post-closure FEPs

→ Achieved by a specified date on the repository timeline (2022 for the purposes of the Update workshop)



Roadmap Update Workshop Goals/Tasks

***Held in Las Vegas, January 2019*:**

1) **Review pre-Workshop R&D Activities (i.e., the "items" to be evaluated and prioritized)—revise as warranted**

2) **Decide upon the SAL rating and its justification for each R&D Activity**

3) **Determine the generic R&D still needed to improve the SAL for each R&D Activity**

4) **Brainstorm and add "Gap" Activities, as appropriate**

5) **Decide upon the ISC rating and its justification for each assigned R&D Activity**

6) **Discuss ongoing and "unresolved" integration issues**

Example R&D Activity Descriptions

109 R&D Activities Documented and Evaluated

A-07 *Analysis of clay hydration/dehydration and alteration under various environmental conditions*

- High temperature experiments on FEBEX bentonite
- Planning of TGA/DSC experiments on FEBEX bentonite
- Review of FEBEX relative humidity (RH) in the heater test

Activity Type	PM, EA, LT
Applicable Codes:	Process model representation with PFLOTRAN, constrained by
Safety Case Elements:	SC element 3.3.1c

A-08 *Evaluation of ordinary Portland cement (OPC)*

- A new aspect of the LANL experimental work is the evaluation of ordinary Portland cement (OPC) interactions with engineered barrier materials.
- Geochemical and mineralogical evaluation of cementitious material interaction with barrier materials (steel, bentonite, clay rock) at elevated pressures and temperatures
- Cross-cuts with EBS

Activity Type	LT, EA, PM, MA
Applicable Codes:	PFLOTRAN, CHNOSZ, EQ3/6
Safety Case Elements:	SC element 3.3.1, 4.3 (Confidence Building)

C-01 *Discrete Fracture Network (DFN) Model*

- Generation and representation of realistic fracture networks (interface with characterization)
- Fluid flow& transport in fracture networks
- Mapping tools (dfnWorks to PFLOTRAN)
- Dual continuum; matrix diffusion - transient flow particle tracker

Activity Type	PM
Applicable Codes:	DFNWorks, PFLOTRAN, mapDFN.py, FracMan
Safety Case Elements:	SC element 4.2

Roadmap Update Workshop Agenda

DAY 1, TUESDAY, 1/15/2019	
9:00 a.m.	**Workshop Methodology & Breakout Group Instructions**
10:15 am - 5:00 pm	**Three Host-Rock Breakout Groups:* [Argillite; Crystalline; Salt]** 1) Decide upon SAL rating and rationale and determine generic R&D still needed to decrease SAL 2) Brainstorm and add "Gap" Activities, as appropriate **also consider EBS, DPC, and International Activities, as assigned*
DAY 2, WEDNESDAY, 1/16/2019	
8:30 am – noon	**Host-Rock Breakout Groups (continued):* [Argillite; Crystalline; Salt]** 1) Complete Day 1 tasks (if incomplete) 2) Decide upon ISC rating and justification 3) Discuss/document "unresolved" integration issues, particularly with PA-GDSA
1:00 pm – 5:00 pm	**Host-Rock Breakout Groups (continued)**, • Complete morning tasks (ISC ratings) **Cross-cutting Breakout Groups [EBS; DPC; International] (begin; split out of the three host-rock breakouts)** • Resolve differing SAL and ISC ratings among host rock groups
DAY 3, THURSDAY, 1/17/2019	
8:30 am – noon	**Full Group: Summary Reports and Integration (30 minutes per breakout)** 1) Host-Rock Groups Summary Reporting (order: Salt, Argillite, Crystalline) 2) Cross-cutting Breakout Groups Summary Reporting (order: International, DPC, EBS) 3) "Other" R&D Tasks (O-1 to O-4): Discuss briefly
1:00 pm – 2:30 pm	**Report/Integrate – Full Group (continued)** 1) Complete morning assignments listed above 2) Discuss future integration/updating still needed, e.g., a follow-up workshop, etc.

Some Workshop Results – R&D Activity Count

- **Host-Rock breakout sessions in January workshop also considered EBS, International, DPC, and PA activities relevant to their host rock concept:**
  - → EBS and International R&D Activities were often evaluated (ISC and SAL) in more than one host-rock breakout session
  - → EBS and International cross-cutting breakout sessions (Day 2 afternoon) resolved different ISC and SAL values for their R&D Activities, given in the three host-rock sessions, if any

Number of R&D Activities considered in each host-rock breakout session

Breakout Session	Total Number of R&D Activities Evaluated
Argillite	31
Crystalline	40
Salt	29
Total	**100**

Number of R&D Activities included in each R&D Activity "Group" or Type (e.g., Argillite)

R&D Activity Group	Total Number of R&D Activities
Argillite	8
Crystalline	17
DPC	6
EBS	20
International	21
Salt	13
Other	7
PA	17
Total	**109**

Prioritization Metrics: SAL and ISC

- **The breakout group chairs and the R&D work-package technical leads made a pre-Workshop draft of ISC and SAL values and rationales**
  - → Theirs was an initial cut only – to facilitate discussion
  - → The main task for Workshop participants was to reach consensus on SAL and ISC in the breakout sessions

- **State-of-the-Art Level (SAL):**
  - → five SAL or knowledge levels, based fairly closely on the "State-of-the-Art" categories used in the original 2012 Roadmap, but simplified and scaled

SAL Numerical Value	SAL Descriptive Value
5	*Fundamental Gaps in Method or Fundamental Data Needs, or Both*
4	*Improved Representation*
3	*Improved Defensibility*
2	*Improved Confidence*
1	*Well Understood*

- **Importance to the Safety Case (ISC):**

ISC Numerical Value	ISC Descriptive Value
5	***High** Importance to SC*
3	***Medium** Importance to SC*
1	***Low** Importance to SC*

Typical Elements of a Safety Case

Safety Case:

1. Introduction, Purpose, and Context

2. Safety Strategy

- 2.1 Management Strategy
- 2.2 Siting and Design Strategy
- 2.3 Assessment Strategy

3. Technical Bases

3.1 Site Selection & Repository Concept

3.2 Pre-closure Basis
- Repository Design
- Construction
- Operations

3.3 Post-closure Basis (FEPs*)
- Waste & Engineered Barriers
- Geosphere/ Natural Barriers
  - –Site Characterization
- Biosphere & Surface Environment
- Uncertainty Characterization

4. Disposal System Safety Evaluation

4.1 Pre-closure Safety Analysis

4.2 Post-closure Safety Assessment
- FEPs Analysis and Scenarios
- Uncertainty/Sensitivity Analysis
- Barrier and Safety Functions

4.3 Confidence Enhancement
- Analogues
- Safety Indicators
- Model/Software V&V
- URLs; Long-Term Monitoring
- Peer Review

5. Synthesis & Conclusions

5.1 Confidence Statements & Robustness Arguments
5.2 Remaining Uncertainties
5.3 Path Forward

*FEP = Feature, Event, or Process

ISC Metric Table

ISC Numerical Value	ISC Descriptive Value	ISC Definition (see Safety Case Elements figure)
5	***High*** *Importance to Safety Case*	Knowledge gained by proposed R&D strongly affects one of the three elements of "Disposal System Safety Evaluation" in the Safety Case (pre-closure safety analysis, post-closure safety assessment*, confidence enhancement*)
3	***Medium*** *Importance to Safety Case*	Knowledge gained strongly affects one of the Technical Bases* elements of the Safety Case but the Technical Basis element itself only weakly or moderately influences a safety assessment metric
1	***Low*** *Importance to Safety Case*	Knowledge gained is only of a supporting nature and does not strongly affect the associated process model or model inputs

*These three SC elements are the most relevant ones for the generic repository phase (see next slide)

SAL Metric Table

SAL Numeric Value	SAL Descriptive Value	SAL Definition	Questions to be answered for: (1) Rationale for current SAL (Column M) (2) R&D to move to next SAL (Column N)
5	*Fundamental Gaps in Method or Fundamental Data Needs, or Both*	The representation of an issue (conceptual and/or mathematical, experimental) is under development, and/or the data or parameters in the representation of an issue (process) is being gathered	Rationale for being at Level 5: • What is under development and what data is being gathered? • What are the fundamental gaps? R&D necessary to get to Level 4?
4	*Improved Representation*	Methods and data exist, and the representation may be reasonable but there is not widely-agreed upon confidence in the representation (scientific community and other stakeholders).	Rationale for being at Level 4: • What methods and data currently exist? • Why is the representation reasonable? • Why is there not widely agreed upon confidence? R&D necessary to get to Level 3? • e.g., what is needed to build agreement and confidence in the representation? and what additional data need to be gathered?
3	*Improved Defensibility*	Focuses on improving the technical basis and defensibility of how an issue (process) is represented by data and/or models	Rationale for being at Level 3: • Why and what needs to be (and can be) improved for defensibility for a generic repository? R&D necessary to get to Level 2? • e.g., What level of effort on data and models would lead to the issue being technically defensible
2	*Improved Confidence*	The representation of an issue is technically defensible, but improved confidence would be beneficial (i.e., lead to more realistic representation).	Rationale for being at Level 2: • Why is it technically defensible? R&D necessary to get to Level 1? • e.g., What R&D would lead to improved confidence?
1	*Well Understood*	The representation of an issue (process) is well developed, has a strong technical basis, and is defensible. Additional R&D would add little to the current understanding	

Some Workshop Results – Expert Consensus on SAL and ISC Values

ID (*gap)	Activity	2019 Score
E-03	*THC processes in EBS*	M-H

Desc
• Engineered barrier (metal-clay-rock) material interactions & experimental data
• Modeling (thermodynamic & reactive transport)Includes temperatures relevant to DPC.Provide chemical constraints for SNF degradation/radionuclide transport.

Type: PM, LT, EA

Codes: PFLOTRAN, CHNOSZ, EQ3/6

Elements: SC element 3.3.1, 4.2 b, 3.2

ISC: High

Rationale: High importance for design/construction arguments affecting disposal system design that utilize backfill/buffer as an engineered barrier and potential generation of preferential pathways through the EDZ- Note this source term model/testing is more important in crystalline case; less important in case of Salt concept AND NOT directly applicable in brine conditions

SAL: 4 Improved Representation

Rationale
• Chemical processes still under development, particularly at elevated temperature conditions.
• Gained improved understanding of phase mineralogy & modeling methods.

R&D Needed: May be of high importance for performance in certain environments and disposal concepts that utilize backfill/buffer as a engineered barrier - governs "source term" release upon failure of waste packages for certain designs in certain environments.
High importance for design/construction - could effect disposal system design that utilize backfill/buffer as an engineered barrier, how it is constructed, and emplacement of waste and backfill/buffer (i.e., size of waste packages and spacing).
High importance for overall confidence - secondary isolation barrier and long-term barrier performance.

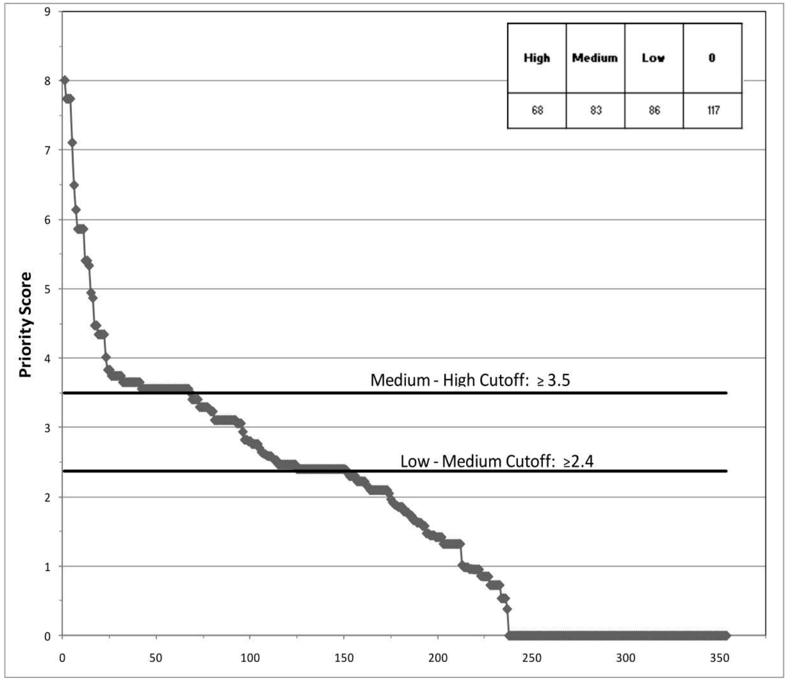
2012 Issue and 2019 Activity Rankings

- **2012 UFD Roadmap rankings – used both numerical ordering and broad categories (H, M, L):**

FEPs or "R&D Issues": **"priority score"**

UFD FEP ID No., Title, and Media	Overall Priority Score
2.2.01.01 - Evolution of EDZ - Clay/Shale	8.00
2.2.08.01 - Flow Through the Host Rock - Salt	7.73
2.2.08.02 - Flow Through the Other Geologic Units - Confining units - Aquifers - Salt	7.73
2.2.08.06 - Flow Through EDZ - Salt	7.73
2.2.08.04 - Effects of Repository Excavation on Flow Through the Host Rock - Salt	7.10
2.2.08.07 - Mineralogic Dehydration - Salt	6.49
2.2.01.01 - Evolution of EDZ - Deep Boreholes	6.13
2.2.09.01 - Chemical Characteristics of Groundwater in Host Rock - Deep Boreholes	5.86
2.2.09.02 - Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Deep Boreholes	5.86
2.2.09.05 - Radionuclide Speciation and Solubility in Host Rock - Deep Boreholes	5.86
2.2.09.06 - Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) - Deep Boreholes	5.86
2.2.09.03 - Chemical Interactions and Evolution of Groundwater in Host Rock - Deep Boreholes	5.40

Quantitative → qualitative score"



- **2019 SFWST Roadmap Update rankings – broad categories only:**
  - → High (H), Medium (M), or Low (L) categories for the R&D Activity priority scores
  - → Priority score or ranking to be derived from the convolution of the *two metrics*: SAL & ISC

R&D Activity Priority Score
(using ISC × SAL product)

ISC (importance to safety case) value:

ISC Numerical Value	ISC Descriptive Value
5	***High*** *Importance to SC*
3	***Medium*** *Importance to SC*
1	***Low*** *Importance to SC*

×

SAL (state of the art) value

SAL Numerical Value	SAL Descriptive Value
5	*Fundamental Gaps in Method or Fundamental Data Needs, or Both*
4	*Improved Representation*
3	*Improved Defensibility*
2	*Improved Confidence*
1	*Well Understood*

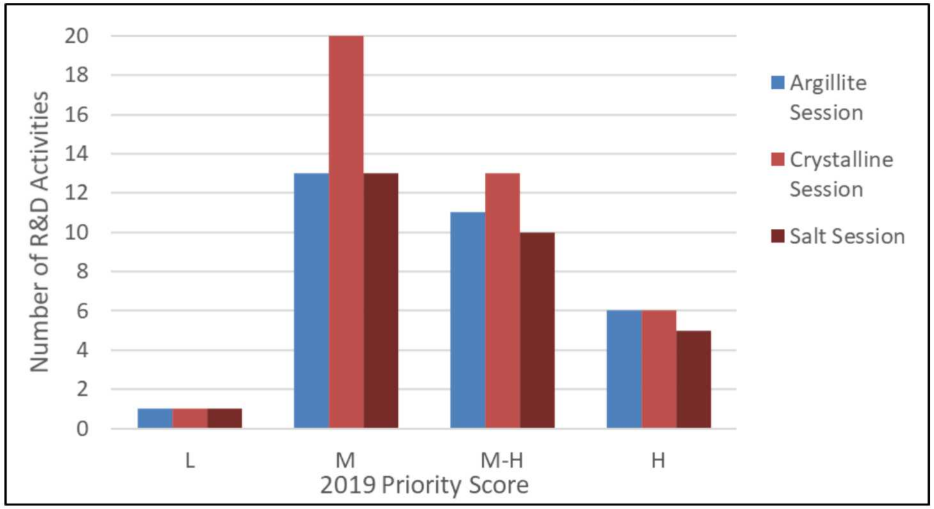
Final R&D Priority Score for an Activity

=

SAL: / ISC:	1	2	3	4	5
High (5)	L	M	M	**M-H**	**H**
Medium (3)	L	M	M	M	M
Low (1)	L	L	L	L	L

Some Workshop Results – Summary of Priority Scores for Host-Rock Sessions

Histogram of R&D Activity Scores



Breakout Session	Total Number of R&D Activities Evaluated
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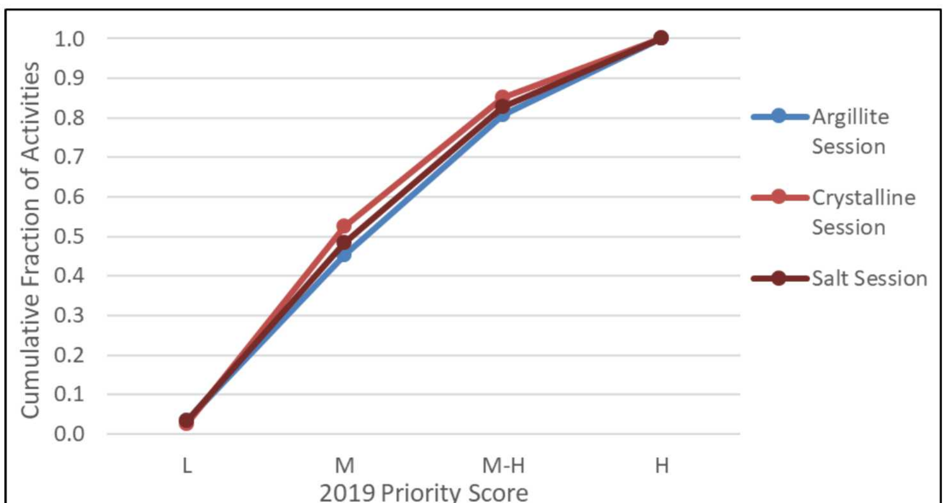
Crystalline	40
Salt	29

Cumulative Fraction of R&D Activity Scores

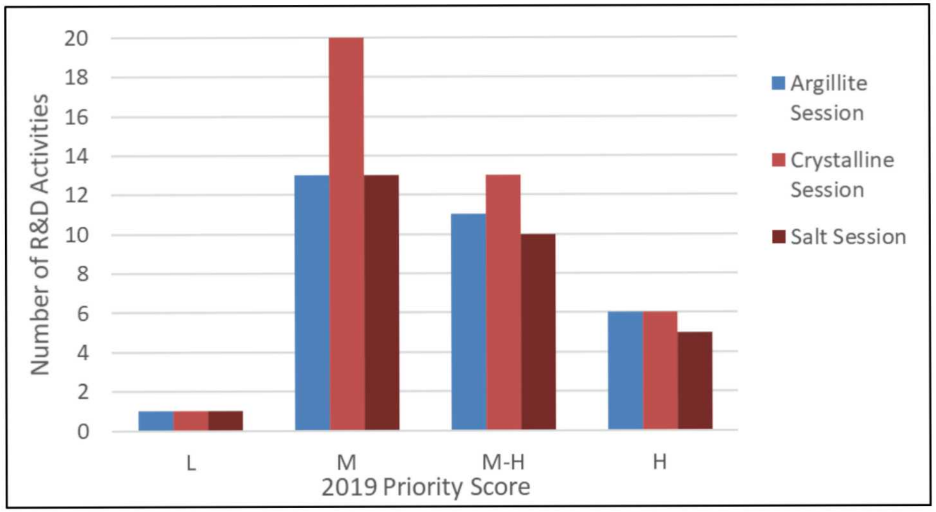


- Apparent uniformity of scoring among host-rock breakout groups
- Good "calibration"?

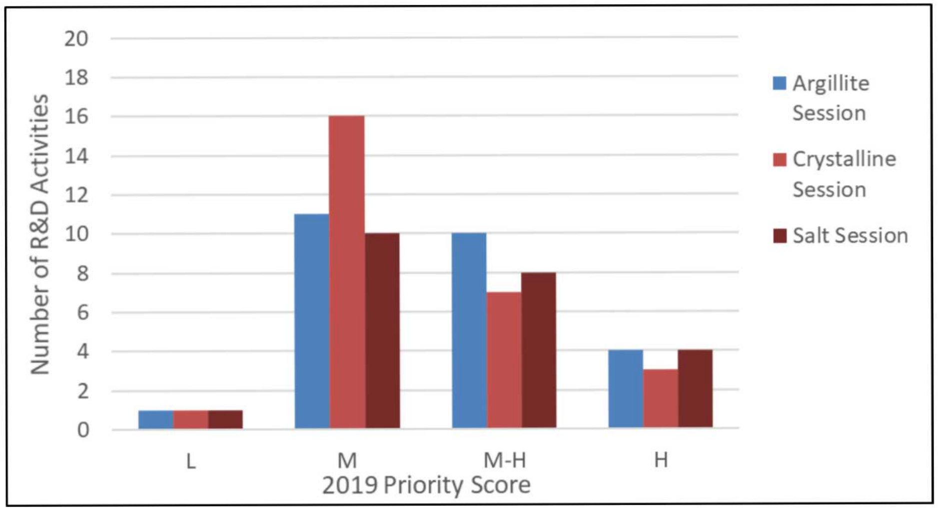
"Gap" Activities

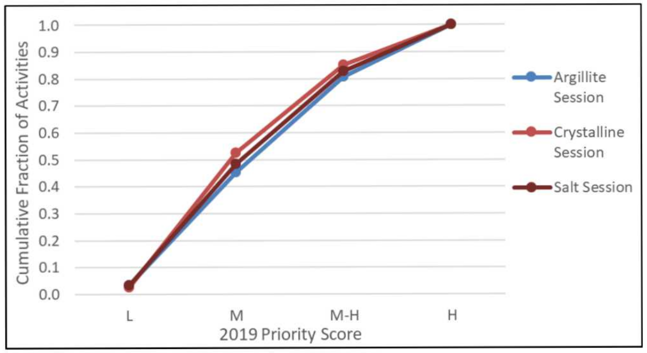
- Gap or long-term activities altered the results somewhat when removed from the charts:

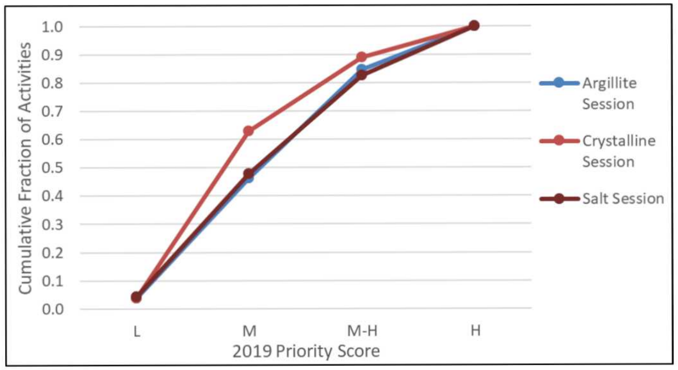
Histogram of all R&D Activity Scores



Histogram of "current" Activities (no "gaps")







"High Impact R&D Topics"

- **Groupings of similar R&D Activities with High and Medium-High Priority Scores:**

High Impact R&D Topics	High Priority	Medium-High Priority
High temperature impacts	D-1, D-4, I-4, I-6, I-16, E-11, S-5	I-2, I-3, I-7, E-10
Buffer and seal studies	I-4, E-9, E-17, A-8, C-15	I-2, I-3, I-7, A-4, C-6, C-8, C-11
Generic PA Models	P-1, P-2, P-3, P-4, P-11, P-13	P-10, P-14
Coupled processes (Salt)	S-1, S-3, S-4	I-12, I-13, I-14, S-2, S-7, S-8, S-11
Gas flow in the EBS	I-6, I-8, I-18	I-9, P-17
Criticality	D-1, D-4, D-5	
Waste Package degradation	C-16, P-12	E-4, E-6
Radionuclide Transport	P-6	C-11, C-13, C-14. P-15, P-16
In-Package Chemistry	E-14	E-2, E-20, P-15, P-16

- **Helpful snapshot of overall R&D program; can help focus future R&D work**

Some Insights

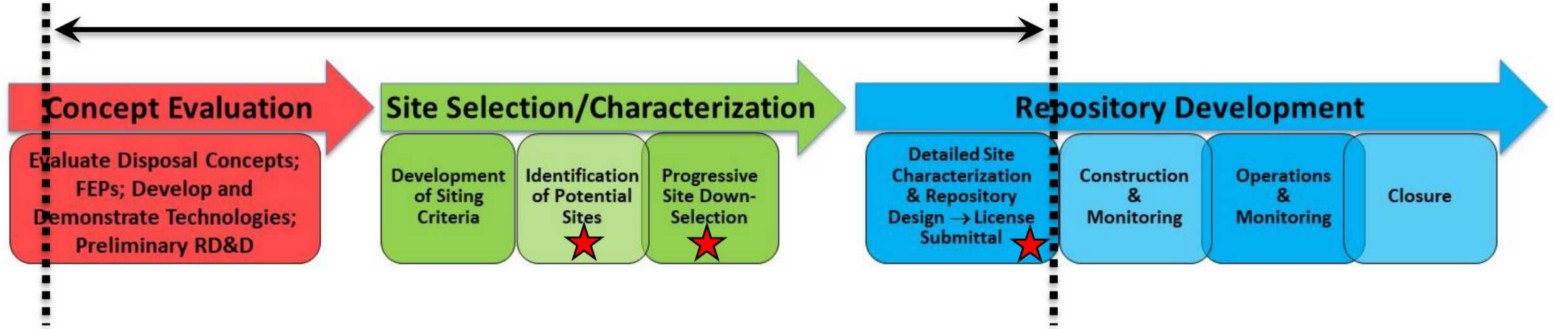
- **Much generic R&D accomplished since 2012 Roadmap:**
  - Through R&D both in the U.S. and through many nicely leveraged International collaborations (most in URLs)
  - State-of-the-Art knowledge level (SAL) has improved for many Activities/FEPs
- **Need for continuing generic R&D in a number of identified "High Impact" Topical Areas, and for several other R&D Activities**
  - Generic R&D needed has been identified by consensus of Project experts during a 3-day decision-analysis Roadmap Update Workshop (January 2019)
- **Some obvious new priorities in the intervening seven years:**
  - Possible direct disposal of dual-purpose canisters (DPCs) implies that criticality FEPs should be re-examined, and mitigation methods considered if necessary
- **PA-GDSA modeling provides insights for the ISC value of various R&D Activities**

Thanks for your Attention!

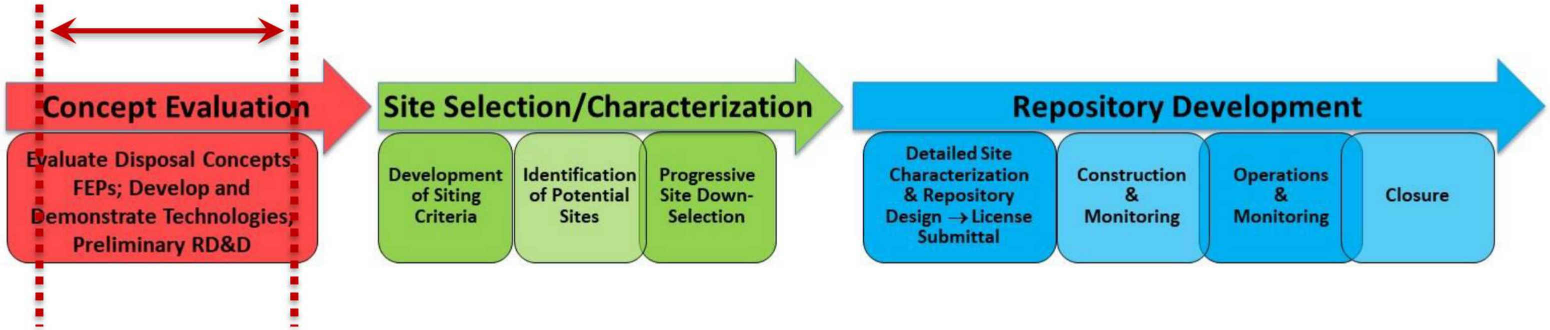
Back-Up Slides

Simplified Prioritization Methodology for 2019

- 2012 UFD Roadmap considered "siting decision points (★)" in its utility (or "scoring") function for R&D Issues



- 2019 Roadmap Update takes a simpler view of generic R&D prioritization, by concentrating more definitely on the generic R&D phase ("Concept Evaluation" phase)—creates a more qualitative utility function:



1. Introduction, Purpose, and Context

2. Safety Strategy

2.1 Management Strategy

a. Organizational/mgmt. structure
b. Safety culture & QA
c. Planning and Work Control
d. Knowledge management
e. Oversight groups

2.2 Siting & Design Strategy

a. National laws
b. Site selection basis & robustness
c. Design requirements
d. Disposal concepts
e. Intergenerational equity

2.3 Assessment Strategy

a. Regulations and rules
b. Performance goals/safety criteria
c. Safety functions/multiple barriers
d. Uncertainty characterization
e. RD&D prioritization guidance

3. Technical Bases

3.1 Site Selection

a. Siting methodology
b. Repository concept selection
c. FEPs Identification
d. Technology development
e. Transportation considerations
f. Integration with storage facilities

3.2 Pre-closure Basis

a. Repository design & layout
b. Waste package design
c. Construction requirements & schedule
d. Operations & surface facility
e. Waste acceptance criteria
f. Impact of pre-closure activities on post-closure

3.3 Post-closure Bases (FEPs)

3.3.1 Waste & Engineered Barriers Technical Basis

a. Inventory characterization
b. WF/WP technical basis
c. Buffer/backfill technical basis
d. Shafts/seals technical basis
e. UQ (aleatory, epistemic)

3.3.2 Geosphere/ Natural Barriers Technical Basis

a. Site characterization
b. Host rock/DRZ technical basis
c. Aquifer/other geologic units technical basis
d. UQ (aleatory, epistemic)

3.3.3 Biosphere Technical Basis

a. Biosphere & surface environment:
- Surface environment
- Flora & fauna
- Human behavior

4. Disposal System Safety Evaluation

4.1 Pre-closure Safety Analysis

a. Surface facilities and packaging
b. Mining and drilling
c. Underground transfer and handling
d. Emplacement operations
e. Design basis events & probabilities
f. Pre-closure model/software validation
g. Criticality analyses
h. Dose/consequence analyses

4.2 Post-closure Safety Assessment

a. FEPs analysis/screening
b. Scenario construction/screening
c. PA model/software validation
d. Barrier/safety function analyses and subsystem analyses
e. PA and Process Model Analyses/Results
f. Uncertainty characterization and analysis
g. Sensitivity analyses

4.3 Confidence Enhancement

a. R&D prioritization
b. Natural/anthropogenic analogues
c. URL & large-scale demonstrations
d. Monitoring and performance confirmation
e. International consensus & peer review
f. Verification, validation, transparency
g. Qualitative and robustness arguments

5. Synthesis & Conclusions

a. Key findings and statement(s) of confidence
b. Discussion/disposition of remaining uncertainties
c. Path forward

Breakout Group Compositions

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R&D "Completion" State for Site Evaluation

- At the time of site evaluation and/or selection, the PA and process models must be "run ready," and a good safety case framework already started
- Models and tools must already be "in hand" to initiate a siting stage in any potential host rock
- Good repository designs for any potential host rock must have already been developed (designs suitable for the U.S. waste packaging, i.e., DPCs)
- Data needed at the beginning of site evaluation process versus that needed after a final site is selected should be documented
- Generic site-characterization plans for each potential host rock

Examples of Activity Quantization

- ***Reasonable*:**

C-1	Discrete Fracture Network (DFN) Model	• Generation and representation of realistic fracture networks • Fluid flow& transport in fracture networks • Mapping tools (dfnWorks to PFLOTRAN) • Dual continuum; matrix diffusion

- ***Too broad*:**

C-13	Reactive transport modeling of groundwater chemistry evolution and radionuclide transport	This task will focus on the following improvements to the existing reactive transport modeling capability: • Incorporation of interfacial reactions (e.g., surface complexation), microbially mediated reactions, colloid-facilitated transport, and radionuclide decay and ingrowth; • Improved representation of spatial heterogeneity of chemical and transport properties • Coupling of radionuclide transport with evolving water chemistry along a transport pathway (e.g. alkaline plumes) • Robustness of numerical algorithms for coupling chemical reactions with solute transport • Explicit consideration of structural complexity of the media in the solute transport (e.g. the fracture-matrix system in DRZ or the micro, macro-pores system for host clay rock).