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Spent Fuel and Waste Science and Technology (SFWST)

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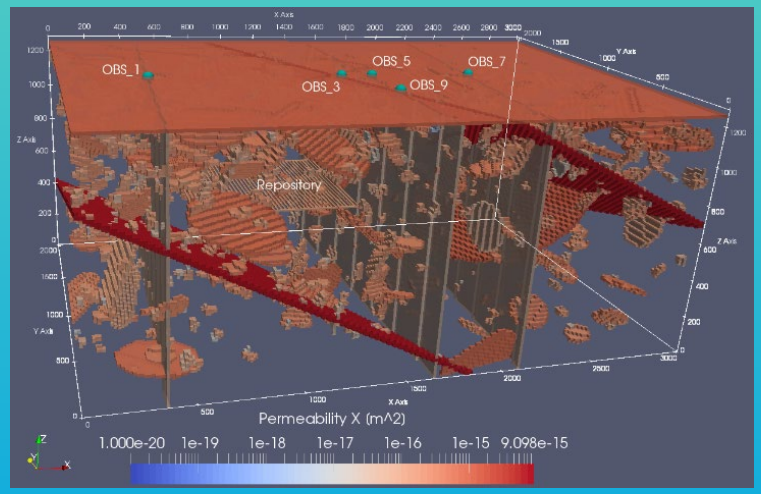

Technical Approach and Prioritization of Activities

U.S. Nuclear Waste Technical Review Board Virtual Fact Finding Meeting
November 04-05, 2020

David C. Sassani, Sandia National Laboratories, National Technical Director, Spent Fuel and Waste Science and Technology (SFWST) Campaign

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Outline

- Introduction
  - Disposal Research Coverage
  - Campaign Planning/Prioritization Overview
- 2012 Roadmap - Priorities and Assessment
  - 2012 Roadmap bases
  - R&D priorities
  - Accomplishments
  - Evolution of R&D focus
- 2019 Roadmap Update
  - Evaluation bases
  - Major findings
  - Gaps and defined focus areas
- Summary and Look Ahead

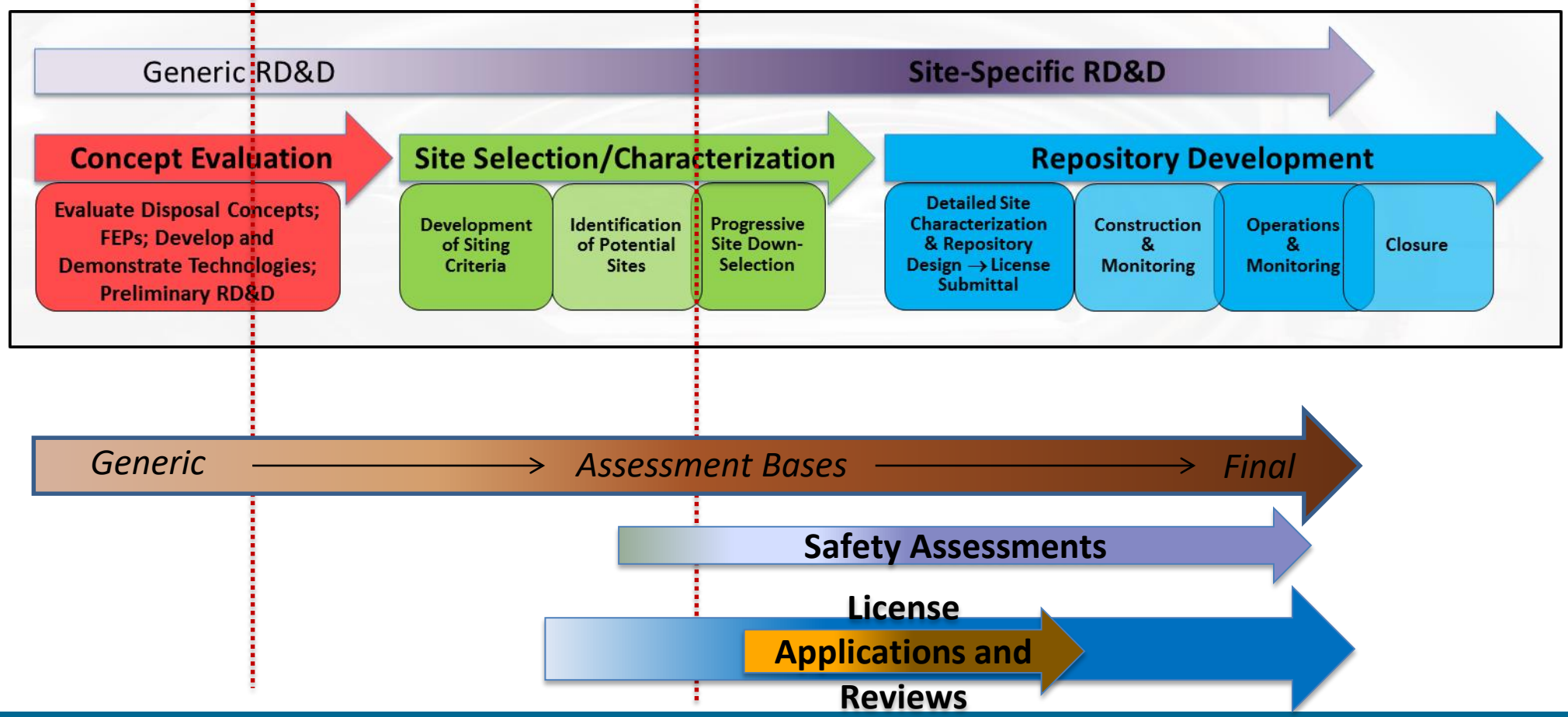
Context of SFWST Campaign Disposal Research

U.S. Program Currently:

- *Concept Evaluation stage*
- *"Generic" stage*
- *Before site-selection*
- *"Pre- CD-0"*

20??

- **Research, Development, and Demonstration (RD&D)**:
  - Demonstrations initially focus on analytical capabilities
  - Characterization/operational demonstrations increase later in a program

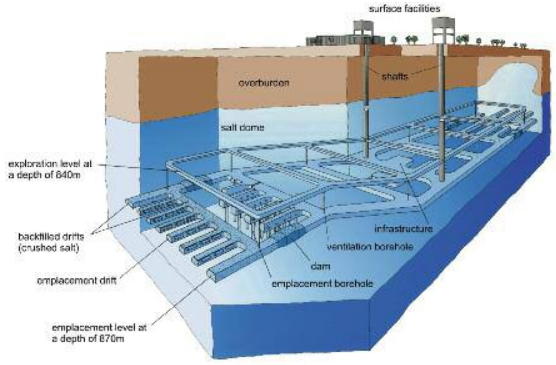


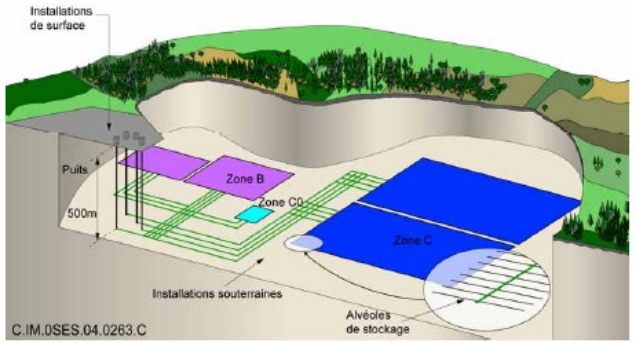
Generic Disposal Concepts and Program Planning

- Provide a sound technical basis for multiple viable disposal options in the US
  - Spent nuclear fuel (SNF)
    - Commercial
    - DOE-managed
  - High-level nuclear waste (HLW) glass
- Increase confidence in the robustness of generic disposal concepts
- Develop the science and engineering tools needed to support disposal concept implementation

Salt Repository Example

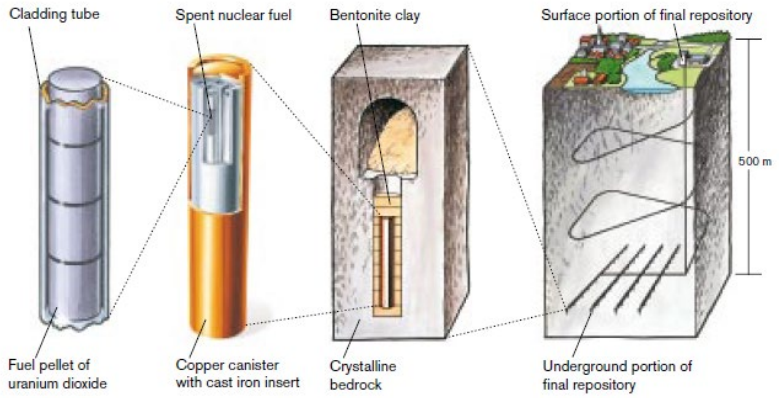
Gorleben, Germany (BMWi 2008)





Argillite Repository Example

Meuse/Haute Marne, France (ANDRA 2005)

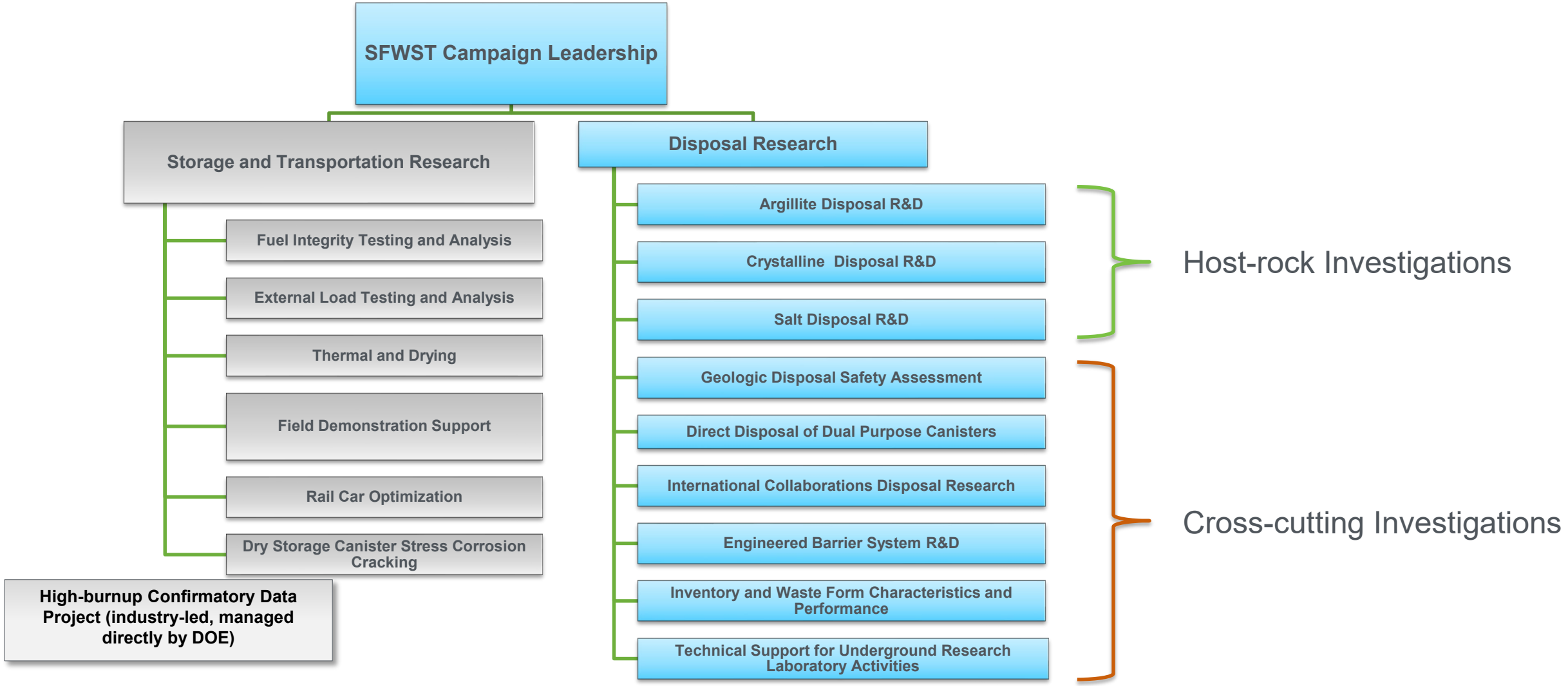


Crystalline Repository Example

Forsmark, Sweden (SKB 2011)

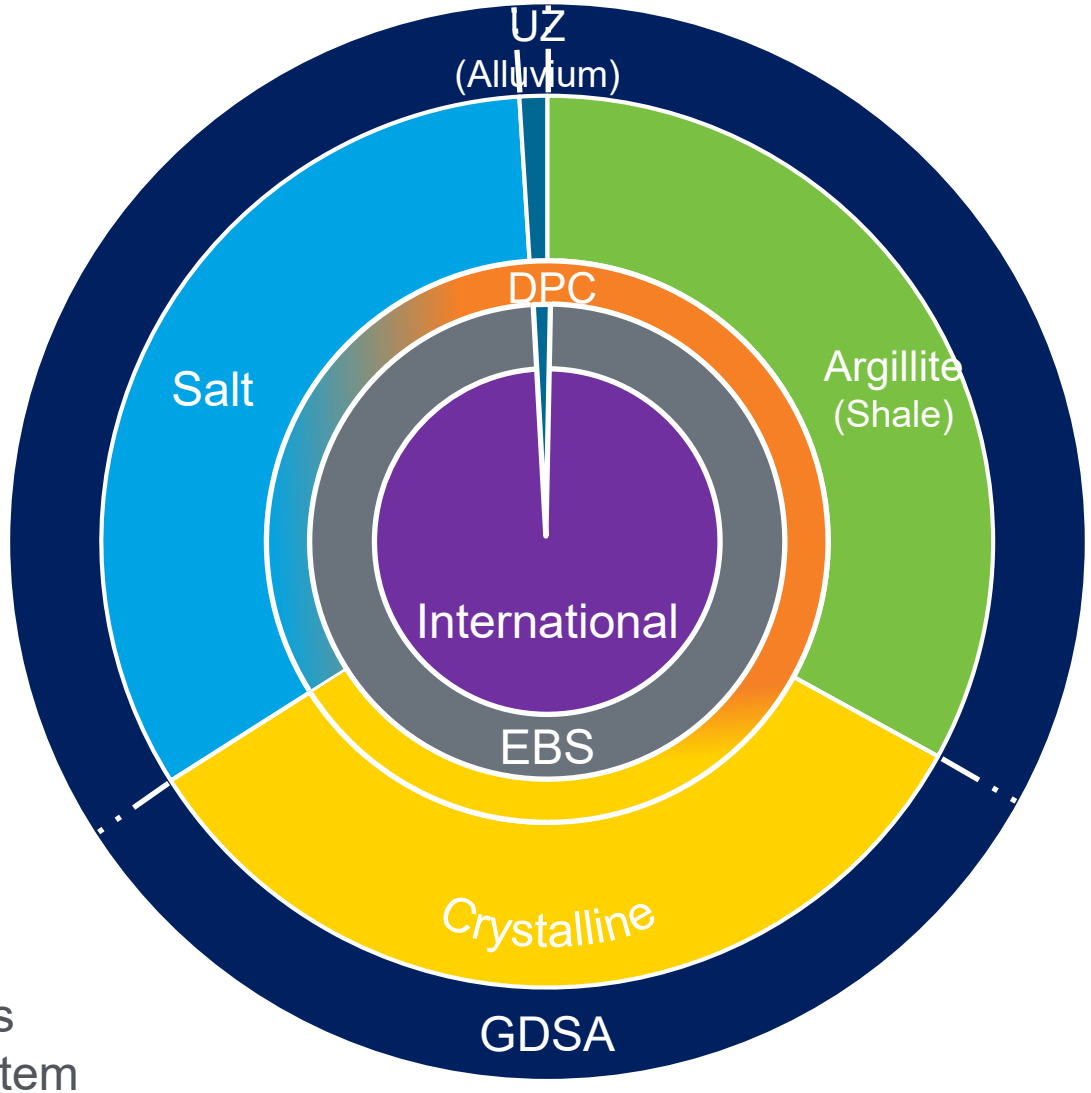
- Challenges:
  - Wide range of geologic disposal concepts
  - Constrain the generic R&D most important for each
  - Define complete enough for generic D&D
  - Utilize vast international experience
  - Integrate cross-cutting aspects clearly

FY 21 SFWST R&D Campaign Structure (from PICS NE 1.08.01)



Visual Depiction of Disposal Research Host Rock and Cross-cutting Activities

- Visual Guide to Disposal Research Discussions
  - Wedges of the pie are for host rocks
  - Concentric circles for cross-cutting activities
  - Shading of circle(s) indicates focus of cross-cutting activities and host rocks



- Host-rock Investigations
  - Argillite/shale
  - Crystalline
  - Salt
- Unsaturated Zone Activities (less mature)
- Cross-cutting Investigations
  - International
  - Engineered Barrier System
  - Dual Purpose Canisters
  - Geologic Disposal Safety Assessment
  - Inventory/Waste Form
  - Underground Research Laboratory (UZ)

UZ = Unsaturated Zone
DPC = Dual Purpose Canisters
EBS = Engineered Barrier System
GDSA = Geologic Disposal Safety Assessment

Planning/Prioritization Disposal Research (DR) Activities Overview

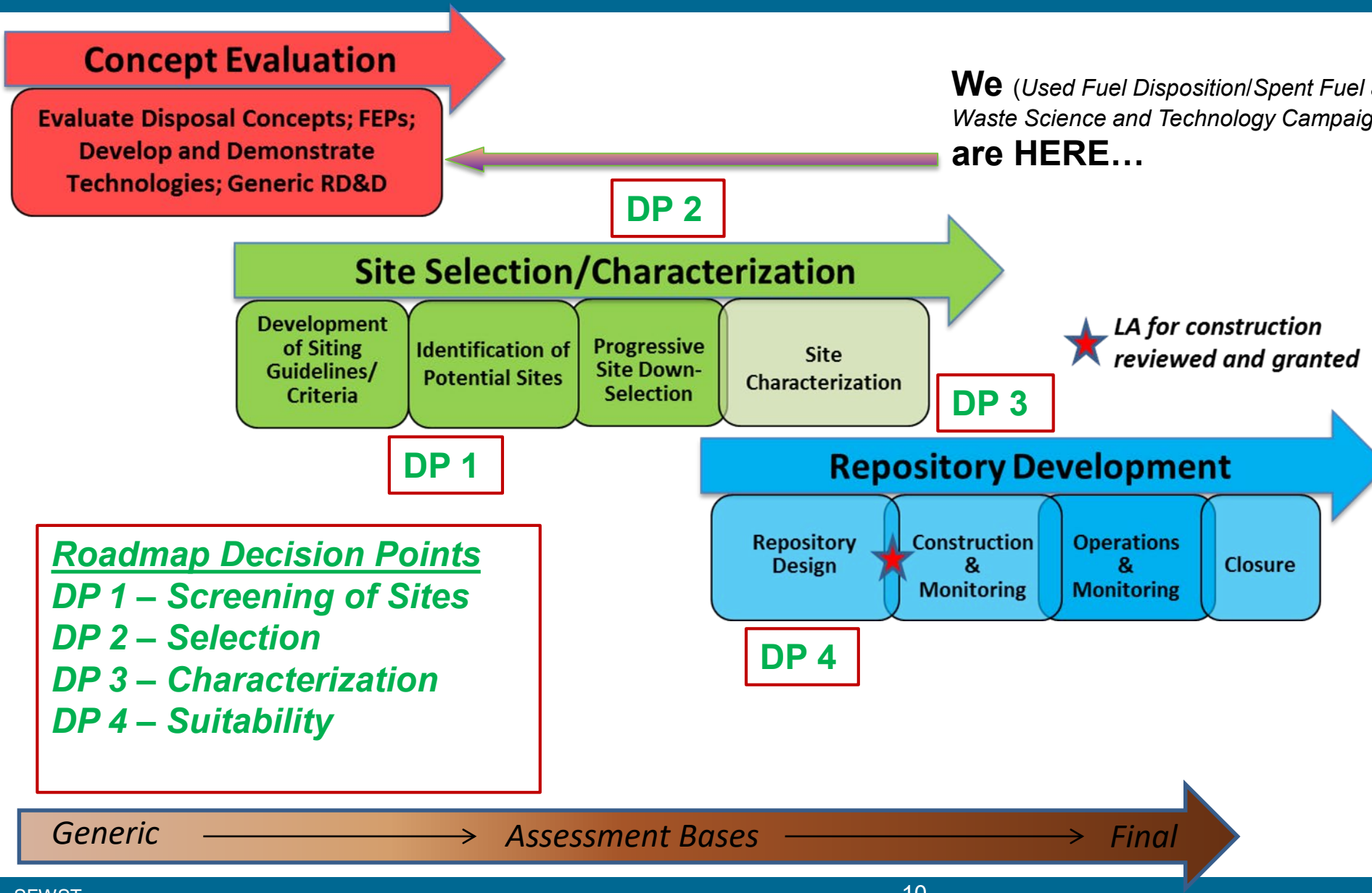
- Major Drivers on Planning/Prioritization of Disposal Research
  - Program Direction includes both technical direction and annual budget process
  - Geologic Disposal Safety Assessment capabilities (all generic disposal concepts)
  - International collaborations (site-specific insights)
- Used Fuel Disposition (UFD) Campaign 2012 Roadmap (Rev. 01; 2012)
  - Features, Events, and Processes (FEP) gap assessment synthesis (UFD Roadmap)
  - Synthesize into High Priority Topics for UFD Campaign work planning
- 2019 Roadmap Update (Rev. 01; 2019)
  - Review DR activities for progress, outstanding gaps, and recent Program Direction
- Development of SFWST Disposal Research Five-year Plan (2020)
  - Incorporate/address updated priorities
  - Identify short-term primary objectives (1-2 years; relatively certain)
  - Provide longer-term vision (3-5 years; general guide)

2012 Roadmap - Priorities and Assessment

Key Objectives of Assessing the Safety of a Geologic Disposal System

- *Demonstrate Sound Understanding* of the Repository System
  - Surface processes, engineered and geologic barriers, and biosphere
  - Show how this understanding is the basis for the **evaluation of long-term performance and safety**
  - Provide **multiple lines of evidence** that support the results of a safety assessment and understanding of the system
  - Quantify and substantiate, **with requisite confidence**, the safety of the repository
- Provide a *Framework to Help Plan and Prioritize Technical Work*
  - As the repository program moves through the various phases of repository development
- Provide a Vehicle to *Communicate the Understanding of Safety* to a Broad Audience of Stakeholders

Disposal Research Program Conceptual Timeline and Roadmap Decision Points



- **Research, Development, and Demonstration (RD&D):**
  - Demonstrations initially focus on analytical capabilities
  - Characterization/operational demonstrations increase later in a program
- **Leads to License Application (LA) to Construct**

Used Fuel Disposition (UFD) Campaign Disposal R&D 2012 Roadmap - Background

- Identified Need for a Disposal Research and Development Roadmap at Inception in June 2009 – *New Program*
- FY10 Activities Focused on Evaluating Knowledge for Other Disposal Concepts
  - What is the state of the art?
  - What are the key technical gaps?
  - Disposal R&D Roadmap 1st Workshop in June 2010
    - Generated a list of potential **R&D opportunities – no priorities**
  - Issued Disposal R&D Roadmap Status Report in September 2010
- Expanded in FY11 Activities
  - **Established process for prioritizing** R&D issues
  - Held 2nd Disposal R&D Roadmap in *December 2010*
    - Developed information prioritization matrix for review
  - **Completed Roadmap on March 30, 2011** (Rev00)
- Revised: 2012 Roadmap (Rev01) September 2012

2012 Roadmap Systematic Approach to R&D Prioritization

- Objectives – Based on Safety Functions
  - Containment
  - Limited Release: Natural and Engineered Systems
  - Dilution (secondary function)
- Utilize *Features, Events, and Processes* (FEP) Structure to *Identify* R&D **"Issues"**
  - Identification of R&D Issues
    - Features: Map features of generic disposal system(s) to objectives
    - Processes used to identify additional Issues
- FEP List (UFD Campaign FY10) Was Used for the Features and the Processes to Identify the R&D Issues

2012 Roadmap Systematic Approach to R&D Prioritization (Continued)

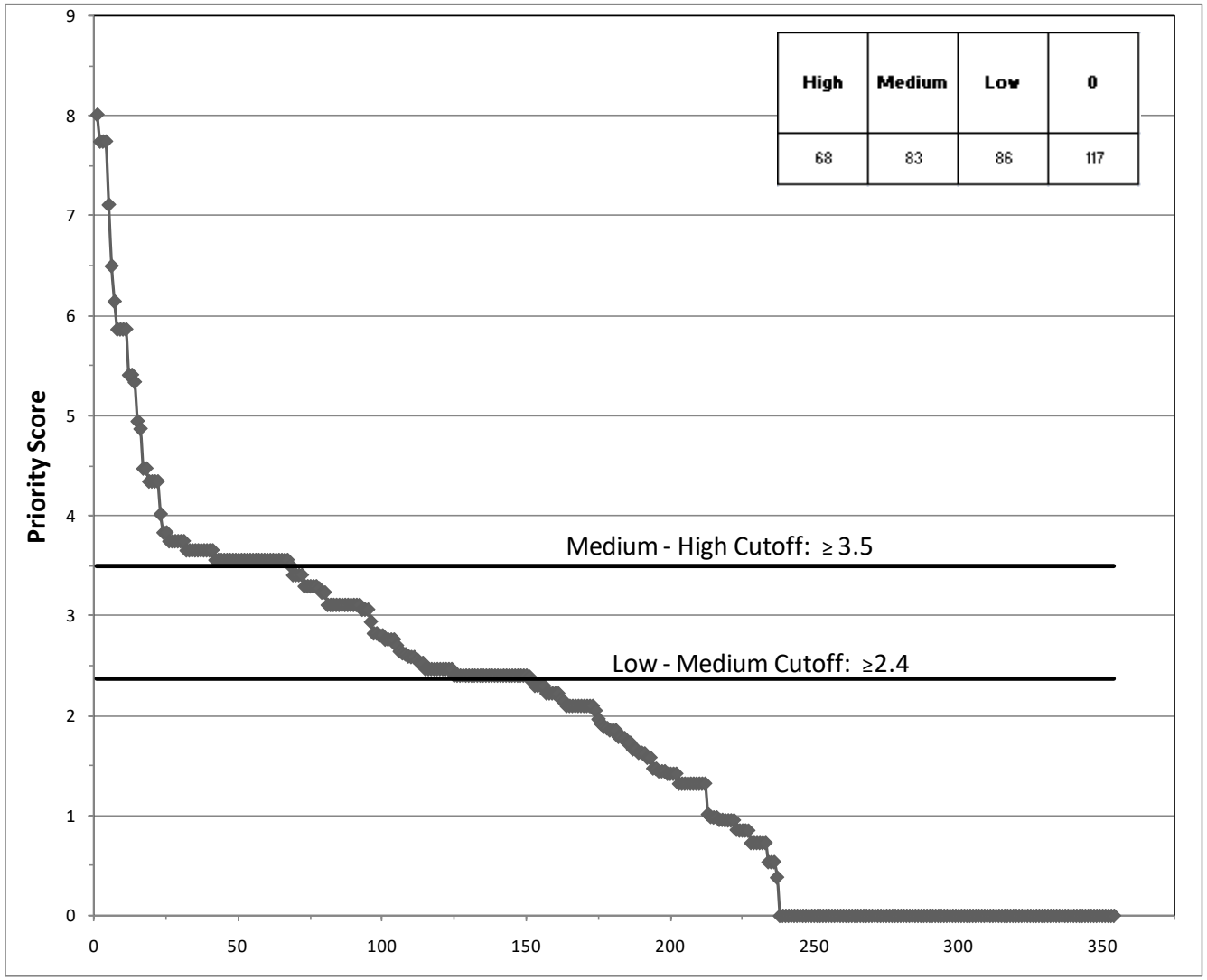
- Can an R&D Issue be Addressed through ***Generic* R&D**?
  - **No**: site specific/design specific
  - **Partially**: some aspect of the issue is amenable
  - **Yes**
- Assess Issues for Importance to "Safety" (High, Medium, Low):
  - **Safety Assessment**:
    - Media and design specific
  - **Design/Construction/Operation**: importance with respect to…
    - Engineered materials -- known well enough to include in a facility design?
    - Construction, fabrication, and operational techniques – well known and/or demonstrated?
  - **Broad Confidence** in safety
    - May not be important directly to above, **BUT *may build confidence*** in the overall safety bases
  - Do for each decision point (1 through 4)
- Assess the State-of-the-Art Knowledge Level for Each Issue

2012 Roadmap Systematic Approach to R&D Prioritization (Continued)

- The **Overall Priority** of an Issue is a Function of
  - The importance of the issue to ***safety***,
    - The importance of the issue to safety at ***each decision point***, and
  - The adequacy and state of the art of ***current information (time evolving)***
  - Issues that are Important for Nearer-term Decision Points are Higher Priority
  - Issues that are "Well Understood" are Low Priority
- For Issues Evaluated for Different Disposal Media, Media-specific Priorities Were Considered

2012 Roadmap R&D Issues Prioritization - Results

- Quantitative Scoring Results (2012 Roadmap Appendix B) of R&D Issues
- The *Relative Priority* of the R&D Issues Were ***Not*** Simply Implemented as a Ranked R&D Priority List
- Instead, Issues Were Synthesized to Define a Ranking (low, medium, high) for Higher-level Topical Areas (***R&D Topics***) to Plan Work



2012 Roadmap Higher-level R&D Topics – Synopsis (and Assessment from FY17)

- Design Concept Development **(High)**
  - Develop a range of generic disposal system design concepts
  - Consider range of fuel cycle scenarios
- Generic Disposal System Modeling **(High)**
  - Generic disposal system models (GDSM) to conduct such safety assessments
  - Support evaluation of issues important within a total-system construct
  - Support future site screening activities, should a decision be made to initiate
- Operations Related Research and Technology Development **(Low)**
  - Capabilities for operations: waste package fabrication, closure, and handling
  - Develop confirmatory data for future licensing proceedings

2012 Roadmap Higher-level R&D Topics – Synopsis (and Assessment FY17 - Continued)

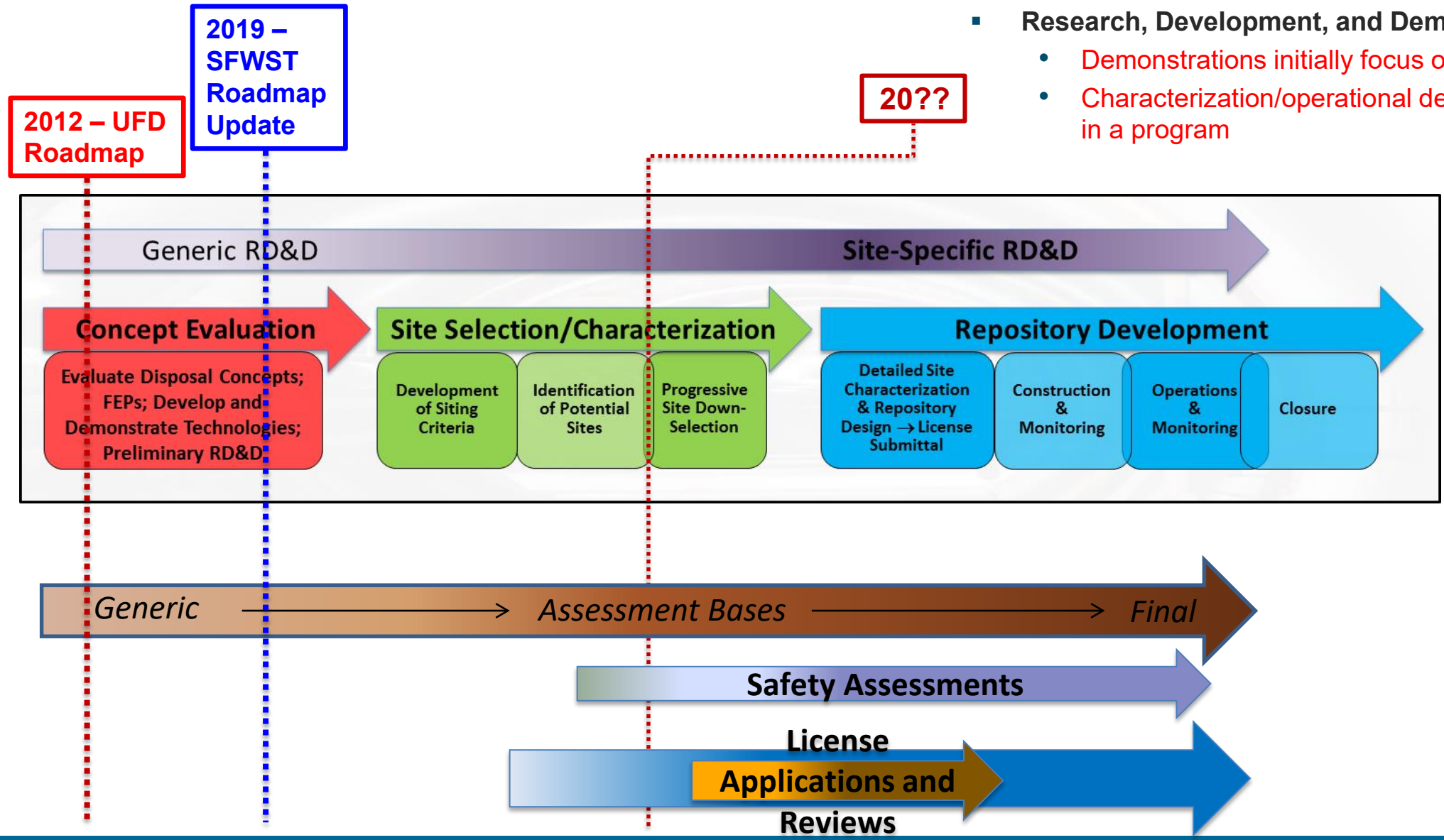
- Knowledge Management **(Medium)**
  - Development knowledge management system
- Site Screening and Selection Tools **(Medium)**
  - Support for siting activities using geospatial decision
  - Geospatial analysis tools at national and regional scales
- Experimental and Analytical Techniques for Site Characterization **(Medium)**
  - Exploration, research, and development of advanced techniques for future siting activities
  - Leverage techniques from other areas: oil/gas, mining, geothermal energy, carbon sequestration
- Underground Research Laboratories (URL) **(Medium)**
  - Conduct experiments designed to address non-site-specific issues
  - Maintain repository development expertise
  - Leverage international Underground Research Laboratories

2012 Roadmap Disposal R&D Summary and Path Forward

- SFWST (UFD) Activities (~FY12 => ~FY17) had
  - Reasonably covered many Roadmap priorities
  - Developed/developing bases for multiple Generic Disposal Concepts (Geologic Disposal Safety Assessment; GDSA)
- Disposal Research R&D Issues Gaps Identified
  - Waste package (WP) degradation
  - EBS chemical environment coupled thermal-hydrologic-chemical (THC) processes
  - Such gaps are understandable because these issues
    - Depend on EBS design details and/or site specific conditions
    - Involve the dimensionally most complex aspects
    - Responses were being considered at high-level in the GDSA work
- Safety Assessment (GDSA) Driver for Roadmap Reevaluation and Update
  - Re-evaluate Disposal Research R&D Activities priorities
    - Consider Program Direction, R&D progress, and knowledge levels
    - Top-down (GDSA, e.g., WP degradation) and bottom-up approaches used

2019 Roadmap Update

Phases of a Repository Project and SFWST Campaign Disposal Research



- **Research, Development, and Demonstration (RD&D)**:
  - Demonstrations initially focus on analytical capabilities
  - Characterization/operational demonstrations increase later in a program

2019 Roadmap Update - Granularity of Disposal Research (DR) "Quanta" or "Items"

- 2019 Roadmap Update - the DR *R&D Activities were prioritized*
  - Starting with a mature program of R&D Activities
    - Spans data collection/testing (lab and field), process models, and safety assessment models
  - The R&D Activities generally address multiple features, events, and processes (FEP)
    - Note FEP are mapped and used for a completeness check
  - Target level is *between the fine level of FEP and the broader level of the DR work scope*
- Prior to Workshop - Principal Investigators (PI) Defined Strawman for the
  - R&D Activities (i.e., the "items" to be evaluated and prioritized)
  - The FEP that map to each R&D Activities
  - The relevance/connection to safety assessment (i.e., GDSA)
  - Potential implementation path to safety assessment (i.e., GDSA)
  - Initial importance to safety
- Conduct Workshop for Consensus on the R&D Activities Prioritization

2019 Roadmap Update Workshop and Report

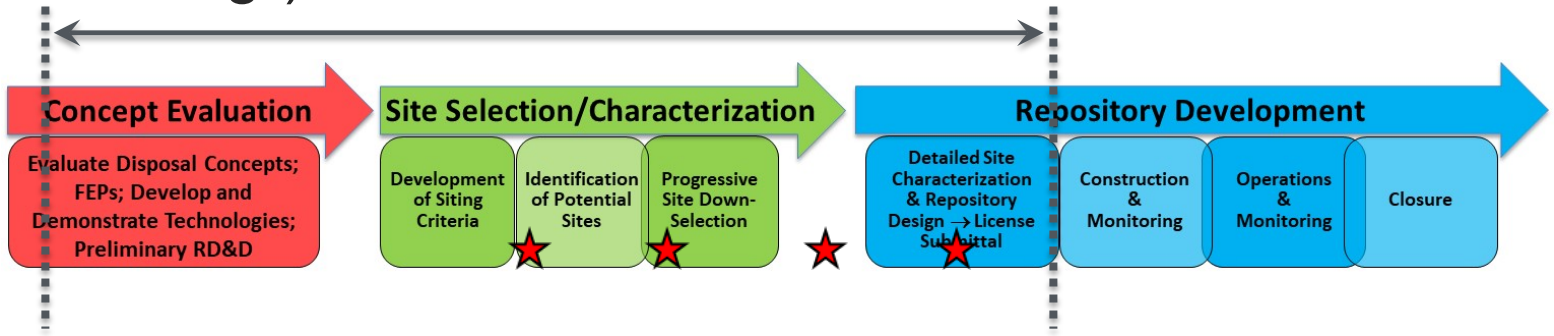
- Workshop Held January 15-17, 2019 in Las Vegas, NV
  - For each R&D Activity
    - Decide upon the State-of-the-Art Level (SAL) rating and justification
    - *Determine the generic R&D still needed* to improve the SAL
    - Brainstorm and add "Gap" Activities, as appropriate
    - Decide upon the Importance to Safety (ISC) rating and justification
  - Evaluations performed in breakout groups for
    - Each host rock
    - Each cross-cutting activity groups
  - Discuss ongoing and "unresolved" integration issues as a group
- 2019 Roadmap Update (Rev01; Sevougian et al., 2019)
  - Assessment of existing R&D activities
  - Identification of research gaps (gap activities)
  - ***Prioritization*** of R&D activities (existing) and gap activities

2019 Roadmap Update - Extensive Team (Sevougian et al., 2019)

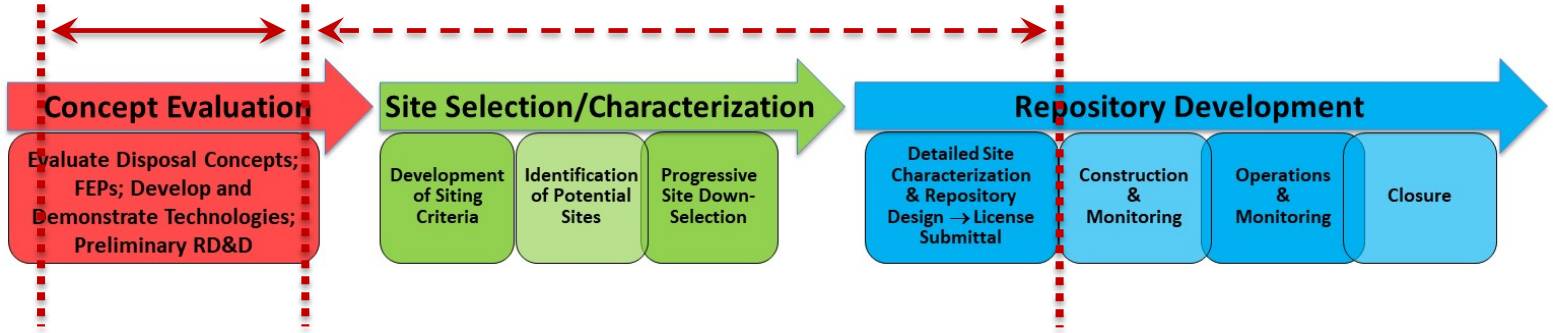
- Co-authors: Paul Mariner, Ralph Rogers, Dave Dobson, Bob MacKinnon, Jeralyn Prouty, Laura Connolly
- Workshop session chairs and rapporteurs, as well as the Technical Leads for the technical areas:
  - Dave Dobson, Argillite Session Chair;
  - Carlos Jove-Colon, Argillite Session Rapporteur and Argillite 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 Integrated Waste Management Campaign experts, national lab staff, and DOE staff who took the time to participate in the Roadmap Update Workshop

2019 Roadmap Update Simplified Prioritization Methodology

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



- 2019 Roadmap Update—generic R&D Activities prioritization emphasized the current mature program to create a simpler priority function (built on previous):



Prioritization Metrics: State-of-the-Art Level and Importance to Safety

- State-of-the-Art Level (SAL) :
  - Five knowledge levels, based fairly closely on the state-of-the-art categories used in the original 2012 Roadmap, but simplified and clarified
- Importance to the Safety (ISC):

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*

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

- The Breakout Groups had a Strawman Initial Set of Values and Rationales
  - Initial cut only – to facilitate discussion in breakout groups
  - The breakout group participants were to develop consensus on the values/rationales in the breakout sessions

2019 Roadmap Update R&D Activity Priority Score

ISC (importance to safety) 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

=

ISC: \ SAL:	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

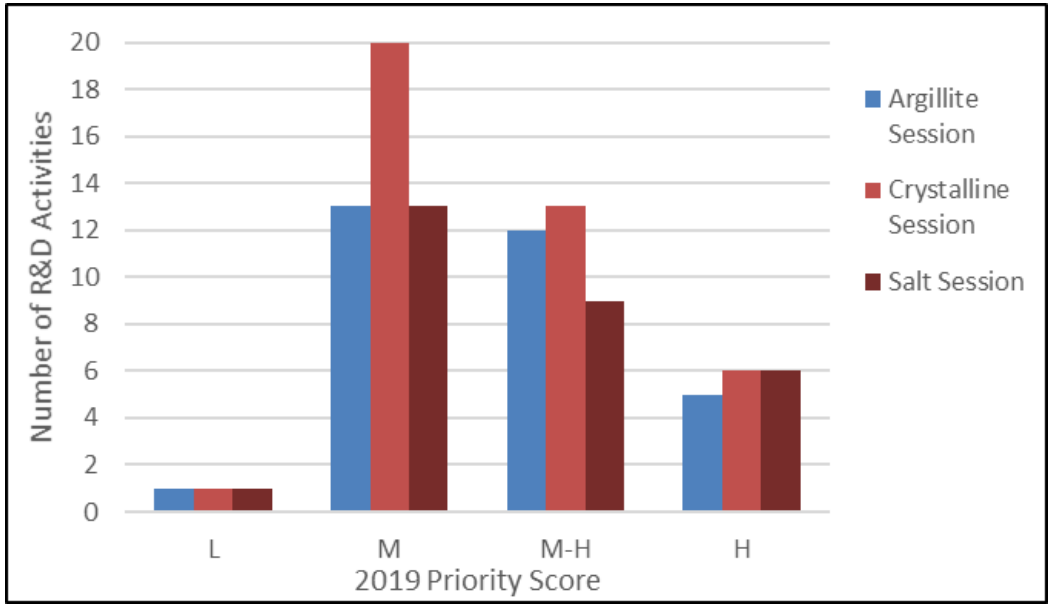
Example Workshop Results – Expert Consensus on Importance to Safety (ISC) and State of the Art (SAL) Values

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

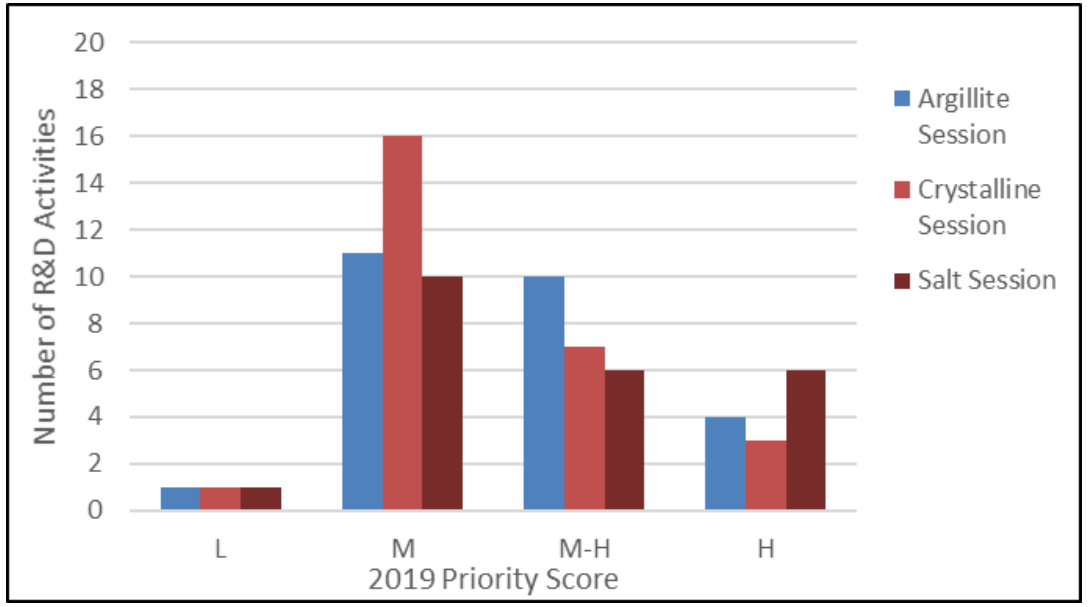
Desc	• Engineered barrier (metal-clay-rock) material interactions & experimental data • Modeling (thermodynamic & reactive transport)Includes temperatures relevant to DPC.Provide chemical constraints for SNF degradation/radionuclide transport.
Type	PM, LT, EA
Codes	PFLOTRAN, CHNOSZ, EQ3/6
Elements	SC 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

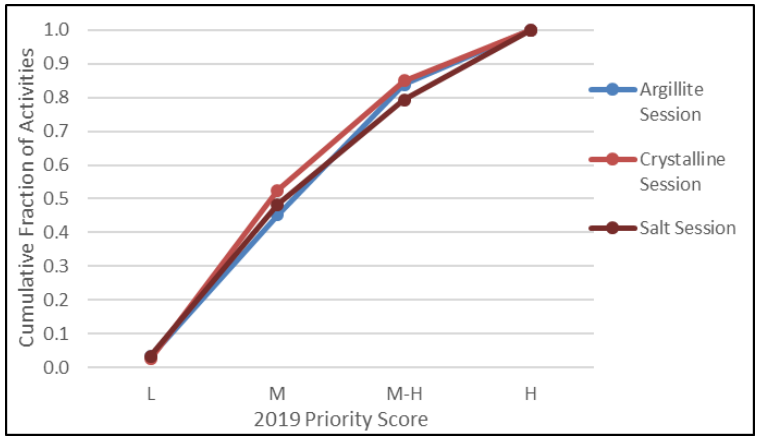
2019 Roadmap Update: Workshop Results – with/without Gap Activities

Histogram of all R&D Activity Scores

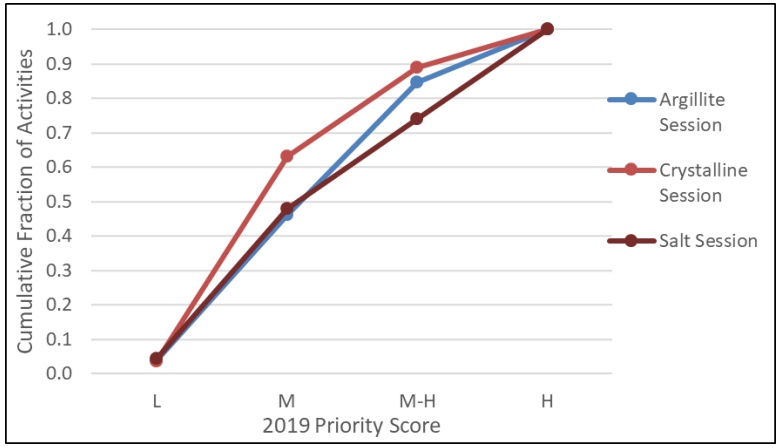


Histogram of "current" Activities (i.e., no "gaps")





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



2019 Roadmap Update: High-Priority R&D Activities

High Priority R&D Activities	
A-08	Evaluation of ordinary Portland cement (OPC)
C-15*	Design improved backfill and seal materials
C-16*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
D-01	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
D-03	DPC filler and neutron absorber degradation testing and analysis
D-04	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
D-05	Source term development with and without criticality
E-09	Cement plug/liner degradation
E-11	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
E-14*	In-Package Chemistry
E-17*	Buffer Material by Design

High Priority R&D Activities	
I-04	Experiment of bentonite EBS under high temperature, HotBENT
I-06	Mont Terri FS Fault Slip Experiment
I-08	DECOVALEX-2019 Task A: Advective gas flow in bentonite
I-12	TH and THM Processes in Salt: German-US Collaborations (WEIMOS)
I-13	TH and THM Processes in Salt: German-US Collaborations (BENVASIM)
I-16*	New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling
I-18*	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport
P-12	WP Degradation Model Framework
S-01	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
S-03	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
S-04	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
S-05	Borehole-based Field Testing in Salt

Activity Designator Legend:

A – Argillite

C – Crystalline

S – Salt

D – Dual Purpose Canisters

E – Engineered Barrier System

I – International

O – Other

P – Performance Assessment

* – indicates Gap Activity

2019 Roadmap Update: High Impact Topic Groups with High and Medium-High Priority R&D Activities Scores

High Impact R&D Topics	High-Priority R&D Activities	Medium-High-Priority R&D Activities
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
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-3, D-4, D-5	
Waste Package Degradation	C-16*, P-12	E-4*, E-6
In-Package Chemistry	E-14*	E-2, E-20, P-15*, P-16*
Generic PA Models		P-1, P-2, P-4, P-11*, P-13*, P-14
Radionuclide Transport		C-11*, C-13*, C-14*, P-15*, P-16*
DFN Issues		I-21*, C-1, C-17*
GDSA Geologic Modeling		O-2, O-3
THC Processes in EBS		E-3

Activity Designator Legend:

A – Argillite
C – Crystalline
S – Salt
D – Dual Purpose Canisters
E – Engineered Barrier System
I – International
O – Other
P – Performance Assessment
* – indicates Gap Activity

2019 Roadmap Update Insights

- Much generic R&D accomplished since 2012 Roadmap:
  - U.S. generic concepts matured via both
    - U.S. Program R&D
    - International collaborations (most in URL)
  - State-of-the-art knowledge level (SAL) had improved for many R&D Issues
- 2019 Update Indicates Continuing Generic R&D focused on
  - High Impact Topic Groups (multiple Activities)
  - Several other Activities (individual)
- There were Program Directed New Priorities
  - For example, expanded Dual Purpose Canister studies
- GDSA Models Provide Information Relevant for the Importance to Safety of R&D Activities

Summary and Look Ahead

- Planning/Prioritization for Generic Disposal Concept RD&D Includes
  - Evaluating safety of multiple generic geologic systems
  - International collaboration (site specific foreign programs/underground laboratories)
  - Program direction changes
- 2012 Roadmap Priorities and Assessment
  - R&D through 2017 reasonably covered 2012 Roadmap priorities (some gaps)
    - Primarily model-based, targeted experiments/testing, integrated international data, models, and collaboration
- 2019 Roadmap Update
  - Prioritized Disposal R&D Activities and identified Gap Activities
  - Synthesized High-Impact Topic Groups, and several other priority R&D Activities
    - Needed generic R&D identified by consensus of Program experts
      - 3-day decision-analysis Update Workshop (January 2019)
- Program R&D Progress Synthesis and Updated Prioritization used for Disposal Research Annual Five-Year Plan (Sassani et al., 2020 – Final Presentation)

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