SAND2018-5167PE

Spent Fuel and Waste Science and Technology

Roadmap Overview and SFWST Progress

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Sandia National Laboratories

SFWST Annual Working Group Meeting

Las Vegas, Nevada

May 22-24, 2018

Acknowledgment: *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-NA-0003525. SAND2018-XXXX PE.*

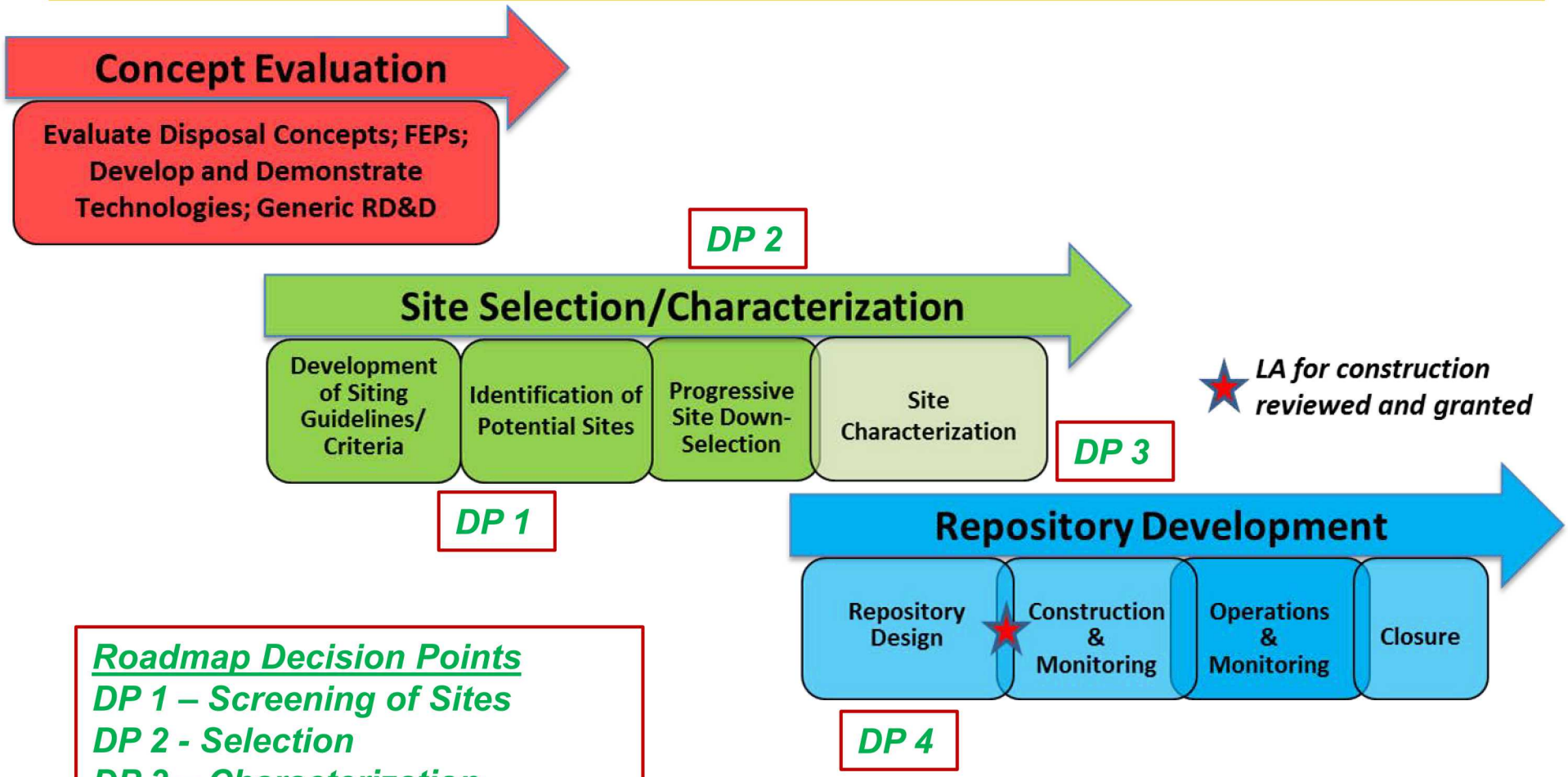
Presentation Outline

- **Objective - Program Integration and Planning**
- **Generic Safety Case**
- **UFD R&D Roadmap (Rev 01 2012)**
  - Roadmap bases
  - R&D priorities
- **UFD Program Progress on Roadmap Priorities**
  - Accomplishments
  - Evolution of R&D focus
- **Integration of R&D Activities within Generic Safety Case**
  - Experiments/testing
  - International
  - Modeling

Safety Case and Safety Assessment

- **License Application (LA) for Construction Authorization**
  - Documentation that demonstrates the repository implementer satisfies all regulatory and technical requirements applicable to the repository and constitutes an adequate basis for the regulator to exercise its statutory licensing authority. *The LA is a comprehensive* ***Safety Case***.
- **Safety Case (Definition from Outcomes of the NEA MeSA Initiative, OECD 2012)**
  - "A safety case is the *synthesis of evidence, analyses and arguments that quantify and substantiate* a claim that the repository will be safe after closure and beyond the time when active control of the facility can be relied on."
- **Post-Closure Safety Assessment (or Performance Assessment)**
  - A *quantitative assessment of repository performance* that evaluates the long-term behavior of a repository, including the ability of the repository barriers to perform their safety functions, and plays a key role in substantiating that a repository will be safe and comply with regulatory safety requirements.

Disposal Program Conceptual Timeline



Roadmap Decision Points
DP 1 – Screening of Sites
DP 2 - Selection
DP 3 – Characterization
DP 4 - Suitability

Schematic Repository Project Timeline
(and maturation of safety case)

U.S. Program currently:

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

20??

Concept Evaluation

Evaluate Disposal Concepts; FEPs; Develop and Demonstrate Technologies; Preliminary RD&D

Site Selection/Characterization

Development of Siting Criteria

Identification of Potential Sites

Progressive Site Down-Selection

Repository Development

Detailed Site Characterization & Repository Design → License Submittal

Construction & Monitoring

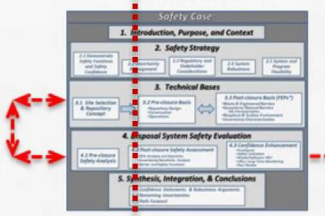
Operations & Monitoring

Closure

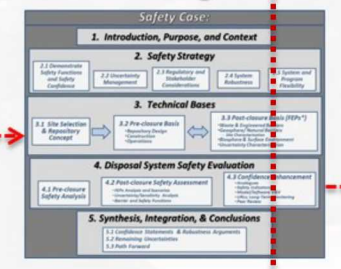
Maturation & Iteration of the Safety Case

Construction → Operations → Closure

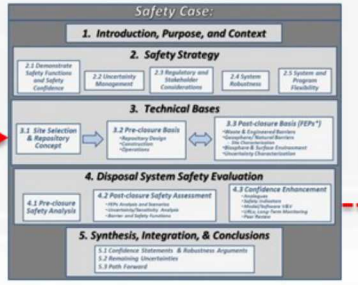
Generic

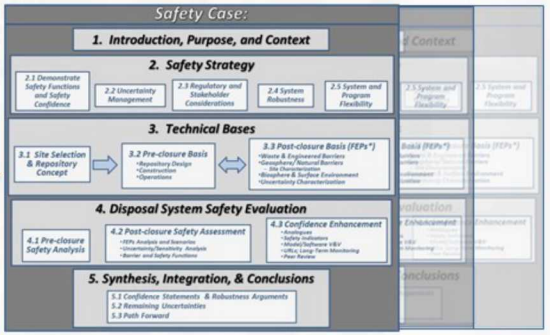


Siting

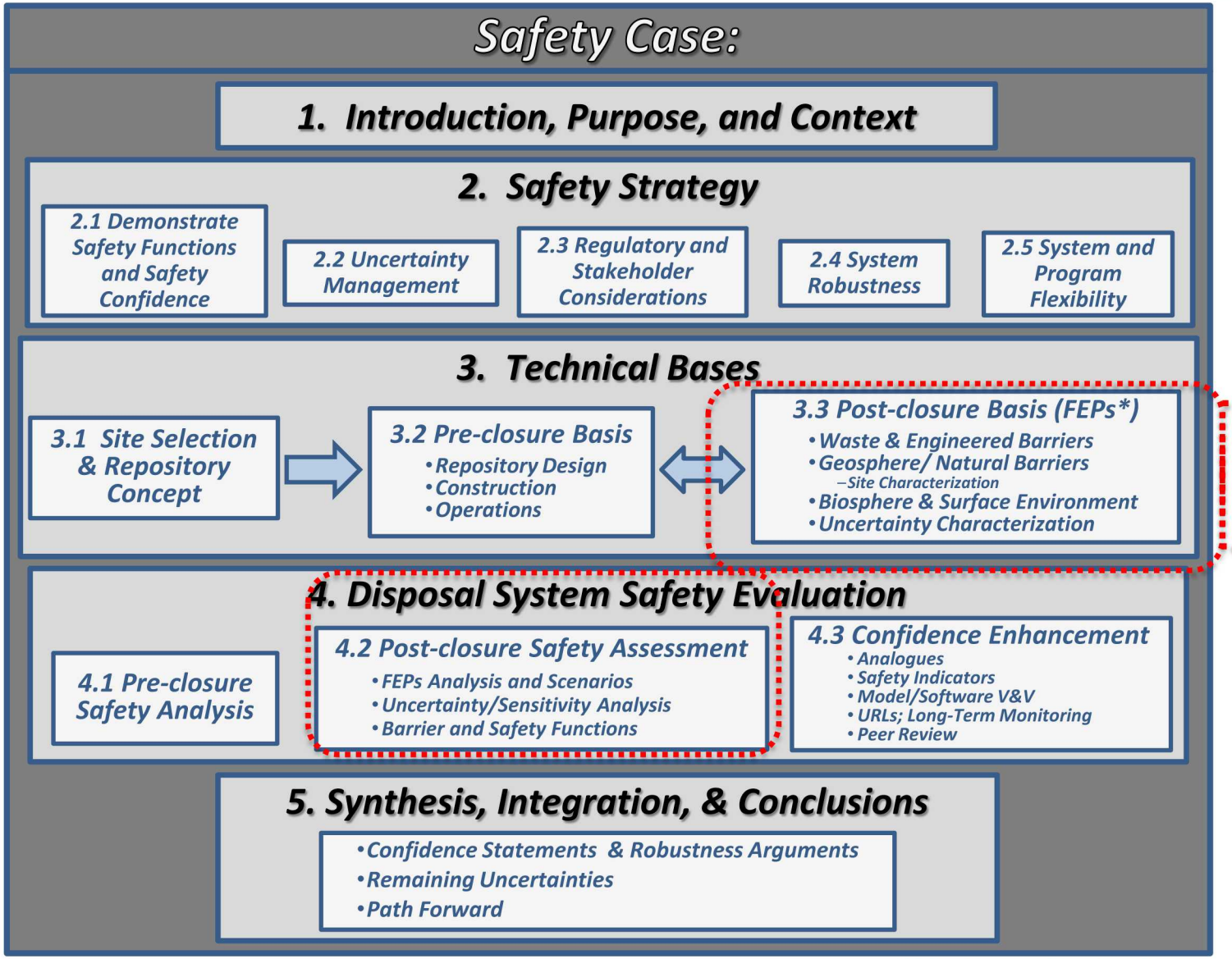


Licensing





Components of Safety Case



Key Objectives of the Safety Case

- ***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**

Used Fuel Disposition Disposal R&D Roadmap - Background

- **UFD recognized the need for a disposal research and development roadmap since its inception in June 2009**
  - FY10 planning included completing a final disposal R&D roadmap
- **FY10 activities focused on gaining an understanding of other disposal concepts**
  - What is the state of the art?
  - What are the key technical gaps?
- **Held the 1st Disposal R&D Roadmap workshop in June 2010**
  - Obtained a list of potential **R&D opportunities – no priorities**
  - FY10 activities subsequent to the workshop identified additional R&D opportunities
- **Issued Disposal R&D Roadmap status report in September 2010 and deferred final Disposal R&D Roadmap to FY11**
  - Need to
    - ***further identify*** *R&D opportunities*
    - *obtain information to* ***support prioritization*** *by UFD management*
- **FY11 activities**
  - **Established process for prioritizing** R&D issues
  - Held 2nd Disposal R&D Roadmap in December 2010
  - Developed information prioritization matrix and draft documents – circulated for review
  - **Completed Roadmap on March 30, 2011**
- **Revised (Rev01) September 2012**

Systematic Approach to R&D Prioritization

- **Objectives**
  - Cannot establish high-level requirements for a "new" repository without a clear definition of the regulatory **framework**
  - Can identify **objectives** based on international (IAEA) safety documents
    - *Containment*
    - *Limited Release: Natural and Engineered Systems*
    - *Dilution (secondary function)*
- **Utilize Features, Events, and Process (FEP) structure to identify R&D "Issues"**
  - Features: Map features of generic disposal system(s) to objectives
  - Identification of R&D "Issues"
    - *Using an "Issue Resolution" type approach: similar to previous site characterization plans*
    - *Processes used to define "Issues"*
- **UFD FEPs list (FY10) was used to identify the features and the processes**

Systematic Approach to R&D Prioritization

- **Generic Applicability: Can an issue be addressed through generic R&D?**
  - No: issue is entirely site specific, design specific or both – no need to conduct generic R&D
  - Partially: Some aspect of the issue can be addressed through generic R&D
    - *Specific data/parameters relevant to an issue may be site specific.*
    - *Generic R&D could be conducted to develop improved field/laboratory/analytic methods to obtain the data.*
    - *Generic R&D could be conducted to develop improved modeling methods*
  - Yes: Generic R&D could be conducted to develop methods and gather data

- **Importance to the Safety Case: UFD is using the NEA definition of the safety case to support prioritization of R&D opportunities (three components)**
  - **Safety Assessment**: importance of an issue to the safety assessment
    - *Media and design specific*
  - **Design/Construction/Operation**: What is the importance of an issue with respect to… For example
    - *Is the behavior of an engineered material, such as concrete, known well enough to include in a facility design?*
    - *Are special construction, fabrication, and operational techniques required? Have they been demonstrated?*
  - **Broad confidence** in the safety case
    - *Issue may not be important to either safety assessment or design/construction/operation*
    - *Addressing an issue may be important to building confidence in the overall safety case*

High Medium Low

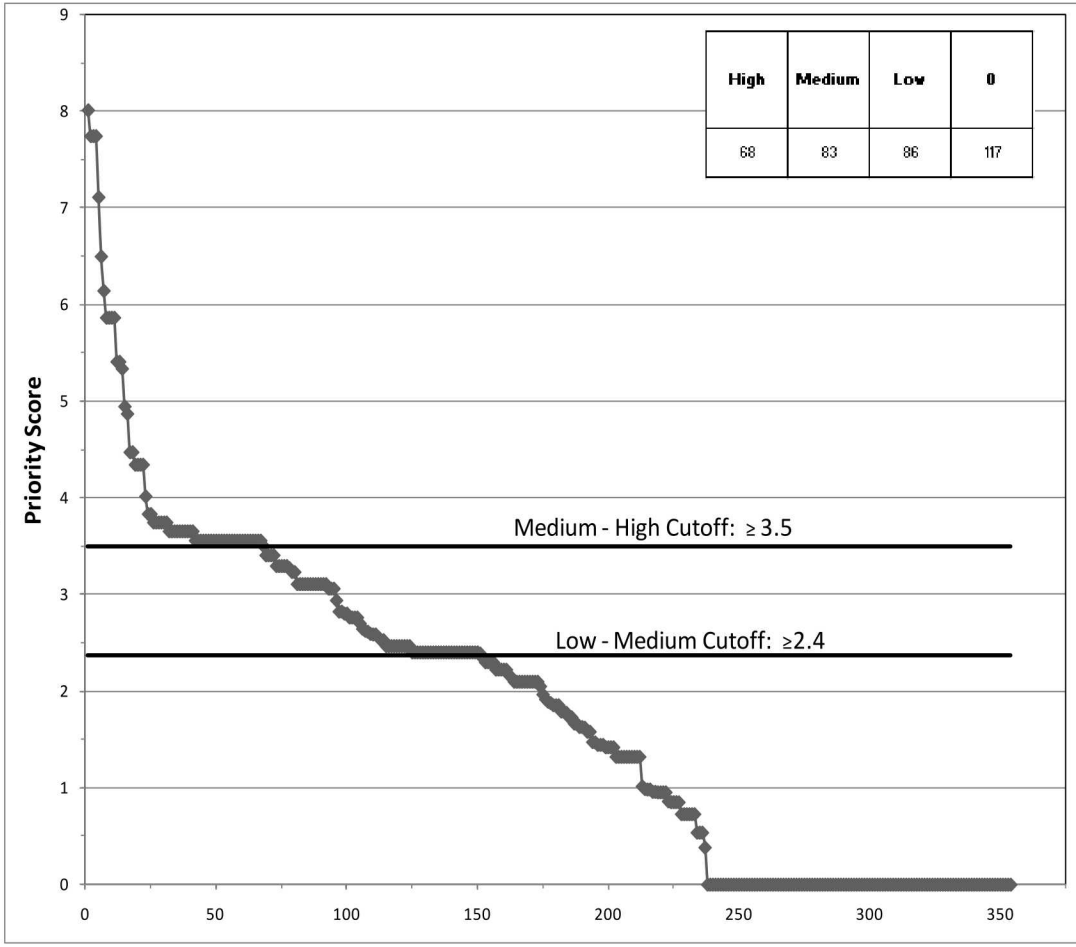
Media / Design Specific

Scoring/Weighting and Results

- **UFD team assigned scores and weights to the different categories**
  - Facilitated by a decision analysis expert
  - UFD laboratory and DOE NE-53 staff
  - Scores and weights can be changed to reflect different judgments
- **Establishment of the relative priorities used the following basic principles:**
  - The **overall priority** of an issue is a function of
    - *the importance of the issue to the safety case,*
    - *the importance of the issue to **each decision point**, and*
    - *the adequacy and state of the art of **current information***
  - The importance of an issue to the safety case is relevant at all decision points;
    - *the relative contribution of the three components to overall importance to the safety case may differ over time and at different decision points*
  - Issues that are important for **nearer-term decisions** are of **higher priority** than those that are not important for near term decisions but important for later decisions
  - Issues for which the current state of the art is well understood, and/or where currently available information is fully adequate to support a particular decision point are of low priority, at least with respect to that decision point
  - For issues evaluated differently for different media, media-specific priorities should be considered

Scoring/Weighting and Results

- **Evaluated quantitative scoring results (Appendix B) and conducted sensitivity studies**
- **The sorted priority rankings serve to identify the relative priority of the R&D issues**
  - Although the numerical scores were sorted, they were ***not*** construed as an issue-by-issue ranked R&D priority list
  - Specific ***R&D Topics*** were identified and evaluated against the issue prioritization



Scoring/Weighting and Results

- **Although quantitative, the underlying foundation is primarily expert judgment**
  - UFD Disposal R&D Roadmap Prioritization Information Matrix and
  - Evaluation of the resultant quantitative priority ranking scores
- **Used to determine an overall subjective ranking of broad topical areas**
  - *Argillite* – EDZ/OGf
  - *Salt* – HRf/OGf/EDZ
  - *DBD* – EDZ/HRc/OGc/ST
  - EBS Environment
  - WP Performance
  - SNF Degradation
  - *Crystalline* – Strat/HR Props

Appendix B

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
2.2.09.04 - Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Deep Boreholes	5.40
1.2.03.01 - Seismic Activity Impacts EBS and/or EBS Components -	4.94
2.1.09.13 - Radionuclide Speciation and Solubility in EBS - In Waste Form - In Waste Package - In Backfill - In Tunnel -	4.86
2.1.03.02 - General Corrosion of Waste Packages -	4.34
2.1.03.03 - Stress Corrosion Cracking (SCC) of Waste Packages -	4.34
2.1.03.04 - Localized Corrosion of Waste Packages -	4.34
2.1.03.05 - Hydride Cracking of Waste Packages -	4.34
2.1.02.01 - SNF (Commercial, DOE) Degradation - Alteration / Phase Separation - Dissolution / Leaching - Radionuclide Release -	4.01

Cross-Cutting R&D Topics - Synopsis

- **Design Concept Development (High)**
  - Develop a range of generic disposal system design concepts to address issues due to couplings and interfaces
  - Fuel cycle scenarios under consideration by the FCT program generate waste streams and waste forms having different characteristics and different design concepts should be considered for the disposal of these wastes in order to evaluate disposal-related metrics

- **Generic Disposal System Modeling (High)**
  - Development and continue refining generic disposal system models (GDSM) will provide the needed tools to conduct such safety assessments and as investigations progress they will become increasingly refined
  - Support evaluation of issue important within a total-system construct
  - Near-term capability would support future site screening activities, should a decision be made to initiate such activities

- **Operations Related Research and Technology Development (Low)**
  - Consider merits of deploying capabilities to address operations-related issues: waste package fabrication, closure, and handling
  - Develop confirmatory data for future licensing proceedings

Cross-Cutting R&D Topics - Synposis

- **Knowledge Management (Medium)**
  - Development of a comprehensive and user-friendly knowledge management system to organize the large quantities of data and information expected to be generated
- **Site Screening and Selection Tools (Medium)**
  - Siting a repository or a storage facility will ultimately require a geospatial decision
  - Development of modern geospatial analysis tools at national and regional scales to allow exploration of the implications of potential siting criteria or guidelines
- **Experimental and Analytical Techniques for Site Characterization (Medium)**
  - Exploration, research, and development of advanced techniques for use in future siting activities
  - Leverage on techniques used in other areas: oil/gas, mining, geothermal energy, carbon sequestration
- **Underground Research Laboratories (Medium)**
  - Conduct experiments designed to address non-site specific issues
  - Maintain repository development expertise
  - Leverage international URLs

Natural System Results Synopsis

Highest Ranked Areas

- Host Rock (properties) all
- Flow and transport pathways in crystalline media
  - *Fractures (DFM)*
  - *Analogs*
  - *Models*
  - *Testing*
  - *International*
- Excavation disturbed zone and chemistry for borehole disposal and shale media
  - *Models*
  - *International*
- Hydrologic processes for salt media
  - *Models*
  - *Testing*
  - *International*
- Chemical transport processes for salt and borehole media
  - *Models*
  - *Testing*
  - *International*
- Thermal processes for borehole and shale
  - *Models*
  - *International*

GEOSPHERE →	Crystalline	Borehole	Salt	Shale
1.2.01. LONG-TERM PROCESSES (tectonic activity)	Low	Low	Low	Low
1.2.03. SEISMIC ACTIVITY				
- Effects on EBS	High	High	High	High
- Effects on NS	Low	Low	Low	Low
1.3.01. CLIMATIC PROCESSES AND EFFECTS	Low	Low	Low	Low
2.2.01. EXCAVATION DISTURBED ZONE (EDZ)	Medium	High	Medium	High
2.2.02 HOST ROCK (properties)	High	High	High	High
2.2.03 OTHER GEOLOGIC UNITS (properties)	Medium	Medium	Medium	Medium
2.2.05. FLOW AND TRANSPORT PATHWAYS	Medium	Medium	Medium	Medium
2.2.07. MECHANICAL PROCESSES	Low	Low	Medium	Medium
2.2.08. HYDROLOGIC PROCESSES	Low	Medium	High	Medium
2.2.09. CHEMICAL PROCESSES - CHEMISTRY	Low	Medium - High	Low - Medium	Medium - High
2.2.09. CHEMICAL PROCESSES - TRANSPORT	Medium	Medium - High	Medium - High	Medium
2.2.10. BIOLOGICAL PROCESSES	Low	Low	Low	Low
2.2.11. THERMAL PROCESSES	Low	Medium	Low	Medium
2.2.12. GAS SOURCES AND EFFECTS	Low	Low	Low	Low
2.2.14. NUCLEAR CRITICALITY	Low	Low	Low	Low

Notes:
1. Shading for an entry indicates that research in that area has been undertaken in other geologic disposal programs
2. FEP number lists includes all FEPs beneath the third level
3. Shading for an entry indicates that research in that area has been undertaken in other geologic disposal programs

Engineered System Results Synopsis

- **Highest ranked issues: Overall higher ranking for Waste Form, Waste Package, and Buffer/Backfill materials**
  - Waste Materials: Waste form issues ranked higher than those for inventory
    - SNF (M, e, I); Glass (m, I); Other (m, i)
  - Waste Package Materials: Waste container issues and chemical processes generally ranked higher than those for specific processes such as hydrologic and biologic: (m)
  - Buffer and Backfill Materials: Issues related to chemical processes generally ranked higher than others.
    - Buffer (M, E, I)
  - Seal and Liner Materials: Issues related to chemical, mechanical, and thermal processes generally ranked higher than those for radiation or nuclear criticality effects.
    - Seal (M, I); Liner (M, E, I)
  - Other Engineered Barrier Materials: Issues related to chemical processes and radionuclide speciation / solubility ranked slightly higher than issues related to thermal, mechanical, and hydrological processes.
    - Spec/Solubility (M, I)
  - Overall, chemical processes in the considered EBS components ranked higher than others but these are strongly coupled to thermal, hydrological, and even mechanical processes within the EBS
    - EBS Chemistry (m, I)

R&D Summary and Direction Versus Roadmap

- **SFWST (UFD) Activities (FY12 – present) have**
  - Reasonably covered Roadmap priorities
    - *Primarily model-based*
    - *Targeted experiments/testing*
    - *International data, models, and collaboration*
  - Developed/developing bases for 4 (+1) Generic Disposal Concepts
    - *Reference Cases*
    - *GDSA models*
    - *Process models*
    - *Integrated international results and collaborative testing*
    - *Targeted Testing – EBS materials*
- **Gaps Identified**
  - WP Degradation
    - *Beginning to be addressed with various modeling approaches*
  - EBS Chemical Environment-couple processes
    - *Beginning to be addressed – coupled THC 1-D EBS model (3-D EBS model)*
  - These gaps are not surprising because
    - *Considered at high-level in the GDSA work to start*
    - *Rely on details of EBS design and site specific conditions*
    - *Represent dimensionally more complex considerations*

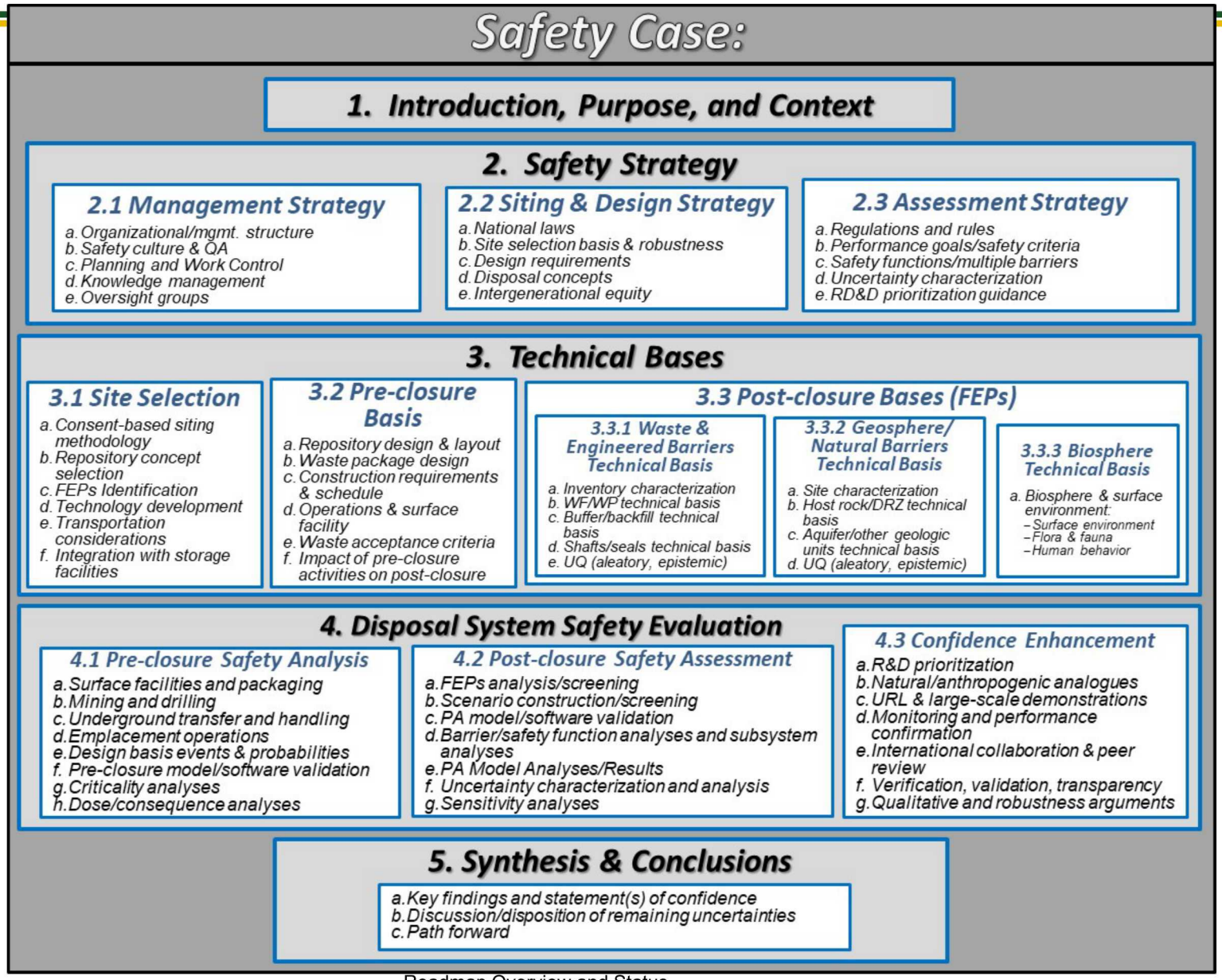
Roadmap Summary: Safety Case and R&D Linkages

- **International Experience and Collaboration**
  - Lessen the technical challenges with building a Safety Case/License Application
  - URL collaboration for
    - *Field-based natural system testing (e.g., Mont Terri)*
    - *Engineered barrier evolution/field-scale behavior (e.g., Febex)*
  - Laboratory data and models
    - *Waste form and materials behavior (e.g., FMDM)*
- **Two Key Objectives of the Safety Case**
  - ***Demonstrate sound understanding*** of the repository system – site surface processes, engineered and geologic barriers, and biosphere
  - Show how this understanding is the basis for the ***evaluation of long-term performance and safety***
- **Development of the Safety Case is an Iterative Process**
  - PA is the framework that integrates repository design and site evaluation/characterization,
  - Reference Case for each generic disposal concept
- **Conceptual repository system models**
  - Provide the detailed framework to develop/document the assessment bases
  - Integrated GDSA approach for repository concepts
    - *Site model for each generic disposal concept*
    - *EBS model for granite/alluvium/argillite/salt/DBD*
    - *Process models*
    - *Experimental/testing results (e.g., colloids, backfill buffer materials)*
- **Prioritization of R&D Activities**
  - *Structure of the Safety Case* should begin early in the process to facilitate evaluation
  - *Formalized* using sensitivity analysis and decision analysis – important to document basis for all decisions
  - *Evolves* – decision points; state-of-the art; progress on R&D

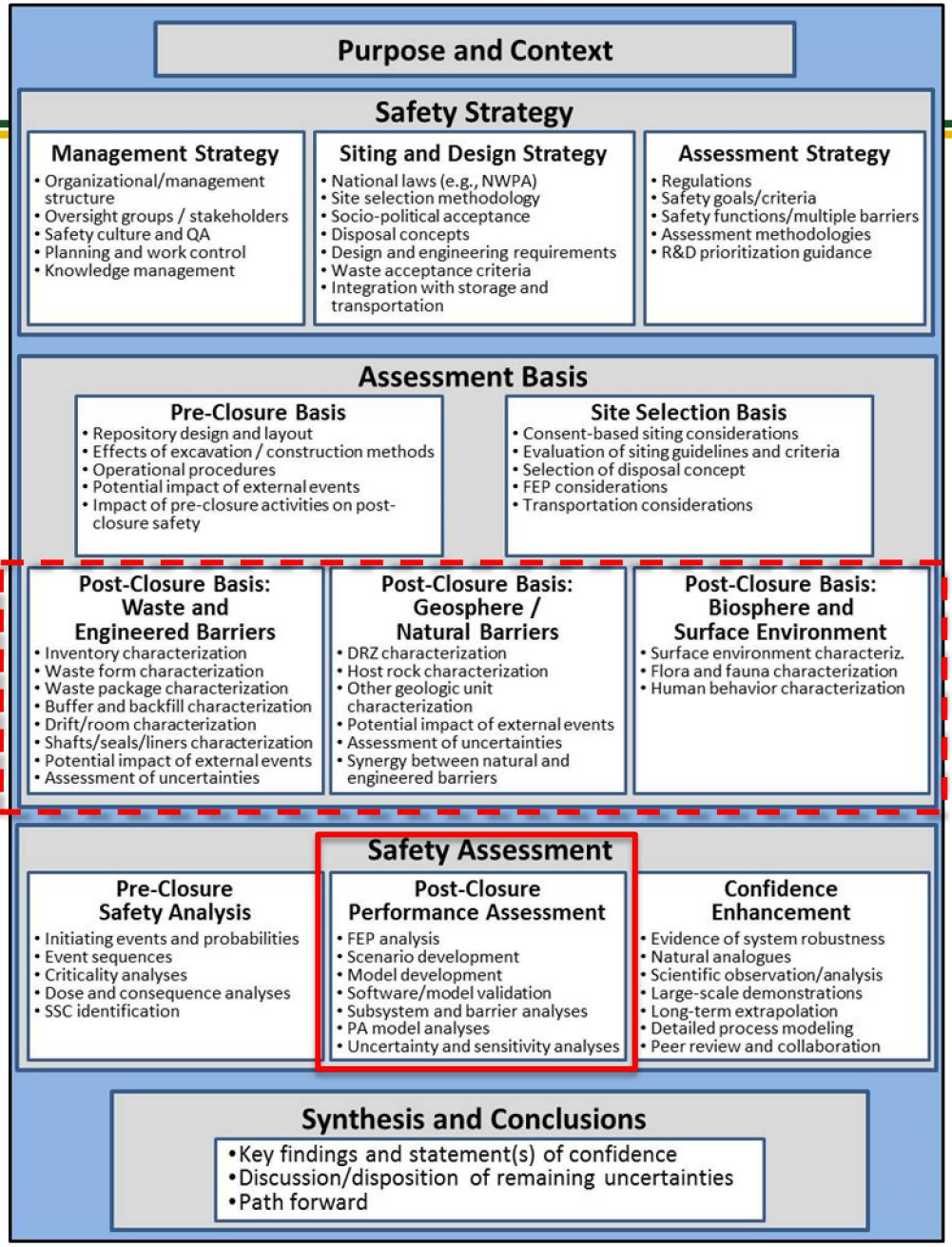
Questions?

Backup Materials

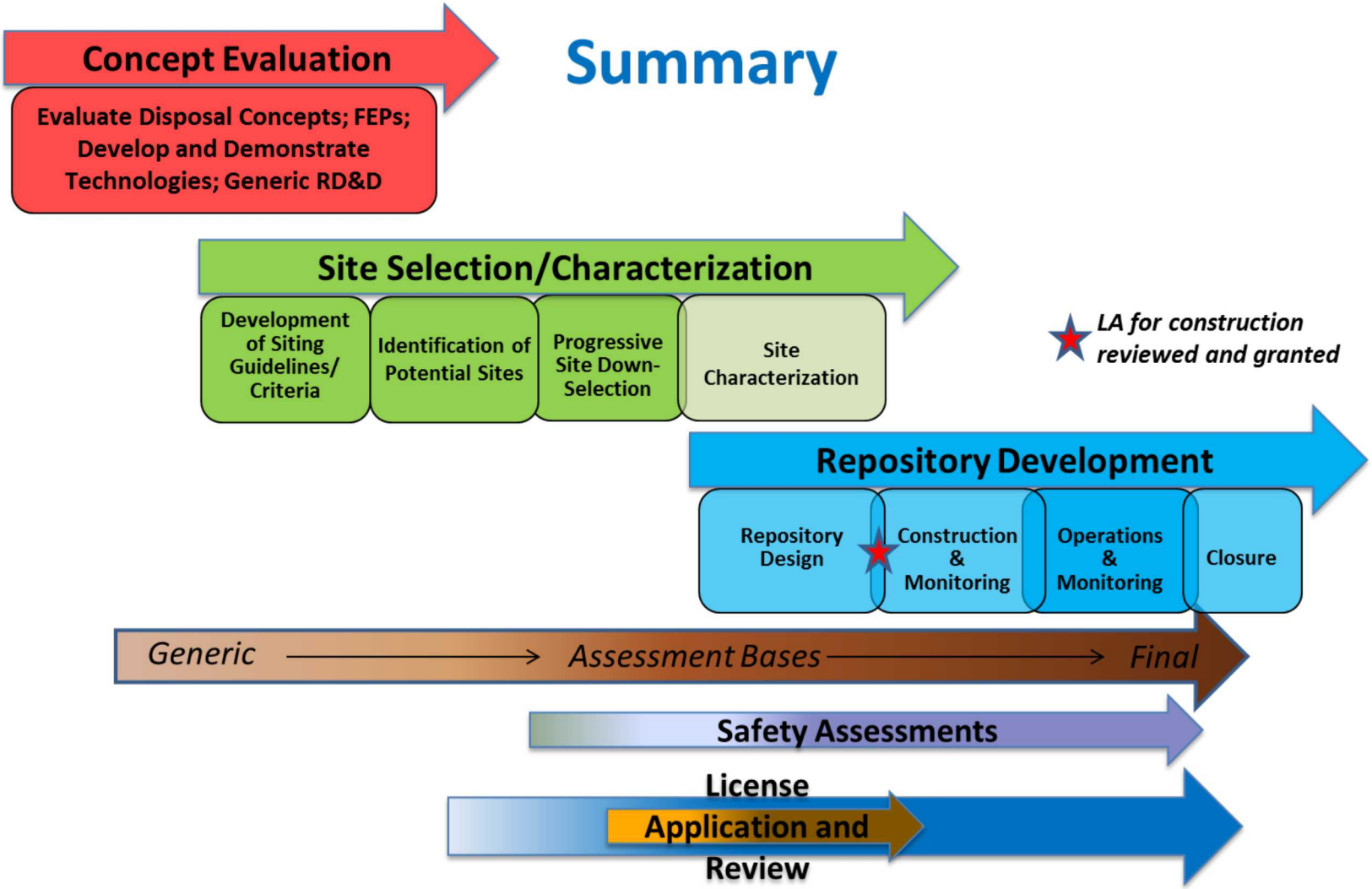
Details of the Safety Case Elements



Detailed Elements of the Safety Case



Safety Case Summary



Engineered System Results Synopsis

- Ranking was not based according to specific engineered barrier materials but rather through the main components of the engineered barrier system and key potential processes that affect performance
- Main reason for this approach is that specific EBS are highly dependent on repository design concepts and these still need to be developed to the point where the engineered components important to waste isolation can be identified and thus evaluated
- Moreover, EBS materials can be considered, to a large extent, independent of the host media, but their performance is inherently important to the safety case

Engineered System Results Synopsis

WASTE MATERIALS → SNF, Glass, Ceramic, Metal	
2.1.01.01, .03, .04: INVENTORY	Low
2.1.02.01, .06, .03, .05: WASTE FORM	High
WASTE PACKAGE MATERIALS → Steel, Copper, Other Alloys, Novel Materials	**Steel**
2.1.03.01, .02, .03, .04, .05, .08: WASTE CONTAINER	High
2.1.07.03, .05, .06, .09: MECHANICAL PROCESSES	Medium
2.1.08.02, .07, .08: HYDROLOGIC PROCESSES	Low
2.1.09.01, .02, .09, .13: CHEMICAL PROCESSES - CHEMISTRY	Medium
- Radionuclide speciation/solubility	High
2.1.09.51, .52, .53, .54, .55, .56, .57, .58, .59: CHEMICAL PROCESSES - TRANSPORT	Low
- Advection, diffusion, and sorption	Medium
2.1.10.x: BIOLOGICAL PROCESSES (no FEPs were scored in this category)	Low
2.1.11.01, .02, .04: THERMAL PROCESSES	Medium
2.1.12.01: GAS SOURCES AND EFFECTS	Low
2.1.13.02: RADIATION EFFECTS	Low
2.1.14.01: NUCLEAR CRITICALITY	Low
BUFFER / BACKFILL MATERIALS → Cementitious, bituminous, mixed materials: clay, salt, crystalline environments	
2.1.04.01: BUFFER/BACKFILL	High
2.1.07.02, .03, .04, 09: MECHANICAL PROCESSES	Medium
2.1.08.03, .07, .08: HYDROLOGIC PROCESSES	Medium
2.1.09.01, .03, .07, .09, .13: CHEMICAL PROCESSES - CHEMISTRY	Medium
- Radionuclide speciation/solubility	High
2.1.09.51, .52, .53, .54, .55, .56, .57, .58, .59, .61: CHEMICAL PROCESSES – TRANSPORT	Medium
- Colloid facilitated transport	Low
2.1.10.x: BIOLOGICAL PROCESSES (no FEPs were scored in this category)	Low
2.1.11.04: THERMAL PROCESSES	Medium
2.1.12.01, .02, .03: GAS SOURCES AND EFFECTS	Medium
2.1.13.02: RADIATION EFFECTS	Low
2.1.14.02: NUCLEAR CRITICALITY	Low

SEAL / LINER MATERIALS → Cementitious, Asphalt, Metal, Polymers	
2.1.05.01: SEALS	Medium
2.1.06.01: OTHER EBS MATERIALS	Medium
2.1.07.02, .08, .09: MECHANICAL PROCESSES	Medium
2.1.08.04, .05, .07, .08, .09: HYDROLOGIC PROCESSES	Low
- Flow through seals	Medium
2.1.09.01, .04, .07, .09, .13: CHEMICAL PROCESSES – CHEMISTRY	Medium
- Radionuclide speciation/solubility	High
2.1.09.51, .52, .53, .54, .55, .56, .57, .58, .59: CHEMICAL PROCESSES - TRANSPORT	Low
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2.1.12.02, .03: GAS SOURCES AND EFFECTS	Low
2.1.13.02: RADIATION EFFECTS	Low
2.1.14.02: NUCLEAR CRITICALITY	Low
OTHER MATERIALS → Low pH Cements, Salt-Saturated Cements, Geo-polymers, Barrier Additives	
2.1.06.01: OTHER EBS MATERIALS	Medium
2.1.07.08, .09: MECHANICAL PROCESSES	Medium
2.1.08.04, .05: HYDROLOGIC PROCESSES	Medium
2.1.09.04, .07, .09, .13: CHEMICAL PROCESSES - CHEMISTRY	Medium
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2.1.13.02: RADIATION EFFECTS	Low
2.1.14.02: NUCLEAR CRITICALITY	Low

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1. Shading for an entry indicates that research in that area has been undertaken in other geologic disposal programs
2. FEP number lists delimited by commas show only the change in the fourth field of the FEP

Appendix B Results (≥ 3.5)

Appendix B

UFD FEP ID No., Title, and Media	Overall Priority Score
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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
2.2.09.04 - Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Deep Boreholes	5.40
1.2.03.01 - Seismic Activity Impacts EBS and/or EBS Components -	4.94

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2.1.09.13 - Radionuclide Speciation and Solubility in EBS - In Waste Form - In Waste Package - In Backfill - In Tunnel -	4.86
2.1.03.02 - General Corrosion of Waste Packages -	4.34
2.1.03.03 - Stress Corrosion Cracking (SCC) of Waste Packages -	4.34
2.1.03.04 - Localized Corrosion of Waste Packages -	4.34
2.1.03.05 - Hydride Cracking of Waste Packages -	4.34
2.1.02.01 - SNF (Commercial, DOE) Degradation - Alteration / Phase Separation - Dissolution / Leaching - Radionuclide Release -	4.01
2.2.07.01 - Mechanical Effects on Host Rock - Salt	3.83
2.2.07.01 - Mechanical Effects on Host Rock - Clay/Shale	3.83
2.2.02.01 - Stratigraphy and Properties of Host Rock - Granite/Crystalline	3.74
2.2.02.01 - Stratigraphy and Properties of Host Rock - Deep Boreholes	3.74
2.2.02.01 - Stratigraphy and Properties of Host Rock - Salt	3.74
2.2.02.01 - Stratigraphy and Properties of Host Rock - Clay/Shale	3.74

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Appendix B

UFD FEP ID No., Title, and Media	Overall Priority Score
2.2.09.51 - Advection of Dissolved Radionuclides in Host Rock - Granite/Crystalline	3.74
2.2.09.51 - Advection of Dissolved Radionuclides in Host Rock - Clay/Shale	3.74
2.2.05.01 - Fractures - Host Rock - Other Geologic Units - Granite/Crystalline	3.65
2.2.05.01 - Fractures - Host Rock - Other Geologic Units - Deep Boreholes	3.65
2.2.05.01 - Fractures - Host Rock - Other Geologic Units - Salt	3.65
2.2.05.01 - Fractures - Host Rock - Other Geologic Units - Clay/Shale	3.65
2.2.08.01 - Flow Through the Host Rock - Granite/Crystalline	3.65
2.2.08.01 - Flow Through the Host Rock - Deep Boreholes	3.65
2.2.08.01 - Flow Through the Host Rock - Clay/Shale	3.65

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2.2.08.02 - Flow Through the Other Geologic Units - Confining units - Aquifers - Granite/Crystalline	3.65
2.2.08.02 - Flow Through the Other Geologic Units - Confining units - Aquifers - Deep Boreholes	3.65
2.2.08.02 - Flow Through the Other Geologic Units - Confining units - Aquifers - Clay/Shale	3.65
2.2.08.06 - Flow Through EDZ - Granite/Crystalline	3.65
2.2.08.06 - Flow Through EDZ - Deep Boreholes	3.65
2.2.08.06 - Flow Through EDZ - Clay/Shale	3.65
2.1.02.06 - SNF Cladding Degradation and Failure -	3.62
2.2.09.01 - Chemical Characteristics of Groundwater in Host Rock - Clay/Shale	3.55
2.2.09.02 - Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Clay/Shale	3.55
2.2.09.05 - Radionuclide Speciation and Solubility in Host Rock - Clay/Shale	3.55
2.2.09.06 - Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) - Clay/Shale	3.55
2.2.09.52 - Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Granite/Crystalline	3.55

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Appendix B

UFD FEP ID No., Title, and Media	Overall Priority Score
2.2.09.52 - Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Clay/Shale	3.55
2.2.09.53 - Diffusion of Dissolved Radionuclides in Host Rock - Granite/Crystalline	3.55
2.2.09.53 - Diffusion of Dissolved Radionuclides in Host Rock - Clay/Shale	3.55
2.2.09.54 - Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Granite/Crystalline	3.55
2.2.09.54 - Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Clay/Shale	3.55
2.2.09.55 - Sorption of Dissolved Radionuclides in Host Rock - Granite/Crystalline	3.55
2.2.09.55 - Sorption of Dissolved Radionuclides in Host Rock - Clay/Shale	3.55
2.2.09.56 - Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Granite/Crystalline	3.55
2.2.09.56 - Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers - Clay/Shale	3.55

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2.2.09.57 - Complexation in Host Rock - Granite/Crystalline	3.55
2.2.09.57 - Complexation in Host Rock - Clay/Shale	3.55
2.2.09.58 - Complexation in Other Geologic Units (Non-Host-Rock) - Granite/Crystalline	3.55
2.2.09.58 - Complexation in Other Geologic Units (Non-Host-Rock) - Clay/Shale	3.55
2.2.09.61 - Radionuclide Transport Through EDZ - Granite/Crystalline	3.55
2.2.09.61 - Radionuclide Transport Through EDZ - Clay/Shale	3.55
2.2.09.64 - Radionuclide Release from Host Rock - Dissolved - Colloidal - Gas Phase - Granite/Crystalline	3.55
2.2.09.64 - Radionuclide Release from Host Rock - Dissolved - Colloidal - Gas Phase - Clay/Shale	3.55
2.2.09.65 - Radionuclide Release from Other Geologic Units - Dissolved - Colloidal - Gas Phase - Granite/Crystalline	3.55
2.2.09.65 - Radionuclide Release from Other Geologic Units - Dissolved - Colloidal - Gas Phase - Clay/Shale	3.55

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UFD FEP ID No., Title, and Media	Overall Priority Score
2.2.11.04 - Thermal Effects on Chemistry and Microbial Activity in Geosphere - Deep Boreholes	3.55
2.2.11.04 - Thermal Effects on Chemistry and Microbial Activity in Geosphere - Clay/Shale	3.55
2.1.04.01 - Evolution and Degradation of Backfill/buffer -	3.50
2.1.05.01 - Degradation of Seals -	3.50

Systematic Approach to R&D Prioritization

- The Fuel Cycle Technology Program is applying system engineering techniques to identify which fuel cycle technology alternatives to pursue
- The UFD campaign is applying system engineering techniques with regard to used fuel storage R&D
- While system engineering techniques are not directly applicable to establishing R&D priorities for disposal research at this stage, the method can be and has been applied (and will be described herein)
- The goal is to conduct R&D on generic systems that could be used in future repository development efforts
- The reality is that funding will be limited – choices on what R&D to do and when to best support future repository development will need to be made

Systematic Approach to R&D Prioritization

- **State of the Art: How well do we understand an issue?**
  - Leverage work that has been completed both in the U.S. and in other countries
  - Categories
    - *Well Understood: representation well developed, has a strong technical basis, and is defensible. Additional R&D would add little to the current understanding*
    - *Fundamental Gaps in Method: the representation of an issue (conceptual and/or mathematical, experimental) is lacking*
    - *Fundamental Data Needs: the data or parameters used to represent an issue (process) is lacking*
    - *Fundamental Gaps in Method, Fundamental Data Needs: Both*
    - *Improved Representation: The representation of an issue may be technically defensible, but improved representation would be beneficial (i.e., lead to more realistic representation).*
    - *Improved Confidence: Methods and data exist, and the representation is technically defensible but there is not widely-agreed upon confidence in the representation (scientific community and other stakeholders).*
    - *Improved Defensibility: Related to confidence, but focuses on improving the technical basis, and defensibility, of how an issue (process) is represented*

Systematic Approach to R&D Prioritization

- **Importance and Adequacy With Respect to Decision Points: How much do we need to know and when?**
  - UFD R&D will support the implementation of a geologic disposal system as it progresses through different decision points.
  - Issues may have different importance or priority for different decisions

Decision	*Type of safety / performance information required*
Site screening [broad siting, site down-select]	*-Identification of show-stoppers.* *-Is there something that makes the site clearly unsuitable in terms of performance, safety, or other screening criteria (e.g., proximity to population centers?)*
Site selection [environment feasibility, concept feasibility, site designation]	*-Relative performance of the sites (for site selection, being able to compare the sites is more important than having a highly accurate model of site performance)* *-Key contributors to isolation, early containment, delay, and dilution for each site (preliminary sensitivity analyses)* *-Potential weaknesses in the safety case for each site*
Site characterization and disposal system design [site characterization]	*-Sufficient understanding of the site and its strengths and weaknesses in terms of performance to design a complimentary engineered system.* *-Sufficient understanding of the ability of the "total system" (and system components?) to isolate, contain, delay, dilute…* *-Ability to model potential releases and dose to human receptors for the site/design combination*
Site suitability [licensing]	*-Ability to model releases and doses and compare them to a regulatory standard* *-Sufficient confidence in models and supporting data to make a convincing case that the site is either suitable or not suitable (i.e., to know with confidence whether or not it will meet the regulatory standard)*

Importance

High: Information is essential to decisions

Medium: Information supports or improves decisions

Low: Information useful but not necessary

Adequacy

Completely sufficient (no additional info needed)

Partially sufficient (issue can be represented but needs improvement)

Insufficient (cannot adequately represent issue)

Allows for Understanding of When R&D Needs to be Completed to Support Future Decisions

Approach to R&D Prioritization

- **Identification of R&D topics**
  - Understanding the overall importance of each issue and the adequacy of current information to support various decisions allows R&D topics to be developed to appropriately address the issue
  - Three information items are needed in order to evaluation the benefit of an R&D topic against the issues
    - *Primary Decision Point Supported: Identifies which decision point completion of the R&D would support, recognizing that partial completion of the R&D could also support earlier decision points.*
    - *Lead Time to Complete: An estimate of how long it will take to complete the R&D*
    - *Cost: An estimate of the total cost needed to complete the R&D*

Prioritize Issues First (R&D Roadmap)
Identify and Prioritize R&D Topics Second (Planning)

Prioritization Information Matrix (Appendix A of the Roadmap)

Objective	Feature	Process (Issue)			Ability to Address through Generic R&D		Importance of Issue/Process to Safety Case				State of the Art Relative to Issue/Process	
		UFD FEP ID	UFD FEP Title	Process/Issue Description	Yes/No/Partial	Discussion	Performance (Safety Analysis)	Design, Construction, Operations	Overall Confidence	Discussion	Status	Discussion
Containment, Limited Release - Engineered Barriers	Engineered Barriers	2.1.07.16	Mechanical Degradation of EBS	- Floor buckling - Fault displacement - Initial damage from excavation / construction - Consolidation of EBS components - Degradation of waste package support structure - Alteration of EBS flow pathways [see also Mechanical Effects from Preclosure in 1.1.02.02, Evolution of Flow Pathways in EBS in 2.1.08.09, Drift Collapse in 2.1.07.02, Degradation in 2.1.04.01, 2.1.05.01, and 2.1.06.01, and Mechanical Effects on Host Rock in 2.2.07.01]	No	"Broad" mechanical degradation of the EBS is made specific and site specific. R&D on generic systems cannot address this topic.						
		2.1.08.00	1.08. HYDROLOGIC PROCESSES									
Limited Release - Engineered Barriers	Engineered Barriers	2.1.08.01	Flow Through the EBS	- Saturated / Unsaturated flow - Preferential flow pathways - Density effects on flow - Initial hydrologic conditions - Flow pathways out of EBS [see also Open Borehole in 1.1.01.01, Thermal-Hydrologic Effects from Preclosure in 1.1.02.03, Flow in Waste Packages in 2.1.08.02, Flow in Backfill in 2.1.08.03, Flow through Seals 2.1.08.04, Flow through Liner in 2.1.08.05, Thermal Effects on Flow in 2.1.11.10, Effects of Gas on Flow in 2.1.12.02]	Partial - Site Specific, Design Specific	Generic R&D captured in flow through individual EBS components above and issues below.	"Broad" Flow through the EBS cannot be assessed through generic R&D. EBS flow processes through specific barrier components/materials addressed below.					
Limited Release - Engineered Barriers	Waste Packaging	2.1.08.02	Flow in and Through Waste Packages	- Saturated/ Unsaturated flow - Movement as thin films or droplets	Yes	Methods and Properties/Parameters	Medium	Low	Medium	Medium Safety Analysis - affects source term from breached waste packages Low - Design/Construction/Operation - Materials will be selected primarily for containment purposes, however understanding of the flow characteristics through waste package perforations is important and understanding would preclude the use of conservative models (i.e., entire waste package degrades) Overall Confidence medium - part of EBS and its performance	Improved Representation	Typically conservative models applied to flow through perforated waste packages.
Limited Release - Engineered Barriers	Backfill/Buffer	2.1.08.03	Flow in Backfill	- Fracture / Matrix flow	Yes	Methods and Properties/Parameters	High	Medium	High	May be of high importance for performance in certain environments - governs "source term" releases upon failure of waste packages for certain designs in certain environments. Medium importance for design - could affect backfill/buffer design and emplacement techniques High importance for overall confidence - secondary isolation barrier	Fundamental Gaps in Method	Other countries have evaluated flow through buffer/backfill materials. Improved models of flow through breaches could increase understanding of releases from the engineered barriers.
Limited Release - Engineered Barriers	Seals	2.1.08.04	Flow Through Seals	- Fracture / Matrix flow - Gas transport	Partial - Site Specific, Design Specific	Also media specific. Specific R&D would require establishment of seal design and selection of material - compatible with site/media. Generic R&D could be conducted on seal materials independent of design and site/media - method and parameter development.	High	High	High	May be of high importance for performance in certain environments - Could provide preferential pathways for release. High importance for design/construction - could be key part of isolation system High importance for overall confidence - potential isolation barrier.	Fundamental Gaps in Method, Fundamental Data Needs	Improved models of flow through breaches could increase understanding of releases from the engineered barriers. For cementitious barriers, reactive transport models need to be developed to assess barrier seal performance from processes such as carbonation, sulfate attack, and coupled phenomena influencing gas transport.
Limited Release - Engineered Barriers	Other Engineered Features	2.1.08.05	Flow Through Liner / Rock Reinforcement Materials in EBS		Partial - Site Specific, Design Specific	Also media specific. Specific R&D would require establishment of sub-surface design and selection of materials - compatible with site/media. Generic R&D could be conducted to develop/improve methods and properties/parameters independent of design and site/media. Methods and Properties/Parameters	Low	High	Medium	Expected to be of low direct importance to long-term performance. Could be of high importance to repository design and construction. Estimated at medium importance for overall confidence	Fundamental Gaps in Method, Fundamental Data Needs	Reactive transport models need to be developed to assess barrier seal performance and interactions with fluids at barrier interfaces that could influence gas generation and transport.

www.nuclear.energy.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

Overarching Conclusion for Moving Forward

- **With respect to the site screening decision point, the development of the UFD Disposal R&D Roadmap indicates that sufficient information currently exists to support a site screening process in the U.S., should a decision be made to begin one**

- **R&D will improve that process and will provide needed information to support future decision points (site selection, characterization, and suitability)**

Application of the Disposal R&D Roadmap

- **FY11 activities planned without completed Disposal R&D Roadmap**
  - Expert judgment on high-priority needs
- **Initial FY11 allocations to work activities were made, but decision was made to wait until R&D roadmap matured before starting to be sure allocations matched priorities**
- **Early results of the R&D roadmap exercise indicated:**
  - Except for two areas, FY11 allocations were correct and appropriately applied
  - Two work areas found to be of low priority and funds were re-allocated
    - *Biosphere Pathways and Infiltration and Soil*
  - Clear need identified to develop “disposal design concepts”
  - Increased funding in Regional Geology & Tectonic Hazard work
  - Initiated stakeholder (social science) R&D
- **Supported development of FY12 and FY13 planning**