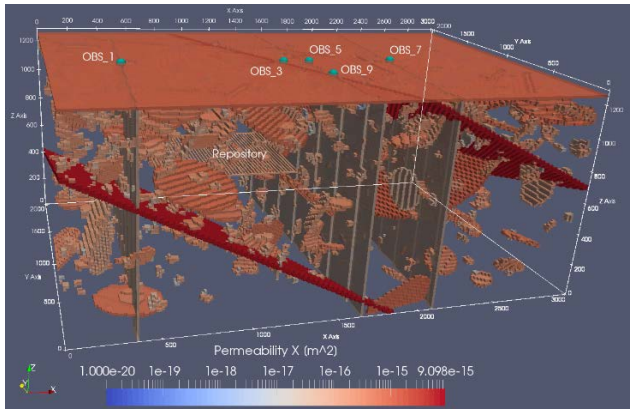


Overview of Disposal R&D Activities

David Sassani

Sandia National Laboratories

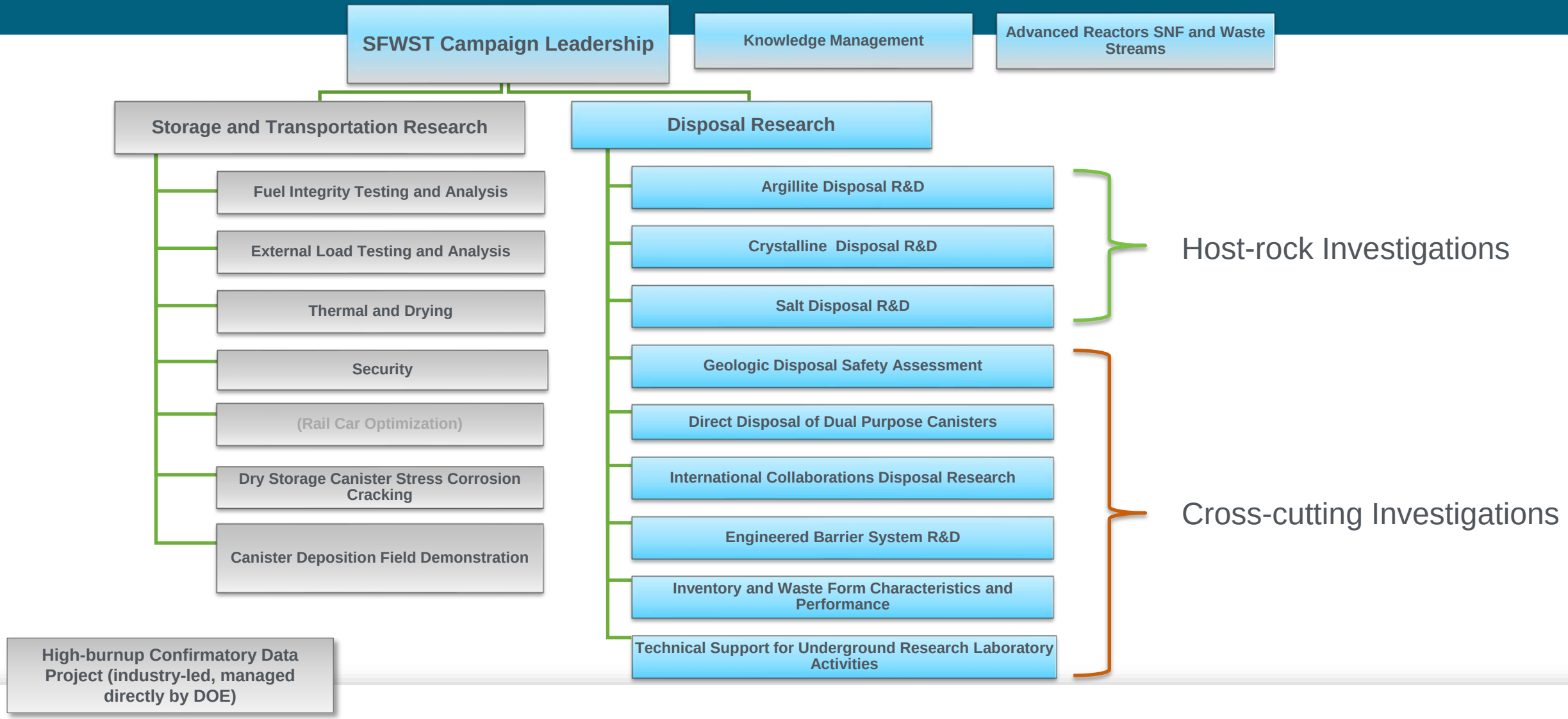
SFWST National Technical Director

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2024-06184PE

Overview of Presentation Materials

- Overview of Program
  - Program technical coverage
  - Disposal concepts – research, development, demonstration
  - Disposal program conceptual schedule
- Capability Development and Demonstrations
- Processes to Assess SFWST Disposal Research (DR) Activity Progress
  - DR Program Planning
    - 2012 Roadmap and assessment
    - 2019 Roadmap reevaluation/gap analysis
    - DR Five-year Plan
  - Geologic Disposal Safety Assessment (GDSA) Framework
  - Roadmap reimagination and Features, Events, and Processes (FEP) Tool
- Summary

FY 24 SFWST R&D Campaign Structure (EVOLVING)



Program Strategic Focus: Disposal Research (DR)

Provide a **sound technical basis for multiple** viable disposal options in the US

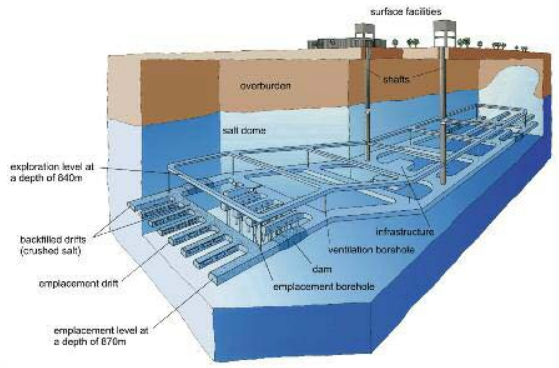
- Spent nuclear fuel (SNF)
  - Commercial
  - DOE-managed
- High-level nuclear waste (HLW)

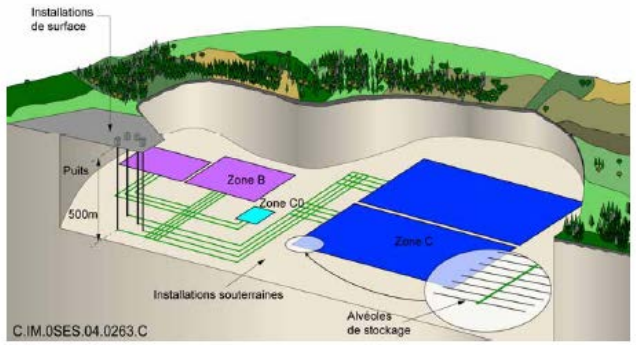
Increase confidence in the robustness of generic disposal concepts

Develop the science and engineering tools needed to support disposal concept implementation

Salt Repository Example

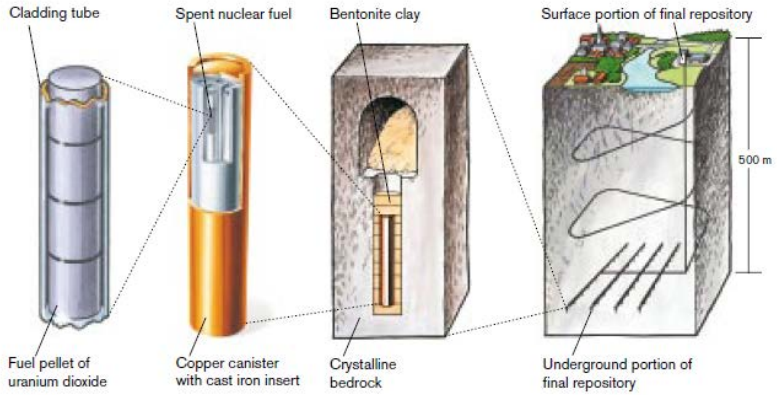
Gorleben, Germany (BMWi 2008)





Argillite Repository Example

Meuse/Haute Marne, France (ANDRA 2005)



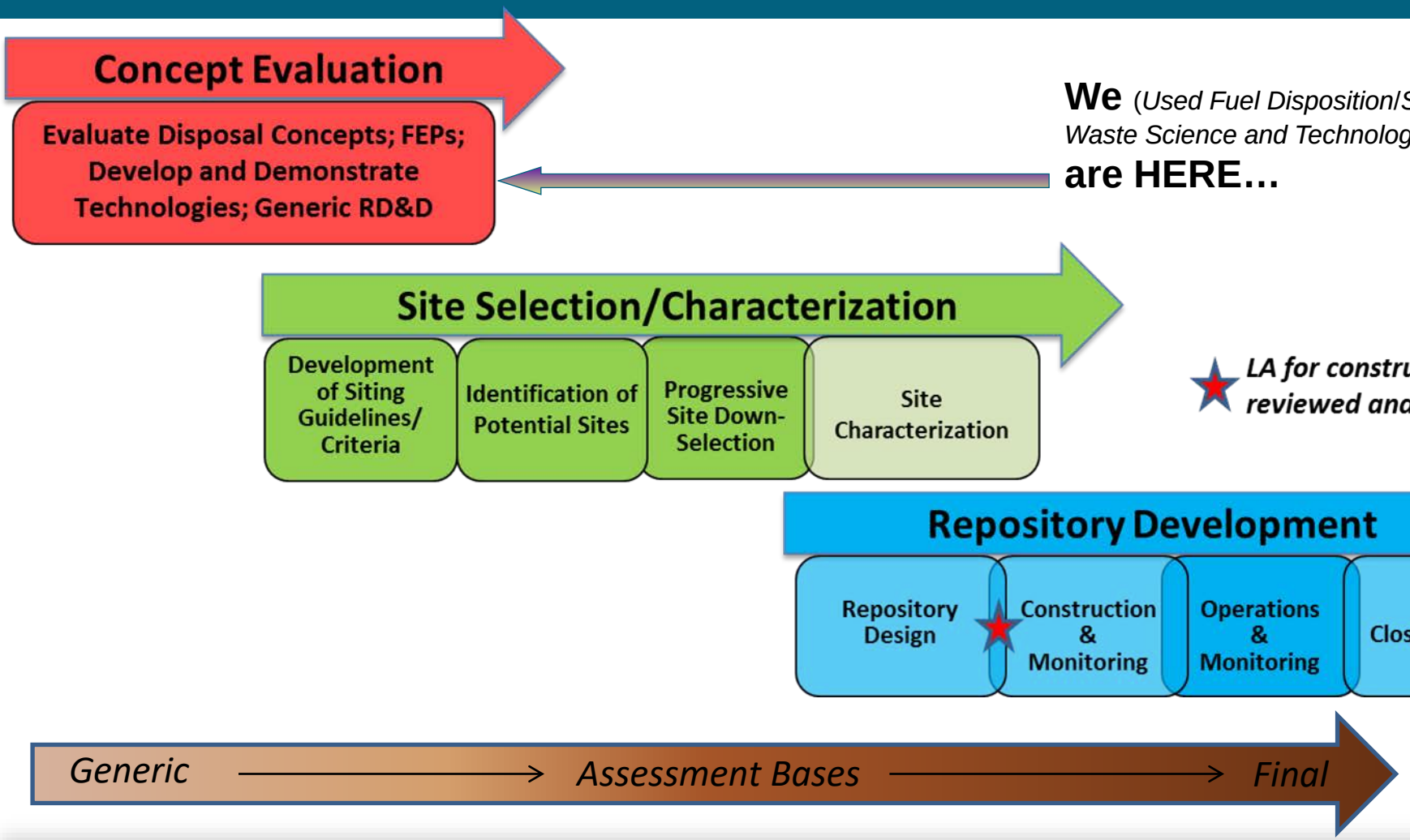
Crystalline Repository Example

Forsmark, Sweden (SKB 2011)

https://www.posiva.fi/en/index/finaldisposal

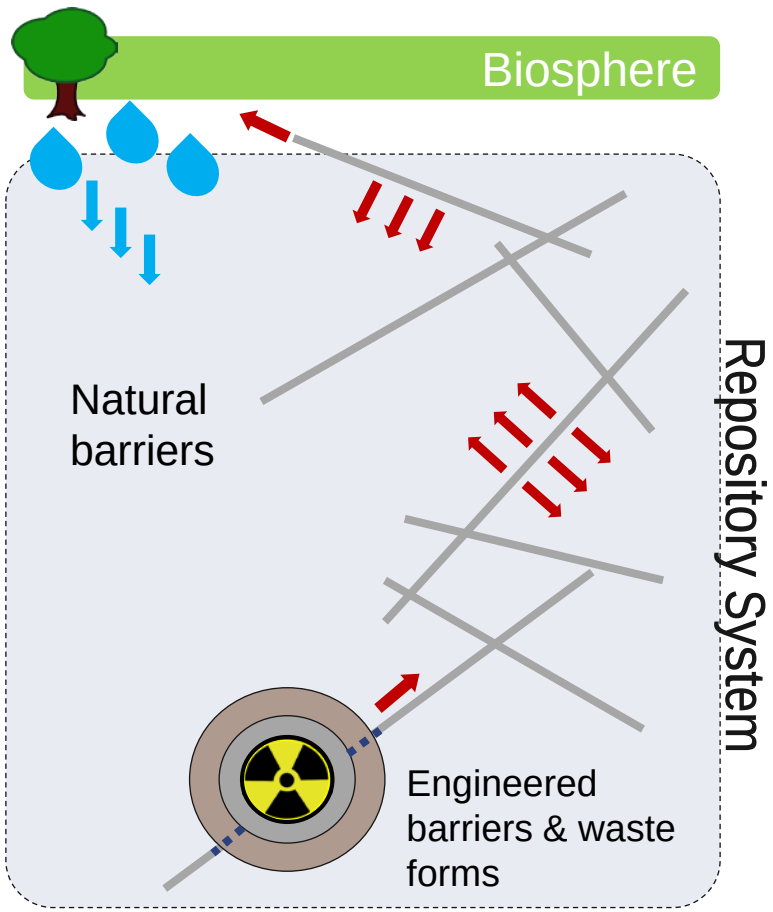
- Wide range of geologic disposal concepts
  - Prioritize the generic R&D for each
  - Define complete enough for generic R&D
- Utilize & contribute to vast international experience
- Integrate cross-cutting aspects clearly
- ***Poise Program to Leap*** into Next Stage

Disposal Research (DR) Program Conceptual Timeline



- **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**

How Repositories Work: Basic Barrier Functions



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

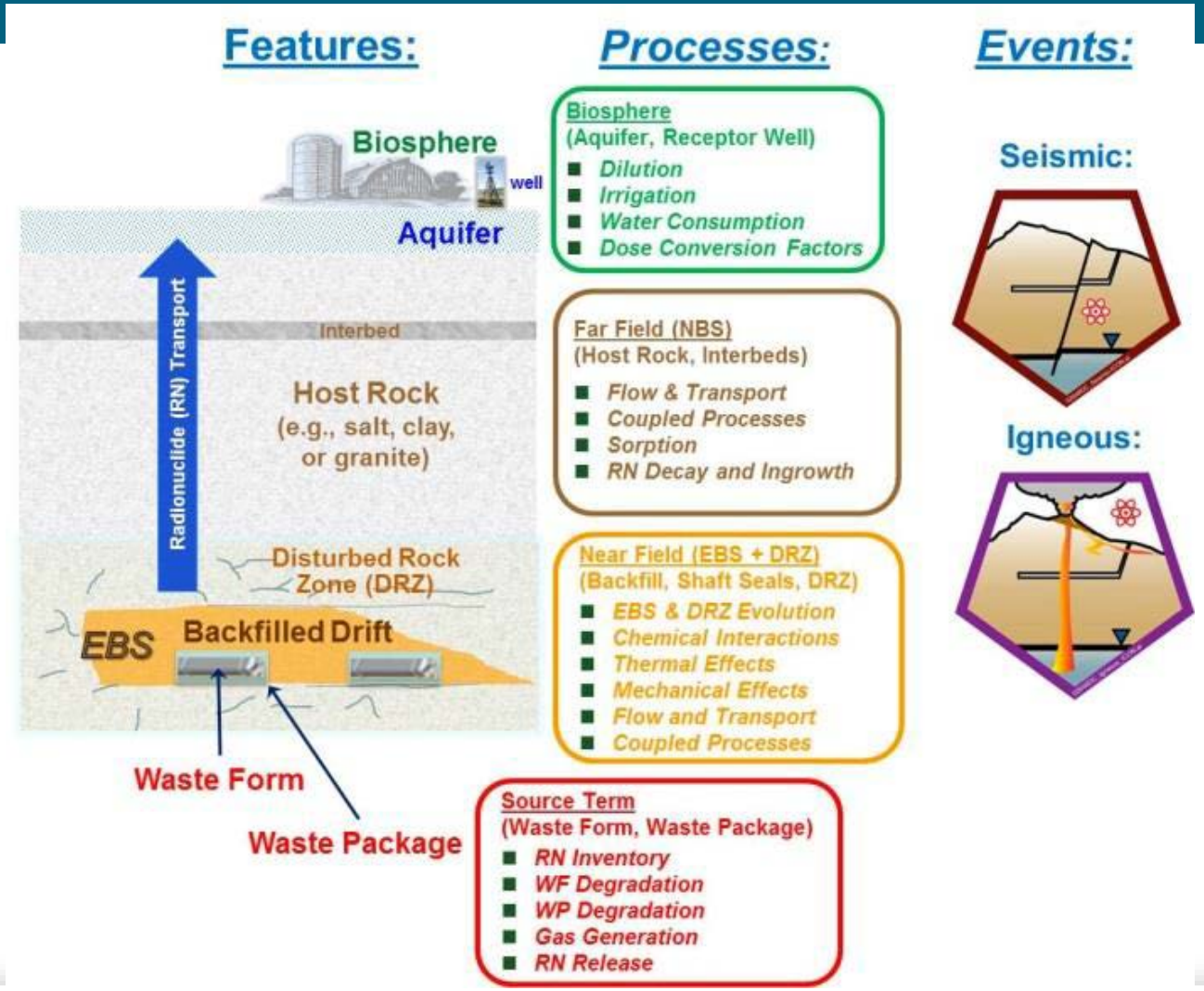
Water Flow & Time (radioactive decay)

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

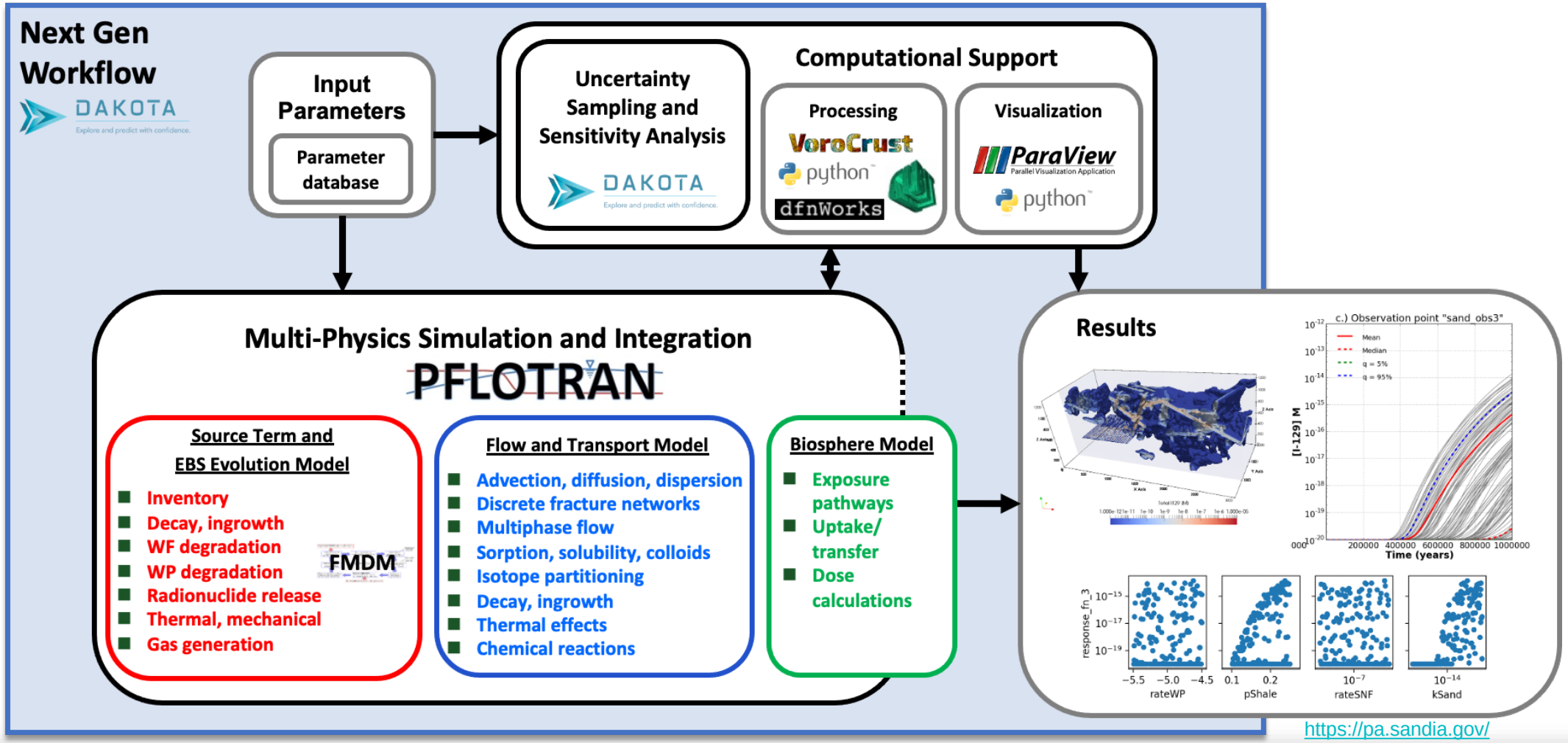
Isolation mechanisms may differ for different radionuclides in different disposal concepts

Features, Events, and Processes (FEP)

- **Features** are physical components of the repository system.
- **Processes** are phenomena that act continually over a long time scale.
- **Events** are phenomena that occur over a short time scale.
- FEP are evaluated and screened for either being
  - Included into, or
  - Excluded from
- The Geologic Disposal Safety Assessment Model (GDSA) of the System Performance



The Geologic Disposal Safety Assessment (GDSA) Model



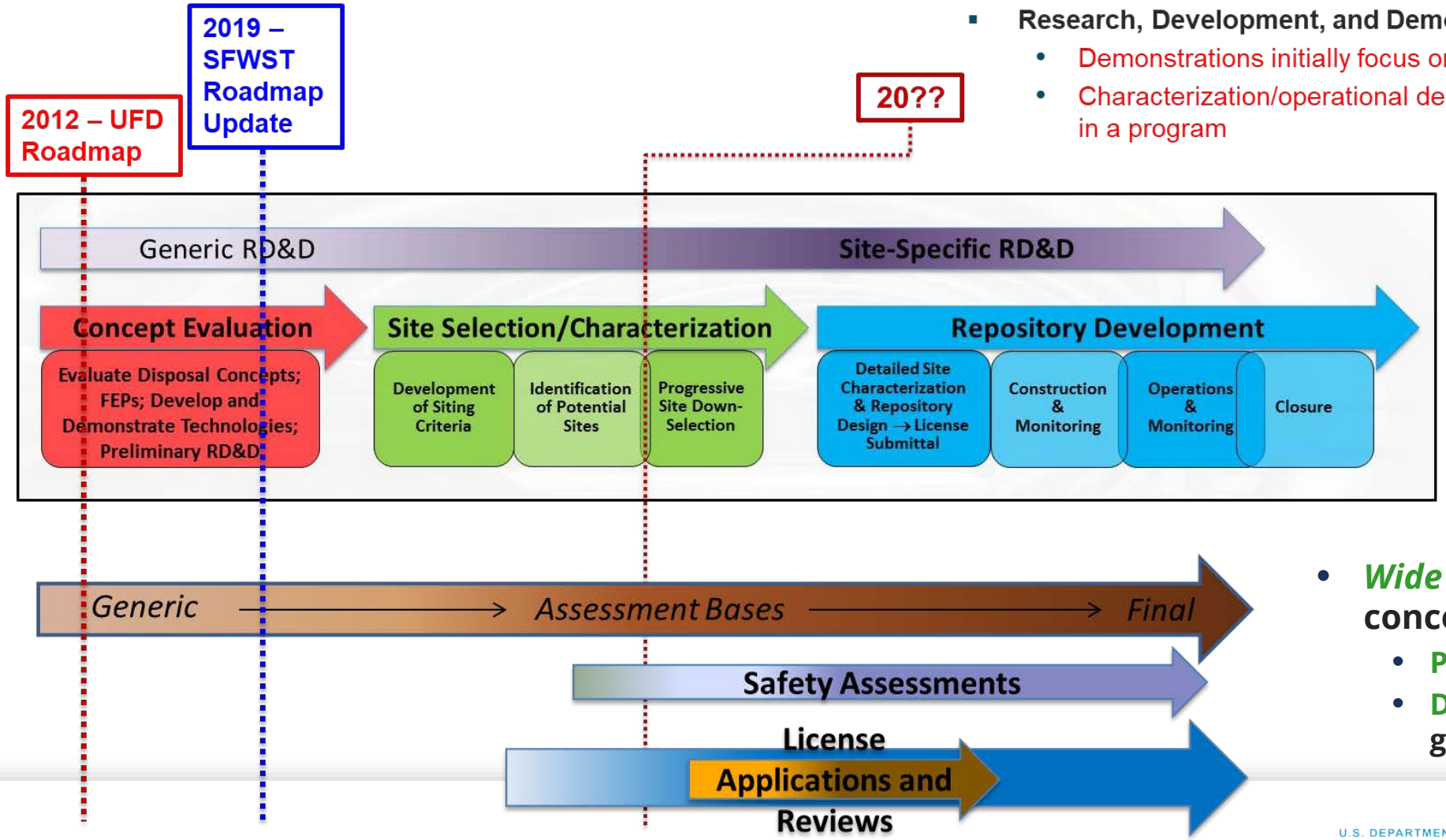
https://pa.sandia.gov/

https://www.nwtrb.gov/meetings/past-meetings/fall-2021-virtual-board-meeting---november-3-4-2021

Capability Demonstrations – Not Safety Assessments

- Demonstrations Build Capabilities/Process Understanding
  - Huge Dinner Party (not just family)
    - Practice meal preparation (until enjoyable or servable?)
    - Iterate cooking and refine ingredients, timing, thermal, technique…
  - Sports or Arts Performances (Paint/Music/Dance)
    - Practice, practice, practice…build skills/know-how/strengths, refine technique…
  - Good Fortune: Develop New Home Plans
    - Where, how big, # floors/levels, plumbing, heating/cooling, roof type…
    - Prelim/draft/final Floor Plans are NOT your New Home
- Features, Events, and Processes (FEP) Evaluations
- GDSA Capabilities Demonstrations

Phases of a Repository Project and Disposal Research



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

- ***Wide range*** **of geologic disposal concepts: challenges:**
  - **Prioritize the generic R&D for each**
  - **Define complete enough for generic R&D**

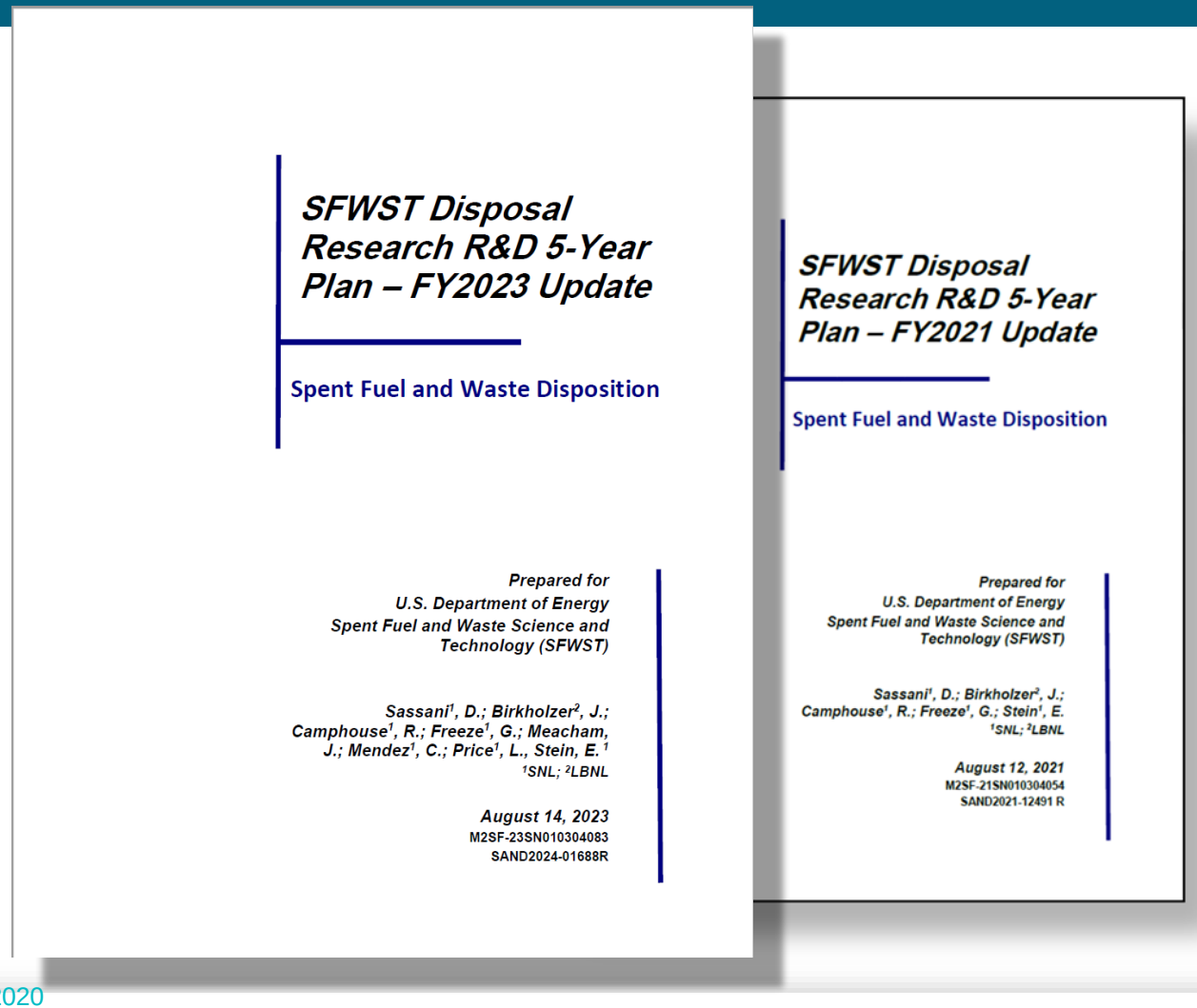
Plan/Prioritize/Status DR Activities – Program Scale

- Used Fuel Disposition (UFD) Campaign 2012 Roadmap
  - Features, Events, and Processes (FEP) gap assessment synthesis
  - Synthesize into High Priority Topics for UFD Campaign work planning
  - 2012 Roadmap Report (Rev. 01; 2012)
- 2019 Roadmap Update
  - Review/prioritize DR Activities for progress, gaps, and recent Program Direction
    - Begin assessment of DR R&D Program in FY2017
  - 2019 Roadmap Update Report (Rev. 01; 2019)
- 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)

https://www.nwtrb.gov/meetings/past-meetings/fall-2020-board-virtual-meeting----december-2-3-2020

Disposal R&D Strategic 5-Year Plan (2023)

- Builds Upon
  - 2012 Roadmap Report (Rev. 01, 2012)
  - 2019 Roadmap Update Report (Rev. 01, 2019)
  - DR 5-Year Plan (2020; 2021)
- Short-term *Primary Objectives* (1-2 years; relatively certain)
- Longer-term *Vision* (3-5 years; general guide)
- *Progress Updates*



https://www.nwtrb.gov/meetings/past-meetings/fall-2020-board-virtual-meeting----december-2-3-2020

GDSA Framework Summary

- GDSA Framework Development Guided by
  - Roadmap
  - FEP analyses
  - DR 5-yr plan
  - International influences
- Model Capability Development Decisions Rely on
  - Readiness considerations
  - Prioritization considerations
- Framework Provides Status of GDSA Model Capabilities

GDSA Status of Generic FEP screening (from Vaughn et al. 2012)

Source (Inventory and Waste Form)
- Radionuclide inventory (heat generation, decay and ingrowth)
- Waste form degradation (dissolution processes)
- *Gas generation*
- Radionuclide release and transport (mobilization, early release [e.g., from gap and grain boundaries], precipitation/dissolution)

Near Field (Waste Package, Buffer, Backfill, Seals/Liner, and DRZ)
- Waste package degradation (corrosion processes, mechanical damage, early failures)
- Evolution/degradation of EBS components and DRZ
- *Effects from rockfall, drift collapse (e.g., salt creep)*
- Fluid flow and radionuclide transport (advection, dispersion, diffusion, sorption, decay and ingrowth)
- Chemical interactions (aqueous speciation, mineral precipitation/dissolution, *reaction with degraded materials*, surface complexation, radiolysis)
- Thermal effects on flow and chemistry
- *Effects from disruptive events (seismicity, human intrusion)*

Far Field (Host Rock and Other Units)
- Fluid flow and radionuclide transport (advection, dispersion, diffusion, sorption, decay and ingrowth)
- Effects of fracture flow (e.g., dual porosity/permeability, discrete fracture)
- *Groundwater chemistry*

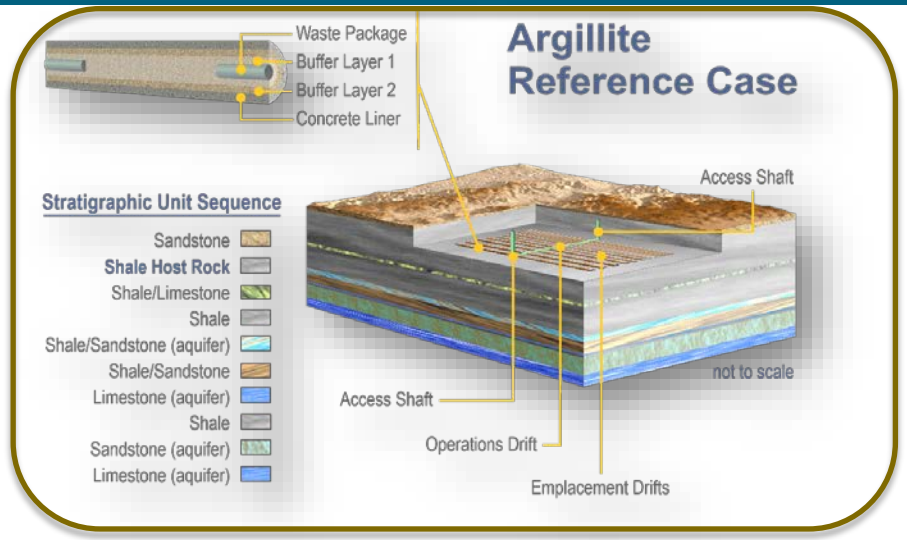
Receptor (Biosphere)
- Dilution due to mixing of contaminated and uncontaminated waters
- Receptor characteristics (basis for converting radionuclide concentrations in groundwater to dose)

Key
Red = FEP included, at least to some degree
Black = FEP capability lacking or excluded so far

DRZ – Damaged Rock Zone
EBS – Engineered Barrier System

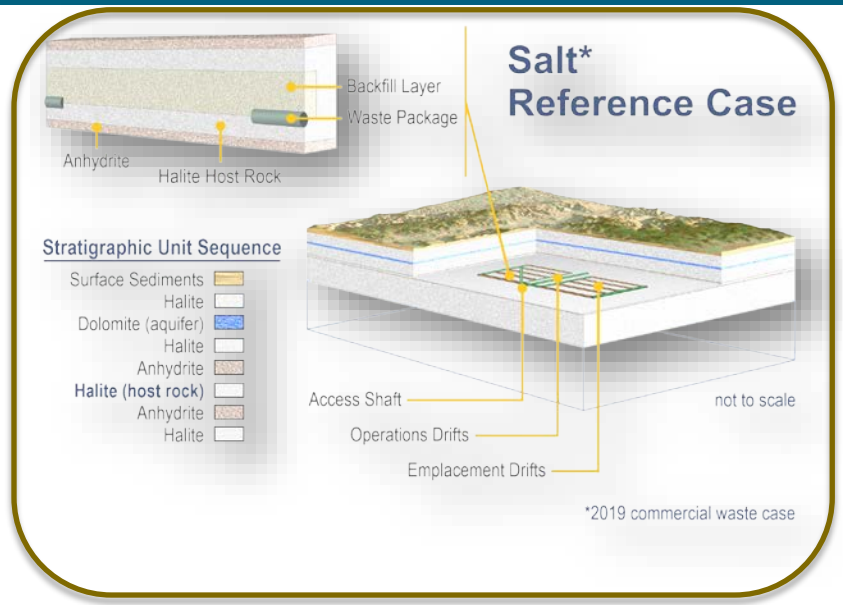
- Features, Events, and Processes (FEP)
  - Many excluded FEP (or yet-to-be-implemented FEP) are chemical, mechanical, and disruptive FEP

Geologic Disposal Safety Assessment (GDSA) is Applicable to Multiple Generic Disposal Concepts



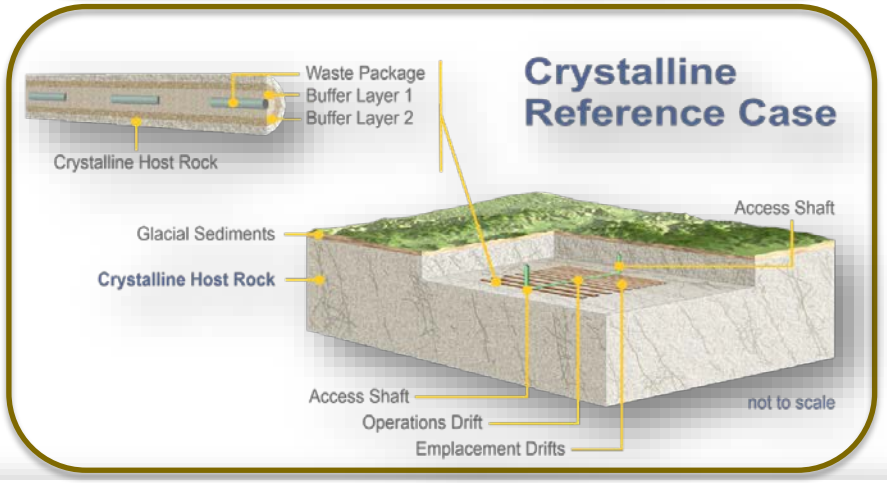
For example:
- France
- Switzerland

https://www.nwtrb.gov/meetings/past-meetings/summer-2022-board-meeting---september-13-14-2022



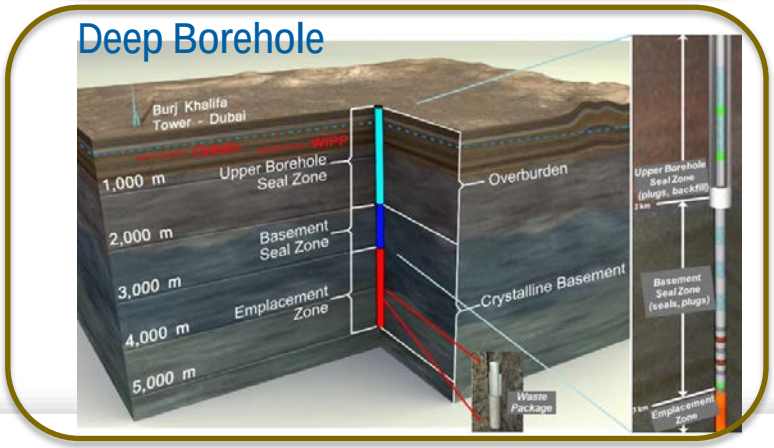
Considered by:
- Germany
- Netherlands

https://www.sandia.gov/salt/home/bats-field-heater-test/



For example:
- Sweden
- Finland

https://www.posiva.fi/en/index/finaldisposal

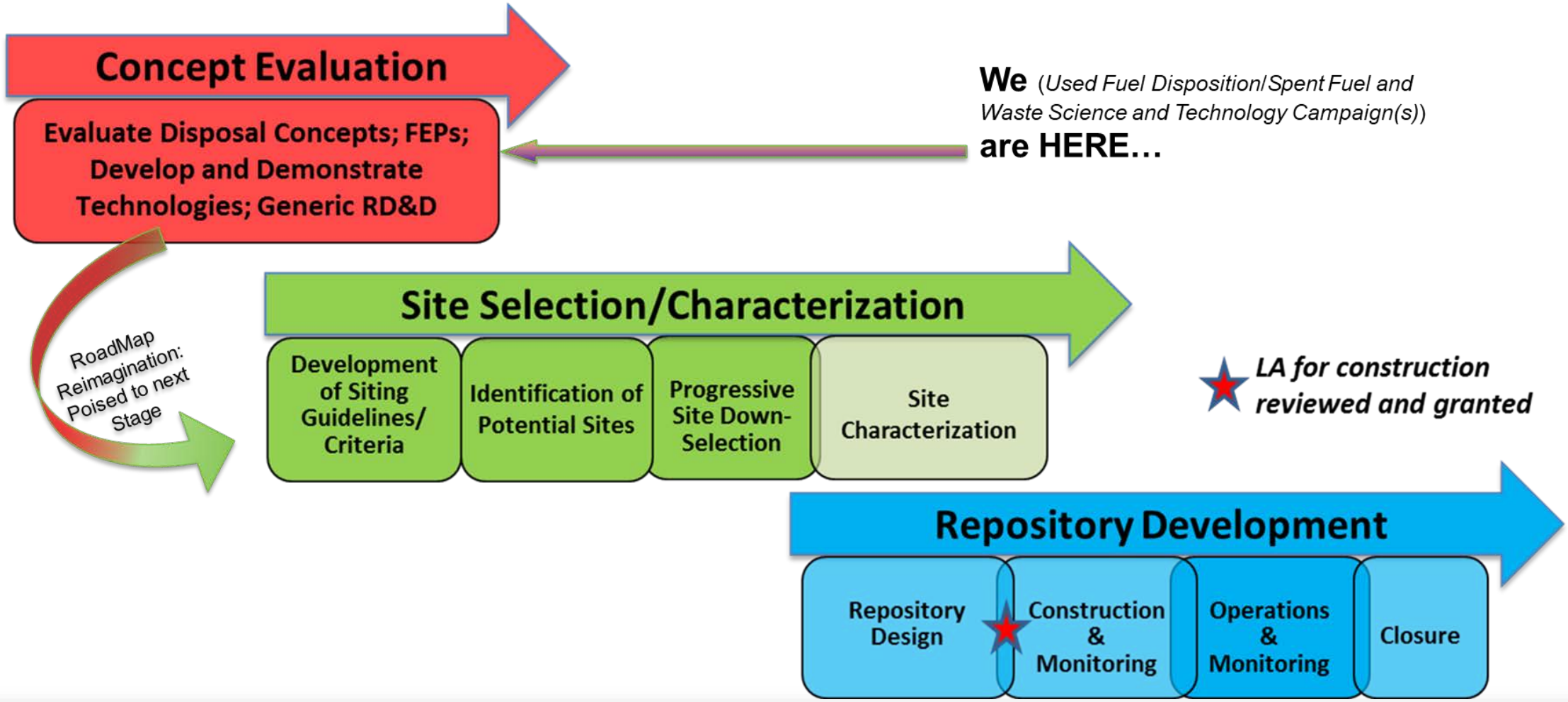


https://energy.sandia.gov/programs/nuclear-waste-management/geologic-disposal-of-nuclear-waste

https://www.iaea.org/publications/14759/underground-disposal-concepts-for-small-inventories-of-intermediate-and-high-level-radioactive-waste

https://www.nwtrb.gov/meetings/past-meetings/board-workshop-2015

DR Progress Will Poise Program to Enter the Next Stage



Features, Events, and Processes (FEP) Database Overview

- Historical Information
  - Generic FEP Defined in 2010
  - YMP & WIPP FEP
  - 2012 Generic FEP Prioritization Results
  - 2010-12 FEP Screening Results for Shale, Crystalline, and Salt
  - 2019 Roadmap Update Activities
  - Reference Cases for Shale, Crystalline, and Salt Defined in Earlier Reports (possibly others in the future)
- General Integration Information – Program Management Team
  - Tied to Thrusts Defined in 5-Year Plan
  - Reports Support Decision Making by Management
  - Database Will Provide Documentation of Progress

FEP Database/Tool Objectives

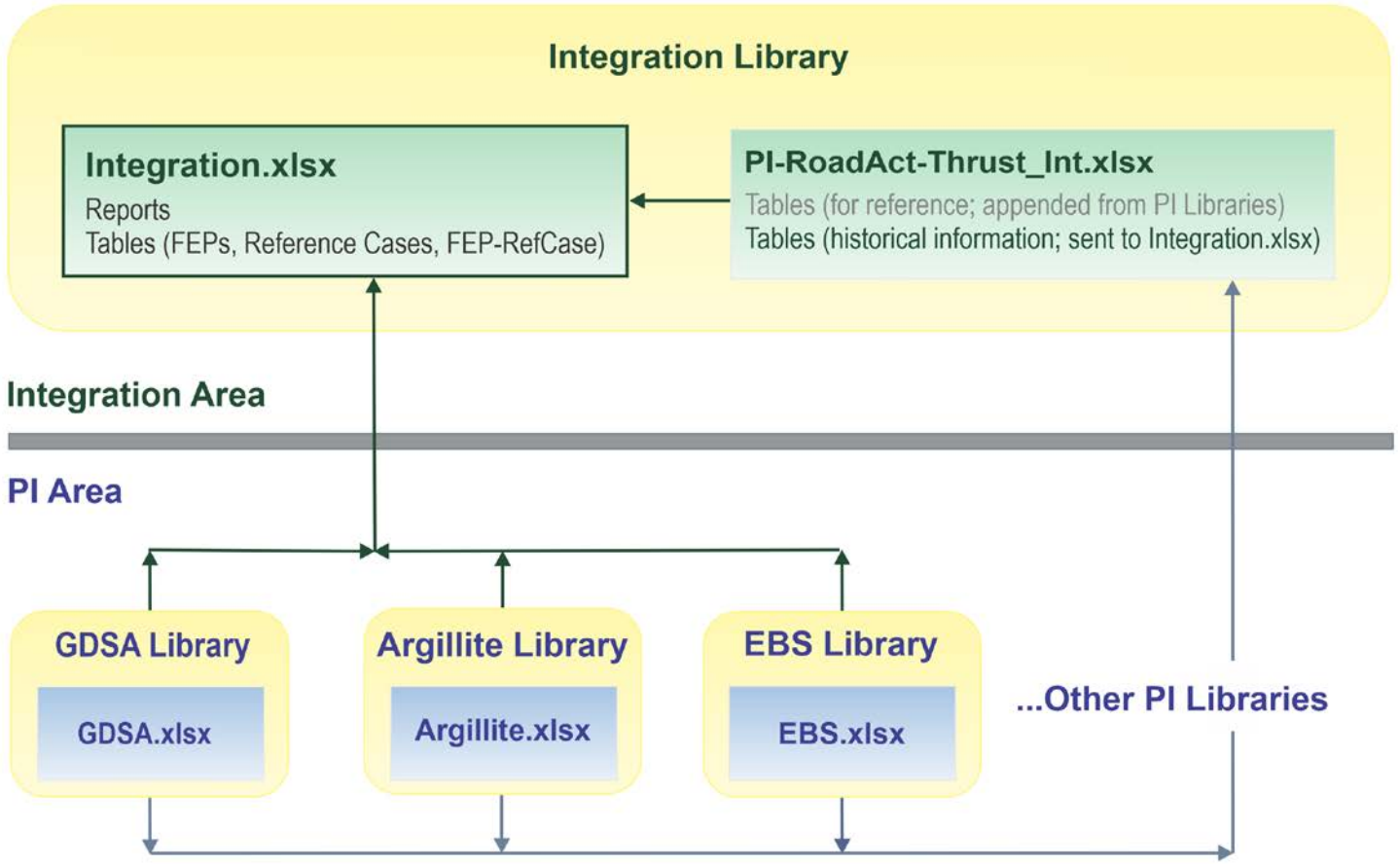
- Use FEP Tool to *Organize*, *Integrate*, and *Status* Activities
  - Online database as planning tool
  - Ties work activities to program thrusts/priorities
  - Each work activity maps to detailed FEP being addressed
  - Documents
    - Activity screening approach for GDSA (in/exclude)
    - Approach for intended inclusion into GDSA
    - Time/effort to complete and extent complete
- *Demonstrate Progress* Toward Program Objectives - Status
- Use for *Continuous* Program *Improvement*
  - Updates to DR 5-year Plan
  - DR Program Roadmap revisions

FEP Database Inputs

Focused on Work Activities

- Principle Investigators (PI) Define Annual Work Activities
  - Control Account
  - Activity Name and Description
  - Implementation (% Complete)
  - Level of Effort
  - FY to Complete
- PI Map Work Activities to Thrusts (*DR 5-yr Plan*)
- PI Map Work Activities to *Roadmap* Update Activities
- *PI Map Work Activities to FEP or subFEP*
  - Results May Support Inclusion in GDSA
  - Results May Provide Justification for Exclusion from GDSA

FEP Database System Architecture



PI Excel files have tables for Activities, Gaps, mapping Activities to Thrusts, mapping Activities to 2019 Roadmap Activities, and mapping FEP-RefCase to Activities and/or Gaps.

Example Input Table (1 of 2)

	A	B	C	D	E	F	G	H
1	Activity ID	Control Account	Work Package	Activity Name	Activity Description	ISC	ISC Rationale	Implementation (%
2	ACT-GDSA-101	GDSA	PFLOTRAN	Agile/Jira system	Software configuration and management			10
3	ACT-GDSA-102	GDSA	Biosphere	Biosphere modeling	Multi-path radionuclide biosphere model for PFLOTRAN repository PA			5
4	ACT-GDSA-103	GDSA	Framework & PFLOTRAN	Buffer erosion	Add Neretnieks et al. (2017) crystalline repository buffer erosion model to PFLOTRAN			2
5	ACT-GDSA-104	GDSA	PFLOTRAN	Buffer evolution	Add smectite-illite transition model to PFLOTRAN			10
	ACT-GDSA-105	GDSA	RSA & Framework	DECOVALEX-2023 Task F:	Lead repository PA modeling comparisons			8

Example Input Table (2 of 2)

	E	F	G	H	I	J	K	L
	Activity Description	ISC	ISC Rationale	Implementation (%)	Implementation Notes	Effort	FY to Complete	Planning Notes
	Software configuration and management			100%	Running well. Annual maintenance required	Medium	2023	Completed
	Multi-path radionuclide biosphere model for PFLOTRAN repository PA			50%	Pathways largely incorporated for several radionuclides. More to do for certain radionuclides.	High	2028	On schedule
	Add Neretnieks et al. (2017) crystalline repository buffer erosion model to PFLOTRAN			20%	1) Conceptual and mathematical models developed and documented; 2) coding in mapDFN and PFLOTRAN underway	Medium High	2024	On schedule
	Add smectite-illite transition model to PFLOTRAN			100%	Model added to PFLOTRAN. Additional features being considered.	Medium High	2023	Completed
3	Lead repository PA modeling comparisons			85%	Completed models and analyses. Writing final	Medium High	2024	On schedule

FEP Database Future

FEP Database Is in Initial Stage of Development. In the Future, It Will…

- Become an *Integral* Part of *Annual Planning*
- Support Future *Roadmap Update* Activities/Long-Term Planning
- *Document* the *Status* of the GDSA Model, FEP Screening
  - For all generic repository concepts
- *Identify Gaps* and *Overlaps* To Be Addressed
- Identify/*Improve* PI *Integration* – All Activities Apparent
- *Make Efficient* Use of *Resources*

Summary

- Program Shift to Disposal Research and Development Focus
  - Currently within generic conceptual disposal system stage
- Capability Development and Demonstrations for Generic Concepts
  - Poise the program to move to the next stage in ~ 2 years
  - Conceptual schedule for disposal programs covers multiple decades
  - Use U.S. and International experience to efficiently progress through stages
- Processes to Assess SFWST Disposal Research (DR) Activity Progress
  - Program-scale Roadmap (~every 7 years) of detailed R&D
  - Disposal Research Five-year plan with 2-year focus and 3- to 5-year outlook
  - Geologic Disposal Safety Assessment (GDSA) Framework
    - Status of what is in the GDSA Capability
- Move to Roadmap Reimagination: Prepare for Next Stage
  - FEP Database Tool for activity status, prioritization, integration, and Program efficiency

Questions?

References

- ANDRA (Agence nationale pour la gestion des déchets radioactifs), 2005. Dossier 2005: Argile. Synthesis: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation. Châtenay-Malabry, France: ANDRA (English translation: original documentation written in French remains ultimately the reference documentation).
- BMWi (Federal Ministry of Economics and Technology, Germany) 2008. *Final Disposal of High-Level Radioactive Waste in Germany—The Gorleben Repository Project.* Berlin, Germany: Federal Ministry of Economics and Technology (BMWi). Available at http://bmwi.de/EN/Service/search.html.
- IAEA (International Atomic Energy Agency) 2013. "Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes," IAEA Nuclear Energy Series No. NW-T-1.24, Vienna, 2013.
- MacKinnon, R. J. 2016. *Safety Case – Iterations from Generic Studies to License Application*, SAND2016-8636PE, presented to JRC (EU Joint Research Centre), Ispra, Italy, September 12-16, 2016.
- McMahon, Kevin A., Bragg-Sitton, Shannon, Mackinnon, Robert James, Saltzstein, Sylvia J., Sorenson, Ken B., Swift, Peter N., and Birkholzer, Jens T. *Update of the Used Fuel Disposition Campaign Implementation Plan.* United States: N. p., 2014. Web. doi:10.2172/1172802.
- 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.
- Sassani, D. C., *Roadmap Overview and SFWST Progress*. Presented at SFWST Annual Working Group Meeting, Las Vegas, NV, May 2018. SAND2018-5167 PE, Sandia National Laboratories, May 22, 2018.
- Sevougian, S. D. and R. J. MacKinnon 2017. "Technology Readiness Assessment Process Adapted to Geologic Disposal of HLW/SNF," in *Proceedings of the IHLRWM 2017 Conference*, April 9 – 13, 2017, Charlotte, NC USA, SAND2017-0179C.
- Sevougian, S. D., G. E. Hammond, P. E. Mariner, R. J. Mackinnon, P. N. Swift, R. D. Rogers, D. C. Dobson and M. C. Tynan (2019a). "Re-Evaluation of U.S. DOE R&D Efforts for Generic Deep Geologic Repositories – Roadmap Update," in *Proceedings of IHLRWM 2019 Conference*, April 15-18, 2019, Knoxville, Tennessee.
- Sevougian, S. D., P. E. Mariner, L. A. Connolly, R. J. MacKinnon, R. D. Rogers, D. C. Dobson and J. L. Prouty (2019b). *DOE SFWST Campaign R&D Roadmap Update, Rev. 1.* SAND2019-9033 R, July 22, 2019. Sandia National Laboratories, Albuquerque, New Mexico.
- 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.
- Used Fuel Disposition Campaign, DOE-NE (UFDC), 2012, *Used Fuel Disposition Campaign Disposal Research and Development Roadmap,* U. S. Department of Energy Used Fuel Disposition Campaign, FCR&D-USED-2011-000065 REV 1.