DOE SFWST Campaign R&D Roadmap Update

Fuel Cycle Research & Development

Prepared for
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Spent Fuel and Waste Science and Technology Campaign

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APPENDIX E
NTRD DOCUMENT COVER SHEET[1]

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NOTE 1: *Appendix E should be filled out and submitted with the deliverable. Or, if the PICS:NE system permits, completely enter all applicable information in the PICS:NE Deliverable Form. The requirement is to ensure that all applicable information is entered either in the PICS:NE system or by using the NTRD Document Cover Sheet.*

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NOTE 2: *If QRL 1, 2, or 3 is not assigned, then the QRL 4 box must be checked, and the work is understood to be performed using laboratory QA requirements. This includes any deliverable developed in conformance with the respective National Laboratory / Participant, DOE or NNSA-approved QA Program.*

NOTE 3: *If the lab has an NQA-1 program and the work to be conducted requires an NQA-1 program, then the QRL-1 box must be checked in the work Package and on the Appendix E cover sheet and the work must be performed in accordance with the Lab's NQA-1 program. The QRL-4 box should not be checked.*

Revision History

REV	EFFECTIVE DATE	REVISION DESCRIPTION
0	April 30, 2019	Initial Issuance
1	July 22, 2019	Reflects corrections to Table 3-7 to be consistent with the information in the Appendices, primarily for PA R&D Activities. Also, revisions to Tables 4-1, 4-2, and 4-3 to reflect the current status of the SFWD Document Archive.

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Thanks go to the National Technical Director of the SFWST Campaign, Peter Swift, and to the DOE Federal Manager, Tim Gunter.

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EXECUTIVE SUMMARY

The Spent Fuel and Waste Science and Technology (SFWST) Campaign of the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE), Office of Spent Fuel and Waste Disposition (SFWD) is conducting research and development (R&D) on deep geologic disposal of spent nuclear fuel (SNF) and high-level nuclear waste (HLW). R&D addressing the disposal of SNF/HLW in the U.S. is currently generic (i.e., “non-site-specific”) in scope, following the suspension of the Yucca Mountain Repository Project in 2010. However, to prepare for the eventuality of a repository siting process, the former Used Fuel Disposition Campaign (UFDC) of DOE-NE, which was succeeded by the SFWST Campaign, formulated an R&D Roadmap in 2012 outlining generic R&D activities and their priorities appropriate for developing safety cases and associated performance assessment (PA) models for generic deep geologic repositories in several potential host-rock environments in the contiguous United States. This 2012 UFDC Roadmap also identified the importance of re-evaluating priorities in future years as knowledge is gained from the DOE’s ongoing R&D activities.

Since 2012, significant knowledge has been gained from these activities through R&D in the U.S. and via international collaborations, especially with countries that operate underground research laboratories (URLs). The 2019 R&D Roadmap Update, described here, summarizes the progress of ongoing generic disposal R&D activities, re-assesses R&D priorities, and identifies new activities of high priority, such as R&D on disposal of DPCs (dual purpose canisters), which now contain a significant fraction of the Nation’s commercial SNF activity.

As described in the 2012 UFD Roadmap (DOE 2012), the UFDC defined and utilized a systematic, decision-analysis-based approach to develop and prioritize the R&D portfolio. The approach involved several steps, including the identification of potential “R&D issues” (information needs and knowledge gaps) and the prioritization of these R&D issues based on evaluation metrics (primarily their importance to the safety case and the state of knowledge regarding the issue). Each identified R&D issue was derived from (actually, equated to) a FEP (Feature, Event, or Process) from the generic list of 208 FEPs considered as important to repository performance. A suite of 354 such R&D Issues was identified, which is greater than the original list of 208 FEPs, because each FEP may have a different importance to the safety case or a different state-of-the-art knowledge level depending on which of the three generic, host-rock concepts (argillite, crystalline, or bedded salt) was being evaluated. Evaluation of the subsequent prioritization rankings of the 354 R&D Issues pinpointed an important set of broader cross-cutting R&D categories and a series of groupings of natural barrier system issues and engineered barrier system issues that were helpful for defining the future R&D program.

The original 2012 UFDC Roadmap promised a re-evaluation of priorities in future years as knowledge was gained from ongoing activities in the U.S. and abroad (DOE 2012, Sec. 2.4). Thus, a re-assessment of R&D priorities was initiated during fiscal year 2018, culminating in a workshop of Campaign experts in early 2019, held at the University of Nevada in Las Vegas from January 15 to 17. In addition, a new document archive was developed to organize and store the various reports generated by the disposal R&D work packages over the course of the UFD and SFWST Campaigns.

The objectives of the 2019 R&D Roadmap Update include the following:

1) Recap the original 2012 Roadmap results and conclusions
2) Document the 2019 Roadmap Update Workshop approach, process, and evaluations
3) Summarize the status, progress, and priority of 2019 SFWST R&D Activities and their relation to the FEPs important to various host rocks and repository designs
4) Identify the generic R&D still needed to advance the state-of-the-art for important R&D Activities and associated FEPs
5) Identify important FEPs that have not been addressed adequately by Campaign R&D Activities
6) Present a new document archive for UFD and SFWST milestone reports

Objectives 3 and 4 are primarily addressed in a series of appendices to this report that capture the wealth of consensus information compiled by Campaign experts during the three-day Roadmap Update Workshop. Regarding Objective 5, this update exercise identified a number of "gap" activities that represent future R&D necessary to adequately advance the state of the art of several high- and medium-priority FEPs.

The 2019 Roadmap Update also utilized a systematic process that was similar in many ways to that used in the 2012 Roadmap (DOE 2012), but with important differences in both the definition of the "items" or "quanta" to be prioritized, and in the criteria and process used for prioritization. There were five basic steps in the 2019 process:

1. Identify a set of items to be evaluated (e.g., R&D activities, issues, or options, …)
2. Identify criteria and associated metrics for assessing the set of items, such as:
    a. *Importance* to the safety case (ISC) (e.g., to performance assessment (PA) calculations, technical bases, confidence-building potential)
    b. Potential to reduce key *uncertainties*, i.e., to advance the state-of-the-art level (SAL) or knowledge
    c. Other factors
3. Evaluate each item (R&D Activity) 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 item (R&D Activity)
5. Compare rankings of the items (R&D Activities)

The goal was to identify R&D items (or "quanta") that provide maximum value to DOE in terms of advancing the program's ability to support future decisions regarding the siting, selection, design, licensing and construction of a geologic repository. For the 2019 R&D Roadmap Update, the SFWST Campaign decided to redefine the R&D items to be prioritized. Instead of using the FEPs list as the basis, the new items to be prioritized were based on ongoing and proposed R&D work scope activities (or tasks) being performed by project participants, and are herein referred to as R&D Activities. For completeness and for a high-level evaluation of R&D progress since 2012, the generic FEPs list was used to both map the R&D Activities to FEPs, and to help identify "gap" activities where existing R&D Activities did not completely address particular FEPs.

The activity-based approach is believed to have several advantages over the UFDC Roadmap FEPs-based approach utilized in 2012. Scientists and engineers planning and executing the R&D program generally do not design experiments or perform analyses that are specific to individual FEPS. Instead, work is conceived and conducted at a broader conceptual level, which provides information on multiple FEPs. For example, experimental test programs typically address both engineered and natural features of the system, as well as multiple processes (e.g., thermal, hydrologic, geochemical and geomechanical) that act on the features. Similarly, the analyses and models developed to simulate the test results and predict long term behavior must likewise address multiple FEPs. The 2019 activity-based approach has the additional benefit of allowing program participants and managers to directly assess the resources (both personnel and costs) required to conduct prioritized R&D, and to understand the costs and benefits of various “multi-FEP” R&D tasks.

The initial list of R&D Activities for the 2019 Update was compiled by the Technical Leads for the SFWST Program, and several additional activities were added to this list during the Update Workshop. Although R&D Activities are generally described more broadly than individual FEPs, they do still vary in their level of discretization—some are quite narrow in scope and some are broad. To ensure that the 2019 Roadmap Update addressed all the R&D Issues identified in the 2012 Roadmap, SWFST staff identified and correlated all the medium- and high-priority FEPs from 2012 with the R&D Activities defined for 2019. In this way, the 2012 FEPs list also served as a completeness check on the R&D Activities list and facilitated gap identification. The R&D Activities Excel spreadsheet compiled for the 2019 Workshop had 109 Activities, with more than 20 columns of information for each Activity. This spreadsheet was actively revised by consensus during the Update Workshop and has since been converted to a Microsoft Access® database, which can be used in the future for tracking and prioritizing project R&D.

The same two primary criteria were used in 2019 to assess the overall importance of each R&D Activity: “Importance to the Safety Case” and “State-of-the-Art.” However, the guidance provided to workshop participants about what to consider and how to rank activities was significantly different. As an example, the 2012 UFD Roadmap attempted to address the time-value of R&D by considering the relative (and variable) importance of its evaluation metrics at different stages of the repository development timeline, such as at site screening, site selection, site characterization, etc. For the 2019 Roadmap Update, this weighting scheme was considered unnecessary, in part because the U.S. Program is currently in the R&D stage for generic repository sites, so the focus is on developing generic safety cases. Furthermore, the overall scores for R&D Activities were assessed more qualitatively in 2019, such that detailed discretization of the utility function is not warranted. Instead of assessing the value of R&D activities at multiple decision points, the 2019 Roadmap Update process established a simpler near-term goal. The SFWST experts were asked to define the generic R&D needed to develop and implement credible and defensible total system PA models for generic sites with “baseline capability” by the year 2022. This meant a capability to run PA models for generic sites that would simulate the effect of all important post-closure FEPs. In addition to the requirement for a baseline PA, a goal was established to improve understanding of important systems and processes by advancing the state-of-the-art metric for each R&D activity by at least one level. Achieving this goal would represent a significant reduction in uncertainty for the overall program, and a meaningful evolution of the generic repository safety cases.

The 2019 R&D Roadmap Update Workshop was organized around the rock types that are the basis for the generic R&D in the SFWST Campaign, i.e. argillite (e.g., clay or shale), crystalline (e.g., granite), and bedded salt. The primary results of the Update Workshop are summarized in this report's appendices. The organization of the appendices includes these generic host rock divisions, as well as other cross-cut groupings of R&D Activities. Specifically, the information presented in the appendices is organized into eight groups of R&D: Argillite, Crystalline, Salt, EBS, International, DPC, PA, and Other. Each group has a defined set of technical activities, or tasks, that form the basis of the prioritization presented in this report. A total of 109 R&D Activities have been defined. These Activities are described in Appendix B, along with their workshop-derived, consensus metric values and computed priority scores.

As noted above, the R&D Activities were assessed from two different perspectives or criteria, and evaluation metrics were defined for these two criteria before the Workshop. Importance to the Safety Case (ISC) was scaled as High, Medium, or Low, with specific definitions of the three scale values being dependent on the importance of the R&D Activity relative to various components or elements of the generic safety case. The State of the Art Level (SAL) was assigned to one of five values based on the level of knowledge currently available and what yet needs to be obtained. These two metrics were combined after the Workshop to define a Priority Score: High, Medium-High, Medium, or Low for each R&D Activity.

Consensus on ISC and SAL metric values was obtained within "breakout" sessions comprised of about ten to fifteen experts each, using the provided metric scales, and with guidance by the session chair and the overall Workshop chair. There were six breakout sessions: first, there were three host-rock (Argillite, Crystalline, Salt) day-long, concurrent sessions; these were followed by half-day concurrent sessions on EBS, DPC, and International R&D Activities. PA and Other R&D Activities did not have their own sessions but were assigned to the six aforementioned sessions, at the discretion of the technical leads.

In addition to providing consensus metric values, the technical specialists also identified the R&D necessary to change each Activity from its current SAL level to the next improved level, as well as other comments and suggestions for future R&D opportunities, integration needs, and emerging issues. The "raw" consensus information (metric values, comments, and other suggestions) is primarily documented in Appendices B and K. Post-workshop mappings of FEPs to Activities and vice-versa are given in Appendices D through I, which help show the comprehensiveness of the current Campaign R&D Activities relative to the important FEPs identified in 2012 (primarily those FEPs identified as of high and medium priority).

Probably the most important categorization of R&D Activities shown here is by generic host-rock breakout session: Argillite, Crystalline, and (Bedded) Salt. These three host rocks form the three core generic repository concepts (and associated safety cases) being developed within the Campaign; however, the R&D Activities that need to be evaluated for these concepts are not just geologic (or natural system) related R&D Activities, since each repository concept consists of both natural and engineered barriers. Therefore, each host-rock breakout session was asked to also consider EBS, DPC, International, and PA R&D Activities that are relevant to their generic repository concept. This resulted in a number of these other R&D Activities being evaluated in more than one host-rock breakout session. Any inconsistencies in the ISC and SAL metric values developed in the host-rock sessions were then resolved in the later EBS, DPC, and International breakout sessions. [Inconsistencies in PA metric values were resolved by PA experts after the Workshop.]

Post-workshop graphical analysis of the final Priority Scores (Low, Medium, Medium-High, High) for the R&D Activities considered in each of the three host-rock breakout sessions showed remarkable uniformity in priority assignment among the three sessions, with all three host-rock sessions resulting in about 50% Medium-priority Activities, 30% Medium-High-priority Activities, and 20% High-priority Activities. This uniformity across host-rock breakout sessions is perhaps indicative of a rather uniform "calibration" of the experts across the sessions. [By comparison, about 55% of Issues were scored Medium and 45% scored High in the 2012 Roadmap—after subtracting out the Low- and Zero-scoring Issues because these latter were not used to design the R&D program following the 2012 Roadmap.]

Of the eight topical R&D Activity groupings mentioned above, the DPC R&D Activity group had, by far, the highest percentage of High-Priority Activities (about 70% of its total), primarily because the recent emphasis on evaluating direct disposal of DPCs in generic deep geologic repository concepts has led to a number of new, emerging issues that are being addressed by these R&D Activities.

Future long-term R&D still thought to be necessary, but not being conducted presently, is identified as a series of "Gap Activities;" and the 2019 prioritization results are presented graphically with and without the Gap Activities, i.e., as charts of Priority Scores for all R&D Activities (current and future), as well as Priority Scores of only current R&D ("without Gap Activities").

A review of High- and Medium-High-priority R&D Activities has led to the identification of a set of "High Impact R&D Topics," including:

- High Temperature Impacts
- Buffer and Seal Studies
- Coupled Processes (Salt)
- Gas Flow in the EBS
- Criticality
- Waste Package Degradation
- In-Package Chemistry
- Generic PA Models
- Radionuclide Transport

These High Impact R&D Topics provide a high-level snapshot of the current and future generic R&D focus. More information on how these High Impact Topics relate to specific R&D Activities, as well as some integration issues involved in generic PA model development, are provided in the main body of this report.

The discussions and interactions that took place during the Workshop were part of an important information exchange between the technical experts of the SFWST Campaign. These discussions took place formally, in breakout sessions, and informally throughout the Workshop. A concluding integration session at the end of the Workshop provided an opportunity to identify cross-cutting issues that had been identified and discussed in the breakout sessions.

The following are several overarching issues that arose during the final integration session:

- Technical integration between R&D Activities is essential because of the complexity of developing generic PA models and generic safety cases
- The temporal framework (or timeline) for "Generic R&D Needed" appeared to vary a lot between breakout sessions and could improve in the future with more intensive inter-group calibration prior to, and at the beginning of, the Workshop
- "Calibration" on the assignment of ISC and SAL metric values is important to develop prior to, and at the beginning of, the Workshop
- Adding a metric for level of effort (LOE) for individual activities would be very useful
- Integration of DPC-relevant parameters into all modeling activities is needed

Although much has been accomplished since 2012, through R&D in the U.S. Program and through international collaborations, especially with those countries that operate underground research laboratories (URLs), the 2019 R&D Roadmap Update reflects the need for continuing R&D on many of the 2012 R&D Issues, plus some obvious new priorities, such as R&D on disposal of DPCs (dual purpose canisters), which now contain a significant fraction of the Nation's spent fuel activity. This new 2019 R&D prioritization effort is closely tied to the development of the Campaign's generic performance assessment model/software framework, *GDSA (Geologic Disposal Safety Assessment) Framework*, which results in much of the R&D being directly related to the supporting process models that feed this PA model and software. Given the importance of post-closure performance assessment in building confidence in the safety case, this is deemed appropriate.

Finally, this deliverable introduces the new SFWD Document Archive website. As a result of the DOE-NE reorganization that created the Office of Spent Fuel and Waste Disposition (SFWD), the Document Management System (DMS)—the former repository for UFD milestone deliverable documents—became unavailable. This gap is now being filled with a restricted-access SharePoint website, called the SFWD Document Archive (SDA). This new document repository captures reports generated in the SFWST Campaign [including both Disposal Research (DR) and Storage and Transportation (S&T) documents] between 2010 and 2019 and Integrated Waste Management (IWM) Campaign documents between 2013 and 2019. Currently, there are 532 DR documents in the SDA, of which 504 are unclassified unlimited release (UUR) and will soon be made available to all SFWD staff who are DOE employees or contractors. There are also 227 S&T documents currently available.

This report fulfills the Geologic Disposal Safety Assessment Work Package Level 2 Milestone – *GDSA Model Integration and R&D Roadmap* (M2SF-19SN010304042).

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ACRONYMS

CDF	Cumulative Distribution Function
CSNF	Commercial Spent Nuclear Fuel
DFN	Discrete Fracture Network
DOE	U.S. Department of Energy
DPC	Dual Purpose Canister
DRZ	Disturbed Rock Zone
EBS	Engineered Barrier System
EDZ	Excavation Disturbed Zone
FEPs	Features, Events, and Processes
FMDM	Fuel Matrix Degradation Model
FY	Fiscal Year
GDSA	Geologic Disposal Safety Assessment
HLW	High-Level Radioactive Waste
ISC	Importance to the Safety Case
NBS	Natural Barrier System
NE	Office of Nuclear Energy
NEA	Nuclear Energy Agency
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PA	Performance Assessment
QA	Quality Assurance
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SAL	State-of-the-Art Level
SDA	SFWD Document Archive
SFWD	Office of Spent Fuel and Waste Disposition
SFWST	Spent Fuel and Waste Science and Technology (Campaign)
SNF	Spent Nuclear Fuel
TAD	Transportation, Ageing, and Disposal Canister
TBD	To Be Determined
THC	Thermal-Hydrologic-Chemical
THCM	Thermal-Hydrologic-Chemical-Mechanical
THM	Thermal-Hydrologic-Mechanical
UFDC	Used Fuel Disposition Campaign
ULR	Unclassified Limited Release
UUR	Unclassified Unlimited Release
WF	Waste Form
WIPP	Waste Isolation Pilot Plant
WP	Waste Package

1. INTRODUCTION

In general, when conducting research and development (R&D) activities supporting large scientific and engineering endeavors of national importance there are significant constraints related to time and available resources. This is particularly true for siting, licensing, constructing, and operating a deep geologic repository for a nation's commercial spent nuclear fuel (SNF) and high-level radioactive waste (HLW). However, because such a repository endeavor involves complex physical-chemical-thermal processes in a heterogeneous rock domain, as well as unique engineering concepts, there are and will always be uncertainties in the future evolution of the complete repository system. R&D conducted to quantify and reduce these uncertainties to the extent practical will build confidence in the post-closure safety of the system, as embodied in a post-closure safety case.

Because the extent of R&D to reduce uncertainties is subject to these time and resource (personnel and funding) constraints, some sort of prioritization must be imposed, with the greatest amount of resources expended on those R&D activities judged to have the greatest potential for reducing uncertainty about the future safety of the system. The judgment regarding prioritization of work is informed by experts with long-standing knowledge of the related areas of science and engineering. This expert prioritization generally has both qualitative and quantitative aspects, used to satisfy the expectations of multiple stakeholders involved in such a project. Resources are usually first apportioned to broader categories of work according to management and expert judgment (using informal qualitative criteria) as to the highest priority needs. Within these broader categories, e.g., a work breakdown structure, resources are further subdivided based on the relative importance of individual R&D "quanta" or "items" (e.g., "R&D issues" and/or "R&D activities"), with their "importance" having generally been derived from numerically based rankings developed during decision analysis workshop(s). Such workshops can use as input various quantitative analyses and calculations, such as system performance assessment simulations.

R&D addressing the disposal of SNF/HLW in the U.S. is currently generic (i.e., "non-site-specific") in scope, following the suspension of the Yucca Mountain Repository Project in 2010. However, to prepare for the eventuality of a repository siting process, the former Used Fuel Disposition Campaign (UFDC) of DOE-NE formulated an R&D Roadmap in 2012 outlining generic R&D activities and their priorities appropriate for developing safety cases and associated performance assessment (PA) models for deep geologic repositories in several potential generic host-rock environments in the contiguous United States (DOE 2012). This 2012 UFDC Roadmap also identified the importance of re-evaluating priorities in future years as knowledge is gained from the DOE's ongoing R&D activities.

Since 2012, significant knowledge has been gained from these activities through R&D in the U.S. and via international collaborations, especially with countries that operate underground research laboratories (URLs). This 2019 R&D Roadmap Update summarizes the progress of ongoing generic disposal R&D activities, re-assesses R&D priorities, and identifies new activities of high priority, such as R&D on disposal of DPCs (dual purpose canisters), which now contain a significant fraction of the Nation's spent fuel activity. The objectives of this report are to

- Recap the 2012 Roadmap results and conclusions
- Document the 2019 Roadmap Workshop approach, activities, and evaluations

- Summarize the status, progress, and priority of disposal R&D activities and their relation to FEPs important to various host rocks and repository designs
- Identify important Features, Events, and Processes (FEPs) that have not been addressed by disposal R&D activities
- Present a new document archive for UFD and Spent Fuel and Waste Science and Technology (SFWST) milestone reports
- Identify the generic R&D still needed to advance the state-of-the-art for important FEPs and activities

Successor to the Used Fuel Disposition (UFD) Campaign that guided disposal R&D priorities from 2010 to 2017, the SFWST Campaign continues to identify alternatives and conduct scientific and technology R&D to enable the Nation to prepare for the future geologic disposal of SNF and HLW and to create a radioactive waste management system that could safely accommodate a variety of strategies that may also include interim storage and transportation from shut-down reactor sites.

This report fulfills the Geologic Disposal Safety Assessment Work Package Level 2 Milestone – *GDSA Model Integration and R&D Roadmap* (M2SF-19SN010304042).

2. 2012 UFDC ROADMAP RECAP

2.1 Objectives

As described in the UFDC Disposal Research and Development (R&D) Roadmap, Revision 1 (DOE 2012), the UFDC was created by DOE-NE to conduct R&D activities related to the storage, transportation, and disposal of spent nuclear fuel (SNF)[1] and high-level nuclear waste (HLW). After the shutdown of the deep geologic repository program at Yucca Mountain, DOE determined that the mission of the UFDC was to identify alternatives and conduct scientific and technology R&D to enable DOE to prepare for the future disposal of SNF and HLW in one or more locations in various geologic media.

The UFDC was intentionally designed to focus on generic research that could be used to reduce uncertainties related to our understanding of processes important to the performance of any proposed generic repository or waste management system. As a result, the information collected should be useful to DOE at any future phase of program development, including facility siting, characterization, design, licensing and construction. The 2012 UFDC Roadmap recognized that the level of knowledge required to support repository related decisions would evolve with time, and the programmatic need at that time was to support the evaluation of disposal concepts and technologies that could be implemented during future phases of the program. As shown on Figure 2-1, DOE anticipated that future research, development, and demonstration (RD&D) activities would evolve from generic studies to site-specific studies as the program moves to future decision points such as site screening, site selection, site characterization, and site suitability evaluations.

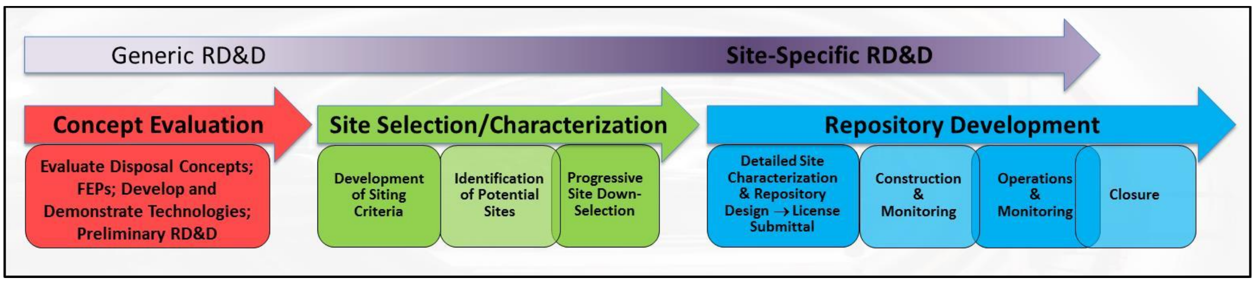


Figure 2-1. Evolution of RD&D Needs During Development of the Repository/Waste Management System.

The program focused on the evaluation of the viability of mined repositories in three generic geologic media (salt, clay, and crystalline rock), and, in addition to mined repository disposal, the use of deep boreholes in generic crystalline basement rock (Arnold et al. 2012; NWTRB 2016).[2] The lithologies were selected because they have been considered and analyzed as potential repository host rocks both in the U.S., and internationally, for several decades. The generic rock types were identified at a broad level: salt includes both bedded and domal salt, clay was defined to include a broad range of fine-grained sedimentary rock types including shales, argillites, and claystones, as well as soft clays, and crystalline rock may include a range of lithologies such as granite, metamorphic gneisses and a variety of igneous rock types.

[1] Used nuclear fuel (UNF) and spent nuclear fuel (SNF) both refer to enriched uranium that is burned (fissioned) in light water reactors in the U.S., assuming a once-through fuel cycle. The term SNF is currently favored because there is no existing U.S. policy for recycling reactor fuel.

[2] DOE Campaign R&D for this concept was discontinued in 2017.

The disposal options were not intended to represent a complete or comprehensive list of possible alternatives, and other options may also have the potential to provide safe long-term isolation. However, DOE and UFDC managers believed that R&D related to the evaluation of the selected generic media was likely to be applicable to nearly any future program that relied on deep geologic disposal.

2.2 Process

The development of the UFDC Disposal R&D roadmap began in 2010 and included an initial workshop held at Argonne National Laboratory in June 2010. Radioactive waste management experts from across the DOE national laboratory complex participated and provided input regarding potential R&D opportunities that should be considered by the UFDC. The input received at that workshop and other studies and analyses performed in FY 2010 were used to develop "*Used Fuel Disposition Research and Development Roadmap – FY10 Status*," (DOE 2010). That report identified potential R&D topics that may warrant consideration by the UFDC but made no effort to prioritize the topics.

As described in the 2012 UFDC Roadmap (DOE 2012), the UFDC defined and utilized a systematic, decision-analysis based approach to developing and prioritizing the R&D portfolio. The process involved five steps:

1. Identify potential R&D issues (information needs and knowledge gaps)
2. Characterize and evaluate R&D issues to support prioritization
3. Identify overall UFDC issue priorities based on the evaluation
4. Identify R&D projects to address high-priority issues
5. Evaluate R&D projects and select projects for funding.

After the R&D issues were identified, two primary criteria were used to evaluate their relative priority. The first was "Importance to the Safety Case," which is a measure of how important each issue was to the demonstration that a repository could safely protect the health and safety of the public and the environment. The UFDC further defined "Importance to the Safety Case" by identifying the specific safety objectives or performance requirements that could apply to a potential repository under any likely regulatory environment. Based on safety guidelines developed by the International Atomic Energy Agency (IAEA 2003; IAEA 2012), the 2012 Roadmap defined four fundamental technical objectives for a repository disposal system. These were:

- Containment
- Limited Release
- Dilution and Dispersion
- Defense in depth and multiple barriers

Each evaluation of ISC considered how important a given R&D issue was to the demonstration that the repository could perform one or more of the performance objectives. Issues that were highly important to the evaluation of key safety functions would be ranked higher in priority than issues that were less important to safety.

The second criterion used to assess the R&D issues was a measure of the scientific level of understanding of each R&D issue, which was defined as the "State-of-the-Art." R&D issues that were not well understood, or which had very high levels of uncertainty, would receive a higher priority ranking than issues that were believed to be well understood.

A second workshop was then held at Argonne National Laboratory in December 2010. The goal of that workshop was to evaluate each R&D issue based on the criteria to support an initial prioritization. UFDC researchers prepared a preliminary version of a detailed spreadsheet called the *UFDC Disposal R&D Roadmap Prioritization Information Matrix* and provided it to workshop participants. A core set of UFDC participants reviewed the matrix that was completed during the workshop and revised it as necessary. After subsequent review and revision by a broader group of researchers, a third workshop was held in March 2011 to calculate an overall priority metric for each R&D issue based on the technical assessments of the importance of the issues to the safety case, the importance of the issues to each decision point, and the adequacy and state of the art of current information. In each of the workshops, the participants relied on a wide range of published information regarding the feasibility and performance of geologic disposal facility concepts developed in the U.S. and internationally. Several reports were specifically prepared and published by Sandia National Laboratories to investigate the feasibility of different disposal concepts and media within the U.S. The final *UFDC Disposal R&D Roadmap Prioritization Information Matrix* summarizes the results of the workshops and describes the results of each individual R&D issue evaluation. The matrix is Appendix A of the 2012 Roadmap (DOE, 2012).

The 2012 Roadmap also describes how the results of the criteria evaluations were combined numerically to calculate an overall priority ranking. The following sub-sections provide additional detail regarding identification of the R&D issues, the criteria definitions and evaluations, and the results.

2.2.1 Identification of R&D Issues

To define the set of R&D issues to be evaluated, the UFDC examined the comprehensive databases of Features, Events, and Processes (FEPs) that had been compiled by the U.S. and international repository programs over the past several decades. The FEPs databases include all aspects of the geologic media in which a repository would be sited, and the engineered physical systems that would be designed to limit radionuclide release (i.e., the natural and engineered features) as well as the processes (e.g., geologic, hydrologic, geochemical, thermal and mechanical processes) and events (e.g., seismic, volcanic, or meteorological or climatic events) that could act on them.

Each individual FEP describes a physical portion of the natural or engineered repository system, and the processes and/or events that may contribute to the ability of a repository to perform its intended functions (the safety objectives discussed above), as illustrated in Figure 2-2. The uncertainty in our current understanding creates the R&D Issues that can be addressed through the UFDC activities. The R&D issues considered in the 2012 Roadmap were derived one-for-one from the set of 208 post-closure FEPs (e.g., see Table 2-1) compiled by the UFDC (Freeze et al., 2010; Freeze et al., 2011; Freeze et al. 2013). Because some FEPS are addressed differently in the various geologic media (crystalline, argillite and salt), a total of 354 separate R&D Issues were identified. This approach ensured that the roadmap priority evaluation would capture essentially all aspects of the physical system(s), processes, and events that could affect the ability of any generic site, in any geologic media, to isolate and contain radionuclides.

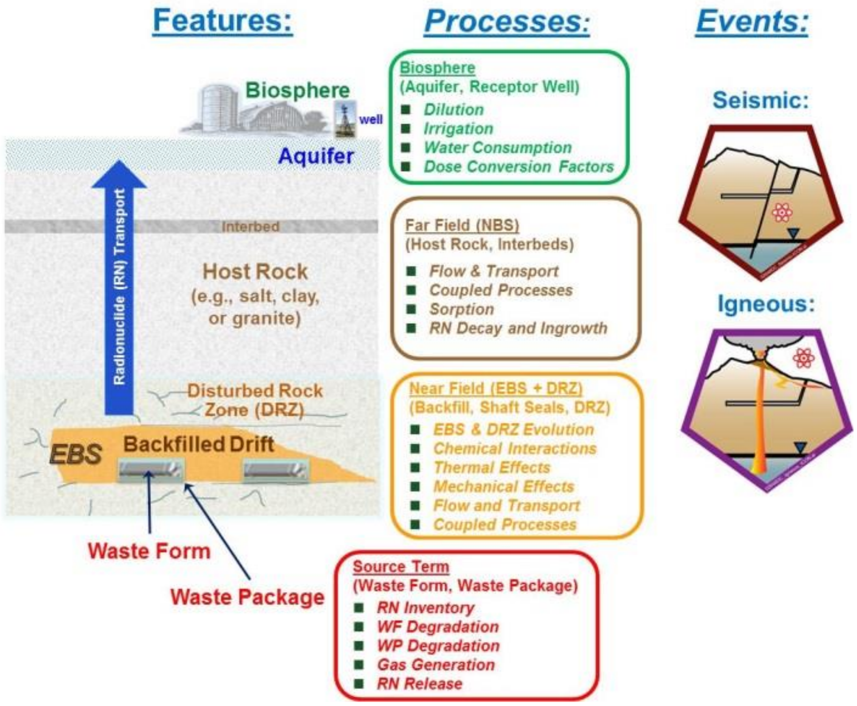


Figure 2-2. Schematic Drawing of Features, Events, and Processes Relevant to a Repository.

Table 2-1. Example of Post-Closure FEPs Descriptions.

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

2.2.2 Importance to the Safety Case

The first metric evaluated for each R&D Issue was its Importance to the Safety Case. The UFDC utilized a definition of the safety case for geologic disposal proposed by the OECD/NEA (NEA 2004):

> "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. The safety case becomes more comprehensive and rigorous as a program advances and is a key input to decision making at several steps in the repository planning and implementation process."

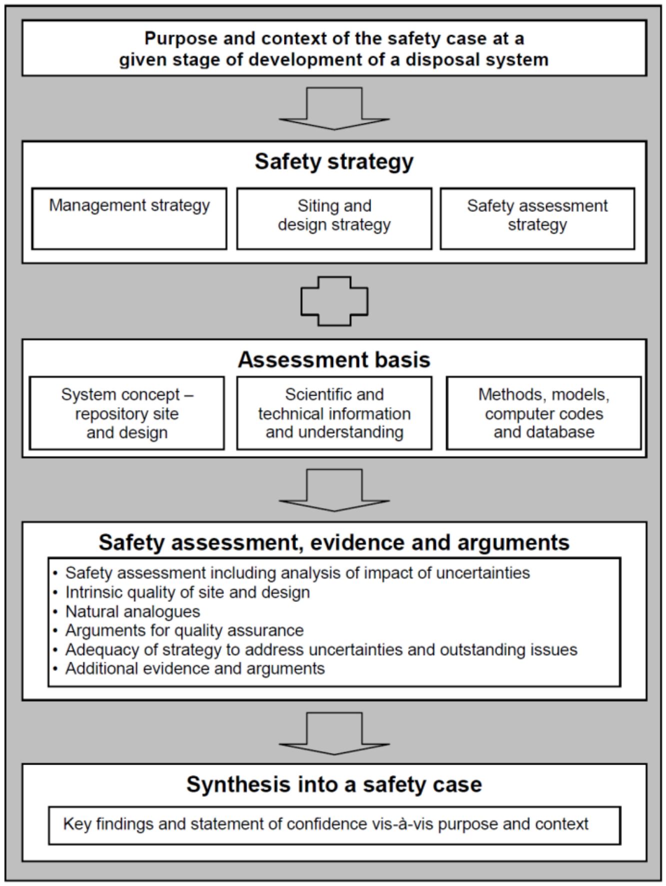


Figure 2-3. Relationship Between the Different Elements of the Safety Case (NEA 2013, Fig. 2.1).

Figure 2-3 provides an overview of the elements or components of a safety case for geologic disposal as proposed by the NEA (NEA 2004; NEA 2013). The UFDC was focused primarily on supporting the development of a defensible future safety Assessment Basis. The Safety Strategy, which describes the overall approach adopted for achieving safe disposal, may evolve over time, and will be informed by results from the UFDC R&D program. In addition to the Safety Strategy and Assessment Basis, the other factors that are just as, or more, important to the safety case are the post-closure Safety Assessment and various qualitative Evidence and Arguments that provide confidence in the overall safety case. The System Concept is also a fundamental part of the safety case. It consists of a description of the repository design including the engineered barriers, the geologic setting and its stability, how both engineered and natural barriers are expected to evolve over time, and how they are expected to provide safety (NEA 2004; NEA 2012). As part of the R&D program, the UFDC committed to develop one or more safety concepts or aspects of the safety concepts for the generic disposal environments in the different geologic media under consideration (at a conceptual level).

In the 2012 UFDC Roadmap the importance of an issue to the safety case was considered to be a function of its importance to each of three components of the safety case (importance to the safety assessment; importance to design, construction and operations; and importance to overall confidence in the safety case). Therefore, an R&D issue could receive a high priority ranking if it was important to any of the three.

Each R&D issue was evaluated and assigned a ranking of low, medium, or high importance to the safety case, and corresponding numerical scores of 1, 2 or 3. Separate scores were compiled for each of the three components in the safety case, which were then weighted and combined into an overall score at each of the key programmatic decision points (i.e., site screening, selection, characterization, and suitability evaluation) (DOE 2012, Section 3.2).

2.2.3 State-of-the-Art

The next criterion evaluated in the 2012 UFDC Roadmap was the “State of the Art” of each issue. The “State of the Art” was defined by describing how well each R&D Issue was currently understood. Issues with the highest level of current knowledge were considered to be “well understood,” and therefore not a high priority for R&D. Issues with the greatest deficiencies in “State of the Art” were associated with high uncertainties because there “… are fundamental gaps in methods, fundamental data needs, or both.” In between these two endpoint levels, three intermediate levels (Improved Representation, Improved Confidence, and Improved Defensibility) were defined that represent various degrees of confidence and defensibility in the models used to analyze the issue. The definitions provided below were provided to help UFDC workshop participants categorize the “State of the Art” for each R&D Issue:

- 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
- Fundamental Gaps in Method: the representation of an issue (conceptual and/or mathematical, experimental) is lacking
- Fundamental Data Needs: the data or parameters in the representation of 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

The goal of the UFDC R&D program was to provide a basic understanding of all systems and processes that have a potentially significant impact on repository performance. For this reason, R&D issues characterized by fundamental gaps in method, or data needs, were high priority for the ongoing generic R&D program, especially if they were associated with issues believed to be important to safety.

2.2.4 Decision Points

The importance of an issue to the safety case is always relevant, but the relative contribution of the aforementioned three components of the safety case (importance to the safety assessment; importance to design, construction and operations; and importance to overall confidence in the safety case) to overall importance could differ over time and at different decision points (see Figure 2-1). Issues that are important for near-term decisions are generally of higher priority than those that are 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 are of lower priority, at least with respect to that decision point. These "time value" considerations were factored into the final priority score for each R&D issue in the 2012 Roadmap.

2.3 Results

The development of relative priorities among all R&D issues (or FEPs) relied on the foregoing criteria:

- 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

In order to facilitate this comparison of relative R&D priorities across the entire program, UFDC staff developed a quantitative method to combine the evaluations of these criteria for each R&D Issue (DOE 2012, Section 3.2). Although the criteria rankings were subjective, and based primarily on expert judgment, the calculated priority scores provided a useful way to compare R&D issues.

Figure 2-4 summarizes the calculated scores for each individual R&D issue. Using the graph, and the list of issues sorted by priority score, the UFDC development team selected two cutoffs (priority scores of 2.4 and 3.5) to identify Low, Medium, and High priority issues. These cutoffs were selected to correspond to the two slope changes shown in Figure 2-4. A significant number of individual issues had a priority score of zero. This could occur for one of several reasons:

- The issue could not be addressed through generic R&D
- The issue could be fully addressed by conducting R&D on other issues, or
- The current level of information was judged to be sufficient for all decision points.

Although the R&D issues were sorted by score, the listing was not intended to be used as an issue-by-issue ranked priority list. Rather, it was intended as a grouping of issues with similar levels of priority. Among the 354 total R&D issues evaluated, a total of 68 were found to be High priority, and 83 Medium priority.

Following this scoring exercise, the generic R&D program was designed to help resolve the uncertainties associated with the highest-ranking issues—primarily High and Medium Issues.

Specific R&D Topics were identified and evaluated against the Issue prioritization scores. R&D Topics, as defined in DOE (2012) are similar to the R&D Activities prioritized in this 2019 Update. In 2012, it was recognized from the outset that the Topics initiated to address the FEPs/R&D Issues could not be addressed in isolation, i.e., the Topic designed to address uncertainties typically provided information relevant to multiple aspects of the systems and processes. As stated in DOE (2012): "…this R&D roadmap focuses on evaluating and prioritizing the R&D issues. R&D topics will be developed following completion of this R&D roadmap. It is anticipated that R&D topic identification will be continual and not a one-time occurrence that occurs once the R&D roadmap is completed."

Because the 2012 R&D Program was mainly designed on the priority of the R&D Topics based around High and Medium Issues and because this 2019 R&D Update is in part trying to determine progress since 2012, it is useful to specify the fraction of 2012 R&D Issues that are scored High versus those that are scored Medium. Subtracting out the Low and Zero Issues (FEPs) gives about 45% High Issues (68/151) and 55% Medium Issues (83/151).

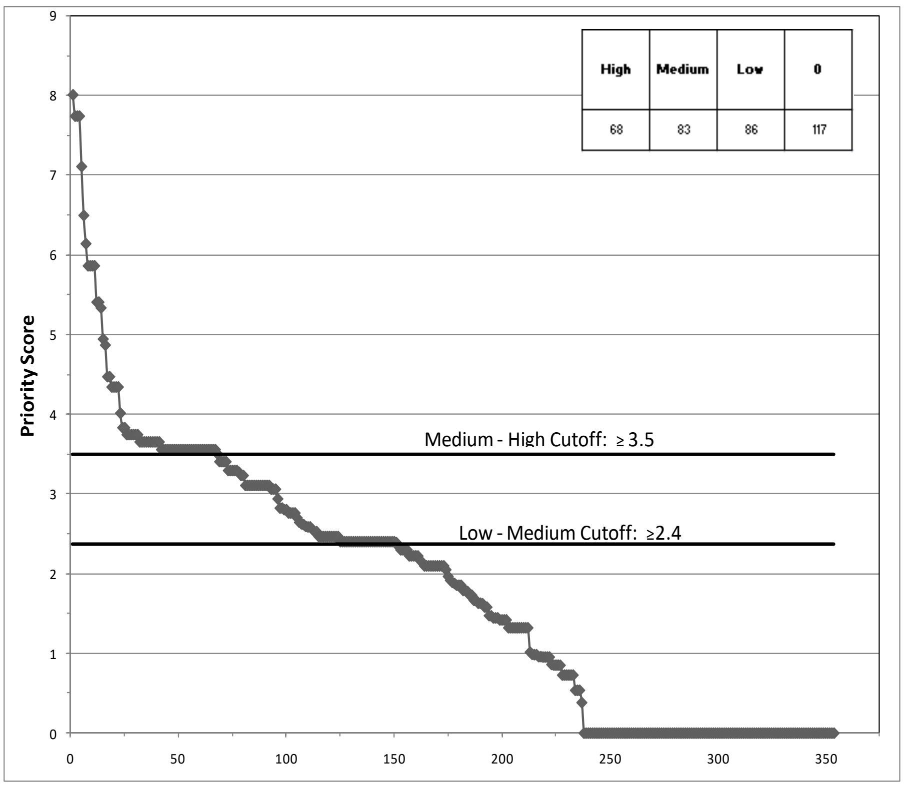


Figure 2-4. Priority Scores for UFDC R&D Issues.

Table 2-2 is a brief excerpt from Appendix B of the 2012 Roadmap (DOE, 2012) showing the highest scoring R&D issues (FEPs) and their priority scores. Appendix A (the UFDC Disposal R&D Roadmap Prioritization Information Matrix) of the 2012 Roadmap presents the rationale for the detailed evaluation of each of the 354 identified R&D Issues compared to the ISC and SAL criteria and decision points discussed above, as well as other information such as the processes associated with each FEP, and the assessment of whether generic R&D could meaningfully address the issue.

In addition to the evaluations of individual R&D issues summarized in Appendices A and B, the 2012 Roadmap (DOE 2012) also contains extensive analyses and discussion of the priority of groups of R&D issues.

Table 2-2. Excerpt of Appendix B (DOE 2012) Showing a few High Priority Issue Scores.

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

Table 2-3 shows the results of an analysis by UFDC experts of the overall priority of categories of FEPs applicable to the natural system, sorted by geologic media (crystalline, salt and shale or argillite). The analysis demonstrated that certain categories of issues/FEPs had a consistently high priority (e.g., Host Rock properties), whereas others could vary considerably between media. For example, flow and transport pathways was ranked as a medium priority in all media, whereas chemical processes ranged from low priority in crystalline rocks to medium-high priority in shale. Excavation Disturbed Zone (EDZ) FEPs were ranked as a medium priority for crystalline and salt repositories, and high priority in shale. Similarly, hydrologic properties ranged from low priority in crystalline rocks to high priority in salt, reflecting the assessment that salt repositories rely primarily on the natural barrier system to limit radionuclide releases.

A similar analysis of the priority of issues related to the engineered barrier system indicated that the priority of R&D issues/FEPs related to Waste Form, Waste Package, and Buffer/Backfill materials generally ranked higher than other engineered systems. Waste container issues and chemical processes generally ranked higher than those for other specific processes such as hydrologic and biologic processes. R&D issues related to chemical processes generally ranked higher than others for most components of the EBS, and they may be strongly coupled to thermal, hydrological, and even mechanical processes.

Table 2-3. Relative Priority of Groups of R&D Issues Sorted by Processes and Geologic Media.

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

In the process of evaluating the R&D issues summarized in Appendix A of DOE (2012), UFDC scientists and engineers also identified several cross-cutting issues and R&D opportunities that do not correspond directly to individual issues in the UFDC Disposal R&D Roadmap Prioritization Information Matrix. However, they either cut across or integrate with several of the specific R&D issues and have therefore been defined as, and been considered part of, the UFDC R&D portfolio. These cross-cutting issues are shown in Table 2-4.

As an example, Design Concept Development was identified as a High-priority cross-cutting issue because many of the R&D issues evaluated at the process-level within the R&D Roadmap matrix (DOE 2012, Appendix A) are linked or coupled, and future analysis will require development of generic disposal concepts in order to conduct R&D on the specific issues. An R&D program to improve the understanding of the processes at material interfaces within the engineered systems requires that disposal concepts be defined. Selection of disposal concepts, engineered barrier design, and the engineered barrier materials also depends on the geologic setting.

Disposal System Modeling was identified as a High-priority cross cutting issue for several reasons. The first is that the UFDC was, and is, developing generic disposal system models to support both short-term and long-term goals related to the program. In the short term, these models provide a capability for evaluating generic disposal system performance to inform future R&D activity prioritization, and to evaluate disposal-related metrics and system engineering activities. Generic performance assessment (PA) models have been developed for each of the geologic media under consideration, and ongoing work to improve the models is in progress. An important future use of these PA models—coupled with advanced, multi-physics models for geologic disposal-related processes—will be to support siting efforts, including site screening and selection. Eventually, the generic PA model will be used to demonstrate compliance with NRC and EPA regulations.

Section 4.2 of the 2012 Roadmap (DOE 2012) describes how each of the cross-cutting issues identified is tied to numerous specific R&D issues evaluated in Appendix A of the Roadmap.

Table 2-4. Synopsis of Cross-Cutting R&D Issues in the UFDC 2012 Roadmap (Table 6).

Cross-Cutting R&D Issue	Priority Score
DESIGN CONCEPT DEVELOPMENT	High
DISPOSAL SYSTEM MODELING	High
OPERATIONS-RELATED RESEARCH AND TECHNOLOGY DEVELOPMENT	Low
KNOWLEDGE MANAGEMENT	Medium
SITE SCREENING AND SELECTION TOOLS	Medium
EXPERIMENTAL AND ANALYTICAL TECHNIQUES FOR SITE CHARACTERIZATION	Medium
UNDERGROUND RESEARCH LABORATORIES	Medium
R&D CAPABILITIES EVALUATION	Medium

3. 2019 ROADMAP UPDATE

3.1 Objectives

The original 2012 UFDC Roadmap promised a re-evaluation of priorities in future years as knowledge was gained from ongoing activities in the U.S. and abroad. Thus, a re-assessment of R&D priorities was initiated during a recent workshop of campaign experts in early 2019, held at the University of Nevada in Las Vegas from January 15 to 17.

The 2019 Roadmap Update has been prepared as part of the SFWST Campaign, which began in Fiscal Year (FY) 2017 and is a successor to the UFD Campaign that guided disposal R&D priorities from 2009 to 2017. The purpose of the 2019 R&D Roadmap Update is to (1) summarize the progress of ongoing R&D activities; (2) reassess the relative priority of ongoing activities and (3) assess the potential need to modify existing activities or identify new high priority activities. An example of new R&D needed is related to evaluating the direct disposal of DPCs (dual purpose canisters-designed for storage and transportation of commercial spent nuclear fuel), which were not in widespread use in 2012, but which now contain a significant fraction of the Nation’s commercial spent fuel. As a result, numerous questions have arisen about how the use of the DPCs, which are larger and typically hotter than the canisters considered in 2012, might affect analyses of repository performance.

3.2 Prioritization Process

The 2019 Roadmap Update utilized a systematic decision-analysis-based process (von Winterfeldt and Edwards 1986; Keeney 1992; Price et al. 2013; Sevougian et al. 2013; Sevougian and Mackinnon 2014) that was similar in many ways to that used in the 2012 Roadmap (DOE 2012), but with important differences in both R&D “issue” definitions, and in the criteria and process used for prioritization. These differences are a natural result of the progress and evolution of the program. There were again five basic steps in the process to assist in the prioritization:

1. Identify a set of items to be evaluated (e.g., options, activities, or issues…)
2. Identify criteria and associated metrics for assessing the set of items, such as:
    a. *Importance* to the safety case (e.g., to performance assessment, to technical bases, to confidence-building potential)
    b. Potential to reduce key *uncertainties*, i.e., to advance the state-of-the-art knowledge
    c. Other factors, e.g., *cost*, redundancies and/or synergies among the items, stakeholder input (Keeney and Raiffa 1993), etc.
3. Evaluate each R&D item (i.e., each “R&D Activity” in the 2019 Roadmap Update, or each “R&D Issue” or FEP in the original 2012 Roadmap) against the metrics
4. Define a “utility function” (or ranking function) to combine the metric values and produce an overall ranking or score (“prioritization level” – see Section 3.3.2) for each R&D item
5. Compare rankings of the R&D items

The goal of the process was to identify R&D Activities that provide maximum value to DOE in terms of advancing the program's ability to support future decisions regarding the siting, selection, design, licensing and construction of a geologic repository. Figure 3-1 is a schematic two-dimensional representation of the value-of-information gained through these prioritized R&D Activities versus the cost of the activities. At this generic R&D stage of U.S. repository development, cost is less a factor than when the site selection and characterization, and the engineering and construction phases begin. Thus, in the current prioritization study (and the original 2012 Roadmap), cost was not formally factored into the prioritization effort. Of course, on a yearly Federal funding schedule, it is clearly a factor.

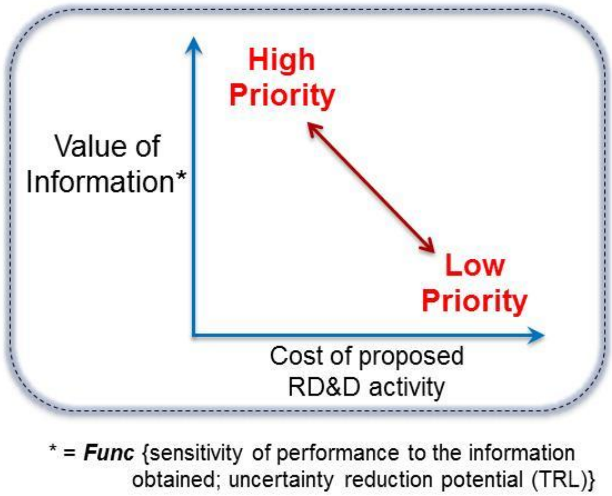


Figure 3-1. Schematic Representation of the Value of R&D Information Versus Cost.

The same two primary criteria were used in 2019 to assess the overall importance of each R&D Activity: "Importance to the Safety Case" and "State-of-the-Art." However, the guidance provided to workshop participants about what to consider, and how to rank activities was significantly different.

As an example, the 2012 UFD Roadmap attempted to address the time-value of R&D by considering the relative (and variable) importance of its evaluation metrics at different stages of the repository timeline, such as at site screening, site selection, site characterization, etc. These project phase transitions were called "decision points" and the overall utility function (or scoring function) incorporated a different weight for different decision points, with the site selection point holding the highest weight (DOE 2012, Table 5).

For the 2019 Roadmap Update, this weighting scheme was considered unnecessary (and perhaps arbitrary), in part because of the current generic R&D focus of the U.S. program. Furthermore, the overall utilities or scores for R&D Activities are assessed more qualitatively in 2019, so that such detailed discretization of the utility function is not warranted. Instead of attempting to define the value of R&D activities at multiple decision points, the 2019 Roadmap Update process established a simpler near-term goal. At the January 2019 workshop, the SFWST experts were asked to define the generic R&D needed to develop and implement a credible and defensible total system PA model with "baseline capability" by the year 2022. This meant a capability to run a PA model that would simulate in some fashion the effect of all important post-closure FEPs. In addition to the requirement for a baseline PA, a goal was established to improve our understanding of important systems and processes by advancing the state-of-the-art metric (SAL ranking) for each R&D activity by at least one level. Achieving this goal would represent an important reduction in uncertainty for the overall generic R&D program, and a meaningful step in the progression of the generic repository safety case and in the "adaptive staging" of the R&D program (Nat. Res. Council 2003).

The key components of the prioritization process implemented for the 2019 Roadmap Update (and the significant differences from the 2012 Roadmap) are summarized briefly below.

3.2.1 Updated R&D Item Definitions

As described in Section 2, the 2012 "R&D Issues" were defined on a one-to-one basis from the set of post-closure FEPs (Features, Events, and Processes) previously developed for the U.S. repository program. This list of over 200 FEPs is a relatively standard list used by repository programs worldwide but has been tailored to the U.S. program (Freeze et al 2013). The FEPs list could have been updated in 2019 to be more comprehensive (Freeze et al, 2014) but for consistency with the 2012 Roadmap, the list was kept the same.

For the 2019 R&D Roadmap Update, the SFWST Campaign decided to equate the R&D Items to be evaluated to the ongoing and proposed Activities (or Tasks) currently being performed by project participants. This approach is believed to have several advantages over the FEPs-based approach utilized in 2012. Scientists and engineers planning and executing the R&D program generally do not design experiments or perform analyses that are specific to individual FEPs. Instead, work is conceived and conducted at a broader conceptual level, which provides information on multiple FEPs. For example, the experimental tests performed in Underground Research Laboratories (URLs) in the International program typically address both engineered and natural features of the system, as well as multiple processes (e.g., thermal, hydrologic, geochemical and geomechanical) that act on the features. Similarly, the analyses and models developed to simulate the test results and predict long-term behavior must likewise address multiple FEPs. Consequently, SFWST managers determined that it would be more useful to define and prioritize the current program at the Activity or Task level. This approach has the additional benefit of allowing program participants and managers to directly assess the resources (both personnel and costs) required to conduct prioritized R&D, and to understand the costs and benefits of various "multi-FEP" R&D tasks.

The initial list of R&D Activities for the 2019 Update was compiled by the technical leads for the SFWST program and it includes all the relevant work scope performed under the program's approved Work Breakdown Structure (WBS). Several additional activities were added to the list at the Las Vegas workshop in January 2019. Although activities are always described more broadly than individual FEPs, they do still vary in their level of discretization; some are quite narrow in scope and some are broad. Examples of R&D Activities include the Waste Package Degradation Model, Evolution of Backfill in a Salt Repository, and Flow and Transport in Fractures. In order to ensure the 2019 Roadmap Update addressed all the R&D Issues identified in the 2012 Roadmap, SWFST staff identified and correlated all the medium and high priority FEPs from 2012 with the Activities defined for 2019. In this way, the 2012 FEPs list also served as a completeness check on the Activities list. SWFST staff also mapped each of the R&D Activities to the work packages and organizations that include their scope.

The R&D Activities Table (an Excel spreadsheet) compiled for the 2019 Workshop has 109 Activities, with more than 20 columns of information for each Activity. The columns include:

- Task numbers, names and brief descriptions
- Responsible organizations
- Activity type (e.g., experimental or field testing, modeling) and codes
- Safety case elements addressed
- FEPs addressed
- State-of-the-Art Level (SAL) assessments and rationale
- Importance to the Safety Case (ISC) assessments
- Generic R&D Needed

The number of Activities to prioritize is still large, but it is considerably fewer than the 354 R&D Issues in the 2012 R&D prioritization (derived from 208 FEPs that were further subdivided according to host-rock environment).

The Update Excel spreadsheet was divided into eight major groupings of R&D Activities:

- Argillite (8 activities)
- Crystalline (17 Activities)
- Salt (13 activities)
- Dual Purpose Canisters (DPC) (6 activities)
- Engineered Barrier System (EBS) (20 Activities)
- International (21 activities)
- Other (7 activities)
- Performance Assessment (PA) (17 activities)

The first three R&D Activity groupings (for the three different host-rock environments) are the most distinct and formed the basis for the primary breakout groups during the Roadmap Update Workshop (see Appendix A). The next three (DPC, EBS, and International) are cross-cutting R&D Activities that in general can apply to each of the three host-rocks. Thus, each of the three host-rock breakout groups (comprising about 15 experts each) were also asked to consider these cross-cutting activities, as appropriate. The "Other" activities category includes issues that also cut across the host rock, EBS, DPC and International categories, but do not fall neatly into another category. The spreadsheet includes 17 Performance Assessment (PA) tasks that were not addressed in detail in the 2019 R&D Roadmap Update Workshop.

The complete set of workshop results contained in the original R&D Activities Table (Excel spreadsheet) has since been converted into an Microsoft Access® database, as described briefly in Section 3.2.5. These workshop results are provided in Appendices B through L of this report and are discussed and analyzed in Section 3.3.

3.2.2 Evaluation of Importance to the Safety Case (ISC)

For the 2019 Roadmap Update, a more detailed description of the elements of the safety case for a geologic repository was prepared and used to document how each R&D Activity contributed to the safety case. As shown on Figure 3-2, the safety case includes the safety strategy, technical bases (which includes the understanding of the major features of the system, including all FEPs), and the disposal system safety evaluation.

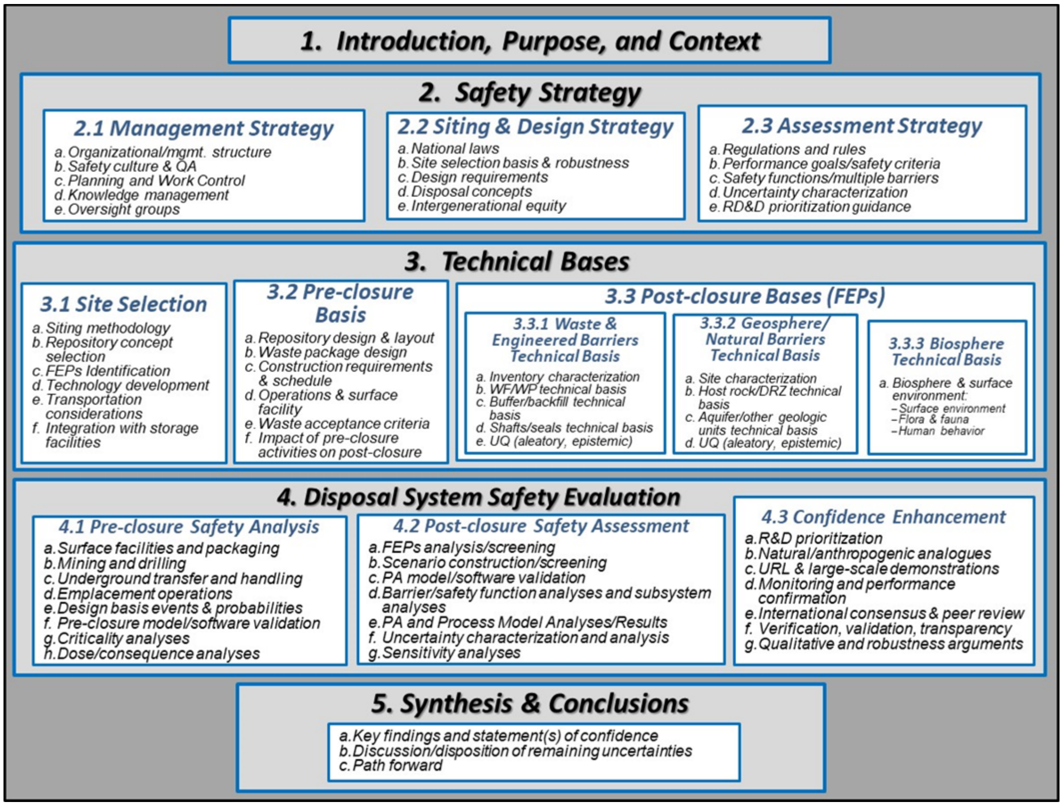


Figure 3-2. Typical Elements of the Safety Case for Geologic Disposal.

As part of the compilation of information in the R&D Activities spreadsheet, SFWST staff identified which aspects of the safety case were addressed by each R&D Activity. For the generic R&D program, most activities are focused on post-closure performance, and contribute to an improved understanding of the either the Post-closure Bases (3.3.1 Waste and Engineered Barriers, or 3.3.2 Geosphere/Natural Barriers), or to the Disposal System Safety Evaluation (4.2 Post-closure Safety Assessment). In addition, numerous generic R&D activities also contribute significantly to 4.3 Confidence Enhancement.

In 2012, the evaluation of the ISC metric was split into three sub-metrics related to three different elements of the safety case included in Figure 3-2 (safety assessment; design, construction, and operations; and confidence-building). Because the 2019 Roadmap Update elected to use a more qualitative metric (i.e., descriptive scoring categories of High, Medium, and Low importance), this level of detail in the ISC evaluation was not desired, nor was it felt to be necessary for R&D in the generic stage. However, all three of these components of the safety case (and others) were considered when assigning an overall ISC value to each R&D Activity. This is demonstrated in the descriptions of the ISC criteria metrics shown in Table 3-1, which were used by the participants of the Workshop within each "break-out" group—see Section 3.3.

Table 3-1. ISC (Importance to the Safety Case) Metric Values and Definitions (see also Figure 3-2).

ISC Numerical Value	ISC Descriptive Value	ISC Definition (see Safety Case Elements figure)
5	***High*** *Importance to SC*	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 SC*	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 SC*	Knowledge gained is only of a supporting nature and does not strongly affect the associated process model or model inputs

Table 3-2. SAL (State-of-the-Art Level) Metric Values and Definitions, with Guidance for Improvement.

SAL Numerical Value	SAL Descriptive Value	SAL Definition	Questions to be answered for: (1) Rationale for current SAL (2) R&D to move to next SAL
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	

3.2.3 Evaluation of State-of-the-Art Level (SAL)

In 2018, the Technical Leads for the SFWST program prepared the initial activity descriptions for the updated R&D Activities spreadsheet. At the same time, they also provided preliminary assessments of the SAL metrics, based on the assumption that the SAL for a given R&D Activity would be based on the SAL for the highest priority FEP addressed by the Activity.

For the 2019 Roadmap Update, workshop participants were presented with detailed and specific guidance to help them define both the current state of knowledge (or SAL metric), as well as what would be required to advance the state of knowledge to the next level (for example from "Fundamental Gaps in Method or Data Needs" to "Improve Representation"). This information, shown in Table 3-2, includes a series of questions intended to evoke clarity regarding the SAL assignments and the additional work needed to the next higher SAL. The questions mainly relate to the definition of R&D that would contribute to the development of improved models and a stronger technical basis for the representation of the systems and processes important to repository performance. By 2022, the goal is to have a generic total system performance assessment model that is credible and defensible for each host rock type under consideration, with a strong and clear technical basis.

3.2.4 Workshop Process and Activities

Appendix A contains the agenda and guidance to participants provided prior to the January 2019 workshop. All SFWST participants in the workshop were assigned to one or two breakout groups based on the R&D Activity categories (i.e., host rock type, EBS, International, DPC). For the first day, and the following morning, everyone participated in sessions that were host rock specific (Argillite, Crystalline or Salt). The key assignments given to the experts in the host-rock breakout groups were as follows (see Appendix A):

1. Review and revise R&D Activity names and descriptions, as warranted
2. Decide upon the SAL rating and its justification for each assigned R&D Activity
3. Determine the generic R&D still needed to decrease the SAL for each R&D Activity
4. Brainstorm and add "Gap" Activities, as appropriate
5. Consider EBS, DPC, and International Activities, as assigned
6. Decide upon the ISC rating and its justification for each assigned R&D Activity
7. Discuss ongoing and "unresolved" integration issues

In the afternoon of the second day, three separate breakout groups for EBS, DPC, and International R&D Activities were requested to compile and resolve the metric scores given to these cross-cutting activities by the three different host-rock breakout groups. Finally, on the third day, the workshop met as a group (about 50 participants) to consolidate all findings in the breakouts and to propose future integration efforts. Each of the sessions (six breakouts and one complete group) had an assigned chair and rapporteur to lead the discussion and to take notes and make real-time changes to the R&D Activity Excel spreadsheet.

In addition to the information gathered in the workshop regarding metric scores for each R&D Activity, many other topics and recommendations were discussed in the breakout sessions and in the final group session. This entire wealth of information, including recommendations for new or modified R&D Activities needed to advance the SAL, as well as ideas for improved integration of the R&D work across the Campaign, is primarily documented in Appendices B and K. In some cases, new activities (termed "Gap Activities") have been recommended to provide data and information that is not being acquired by the current program. Much of this type of information is generated by answering the questions in the last column of Table 3-2. See Section 3.3 for more information on these Gap Activities.

3.2.5 Microsoft Access Database

After the workshop was completed, the R&D Activities Table (Excel spreadsheet) was updated and finalized to incorporate the results of the six breakout sessions. This was a major undertaking needed to consolidate and integrate the large amount of information gathered in the breakout sessions. Then the data and information in the Excel file were entered into a Microsoft Access® database to facilitate the analysis of the results, and to be used in the future (if desired) to help guide the R&D program. A relational database, such as Access, is more amenable to analysis than a simple Excel spreadsheet.

3.3 Workshop Results

The results of the R&D Roadmap Update Workshop are analyzed here and summarized in detail in Appendices B through L. The information in these appendices documents the input from the technical experts and specialists that participated in the Workshop, as well as analyses of this input after the Workshop. The technical experts had a wide range of backgrounds, interests, and preferences, and this range of abilities and interests is one of the strengths of the Workshop. It also led to some interesting, but insightful, variability in the results. Examples of this variability can be seen in the defined scope of the R&D Activities or the identification of FEPs related to a given R&D Activity.

As described in Section 3.2, the Workshop was organized around the rock types that are the basis for the generic R&D in the SFWST Campaign, i.e. argillite (e.g., clay or shale), crystalline (e.g., granite), and bedded salt (see Appendix A). The organization of the appendices includes these rock type divisions, as well as the other groupings of R&D Activities described in Section 3.2.1. The International Activities grouping is unique for a couple of reasons. First, these Activities are generally defined and conducted by researchers outside of the SFSWT Campaign. Second, the International Activities are, for the most part, tied to *in-situ* testing in Underground Research Laboratories (URLs). Data from this testing provides valuable inputs to PA models, and integration of these International Activities with other host-rock-specific SFWST R&D is crucial.

R&D Activities directly related to Dual Purpose Canisters (DPCs) were grouped separately because this is an area of new emphasis. The large quantities of SNF currently being stored in DPCs and the relative lack of study of the impacts of DPCs on post-closure performance has led to this new emphasis. Because the DPC are an integral part of the EBS in a disposal system, integration with EBS R&D Activities was identified as essential. EBS R&D Activities are also grouped separately, which reflects the importance of these EBS Activities to PA and the fact that many of these R&D Activities are relevant to more than one rock type. Furthermore, most of the *in-situ* testing in the URLs is focused on EBS issues, making integration between EBS and International Activities important. There is also a category of Activities labeled “Other” that includes Activities that support the SFSWT Campaign as a whole but are not rock type specific. The final R&D Activities grouping includes the R&D Activities that directly support development of generic PA models.

The goal of the Workshop was to develop a consensus of the technical experts on the priority and state-of-the-art of the current (and gap) R&D Activities. The consensus information is summarized in several ways in the appendices, which include some information from the 2012 Roadmap evaluation (DOE 2012), but primarily the results from the 2019 Update Workshop. The 2012 information (“State of the Art” assignments and FEPs) is included to demonstrate R&D progress and comprehensiveness since 2012. It is important to remember that the 2012 evaluation was based on FEPs and the current assessment is based on R&D Activities, so the appendices have several mappings between FEPs and Activities.

The complete list of R&D Activities in Appendix B provides an alphanumeric identifier and a brief description of the work for each R&D Activity. The alphanumeric identifier is used throughout this report to refer to the R&D Activity. Software and process model codes associated with the R&D Activity are also identified in Appendix B, as well as the Safety Case elements (Figure 3-2) supported by each R&D Activity. Gap Activities, i.e. R&D Activities that have not started or are very long-term (i.e., most of the work envisioned for future years), are identified with an asterisk next to the alphanumeric identifier. Activities are also classified according to type as follows: L = Literature Review, PM = Process Model, PA = PA Model or submodel, LT = Lab Test, FT = Field Test or URL, EA = Experimental Data Analysis, and MA = Model Output Analysis. It should be noted that many of the defined R&D Activities include more than one of these "types." A fuller discussion of the various R&D Activities and why they belong to more than one of these "type" classifications can be found in SFSWT reports and deliverables (see Section 4).

Metric scores (for SAL and ISC), the associated Rationale for these scores, and the future R&D Needed (to move the R&D to the next improved SAL), as documented in Appendix B, are the primary results and information gathered in the Update Workshop from the 50+ Campaign experts. There are a few R&D Activities where some of this information was not developed during the workshop, and consequently is not provided. In most cases, these are designated Gap Activities.

Because the 2019 Roadmap Update Workshop was organized around Activities, FEPs are not central to the analysis and prioritization, but the mapping between Activities and FEPs is documented in Appendices D through I, to ensure completeness relative to the original 2012 R&D Roadmap prioritization. The FEPs mapping to the 2019 R&D Activities focuses on FEPs that were identified as high or medium priority FEPs in the original Roadmap report (DOE 2012). In a few cases, low priority FEPs are mapped to current R&D Activities, but in most cases FEPs rated as low priority in 2012 are omitted from the appendices, since most of those FEPs are still considered as not important to generic repository research, or enough information is known about them during the generic repository phase. Exceptions, such as DPC criticality events, are discussed below.

Mapping FEPs to current R&D Activities serves two additional purposes. First, it helps to define the scope and purpose of a given Activity. Second, it provides a means to evaluate the extent that current R&D Activities address the range of FEPs that are relevant to generic PA models.

As mentioned above, each R&D Activity was further characterized by identifying the element(s) of the Safety Case that it supports. The assignments were made using the categories defined in Figure 3-2. Most of the Activities support elements 3.3 (Post-closure Bases (FEPs)) and/or 4.2 (Post-closure Safety Assessment). These assignments were an important part of the ISC metric evaluation during the Workshop.

3.3.1 R&D Activity Prioritization Rankings and Analysis

This section presents an analysis of the expert input from the 2019 Roadmap Update Workshop. Specifically, the SAL and ISC metric scores (reached by expert consensus within each breakout session) are combined to derive an overall Priority Score (Low, Medium, Medium-High, High) for each R&D Activity, similar to the qualitative rankings (Low, Medium, High) or groupings of R&D Issues in the 2012 Roadmap (see Figure 2-4). Appendix B contains both the expert-derived SAL and ISC metric scores, as well as the computed Priority Scores. In addition, other results and information are presented in Appendices D through J, including several mappings between 2019 R&D Activities and 2012 R&D Issues (i.e., the FEPs) to show evolution and progress from 2012 and to ensure comprehensiveness of FEPs coverage in the current suite of SFWST Campaign R&D Activities.

Table 3-3 shows how the output Priority Scores are derived from the input ISC and SAL metric values documented in Appendix B.

Table 3-3. Priority Score (PS) Matrix (combination of SAL and ISC) for R&D Activities.*

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

* H = High; M-H = Medium-High; M = Medium; L = Low

3.3.1.1 Graphical Analysis of Priority Scores by Host-Rock Breakout Session

As described in Section 3.2.4, there were three primary breakout sessions, which lasted about one day (Appendix A). These were the sessions that revolved around R&D Activities for the three generic host-rock categories: argillite, crystalline, and bedded salt. Prior to the Workshop, the chair of each of the three host-rock breakout sessions had determined the R&D Activities that would be reviewed during their individual session. However, it is not only the R&D Activities specific to each host rock and designated as A-#, C-#, and S-# (see Appendix B) that were considered in each of the three host-rock sessions. This is because many EBS and International R&D Activities (as well as PA Activities) were considered to be "cross-cutting,", i.e., relevant to more than one host-rock concept. These choices for the cross-cutting R&D Activities to be considered in each host-rock breakout session are recorded by checked boxes shown in Appendix C, with the total number of R&D Activities reviewed in each session given in Table 3-4.

Table 3-4. Number of R&D Activities considered in each breakout session.

Breakout Session	**Total Number of R&D Activities Evaluated**
Argillite	31
Crystalline	40
DPC	6
EBS	20
International	21
Salt	29
Total	**147**

After the three concurrent and separate host-rock breakout sessions, there were concurrent review sessions for EBS, International, and DPC R&D Activities. These last three breakouts included some of the technical experts (about half) who participated in each of the host-rock breakout sessions. These experts provided input from their host-rock breakout sessions, thus representing a means of integration between the host rock sessions. This integration was necessary because, as mentioned, many EBS and International R&D Activities are cross-cutting. [The PA and Other

Activity groups did not have separate review sessions, but technical experts representing PA Activities were in attendance in each breakout session.]

Figures 3-3 to 3-5 are graphical presentations of the R&D Activity prioritization results from the three host-rock breakout sessions, based on the suite R&D Activities included in each of these sessions, as documented in Appendix C. Figure 3-3 is a histogram representation of the priority score results, whereas Figures 3-4 and 3-5 are discrete cumulative distribution functions (CDFs). Figure 3-4 is the cumulative number of R&D Activities, while Figure 3-5 is the cumulative fraction of R&D Activities. A given cross-cutting R&D Activity from Appendix C may be included in more than one bar (or curve) in Figures 3-3 to 3-5 because it may have been reviewed by two or three host-rock breakout sessions. A total of thirty-eight cross-cutting R&D Activity reviews were completed in the host rock sessions (i.e., a total of thirty-eight EBS, International, and PA Activities).

It is clear from Figure 3-3 that the Crystalline breakout reviewed the most R&D Activities, followed by Argillite and Salt. An interesting but possibly coincidental result is the distribution of R&D Activities among the Priority Score classes, i.e., the distribution among Low, Medium, Medium-High, and High. Figure 3-5 clearly shows that this distribution was about the same for three breakout sessions, perhaps indicating a rather uniform "calibration" of the experts across the sessions. This uniformity in Priority Scores among the three sessions is represented by about 50% Medium-priority Activities, 30% Medium-High-priority Activities, and 20% High-priority Activities for all three host-rock breakout sessions. This distribution among the Priority Score classes can be compared to the distribution of High- and Medium-priority Issues in 2012 (see Figure 2-4 and its discussion), which was about 55% Medium and 45% High.

Figures 3-6 to 3-8 are graphical presentations of the prioritization results from the three host-rock breakout sessions with the Gap Activities removed. The Gap Activities are work that has not begun, or work that is very long-term with most of the effort being completed in outyears. Figure 3-6 is a histogram representation of the priority score results, whereas Figures 3-7 and 3-8 are discrete cumulative distribution functions (CDFs). Figure 3-7 is the cumulative number of R&D Activities, while Figure 3-8 is the cumulative fraction of R&D Activities. Figure 3-8 again shows similar uniformity of scoring across the separate breakout sessions but with Crystalline having a slightly higher proportion of Medium scores relative to Argillite and Salt, which could imply a greater advancement of knowledge (SAL) in the Crystalline-relevant suite of R&D Activities.

An additional point regarding the workshop process is that although EBS and International Activities were reviewed in these three host-rock breakout sessions, and generally in more than one of the host-rock sessions, it was the subsequent EBS and International specific breakout sessions (see Appendix A) that had the final say as to the ISC and SAL scores assigned to their corresponding EBS and International R&D Activities, taking into consideration the notes and expert input from the host rock sessions. The Priority Scores in Appendix B reflect this fact.

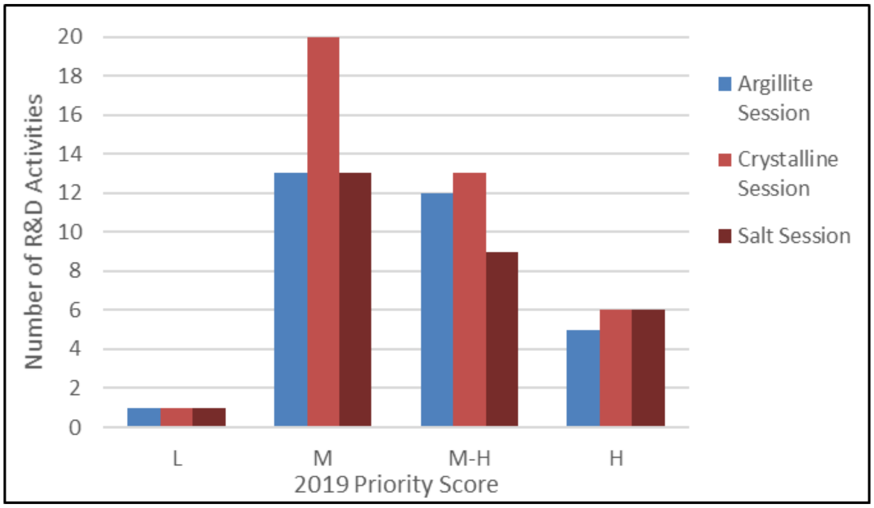


Figure 3-3. Histogram of Priority Scores for each Host-Rock Breakout Session (<u>including</u> Gaps).

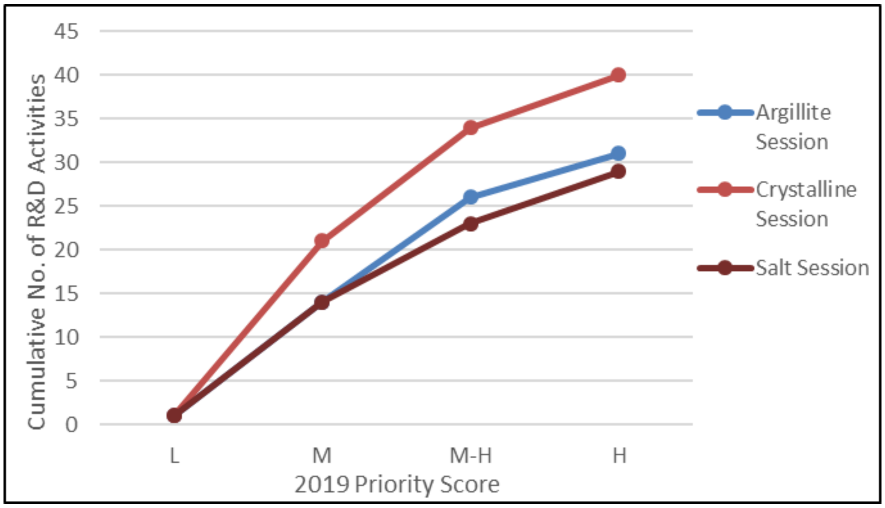


Figure 3-4. Number CDF of Priority Scores for each Host-Rock Breakout Session (<u>including</u> Gaps).

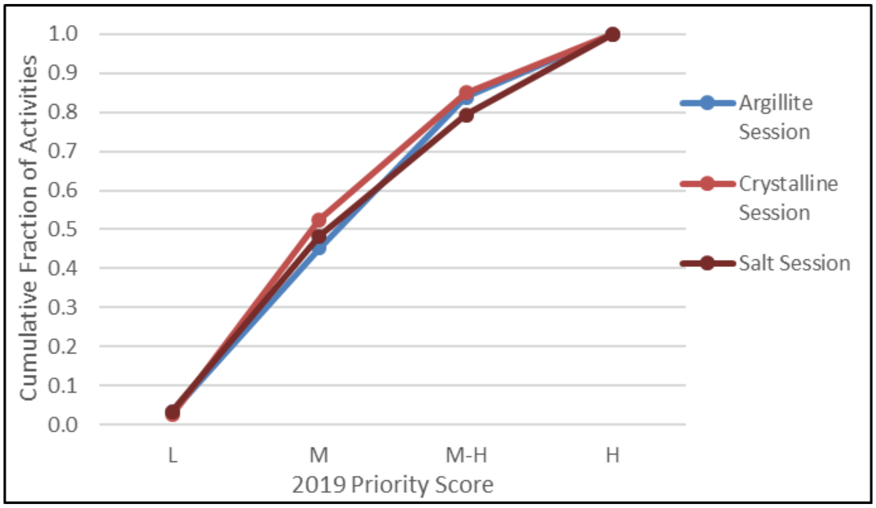


Figure 3-5. Fraction CDF of Priority Scores for each Host-Rock Breakout Session (<u>including</u> Gaps).

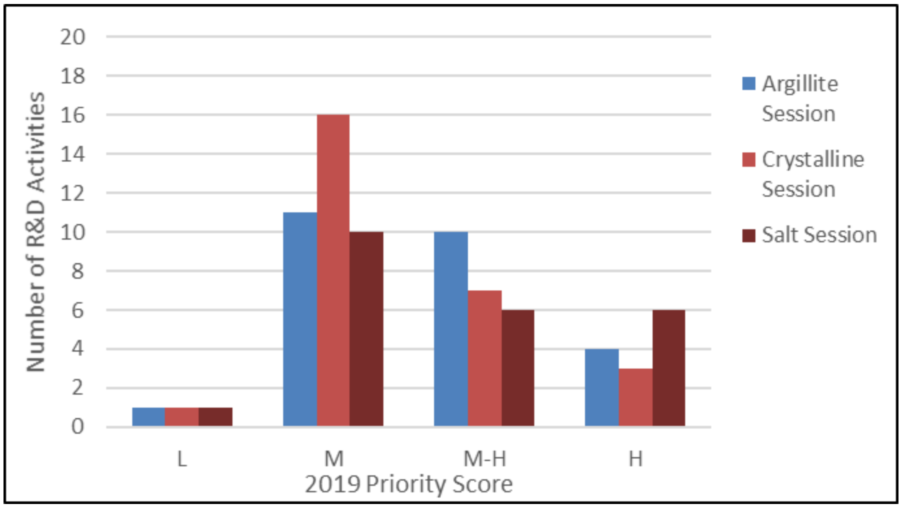


Figure 3-6. Histogram of Priority Scores for each Host-Rock Breakout Session (without Gaps).

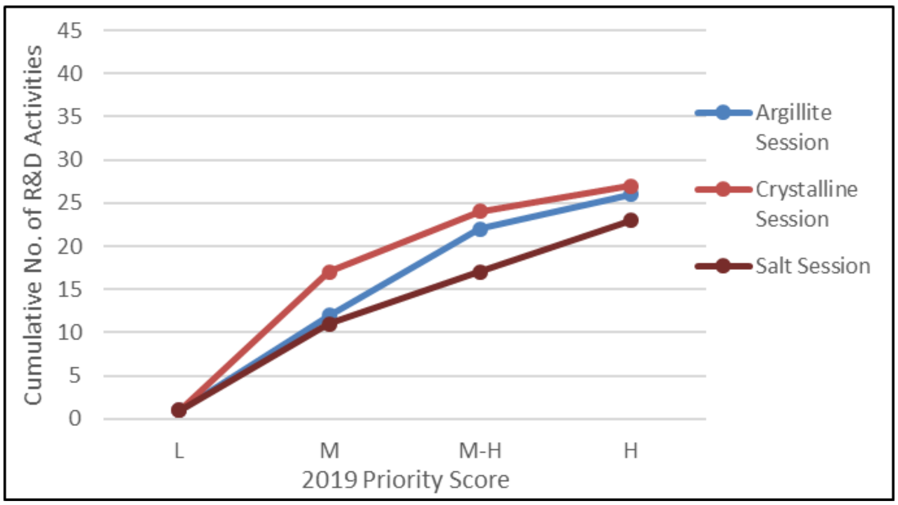


Figure 3-7. Number CDF of Priority Scores for each Host-Rock Breakout Session (without Gaps).

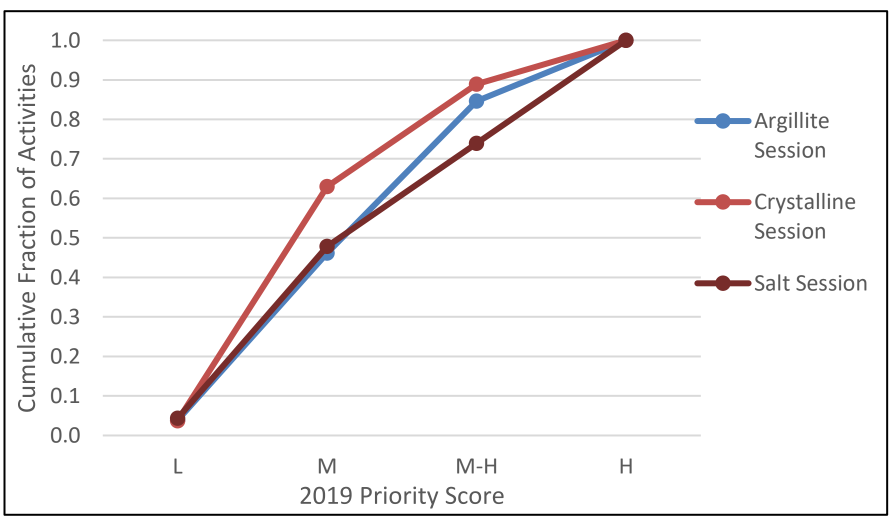


Figure 3-8. Fraction CDF of Priority Scores for each Host-Rock Breakout Session (without Gaps).

3.3.1.2 Graphical Analysis of Priority Scores by R&D Activity Grouping

In this section, summary graphs are presented that tabulate Priority Scores strictly according to R&D Activity Group, i.e., the arrangement of Activities is not according to what breakout session they were considered in but just according to their Activity Group designation. So, for example, "Argillite" in the following graph legends refers only to Activities listed in Appendix B that are designated as "A-#" and does not include the various EBS, International, and/or PA R&D Activities considered in the Argillite breakout.

Figures 3-9 through 3-11 are a graphical presentation of the Priority Score classes by R&D Activity Group. Figure 3-9 is a histogram that shows that the score class with the most High-priority R&D Activities is International, with seven. EBS, DPC, and Salt each have four High-priority R&D Activities. PA has one high priority activity. PA has the most Medium-High-priority R&D Activities, with nine, followed by Crystalline, with seven. EBS and International each have six Medium-High-priority activities. The largest Priority Score class, in terms of number of R&D Activities, is Medium. EBS, International, and Crystalline all have eight Medium-priority Activities. Salt, Argillite, and PA each have five Medium-priority Activities. The group with the largest number of Low-priority Activities is Other, with four.

Figure 3-10 presents the prioritization results as a CDF. This type of format facilitates an assessment of the relative importance of the different priority classes within each R&D Activity group. For instance, the International group has no Low-priority Activities but has a large number of Medium- and Medium-High-priority Activities. The large number of Medium- and High-priority R&D Activities results in a steep slope for the International line. The slope of the International group line decreases slightly in the Medium-High-priority range of the graph, indicating a smaller number of Medium-High-Priority International R&D Activities. The initial slope of the EBS and Crystalline group lines is the same as the slope of the International group, indicating that all three groups have the same number of Medium-priority R&D Activities.

Figure 3-11 is also a CDF format, one which emphasizes the relative percentage of R&D Activities in each Priority Score class for each R&D Activity group. The steepest slope on this graph is for the High-priority DPC R&D Activities, reflecting the large percentage of High-priority R&D Activities within the DPC group. This is to be expected because DPC is a relatively new "high emphasis" area of R&D for the SFWST Campaign, reflecting the greatly increased percentage of the Nation's spent fuel stored in DPCs relative to the time of the original UFD Roadmap in 2012. The initial portion of the Argillite group line is also nearly as steep, indicating a large percentage of Medium-priority R&D Activities in this group, which reflects progress made since 2012.

Figures 3-12 to 3-14 present the prioritization results for R&D Activity Groups with the Gap Activities removed. The histogram in Figure 3-12 indicates that International has the highest number of High-priority R&D Activities with five, followed by DPC and Salt with four each. International and EBS have the most Medium-High-priority R&D Activities, with five each. PA has four Medium-High-priority R&D Activities, and Salt and Crystalline each have three. Crystalline has the largest number of Medium-priority R&D Activities, with six. Argillite and International each have five Medium-priority R&D Activities. It should be noted that Crystalline has no High-priority Activities when the Gap Activities are removed. Similar to the comment in the previous section, this could be interpreted to reflect a greater advancement of knowledge (SAL) in Crystalline R&D over the preceding seven years relative to Argillite and Salt, but this may be an over-interpretation of the results.

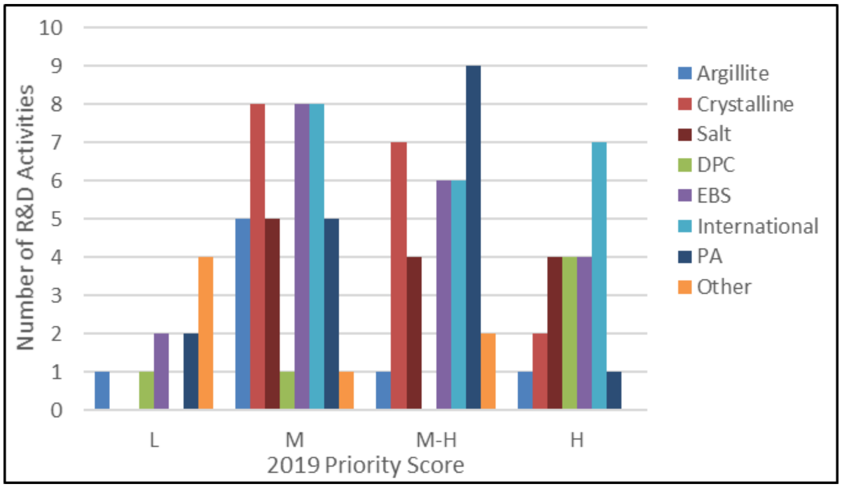


Figure 3-9. Histogram of Priority Scores for each R&D Activity Grouping (<u>including</u> Gaps).

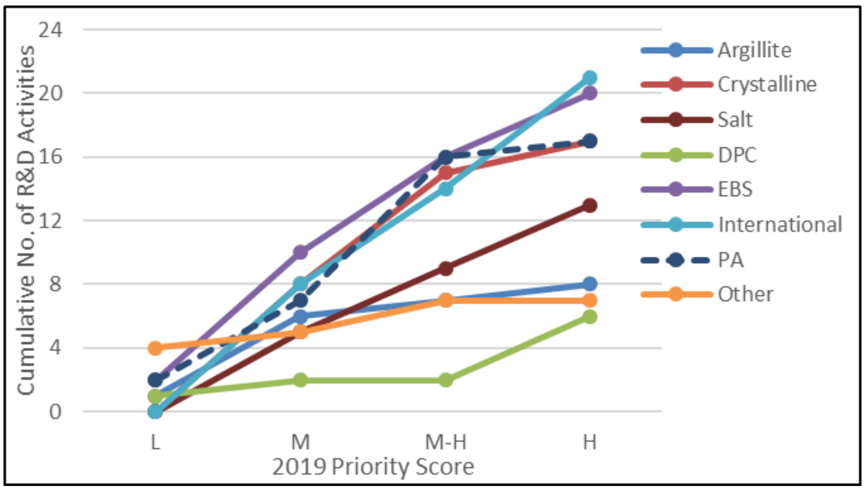


Figure 3-10. Number CDF of Priority Scores for each R&D Activity Grouping (<u>including</u> Gaps).

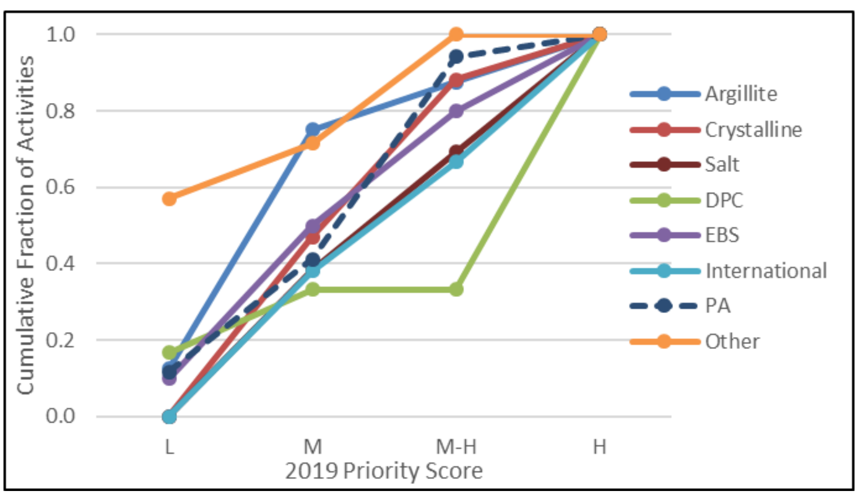


Figure 3-11. Fraction CDF of Priority Scores for each R&D Activity Grouping (<u>including</u> Gaps).

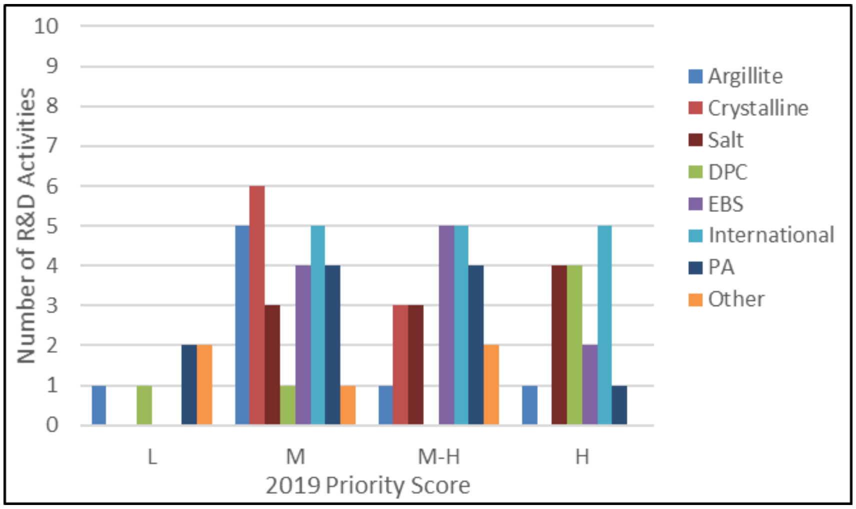


Figure 3-12. Histogram of Priority Scores for each R&D Activity Grouping (without Gaps).

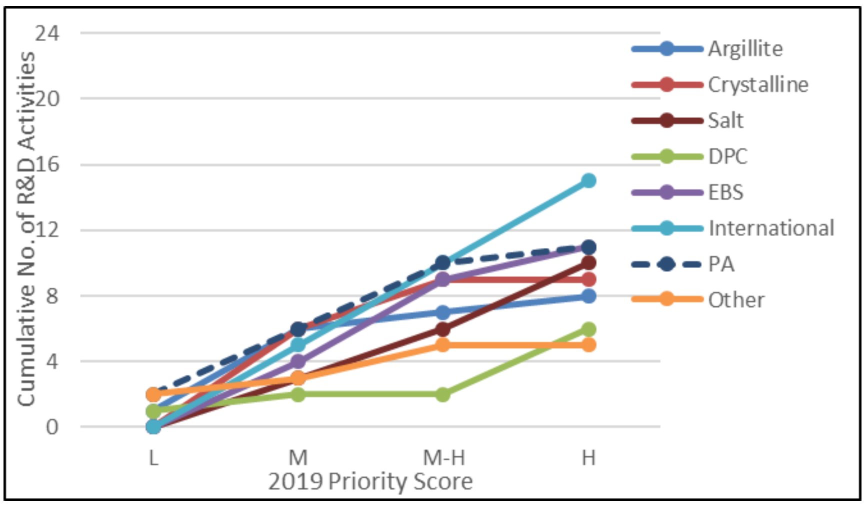


Figure 3-13. Number CDF of Priority Scores for each R&D Activity Grouping (without Gaps).

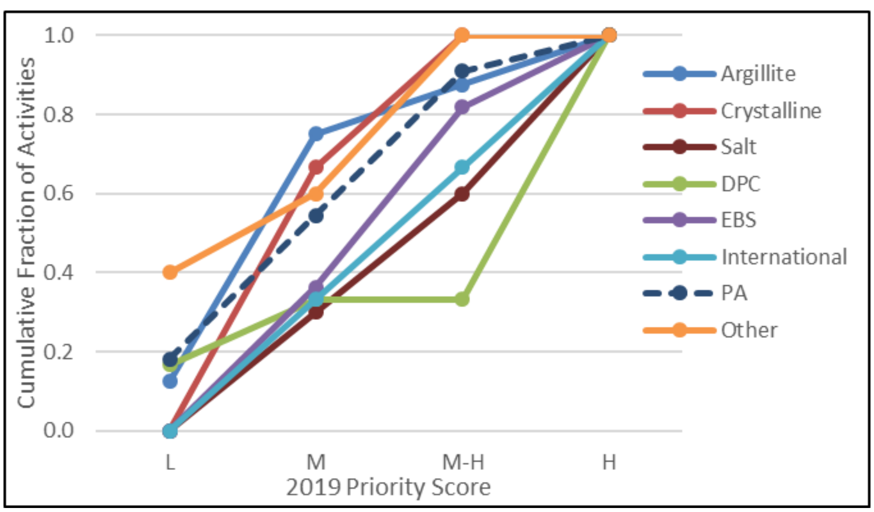


Figure 3-14. Fraction CDF of Priority Scores for each R&D Activity Grouping (without Gaps).

Figure 3-13 presents a discrete CDF of the prioritization results for R&D Activity Groups without the Gap Activities. International still has the most R&D Activities, but the number has been reduced to fifteen. The slopes of the various lines are similar, indicating a fairly uniform distribution of Priority Score classes. The High priority portion of the DPC line has the steepest slope, again reflecting the new emphasis on DPC R&D. The High priority portion of the Salt line has a similar slope.

Figure 3-14 is similar to Figure 3-13 but plotted as a cumulative fraction of the total number of R&D Activities in each R&D Activity group. The steepest slopes are the initial portions of the Crystalline and Argillite lines, the intermediate portion of the Other and EBS lines, and the High-priority portion of the DPC line. The Crystalline, Argillite, and Other groups have a higher proportion of Medium-priority R&D Activities and, in the case of the EBS group, of Medium-High-priority R&D Activities, while the DPC group again indicates a large fraction of High-priority Activities, indicative of the new emphasis on DPC research.

3.3.1.3 Identification of High Priority R&D Activities and High Impact R&D Topics

Based on the information in Appendix B, twenty-three R&D Activities were scored as High priority (Table 3-5). One Argillite Activity, two Crystalline Activities, four DPC Activities, four EBS, seven International Activities, one PA Activity, and four Salt Activities rank as High priority. The large number of International Activities that rank as High priority reflects the importance of the data collection from tests being conducted in the international URLs. The high priority Salt Activities include in-situ thermal testing at the Waste Isolation Pilot Plant (WIPP). The relatively large number of EBS Activities that are ranked as High priority reflect a transition in the emphasis of SFWST work from initial development of generic host-rock PA models to improvement of the representation of model elements important to barrier capability. A relatively large number of DPC Activities are ranked as High priority because this is a new area of research emphasis.

Thirty-five R&D Activities were scored as Medium-High priority (Table 3-6). One Argillite Activity, seven Crystalline Activities, six EBS Activities, six International, two “Other” Activities, nine PA Activities, and four Salt Activities rank as Medium-High priority. PA, International and EBS Activities are prominent among the Medium-High-priority Activities because of their cross-cutting nature. The two “Other” Activities involve geologic mapping and visualization tools and products. The large number of Crystalline medium-high priority Activities reflects the complexity of the Crystalline PA model, arising from host-rock spatial heterogeneity and fast transport in the fracture field. The long-term (“gap-like”) nature of most of these Crystalline Activities is also a factor in the Medium-High prioritization. The importance of completing research on these long-term Activities will increase later during detailed site characterization and design.

Review of the Priority Scores of all R&D Activities allows for the identification of several “High Impact R&D Topics.” The listing of the Activities with High or Medium-High Priority Scores (Tables 3-5 and 3-6) is the starting point. These tables reveal a spectrum of types of Activities with High and Medium-High Priority Scores. However, there are commonalities among these Activities that can be used to compile R&D Activities into topical areas. Table 3-7 presents just such a grouping of the High and Medium-High-priority Activities into “High Impact R&D Topics” that are the current focus of R&D in the SFWST Campaign. Note that the effect of high repository temperatures is a common aspect of a number of High- and Medium-High-priority Activities. In part, this is a result of the new interest in DPCs. But there is also International interest in this topic, as reflected in HotBENT and the long term FEBEX heater test. These heat effects play a role in evaluation of EBS barrier performance.

Table 3-5. 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
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

Table 3-6. Medium-High Priority R&D Activities.

Medium-High Priority R&D Activities	
A-04	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
C-01	Discrete Fracture Network (DFN) Model
C-06	Buffer Erosion (is this a gap in our program?) is it too site specific for generic R&D
C-08	Interaction of Buffer w/ Crystalline Rock
C-11	Investigation of fluid flow and transport in low permeability media (clay materials).
C-13	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport
C-14	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
C-17	Model DFN evolution due to changes in stress field
E-02	SNF Degradation testing activities
E-03	THC processes in EBS
E-04	Waste Package Degradation Model (mechanistic)
E-06	Waste Package Degradation Testing
E-10	High-Temperature Behavior
E-20	Colloid source terms
I-02	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
I-03	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
I-07	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
I-09	DECOVALEX-2019 Task C: GREET (Groundwater REcovery Experiment in Tunnel) at Mizunami URL, Japan
I-14	TH and THM Processes in Reconsolidating Salt: German-US Collaborations (KOMPASS)
I-21	New Activity: SKB Task 10 Validation of DFN Modeling
O-02	GDSA Geologic Modeling
O-03	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
P-01	CSNF repository argillite reference case
P-02	CSNF repository crystalline reference case
P-04	CSNF repository unsaturated zone (alluvium) reference case
P-11	Pitzer model
P-13	Full Representation of Chemical processes in PA
P-14	Generic Capability Development for PFLOTRAN
P-15	Species and element properties
P-16	Solid solution model
P-17	Multi-Component Gas Transport
S-02	Salt Coupled THM processes, creep closure of excavations
S-07	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)
S-08	Evolution of run-of-mine salt backfill
S-11	THMC effects of anhydrites, clays, and other non-salt components

Table 3-7. High Impact R&D Topics.

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

Buffer and seal studies are included in several High- and Medium-High-priority R&D Activities. International testing, including HotBENT, FEBEX-DP, and DECOVALEX-2019 Task E, are addressing issues related to buffers and seals. R&D Activities are looking at materials that are currently being used and novel new materials that could be used in the future. The performance of buffer and seal materials during potential future repository operation is also being evaluated.

Generic PA model development and implementation continue to be High-priority Activities and is a High Impact Topic. A lot has been accomplished with the generic rock type models, but there is still a lot to be done especially integration of new results from process model developments. The generic unsaturated zone (alluvium) reference case is only beginning development.

Coupled process testing and modeling for a salt repository is a High-Impact Topic. Although extensive modeling of salt repositories at low temperature (e.g., WIPP) has been performed, significantly less work has been conducted for disposal of HLW/SNF at higher temperatures. Significant uncertainties remain regarding coupled THM processes, especially for the evolution of the EDZ and backfill. Activities include proposed field scale heater tests at WIPP.

Gas flow in the EBS is another High Impact Topic. Significant work related to the development, testing and implementation of coupled models including chemical processes and thermodynamic databases has been completed both within the U.S. (e.g., FMDM – see Appendix B, Activity E-01), and through U.S. participation internationally (e.g., FEBEX, HOTBent, GREET). However, direct incorporation of the process models into *GDSA Framework* (PFLOTRAN) has not yet been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of model confidence building and model validation.

Criticality is a new High Impact Topic. It was excluded from the 2012 prioritization evaluation. The potential for direct disposal of DPCs has led to a higher priority for criticality studies, e.g., see Activities D-01 and D-04.

3.3.2 Comparison between 2012 and 2019 Workshops – FEPs Completeness Check

R&D Activities with Related FEPs are documented in Appendix D, which provides a listing of FEPs (from the 2012 Roadmap) that are addressed by each 2019 R&D Activity. The number of FEPs addressed by an R&D Activity is variable. In some cases, only one or two FEPs are identified and in other cases ten or twenty may be identified. There are two main reasons for this variability. Mostly, this reflects variability in the scope of the defined R&D Activities. But it also reflects variability in the way the technical leads interpreted FEPs with respect to their relevancy to the R&D Activities. This sort of FEP-to-Activity variability is to be expected when the express purpose of R&D Activities is to address one or more FEPs in logical "system-oriented" fashion—an R&D Activity usually is an experiment, model, or analysis that includes multiple physical-chemical processes (which implies it must address more than one FEP).

The mapping of FEPs in Appendix D is primarily for those FEPs that had a Medium or High Priority from the 2012 Roadmap (see Figure 2-4). However, technical leads (i.e., the SFWST Campaign work package managers for the seven R&D Activity Groups—not including the "Other" Group, which is an informal grouping) were also asked to reconsider Low priority FEPs from the 2012 Roadmap because of potential new constraints and inputs to the Disposal Research program. Criticality provides a good example. The 2012 evaluation excluded criticality from the evaluation (criticality was given a Low priority score) because most spent fuel was to be disposed of in TAD (Transportation, Ageing, and Disposal) canisters according to the Yucca Mountain License Application (DOE 2008). However, with the subsequent large increase in SNF inventory stored in DPCs (which present different considerations for criticality evaluation), Criticality FEPs should be re-evaluated and likely assigned a higher priority. In fact, this is clearly reflected in the High priority given to DPC Activities in this 2019 Update.

FEPs with Related R&D Activities (Appendix E) presents the same information as Appendix D but organized by FEP instead of R&D Activity. This presentation facilitates assessing the "coverage" of FEPs provided by the R&D Activities evaluated by the workshop.

More useful than the complete mapping of all R&D Activities to the FEPs, as shown in Appendix E, are the three mappings of host-rock-breakout-session R&D Activities to all FEPs, shown in Appendices F, G, and H. This improved utility is due to the numerical ordering of FEPs in Appendices F, G, and H according to their 2012 FEP priority score (see Appendix B in the 2012 Roadmap for this complete priority ordering of FEPs). In other words, these three appendices are meant to show the degree of comprehensiveness of current SFWST Campaign R&D Activities and to indicate that the current R&D Activities are addressing almost all the High and Medium ranked FEPs from the 2012 Roadmap—see Figure 2.4 for the 2012 cutoff scores for these High and Medium FEP ("Issue") categories. [Again, the FEPs in each of these three appendices are correlated to *all* the R&D Activities considered in each host-rock breakout, so various EBS, International, and PA Activities are included.]

However, there are a few High- and Medium-Scoring FEPs from 2012 that are not currently being addressed by the 2019 R&D Activities. This is shown in Appendix I. There are nineteen FEPs in this Appendix and, of these, nine are for "Other Geologic Units," meaning they are site-specific and cannot really be addressed in a generic R&D program. Another ten are either "Host Rock" or "Host Rock and Other Geologic Units," which again are mostly site-specific, although it might be argued that for the three generic, host-rock concepts being investigated (argillite, crystalline, bedded salt), some generic research might be conducted for these latter ten. However, most of these ten FEPs are related to chemistry and solubility, which are being incorporated into the Campaign's generic reference cases via literature searches (Mariner et al. 2016; Mariner et al. 2017; Mariner et al. 2018; Sevougian et al. 2019).

3.3.3 Assessment of State-of-the-Art Evolution

Appendix J provides a comparison between the consensus SAL descriptive values (see Table 3-2) developed in the 2019 Update Workshop (as documented in Appendix B) with the comparable "State-of-the-Art" assignments in the 2012 Roadmap (DOE 2012, App. A). This comparison is not exact because it was FEPs ("Issues") that were evaluated and scored in 2012, while Activities were evaluated and scored in 2019. However, although in general there are multiple FEPs being addressed by each R&D Activity (see Appendices D and E), there is usual a "primary" or "dominant" FEP that can be associated with each R&D Activity. The 2012 "State-of-the-Art" value (see Section 2.2.3) for this primary FEP (DOE 2012, App. A) can be compared to the 2019 SAL descriptive value (see Table 3-2) for its R&D Activity to provide a qualitative idea of the R&D progress since 2012. This is shown in Appendix J, wherein many of the SAL levels have improved (moved lower), based on the ordering of levels given in Table 3-2. The primary FEP for each 2019 R&D Activity is often, but not always, the related FEP in Appendix D of this document (for each Activity) that has the highest numerical priority score from Appendix B of DOE (2012).

3.3.4 Additional Information on Activities and Integration

Appendix K, "Additional Information on Activities and Integration", presents further insights developed during the workshop for individual R&D Activities, as well as for integration among the various R&D Activities. Many of these comments address aspects of the integration between process level models and the GDSA reference-case models (P-01, P-02, P-03, P-04). This integration may involve direct implementation into PFLOTRAN (the implementation code for PA process modeling) or the development of a surrogate model (or response surface) to represent a given process. Some comments discuss how R&D Activities relate to one another, or how a given R&D Activity may support a different R&D Activity. Some comments simply provide more information about the given R&D Activity. The information in Appendix K was collected as part of the third assigned task on Day 2 of the Workshop (see Appendix A), described as "Discuss and document ongoing and "unresolved" integration issues, particularly with PA-GDSA (Column T)," where "Column T" refers to the original R&D Activities Excel spreadsheet.

In addition to the foregoing information, other relevant integration issues were collected during the course of the Workshop, especially with regard to integration of R&D on DPCs. Many of these issues were summarized by the breakout session chairs and presented on Day 3 of the Workshop as part of the concluding Summary Reporting task. For DPC integration, the following cross-cutting integration issues were identified:

- Thermally driven process models need to use DPC-relevant inputs (e.g., thermal power and duration) especially in EBS studies. The models in argillite especially should be exercised with DPC-relevant inputs. Those inputs still need to be developed and a number of R&D Activities, especially EBS Activities, are addressing high temperature effects.

- PA submodels for cladding (E-15), in-package flow (E-16), and other near-field processes need to be developed to be compatible with evaluating DPC disposal. Care must be taken because conservative choices for performance related to radionuclide release from the source-term are generally not conservative relative to evaluating criticality. As an example, choosing a high fuel degradation rate is not conservative in terms of criticality. In this case, it would be important not to assume a large degradation rate beyond what can be justified.
- PA disruptive event scenarios should be consistent with reasonable DPC disposal concepts.
- In-package chemistry will be affected as a result of a criticality event because of a variety of factors including high temperatures and evaporation, or by materials included internal to DPC that are not yet considered. The ability to account for such in-package chemistry changes needs to be developed and included in PA (E-14).
- A waste form degradation model should be developed that meets the fidelity needs of DPC studies. The idea is to start with the best baseline PA model possible and then build the fuel matrix degradation model (FMDM) features into that (E-01). For example, the role of cladding degradation, ignored for source-term performance considerations, is perhaps central to criticality analyses for DPC studies. However, the effort needs to make sense in terms of criticality.
- The criticality FEPs are subject to change now that the context for investigating criticality has changed because of DPCs. Based on the 2012 FEPs, there is only one internal criticality FEP, but there probably need to be more to facilitate a closer examination of various aspects of internal criticality.
- In Argillite repository concepts considering DPC disposal, there is a need to better specify DPC overpack function and material properties for evaluating the evolution of the EBS.
- Possible colloid formation and persistence, arising from a criticality event, needs to be investigated. This issue could cause a change in source-term conditions for such a disturbed scenario event.

These integration issues are currently being worked with the other R&D Activity groups and staff.

Although integration is an important issue for all SFWST R&D Activities, integration issues related to EBS Activities are more complex than most because they generally involve all the other R&D areas of the SFWST program (for example, all of the DPC related aspects above). A single EBS Activity may require integration with two or three other areas. For instance, an Activity investigating buffer/backfill behavior could require integration with the Crystalline and Argillite programs, as well as PA and International if a field test is ongoing.

Coupled THMC processes present good examples of integration issues addressed by EBS Activities. Activities addressing THC processes, such as E-3, E-10 and E-11, are evaluating engineered barrier material interactions, i.e. metal, clay and rock, and analyzing applicable experimental data. The impact of materials on in-package and in-drift chemistry is being evaluated in Activities E-14 and E-17. Activity E-7, as well as several Salt Activities, are addressing the impact of THM coupled processes on the evolution of in-drift conditions for a generic bedded salt repository.

Information gaps regarding the waste package (WP) have cross-cutting impacts for crystalline, DPC, and GDSA. Corrosion degradation data and models exist for various metal alloys, including information from SFWST studies, work done for the Yucca Mountain License Application (DOE 2008), and International literature. These are being incorporated in generic repository models, as appropriate. Identification of additional WP barrier materials (e.g., for DPC overpacks) is needed both for defining missing degradation model approaches, as well as for considerations of bulk chemical effects in the EBS. Information gaps have also been identified for waste package mechanical strength evolution, including the effects of phenomena such as rockfall, overburden, and internal gas pressure. For example, the structural integrity of the waste package could decrease enough that it can no longer withstand the internal pressure resulting in a breach.

Regarding International R&D Activity integration, these Activities are often cross-cutting and are closely related to many of the host-rock-specific and EBS Activities in Appendix B. Since these International Activities focus on process technical bases and are already well integrated with the Argillite, Crystalline, Salt, and EBS R&D Activity groups, integration with GDSA is via these other work packages, so there is no need for direct PA (GDSA) integration.

3.3.5 Lessons Learned

The most important product of the workshop is the R&D Activity prioritization and supporting information presented in Appendix B. Appendix B presents the results of many hours of effort from a large group of technical specialists and experts. It is part of an ongoing planning, or roadmap, process. Another important product from the workshop is an assessment of "Lessons Learned" that can be used to improve the ongoing R&D evaluation and prioritization process.

Appendix B includes a variety of types of information. There is information about R&D Activities currently be conducted or being planned by the various technical staff and managers. There is information describing the type of work being conducted and the scope of work. There is also information on how the tasks relate to broader topics. The experts were asked to evaluate how their tasks related to the Safety Case for nuclear waste disposal and how their tasks related to the state of the art for the technical area that includes the task. The experts were asked to identify the FEPs that are addressed by their Activities.

Tools were developed to help the experts present the information. A categorization was developed to define types of Activities. A figure was developed showing "typical elements" of a deep geologic repository safety case. Criteria were developed to help assess ideas like Importance to the Safety Case and State of the Art Level. The criteria were incorporated into a suite of questions that were designed to help the experts assign values for these ideas.

As might be expected, there was variability in how the tools and information were implemented by the experts while evaluating their tasks both before and during the Update Workshop. The variability started with the definition of the Activities. The scope of the defined Activities varied both in terms of the level of effort, i.e. number of FTEs required in the years leading up to 2022 (see Section 3.2), and the time frame required for completion of the task. Also, some of the Activities, particularly Gap Activities, have time frames well beyond the guidance given regarding 2022. In fact, some can be argued to be decades-long Activities, e.g., see C-13, C-15, C-16. The identification of FEPs addressed by an R&D Activity was also variable, as described in the preceding section. All of the foregoing factors contributed to variability that is evident on examination of Appendix B.

The implementation of the SAL metric requires some special discussion. This is clearly a subjective assessment, so some variability is inevitable. Special effort was put into developing the metric value definitions (see Table 3-2) and that effort was beneficial. The experts were also asked to assess the R&D required to move the task to the next lower value of SAL. This may be the area with the most variability. Part of the variability is a direct result of issues discussed above. Large differences in the scope and duration of Activities will lead to variability in the assignment of SAL values, both because tasks with a large scope and duration will include a spectrum of SAL values and because the priority evaluation will change with different stages of repository development. The technical background of the evaluator can also influence the assignment of SAL values. And technical disagreements about the significance of results can influence the assignment of SAL values. However, as pointed out in the discussion of Figure 3-5, there did appear to be some uniformity in the assignment of SAL values across the three host-rock breakout sessions.

The foregoing issues of variability could be addressed through additional training prior to future decision analysis workshops. The training would provide more "calibration" for the required technical assessments. This is especially important for assessments that are, in most part, subjective. Calibration on assessing SAL for technical Activities and R&D needs for improving the SAL could help to reduce variability. This needs to be combined with careful definition of SAL values or categories. This training should focus on breakout session chairs and rapporteurs, and especially the technical leads for the host-rock-specific work packages, and would be best accomplished during a face-to-face meeting. However, it was noted earlier that the "calibration" among host-rock sessions may have been better than foreseen, as evidenced by Figure 3-5.

3.3.6 Summary of R&D Activities and R&D Activity Groups

Appendix L provides additional detail on the discussions and interactions that took place during the breakout sessions but is mostly a summary of the R&D Activities within each R&D Activity group. An important point with respect to the Activity Group breakout sessions is that they represented a valuable information exchange and integration among technical experts in the SFWST Campaign. This is useful for efficiently guiding future R&D that is occurring across the DOE National Laboratory complex at widely separate physical locations.

4. SFWD DOCUMENT ARCHIVE

As a result of the DOE-NE reorganization that created the Office of Spent Fuel and Waste Disposition (SFWD), the Document Management System (DMS)—the former repository for UFD milestone deliverable documents—became unavailable. This gap is now being filled with a new restricted-access SharePoint website, called the SFWD Document Archive (SDA). This new document repository captures reports generated in the Disposal Research (DR), Storage and Transportation (S&T), and Integrated Waste Management (IWM) areas of SFWD.

The SDA includes copies of both UUR and unclassified limited release (ULR) deliverable documents and concise information about their pedigree (e.g., "downloaded from OSTI," "best available draft from author," etc.) and their release status (e.g., "ULR," "internal use only, do not cite or release," etc.), and it will be a searchable and sortable resource for SFWD participants. Although the SDA is not open to the general public, the section of it called the "NE 81 Public Milestones Library," which contains unclassified unlimited release (UUR) DR and S&T milestone deliverable documents, will soon be made available to all SFWD staff who are DOE employees or contractors. Tables 4-1, 4-2, and 4-3 show the current status of the SDA.

Table 4-1. NE 81 Disposal Research (DR) Documents.

Total DR milestone deliverable documents referenced in PICS:NE[1]			527
Total DR documents collected in the SDA[2]			532
Total DR deliverables that still need to be collected			4
	Total DR milestone deliverable documents referenced in PICS:NE	**Total DR milestone documents collected in SDA**	**# of documents still needed**
Level 1	1	1	0
Level 2	105	109	0
Level 3	142	148	1
Level 4	269	281	3
Level 5	10	9	0

[1] Program Information Collection System: Nuclear Energy (PICS:NE) is a web-based tool used by the Department of Energy, Office of Nuclear Energy (DOE-NE) for tracking program scope, schedule, budget, and deliverables.

[2] There is a small discrepancy between the number of milestone documents from PICS:NE and the milestone documents collected in the SDA because sometimes multiple documents are associated with single milestones (e.g., like the current document, which has two revisions, Rev.0 and Rev.1). Also, a very small number of other important documents have been added to the SDA. 504 of the 532 collected DR documents in the SDA are UUR and can be found in the NE-81 Public Milestones Library section of the SDA.

Table 4-2. NE 81 Storage and Transportation (S&T) Documents.

Total S&T milestone deliverable documents referenced in PICS:NE	298
Total S&T documents collected in the SDA[2,3]	288
Total S&T deliverables that still need to be collected	14 (Levels 4 and 5)

[3] 227 of the 288 collected S&T documents in the SDA are UUR and can be found in the NE 81 Public Milestones Library.

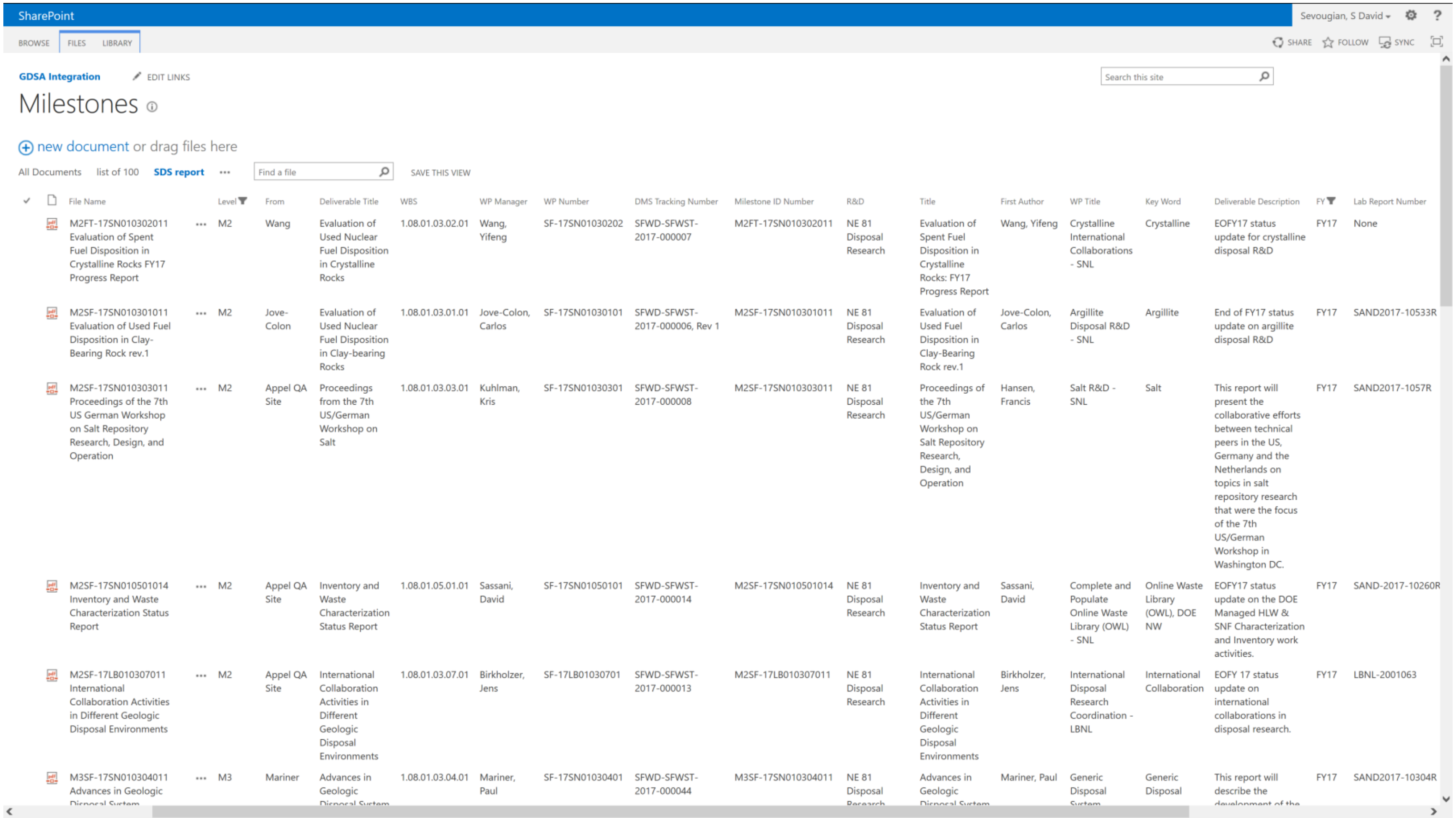
Table 4-3. NE 82 Integrated Waste Management (IWM) Documents.

Total IWM milestone deliverable documents referenced in PICS:NE	528
Total IWM documents collected in the SDA[4]	346
Total IWM deliverables that still need to be collected	182 ((8 Level 2, plus 174 Levels 3, 4, and 5)

[4] These documents will be made available to SFWD staff at a later date.

Table 4-4 below is a screenshot of the SDA SharePoint website indicating the display format and the type of information available.

Table 4-4. Screenshot of the SFWD Document Archive SharePoint site.



SharePoint

Sevougian, S David

BROWSE FILES LIBRARY

SHARE FOLLOW SYNC

GDSA Integration EDIT LINKS

Search this site

Milestones

new document or drag files here

All Documents list of 100 **SDS report** ••• Find a file SAVE THIS VIEW

File Name		Level	From	Deliverable Title	WBS	WP Manager	WP Number	DMS Tracking Number	Milestone ID Number	R&D	Title	First Author	WP Title	Key Word	Deliverable Description	FY	Lab Report Number
M2FT-17SN010302011 Evaluation of Spent Fuel Disposition in Crystalline Rocks FY17 Progress Report	•••	M2	Wang	Evaluation of Used Nuclear Fuel Disposition in Crystalline Rocks	1.08.01.03.02.01	Wang, Yifeng	SF-17SN01030202	SFWD-SFWST-2017-000007	M2FT-17SN010302011	NE 81 Disposal Research	Evaluation of Spent Fuel Disposition in Crystalline Rocks: FY17 Progress Report	Wang, Yifeng	Crystalline International Collaborations - SNL	Crystalline	EOFY17 status update for crystalline disposal R&D	FY17	None
M2SF-17SN010301011 Evaluation of Used Fuel Disposition in Clay-Bearing Rock rev.1	•••	M2	Jove-Colon	Evaluation of Used Nuclear Fuel Disposition in Clay-bearing Rocks	1.08.01.03.01.01	Jove-Colon, Carlos	SF-17SN01030101	SFWD-SFWST-2017-000006, Rev 1	M2SF-17SN010301011	NE 81 Disposal Research	Evaluation of Used Fuel Disposition in Clay-Bearing Rock rev.1	Jove-Colon, Carlos	Argillite Disposal R&D - SNL	Argillite	End of FY17 status update on argillite disposal R&D	FY17	SAND2017-10533R
M2SF-17SN010303011 Proceedings of the 7th US German Workshop on Salt Repository Research, Design, and Operation	•••	M2	Appel QA Site	Proceedings from the 7th US/German Workshop on Salt	1.08.01.03.03.01	Kuhlman, Kris	SF-17SN01030301	SFWD-SFWST-2017-000008	M2SF-17SN010303011	NE 81 Disposal Research	Proceedings of the 7th US/German Workshop on Salt Repository Research, Design, and Operation	Hansen, Francis	Salt R&D - SNL	Salt	This report will present the collaborative efforts between technical peers in the US, Germany and the Netherlands on topics in salt repository research that were the focus of the 7th US/German Workshop in Washington DC.	FY17	SAND2017-1057R
M2SF-17SN010501014 Inventory and Waste Characterization Status Report	•••	M2	Appel QA Site	Inventory and Waste Characterization Status Report	1.08.01.05.01.01	Sassani, David	SF-17SN01050101	SFWD-SFWST-2017-000014	M2SF-17SN010501014	NE 81 Disposal Research	Inventory and Waste Characterization Status Report	Sassani, David	Complete and Populate Online Waste Library (OWL) - SNL	Online Waste Library (OWL), DOE NW	EOFY17 status update on the DOE Managed HLW & SNF Characterization and Inventory work activities.	FY17	SAND-2017-10260R
M2SF-17LB010307011 International Collaboration Activities in Different Geologic Disposal Environments	•••	M2	Appel QA Site	International Collaboration Activities in Different Geologic Disposal Environments	1.08.01.03.07.01	Birkholzer, Jens	SF-17LB01030701	SFWD-SFWST-2017-000013	M2SF-17LB010307011	NE 81 Disposal Research	International Collaboration Activities in Different Geologic Disposal Environments	Birkholzer, Jens	International Disposal Research Coordination - LBNL	International Collaboration	EOFY 17 status update on international collaborations in disposal research.	FY17	LBNL-2001063
M3SF-17SN010304011 Advances in Geologic	•••	M3	Mariner	Advances in Geologic	1.08.01.03.04.01	Mariner, Paul	SF-17SN01030401	SFWD-SFWST-2017-000044	M3SF-17SN010304011	NE 81 Disposal	Advances in Geologic	Mariner, Paul	Generic Disposal	Generic Disposal	This report will describe the	FY17	SAND2017-10304R

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5. SUMMARY

R&D addressing the disposal of SNF/HLW in the U.S. is currently generic (i.e., "non-site-specific") in scope, following the suspension of the Yucca Mountain Repository Project in 2010. However, to prepare for the eventuality of a repository siting process, the former Used Fuel Disposition Campaign (UFDC) of DOE-NE, which was succeeded by the Spent Fuel and Waste Science and Technology (SFWST) Campaign, formulated an R&D Roadmap in 2012 outlining generic R&D activities and their priorities appropriate for developing safety cases and associated performance assessment (PA) models for generic deep geologic repositories in several potential host-rock environments in the contiguous United States. Following this exercise, R&D was initiated and has been ongoing to help identify and resolve the uncertainties associated with the highest-ranking issues.

The original 2012 UFD R&D Roadmap promised a re-evaluation of priorities in future years as knowledge was gained from ongoing activities in the U.S. and abroad. Thus, a re-assessment of R&D priorities was initiated during a recent decision analysis workshop of DOE's SFWST Campaign experts in early 2019. The objectives of the 2019 R&D Roadmap Update include the following:

1) Recap the 2012 Roadmap results and conclusions
2) Document the 2019 Roadmap Update Workshop approach, process, and evaluations
3) Summarize the status, progress, and priority of 2019 SFWST R&D activities and their relation to the FEPs important to various host rocks and repository designs
4) Identify the generic R&D still needed to advance the state-of-the-art for important R&D Activities and associated FEPs
5) Identify important FEPs that have not been addressed adequately by Campaign R&D Activities
6) Present a new document archive for UFD and SFWST milestone reports

Objectives 3 and 4 are primarily addressed in a series of appendices to this report that capture the wealth of consensus information compiled by Campaign experts during the three-day Roadmap Update Workshop. This information, the most important of which were the consensus values for the metrics ISC (Importance to the Safety Case) and SAL (State-of-the-Art Level), along with an explanation (or "rationale") for the expert-assigned values, was analyzed similarly to the 2012 Roadmap to provide Priority Scores for each 2019 R&D Activity, with score classes of High, Medium-High, Medium, and Low. A review of the 2019 High- and Medium-High-priority R&D Activities has led to the identification of a set of "High Impact R&D Topics," including:

- High temperature impacts
- Buffer and seal studies
- Generic PA Models
- Coupled processes (Salt)
- Gas flow in the EBS
- Criticality
- Waste Package Degradation

- Radionuclide Transport
- In-Package Chemistry

These High Impact R&D Topics provide a high-level snapshot of the current and future generic R&D focus.

Regarding Objective 5, this update exercise identified a number of “gap” activities that represent future R&D necessary to adequately advance the state of the art of several high- and medium-priority FEPs.

Although much has been accomplished since 2012, through R&D in the U.S. and through international collaborations, especially with those countries that operate underground research laboratories (URLs), the 2019 R&D Roadmap Update reflects the need for continuing R&D on many of the 2012 R&D Issues, plus some obvious new priorities, such as R&D on disposal of DPCs (dual purpose canisters), which now contain a significant fraction of the Nation’s spent fuel activity. This new 2019 R&D prioritization effort is closely tied to the development of the Campaign’s generic performance assessment model/software framework, *GDSA (Geologic Disposal Safety Assessment) Framework*, which results in much of the R&D being directly related to the supporting process models that feed this PA model and software. Given the importance of post-closure performance assessment in building confidence in the safety case, this is deemed appropriate.

Finally, this deliverable introduces the new SFWD Document Archive website. As a result of the DOE-NE reorganization that created the Office of Spent Fuel and Waste Disposition (SFWD), the Document Management System (DMS)—the former repository for UFD milestone deliverable documents—became unavailable. This gap is now being filled with a restricted-access SharePoint website, called the SFWD Document Archive (SDA). This new document repository captures reports generated in the SFWST Campaign [including both Disposal Research (DR) and Storage and Transportation (S&T) documents] between 2010 and 2019 and Integrated Waste Management (IWM) Campaign documents between 2013 and 2019. Currently, there are 532 DR documents in the SDA, of which 504 are unclassified unlimited release (UUR) and will soon be made available to all SFWD staff who are DOE employees or contractors. There are also 227 S&T documents currently available.

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APPENDIX A: FY19 SFWST ROADMAP UPDATE WORKSHOP AGENDA

FINAL AGENDA

UNLV Campus
Science & Engineering Building (SEB)
4505 S Maryland Pkwy
Las Vegas, NV 89154

January 15-17, 2019

DAY 1, TUESDAY, 1/15/2019		
8:00 a.m.	**Sign in and obtain name tag**	SEB foyer
8:30 a.m.	**Opening Remarks,** *DOE (Gunter, Tynan); SNL (Swift)*	Room 1242
9:00 a.m.	**Workshop Methodology & Breakout Group Instructions,** *Dave Sevougian*	Room 1242
10:00 a.m.	*Break*	Room 1242
10:15 a.m.	**Host-Rock Breakout Groups:*** **[Argillite (Rm 1243); Crystalline (Rm 1242); Salt (Rm 1240)]** 1) Review and revise existing R&D Activity names/descriptions, as warranted (Columns B and C – and D, E, F, as needed) 2) Decide upon SAL rating and rationale (Columns K, L, M), and determine generic R&D still needed to decrease SAL (Column N) 3) Brainstorm and add "Gap" Activities, as appropriate (add new rows) ***(*****PLEASE** *follow the detailed breakout group assignments given on p. 4)* *(consider EBS, DPC, and International Activities, as assigned – complete one-half of the host rock R&D Activities first; then switch to cross-cutting EBS, DPC, and Intl. – see p. 5 for list of assigned Activities)*	Rooms 1240, 1242, 1243
11:45 a.m.	*Lunch (on your own, but at the UNLV cafeteria—to save time)*	
1:00 p.m.	**Host-Rock Breakout Groups (continued)**, *All* • Continue with the Day 1 tasks listed above	Rooms 1240, 1242, 1243
5:00 p.m.	*Adjourn for the day*	

DAY 2, WEDNESDAY, 1/16/2019		
8:30 a.m.	**Host-Rock Breakout Groups (continued):*** **[Argillite (Rm 1243); Crystalline (Rm 1242); Salt (Rm 1240)]** 1) Complete Day 1 tasks (if incomplete) 2) Decide upon ISC rating and justification (Columns O, P, Q) 3) Discuss and document ongoing and "unresolved" <u>integration</u> issues, particularly with PA-GDSA (Column T) *(***PLEASE*** follow the detailed breakout group assignments given on p. 4)*	Rooms 1240, 1242, 1243
11:45 a.m.	*Lunch (on your own, but at the UNLV cafeteria—to save time)*	
1:00 p.m.	**Host-Rock Breakout Groups (<u>continued</u>)**, • Complete morning tasks (ISC ratings)	Rooms 1240, 1242, 1243
	Cross-cutting Breakout Groups Reporting Prep (<u>begin</u>) • Three Cross-cutting Breakout Groups Summary Development [EBS (Rm 2151); DPC (Rm 1245); International (Rm 2212)]	Rooms 1245, 2151, and 2212
2:45 p.m.	*Break*	
3:00 p.m.	**Preparation for Thursday Reporting – Reporting Preparation** • Three Host-Rock Groups Summary Development (<u>begin</u>) • Three Cross-cutting Breakout Groups Summary Development (continued)	Rooms 1240, 1242, 1243, 1245, 2151, and 2212
5:30 p.m.	*Adjourn for the day*	
7:00 p.m.	***Group Dinner ("Dutch Treat") – Sassani is organizing***	

<u>**Summary Reporting Tasks**</u> (at 1:00 pm for Cross-cutting and 3:00 pm for Host-Rock Groups):

Each breakout group chairman/rapporteur summarizes (with the help of the R&D Activities spreadsheet, if appropriate):

1) Unresolved integration issues (e.g., with GDSA)
2) Key R&D priorities (generic R&D needed) going forward, along with SAL and ISC ratings for these, and justifications
3) Major gap activities or needs identified, if any—especially those for H and M FEPs not currently being worked on
4) If time allows, key points of progress since 2012: e.g., changes to SAL values since 2012, which would be a comparison between the highest scoring 2012 FEP for an R&D Activity with the new SAL for the Activity itself

DAY 3, THURSDAY, 1/17/2019		
8:30 a.m.	**Summary Reports and Integration (30 minutes per breakout),** *Everyone* 1) Host-Rock Groups Summary Reporting (order: Salt, Argillite, Crystalline) 2) Cross-cutting Breakout Groups Summary Reporting (order: International, DPC, EBS)—be sure to point out <u>commonalities and/or differences in host-rock breakout group findings</u> 3) "Other" R&D Tasks (O-1 to O-4): Discuss briefly (lead for each task – Sassani, Perry, Zavrin)	Room 1242
11:45 a.m.	*Lunch (on your own, but at the UNLV cafeteria—to save time)*	
1:00 p.m.	**Report/Integrate – Full Group (<u>continued</u>)** 1) Complete morning assignments listed above, *All* 2) Summary of new Activity and/or FEP R&D priorities, *Sevougian/Dobson* 3) Discuss future integration/updating still needed, e.g., a follow-up workshop, etc.	Room 1242
2:30 p.m.	*Adjourn*	

Breakout Group Assignments – Details

- **Instructional NOTES:**

1) Rapporteurs please take attendance at each session! (list of names). Please bring your laptop!!!
2) Rapporteurs to create a "Parking Lot" (separate Word file) for off-track topics or issues that need to be resolved—can come back to them at the end of their session; can also be used for "closed" (i.e., no longer funded) Activities that have been completed (or we can compile these after the Workshop)
3) Discussions and revisions to *R&D Activities Table* (spreadsheet) are to be documented via real-time revisions to the *R&D Activities Table* by the group rapporteur
4) Each host-rock breakout group will consider their own R&D Tasks plus the EBS R&D Tasks, DPC R&D Tasks, and International R&D Tasks that have been assigned to their group—see below. *Please consider effect of DPC high heat output on post-closure FEPs, models, tests, etc*.
5) Address one-half of your host rock activities first, then switch to cross-cutting Activities (DPC, EBS, Intl.)
6) PA R&D Activities are "fair game" to consider, e.g., the reference cases P-1 to P-4; but don't spend a lot of time on them (especially UZ, which was not a potential host rock in 2012)
7) Do NOT address PICS-NE entries (Column I)
8) Columns L and P can only have numerical entries!! No additional text of any kind, please.

- **Specific Breakout Assignments (Days 1 and 2—see Agenda assignments above):**

1) *R&D Activities (Tasks) Completeness and Accuracy*: Review and revise existing R&D Activity names/descriptions, as warranted, i.e., Columns B and C (and D, E, F, as needed);
2) *State-of-the Art Level (SAL) Rankings and Justifications*:*
   a. Columns K and L: Assign a current (2019) SAL for each R&D Activity and its associated highest ranking FEP(s)—see SAL metric table
   b. Column M (rationale): Answer SAL questions for each R&D Activity (and its associated highest-ranking FEP)—see the last column of the SAL metric table
   c. Column N: Propose generic R&D necessary to reach next SAL (e.g., to change a SAL=5 to a SAL=4)—with the goals of achieving *GDSA baseline capability* in 2022 and supporting an initial generic safety case (final site selection may require additional site-specific R&D).
3) *Gap Activities*:*
   a. Review and/or identify H and M Issues (FEPs from 2012 Roadmap) that are not currently being addressed by ongoing R&D Activities/Tasks (consider L FEPs, if necessary or appropriate, e.g., Criticality)—see the Excel spreadsheet entitled *UFD RD Roadmap FEP-Activity Correlation*
   b. Propose "gap" R&D Activities (new rows) to address missing FEPs, as appropriate. [Not expected to be a one-one mapping—multiple FEPs are expected to map to each R&D Activity/Task.]
   c. Propose other "gap" R&D Activities if needed (within reason!)—see R&D Activities spreadsheet for some gap activities that have already been identified
   d. R&D Activities ("gap" and otherwise) should be quantized (or discretized) somewhere *between the fine level of FEPs and the broad level of PICS-NE*

4) *Importance to the Safety Case (ISC) Rankings and Justifications:*
    a. Column G: Review assignment of R&D Activities/Tasks to the Safety Case elements—see Safety Case Elements figure
    b. Columns O and P: Assign a current (2019) ISC for each R&D Activity and its associated highest ranking FEP(s)—see ISC metric table
    c. Column Q (rationale): Provide justification for the ISC value—see the last column of the ISC metric table, as well as the Safety Case Elements figure
5) *Ongoing and/or "Unresolved" Integration Issues":*
    a. Column T: Synopsis of the status of your integration with GDSA
    b. Column T (and/or Columns M or N): Integration with other R&D Activities that needs to occur
6) *Mapping of Past Accomplishments, Deliverables, Reports, Papers, etc.*. Document at a *high level* (and point to references for details) accomplishments to date for generic repositories, i.e., work that has been completed since 2012 for the current R&D Activities/Tasks that addresses their associated FEPs—this item is part of the Day 3 reporting but the actual mapping of deliverables may have to occur subsequent to the Workshop.

*<u>NOTES</u>:

a. When considering potential "gap" activities, identify how much R&D needs to be performed "in-house" versus how much can be leveraged internationally

b. When considering how much R&D is still needed, keep in mind and identify the type of coupling with *GDSA Framework* that is appropriate at the "baseline capability" point (2022)

Assigned cross-cutting Activities by host-rock group:

<u>Argillite</u>: I-2, I-3, I-4, I-5, I-6, I-7, I-9, I-14, E-1, E-2, E-3, E-4, E-5, E-6, E-10, E-11, E-12, E-13, E-14, O-4, P-13

<u>Crystalline</u>: I-1, I-2, I-4, I-8, I-9, I-10, I-11, I-14, E-1, E-3, E-4, E-5, E-6, E-8, E-13, E-14, A-7, P-6, P-7, P-17

<u>Salt</u>: I-11, I-12, I-13, I-14, E-7, E-8, E-10, E-12, O-4, O-5, A-7, P-3, P-11, P-13, P-14

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Argillite members: 18; Crystalline members: 18; Salt members: 15; DPC members: 9; Intl members: 10; EBS members: 9

APPENDIX B: ACTIVITY DESCRIPTIONS, SCORES, RATIONALE, AND R&D NEEDED

ID (*gap)	Activity	2019 Score
A-01	*Two-Part Hooke's Model(saturated)*	L
Desc	• Clay deformation, constitutive model development for damage and EDZ evolution in argillite and crystalline rock.	
Type	PM	
Codes	TPHM-FLAC3D	
Elements	SC elements 3.3 & 4.2	
ISC	Low	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	3 Improved Defensibility	
Rationale	It is a modeling concept that had been proposed and tested in limited case. It has not been the mainstream concept for modeling clay deformation and its relevance has to be further examined. The Two-Parts Hooke's model should be viewed as a constitutive model that has been implemented into FLAC3D (and TOUGH-FLAC). The application can be, among others, EDZ evolution (how permeability, porosity and stiffness varies) and displacements in damage zones. However, it has already been developed and should therefore be included as part of Argillite THM Coupled Processes models.	
R&&D Needed	Continued activity cross-cutting with international. Testing with field experiments	
A-02	*Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization*	M
Desc	• THMC processes affecting clay illitization • Simplified representation of coupled process models • Representation of thermal effects on buffer / host rock • Focus on backfill/buffer degradation, not RN releases • Impact on EBS and host rock materials and transport	
Type	PM, MA	
Codes	TOUGH REACT/FLAC3D, PFLOTRAN	
Elements	SC elements 3.3 & 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	4 Improved Representation	
Rationale	Coupled THMC model that has been tested with in situ data was developed. Chemical-Mechanical coupling is achieved through a dual-structure model that evaluates how chemical changes may effect the mechanical behavior of bentonite in terms of effective/net and total stress. The analysis is limited to the effects of ion concentration and illitization on swelling and do not include other potential effects of chemical changes on mechanics. Swelling stress reduction related to illitization and temperature effects have been evaluated in modeling studies. Thermodynamic analysis of phase stability relations as a function of fluid chemistry, temperature, and pressure is crucial to predict illite formation under elevated temperature conditions. Although this is	

ID (*gap)	Activity	2019 Score
	currently possible, there are some limitations to this analysis plus the inclusion of clay	
R&&D Needed	Cross-cutting to EBS/International Other countries have performed considerable investigations into different backfill and buffer materials (bentonite and cementitious materials). Additional R&D needed to better understand processes associated with backfill/buffer for these materials.Little/no information available regarding new/novel buffer/backfill materialsThe effect of bentonite clay composition on silica activity and the formation of zeolites (e.g., analcime) and illite Need to integrate high temperature studies from A-3Need consideration of multiple thermal pulses	
A-03	*Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS*	M
Desc	• Input from high temperature experimental data, including lack of illitization - dependence on bulk chemistry • Full chemistry reactive transport (RT) representation without mechanics	
Type	PM, LT	
Codes	Experimental data to inform TOUGH REACT/FLAC3D, PFLOTRAN, CHNOSZ	
Elements	SC element 3.3.1c	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	4 Improved Representation	
Rationale	Chemical processes still under development, particularly at elevated temperature repository-relevant conditions. Ongoing hydrothermal experiments replicate a high temperature repository within an argillaceous geologic environment. Steel/bentonite interface reactions and corrosion rates in steel coupons at elevated temperatures are also being investigated.	
R&&D Needed	Other countries have performed considerable investigations into different backfill and buffer materials (bentonite and cementitious materials), mainly under ambient conditions. Additional R&D needed to better understand processes associated with backfill/buffer interactions for these materials at elevated temperatures. Little/no information available regarding new/novel buffer/backfill materials or amended	
A-04	*Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)*	M-H
Desc	• Coupled thermal-hydrological-mechanical processes in Argillite host rock repository, including EBS (bentonite and backfill), and excavation disturbed zone (EDZ) • Integration with GDSA/PA	
Type	PM, MA	
Codes	TOUGH-FLAC	
Elements	SC elements 3.3, 4.2, & 4.3	
ISC	High	
Rationale		
SAL	4 Improved Representation	

ID (*gap)	Activity	2019 Score
Rationale	The basic framework for these modeling activities is the TOUGH-FLAC simulator. This basic framework has been modified to incorporate Bentonite and Shale constitutive models, i.e. BBM and BExM. EDZ models have been developed including: Empirical stress-permeability model Non-linear elastic and brittle failure model Anisotropic continuum damage model These models are being validated by activities evaluating data from the Mont Terri FE experiment, Heater experiments at Bure in COx Clay Stone (DECOVALEX-2019 Task E), and Gas Migration in Clay (DECOVALEX-2019 Task A).	
R&&D Needed	FY19 workscope: R&D for (1) confident modeling bentonite dual-structure behavior on permeability and resaturation, (2) confident modeling of EDZ evolution, including long-term sealing and healing and (3) model development for gas migration in bentonite and clay host rocks. Continued model validation of large scale field experiments related to international activities (Mont Terri Project and DECOVALEX 2019). Expand for modeling of fault activation and fluid migration along faults. Linking of new TOUGH3 code with new FLAC3D V6 for more efficient simulations. FY20-21 workscope: Continued model development and validation related to DECOVALEX-2023, including (1) Fault activation and fluid migration along faults, (2) field experiments on gas migration, and potential other tasks in DECOALEX-2023. Prioritize work for integration with PA (PFLOTRAN) including calculation of response surfaces for defined GDSA cases. Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt).	
A-05	*THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)*	M
Desc	• Discrete Fracture Network (DFN) with THM (argillite/clay) • Applied to gas migration studies (DECOVALEX19)	
Type	PM, MA	
Codes	TOUGH2-RBSN	
Elements	SC elements 3.3 & 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	4 Improved Representation	
Rationale	Current representation includes adequate constitutive relations for argillaceous rocks implemented using the TOUGH2/RBSN code. Validation is ongoing including international collaborative activities analyzing data from URLs. The TOUGH2/RBSN simulator is being used to model gas migration, i.e. two phase flow, including mechanical deformation and fracture/damage processes, through argillaceous material.	
R&&D Needed	Continued discrete fracture modeling of gas migration experiments along with the DECOVALEX-2019 project. Validation of anisotropic, layered shale, strength and elastic properties against laboratory data from Opalinus Clay and other shales. Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill.	

ID (*gap)	Activity	2019 Score
A-06	*Diffusion of actinides through bentonite(including speciation)*	M
Desc	• Speciation, sorption, diffusion input data • Cross-cuts with EBS (E-8)	
Type	LT, EA	
Codes	CrunchEDL, PHREEQC	
Elements	SC element 3.3.1c	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	4 Improved Representation	
Rationale	Two complementary approaches to modeling ion diffusion through clays have been developed. The first makes use of a Donnan Equilibrium or Mean Electrostatic Approach, in which a mean electrostatic potential is defined for the electrical double layer to balance the fixed negative charge of the clays. The second approach involves the use of the Nernst-Planck and Poisson-Boltzmann equation (termed the PBNP method). The Donnan Equilibrium or Mean Electrostatic Approach was tested in benchmark studies using the software codes CrunchEDL versus PHREEQC. Differences between the calculations in one of the benchmark studies were found to be a result of the neglect of the longitudinal gradient in the mean electrostatic potential in CrunchEDL. Comparisons between CrunchEDL calculations and DR-A test results provide evidence that the electric double layer influences anion diffusion rates in the Opalinus Clay.	
R&&D Needed	Improved understanding of solubility controls and dissolved concentration limits would lead to improved radionuclide transport models and better understanding of disposal system performance. Large knowledge gaps on radionuclide solubilities at elevated temperatures and in concentrated electrolyte solutions. Accurate redox speciation chemistry of important radionuclides such as Pu and Np are still a matter of investigation.	
A-07	*Analysis of clay hydration/dehydration and alteration under various environmental conditions*	M
Desc	• High temperature experiments on FEBEX bentonite • Planning of TGA/DSC experiments on FEBEX bentonite • Review of FEBEX relative humidity (RH) in the heater test	
Type	PM, EA, LT	
Codes	Process model representation with PFLOTRAN, constrained by experimental data	
Elements	SC element 3.3.1c	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	• Chemical processes still under development, particularly at elevated temperature conditions Developing an understanding of bentonite buffer “dry-out” and clay hydration. During heating, it is anticipated that water will be driven from clay buffer materials. Improved understanding of the effects of this dry-out on the ensuing clay pore matrices, and on the resulting fluid permeability, is needed. Restoration or healing of pore matrices upon re-saturation (when the repository has cooled down) also needs improved	
R&&D	Flow in the EDZ is closely tied to the evolution of the EDZ.	

ID (*gap)	Activity	2019 Score
Needed	R&D related to FEP 2.2.01.01 Need to understand clay hydration phenomena (TGA/DSC), mineral phase transformation, & stability Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill. Need to understand re-saturation phenomena under non-isothermal conditions.	
A-08	*Evaluation of ordinary Portland cement (OPC)*	H
Desc	• 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	
Type	LT, EA, PM, MA	
Codes	PFLOTRAN, CHNOSZ, EQ3/6	
Elements	SC element 3.3.1, 4.3 (Confidence Building)	
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	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	This will baseline the chemical reactions of a shotcrete liner in contact with engineered barrier materials. As part of the new scope, the emphasis will be on the characterization of (secondary) cementitious phases in response to hydrothermal alteration. This will include steel corrosion measurements, which will provide data revealing if corrosion is inhibited in the presence of cement.	
R&&D Needed	Improved understanding of solubility controls and dissolved concentration limits would lead to improved radionuclide transport models and better understanding of disposal system performance. Large knowledge gaps on radionuclide solubilities at elevated temperatures and in concentrated electrolyte solutions. Accurate redox speciation chemistry of important radionuclides such as Pu and Np are still a matter of investigation.	
C-01	*Discrete Fracture Network (DFN) Model*	M-H
Desc	• 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	
Type	PM	
Codes	DFNWorks, PFLOTRAN, mapDFN.py, FracMan	
Elements	SC element 4.2	
ISC	High	
Rationale	Fractures are main flow pathway for transport to accessible environment. e.g. Plume dispersion.	
SAL	4 Improved Representation	

ID (*gap)	Activity	2019 Score
Rationale	A simulation tool (dfnWorks) for fracture network generation and for simulating fluid flow and transport in discrete fracture network was developed (and won a R&D100 award). The model was used to simulate the Long-Term Sorption Diffusion Experiment (LTDE) conducted at the Äspö Hard Rock. A fully coupled thermal-hydrological-mechanical-chemical model for fracture opening and closure was formulated by explicitly accounting for the stress concentration on aperture surface, stress-activated mineral dissolution, pressure solution at contacting asperities, and channel flow dynamics.	
R&&D Needed	Continued improvement of models of RN F&T in fractured media by simulation of field scale and laboratory testing programs, particularly in coordination with international programs in crystalline rock, will result in increased confidence and better validation of models. Develop a reduced order model based DFN simulations for total system performance assessments. Ongoing work in DECOVALEX addresses this activity and	
C-02	*Flow and Transport in Fractures - modeling approaches*	M
Desc	• Different modeling approaches - graphs, pruning, FCM, other ECPM, particle tracking v. reactive transport. Validation of simpler models against more mechanistic. Embed fractures in matrix (octree mesh)	
Type	PA, PM	
Codes	DFN, PFLOTRAN, DAKOTA, FracMan	
Elements	SC element 4.2	
ISC	High	
Rationale	Fractures are main flow pathway for transport to accessible environment.	
SAL	3 Improved Defensibility	
Rationale	A work flow was developed for mapping field fracture distribution data to a DFN model. Flow and transport in a hypothetical fracture network were performed using both particle tracking and advection-diffusion approaches. The particle tracking method generates a sharper breakthrough peak. Preliminary statistical analysis showed that, depending on the actual fracture distribution parameters, a relatively large number of realizations may be needed to obtain a stable statistical representation for flow and transport. PFLOTRAN code was coupled with DAKOTA for Monte-Carlo simulations.	
R&&D Needed	Future activities will focus on understanding the uncertainty in fluid flow and radionuclide transport associated with different modeling approaches. We will consider different modeling approaches - graphs, pruning, FCM, other ECPM, particle tracking v. reactive transport, as well as validation of simpler models against more complex, mechanistic ones. Further evaluate the statistical stability of multiple DFN realizations	
C-03	*Fracture-Matrix Diffusion - Modeling approaches*	M
Desc	• Crystalline rock - see also SKB GWFTS Task (I-10) and consider relation to microstructure DFN	
Type	EA, MA	
Codes	DFNWorks, PFLOTRAN	
Elements	SC Element 3.3.2b, 4.2	
ISC	High	
Rationale	Matrix diffusion (or absence of) can have major impact on dose.	
SAL	3 Improved Defensibility	
Rationale	In 2018, modeling to simulate the Long-Term Sorption Diffusion Experiment (LTDE),	

ID (*gap)	Activity	2019 Score
	conducted at the Äspö Hard Rock, was completed, as well as a flow-transport model demonstration using Mizunami site data as part of DECOVALEX.	
R&&D Needed	Continued participation in DECOVALEX and other modeling efforts will result in improved confidence and validation of coupled F&T models of repository performance, both in the EDZ and undamaged host rock. Additional column and field scale testing on matrix diffusion and upscaling modeling are needed. Incorporate modeling advances from International work in our methods.	
C-04	*Lab and modeling study of EDZ - Crystalline*	M
Desc	• Hydrologic properties of damage zone in crystalline rocks. Modeling and lab studies (LBL Seiji Nakagawa). Relevant to extent of EDZ/probability of connecting to transmissive feature. Thermal effects (DPCs).	
Type	LT, EA, MA	
Codes	RBSN	
Elements	SC Element 3.3.2b; 3.3.1d	
ISC	Medium	
Rationale	Affects likelihood of connecting to transmissive feature. Does not drive PA.	
SAL	4 Improved Representation	
Rationale	Evolution of the EDZ and EBS is closely related to flow and transport of RN. Lab experiments and RBSN modeling of deformation and fracturing in crystalline rocks provides improved understanding of excavation effects on hydrologic and transport properties. Modeling simulations show the importance of conditioning DFN model development on actual locations of fractures on a tunnel or borehole surface in predicting fluid flow and transport. There is not agreed upon representation in models. Models are being developed but have not yet been validated.	
R&&D Needed	Continue to improve confidence in models by improving characterization techniques (e.g., geophysical methods) . Testing rock samples from field laboratories, including samples from the Grimsel and Stripa mines will help validate models and the understanding of the hydro-mechanical-chemical interaction between the filling materials within the excavation and the EDZ. Concurrently, we plan to simulate the laboratory-observed EDZ development using the RBSN model, and predict the development of an EDZ in the field and its hydro-mechanical properties. Develop methods to differentiate background fractures from excavation induced fractures on a tunnel surface. Have not yet demonstrated that the modeling can match the observations. Also need to address upscaling. How do observations at core scale relate	
C-05	*Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization*	M
Desc	Existing non-invasive geophysical techniques are adequate for characterizing large-scale subsurface features and physical properties, but continued advances could help achieve high-resolution images of time-varying properties and structural changes that may be important during the site selection or characterization stages. This task will focus on the development of new geophysical techniques that can provide unprecedented high spatial resolutions. Develop invasive (downhole) hydrological characterization techniques to resolve flowing	

ID (*gap)	Activity	2019 Score
	fractures in a borehole. Understand issues of scale (and direction). Which techniques give the most/best information? Understand which features (e.g. stress state, fracture orientation, ...) have greatest influence on which fractures are flowing and which are not? Develop novel techniques for characterizing groundwater chemistry. The emphasis will be given to the techniques that can provide fast, accurate, in-situ and high spatial resolution measurements (e.g., in boreholes) with minimum human perturbations. The techniques that can characterize flow localization and the associated chemical	
Type	LT, FT, EA	
Codes	NA	
Elements	SC Element 3.3.2b, 3.3.2c, 4.2	
ISC	High	
Rationale	Probability distribution of flowing fractures or calibration of DFN to flowing fractures could be direct input to PA.	
SAL	3 Improved Defensibility	
Rationale	• A comprehensive literature review was performed on geophysical characterization of fracture media. • Use of flowing fluid electrical conductivity (FFEC) logs to identify borehole inflow zones was demonstrated using the 2.5 km deep “Collisional Orogeny in the Scandinavian Caledonides” (COSC) scientific borehole in central Sweden. • Preliminary streaming potential testing was conducted in collaboration with Korean Atomic Energy Research Institute (KAERI). • A packer test was initiated with KAERI but not further pursued.	
R&D Needed	Continue development and demonstration of geophysical techniques for site characterization. One particular area to look into is the possibility of using acoustic wave to characterize fractures in a DRZ. Use boreholes as analog for characterizing DRZ. Develop methodology for transferring field observations to better DFN model. DFN distributions include only flowing probability distributions? DFN is directly calibrated to include observed flowing fractures?	
C-06	*Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D*	M-H
Desc	• In crystalline rock, low ionic strength fluids erode engineered barrier (e.g. glaciation) relevant to sites where future glaciation is expected or other process causes big change in infiltration. This process is also directly linked to colloid generation and transport.	
Type	PM	
Codes	PFLOTRAN?	
Elements	SC Element 3.3.1c, 4.2	
ISC	High	
Rationale	ever vs. never (for site w/ potential glaciation)	
SAL	4 Improved Representation	
Rationale	This FEP is not really relevant to generic repository performance, as it relates to the site specific possibility that significant increases in infiltration caused by retreating glaciers could physically erode the EBS and/backfill. Unless the U.S. program considers siting a repository in a glaciated area, this FEP will be screened out. SKB and Posiva did experimental work on buffer erosion, modeling work to determine what it takes to get	

ID (*gap)	Activity	2019 Score
	low ionic strength water to depth.	
R&&D Needed	If the repository program considers potential sites in glaciated areas, site specific studies to assess the potential changes in infiltration flux associated with climate change would be necessary. Development of mechanistic model for buffer erosion for inclusion in PA?	
C-07	*Colloids in Fractures and Matrix*	M
Desc	• See also Grimsel task (I-1) Combine I-1 with this one? This task will focus on two key aspects of the CFT: (1) colloid particle formation and transport in porous geologic media and (2) radionuclide partitioning among pore water, colloid particles, and stationary substrates. Particle size dependent colloid transport and radionuclide uptake.	
Type	LT, PM, PA	
Codes	N/A	
Elements	SC Elements 3.3.2b (Post-Closure Basis)	
ISC	Medium	
Rationale	SKB and YM suggest that generally too few colloids to have big impact on transport. (Stability constraints on keeping them in suspension. Reversible sorption allows rn to hop off into matrix.)	
SAL	4 Improved Representation	
Rationale	Significant work has been done in the past few years, including analysis and modeling of colloid facilitated transport in field scale tests at the Grimsel Test Site in Switzerland, supplemented by laboratory testing and analysis to assess the effects of colloid aging on colloid-facilitated transport of 137Cs through crushed analcime columns.	
R&&D Needed	Continue to improve models to simulate colloid transport, and improve techniques for in situ characterization and quantification of colloids. Leverage information from NAGRA working group on colloids. Need to better understand colloid formation from clay materials, and address uncertainties related to sorption/desorption (attachment/detachment) and colloid instability in high ionic strength environments. Need to reduce uncertainty in infiltration, improve representation of heterogeneous behavior of colloids, colloid transport behavior in unsaturated environments, multiple rate kinetics and irreversibility of radionuclide sorption onto colloids, and better	
C-08	*Interaction of Buffer w/ Crystalline Rock*	M-H
Desc	• Chemical interactions, effect on buffer stability, related to buffer erosion, colloid generation and transport, buffer materials by designIntegrate colloid experimental work with DFN modeling Tie in to heater tests at Grimsel and hotBENT. Longer thermal pulse associated with DPCs requires examination of processes at temperature and in the presence of canister breaching/radiologic source term.	
Type	EA, PM	
Codes	DFN, PFLOTRAN, TOUGH/FLAC3D	
Elements	SC Element 3.3.1c, 3.3.2b, 4.2	
ISC	High	
Rationale	Safety case relies on buffer performance, particularly (lack of) buffer erosion and (low) buffer permeability.	

ID (*gap)	Activity	2019 Score
SAL	4 Improved Representation	
Rationale	Initial models analyzing coupled THC processes have been developed based on field tests performed at the LTDE-SD test at the Äspö HRL in Sweden, the REPRO project at Onkalo URL in Finland, and FEBEX at the Grimsel Test Site in Switzerland. In addition, LBNL scientists recently completely modeling to determine the extent of coupled geochemical alterations expected in the proposed HotBENT experiment (Zheng et al. 2018a). However, much work remains to develop fully validated models, especially at T > 100°. Longer thermal pulse and concomitant canister breaching of DPCs requires examination of RN interaction during hydrothermal buffer and rock alteration.	
R&&D Needed	DOE's continued participation in multinational programs analyzing potential repositories in crystalline rocks are an excellent and very cost effective way to developed improved, validated THMC models that could be directly applicable to the US program. As an example, HotBENT could provide highly relevant experimental validation of important repository processes at high temperature. Substantial cost savings would be achieved in the design of a repository if HotBENT demonstrates that the maximum temperature of bentonite backfill can be raised without drastic performance implications.	
C-09	*Development of a centralized technical database for crystalline disposal system evaluation*	M
Desc	The data to be collected will include thermodynamic data for radionuclide speciation and sorption, groundwater chemistry, hydraulic and mechanical property data, mineralogical and compositional data of representative host and far-field media, spatial distributions of potential host formations, etc. To support site screening and selection, there is a need to develop tools for spatial data analysis and visualization (e.g., a geographic information system). O-2, O-4 cross cut to GFM and to thermodynamic database	
Type	PA/PM/L	
Codes	ARC-GIS, SUPERCRIT.	
Elements	SC Element 4.2	
ISC	Medium	
Rationale	It is important to use a consistent set of properties data across all the activities for improved defensibility.	
SAL	3 Improved Defensibility	
Rationale	• Representative site characterization data were collected for a generic repository in crystalline rocks. The data include the distribution of crystalline rocks, fracture distributions, water chemistry, rock compositions, sorption data (Kd values), etc. • A significant portion of thermodynamic data was collected. • Regional geologic data have been collected and managed using a geographic information system. • A relationship with NEA thermodynamic database development was established.	
R&&D Needed	A data management plan was developed but not implemented. Actual implementation of the central database is needed. This development effort may be coordinated with Frank Perry's work and LANL GFM work package.	
C-10 *	*Collate data from International URLs*	M
Desc	Identify and collate potential data sets from URLs that support/inform the crystalline	

ID (*gap)	Activity	2019 Score
	reference case and/or development of process models, includinggroundwater chemistry, rock mineralogy, associated radionuclide retardation parameters, fracture distribution, flow in fractures, groundwater residence times (pores, fractures)site testing data (e.g. tracer tests) for model validation. Formulate a strategy for domestic URL develoment. crosscut to O-2, O-4, and tie-in to C-9.	
Type	L, EA, MA, FT, PM, PA	
Codes	N/A	
Elements	SC Element 4.2	
ISC	Medium	
Rationale	These data are needed to parameterize the reference model.	
SAL	3 Improved Defensibility	
Rationale	Through international collaborations, site characterization data have been collected from Korean Underground Research Tunnel (KURT), Czech Bedrichov Tunnel, Japanese Mizunami site, and Swedish underground facility.	
R&&D Needed	Continue site characterization data collection through international collaborations and make fully use of the data for modeling development and validation.	
C-11 *	*Investigation of fluid flow and transport in low permeability media (clay materials).*	M-H
Desc	Understanding water movement in such media is crucial for the performance assessment of a waste isolation system. It was recently discovered that fluid flow and chemical diffusion in low-permeability media may not follow traditional linear laws such as Darcy's law and Fick's law. This task will systematically study water flow regimes and their transport behaviors in clay formations as a function of clay formation texture and pore geometry.	
Type	PM/PA	
Codes		
Elements	SC Element 4.2	
ISC	High	
Rationale	The underlying processes are not fully understood	
SAL	4 Improved Representation	
Rationale	• Model was developed for gas migration in a water saturated compacted clay material, using the gas injection data obtained from the British Geological Survey. Both data and model analysis show that gas migration in such media exhibits rich nonlinear dynamics. • Non-Darcian flow model in clay formations was formulated. • Using small-angle neutron scattering techniques to characterize pore structure and water movement in clay was explored.	
R&&D Needed	• Refine the existing model to better match experimental data. • Understand a potential thermal effect on Non-Darcian flow.	
C-12 *	*Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock*	M
Desc	• Coupling of radionuclide transport with evolving water chemistry along a transport pathway (e.g. alkaline plumes). This is a modeling project for which the tools already	

ID (*gap)	Activity	2019 Score
	exist. Developing flexible modeling tools for simulating radionuclide sorption/desorption behavior for GDSA. • Robustness of numerical algorithms for coupling chemical reactions with solute transport - Gibbs free energy minimization may be more robust than equilibrium constants. • C-2 Explicit consideration of structural complexity of the media in the solute transport	
Type	PM	
Codes		
Elements	SC Elements 4.2, 4.3 (modeling validation using field data from URLs will increase	
ISC	Medium	
Rationale	Site data for model validation and uncertainty quantification are still scarce, and Systematically model validation is still missing	
SAL	4 Improved Representation	
Rationale	• The module for calculating radionuclide decay and ingrowth was added to PFLOTRAN. • Fluid flow and tracer transport at Bedrichov Tunnel (Czech Republic) and Mizunami site (Japan) were simulated and modeling simulations were compared with field	
R&&D Needed	• Future work may include additional chemical processes other than a simple Kd-based sorption-desorption process. • A future model should also consider the of multiple scale heterogeneities and more robust uncertainty quantification.	
C-13 *	*Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport*	M-H
Desc	This task will develop modeling capabilities to capture the effects of the spatial heterogeneity (e.g., Kd values) on radionuclide transport in natural systems. The work will include two parts: the modeling capabilities for realistic representation of spatial heterogeneity and the experimental technique for quantification of this heterogeneity. The work will significantly reduce both the predicted total radionuclide release from a repository and the associated uncertainty through improved performance prediction of the natural barrier system. • Improved representation of spatial heterogeneity of chemical and transport properties. Development of spatial correlation fields for things like Kd or for spatial heterogeneity in water chemistry and mineralogy and its relationship to Kd variability (via surface complexation/ion exchange). This task will systematically evaluate the existing techniques for upscaling key hydrologic and geochemical parameters, identify the gaps in upscaling, and develop new methodologies for bridging the identified gaps. The parameters of interest include matrix diffusion coefficients, sorption coefficient, chemical reaction kinetics, etc. The laboratory and field experiments of various scales will be explored for conceptual model development and validation.	
Type	PM/PA	
Codes		
Elements	SC Element 4.2	
ISC	High	
Rationale	Significantly predicted peak dose.	
SAL	4 Improved Representation	
Rationale	• Using the DFN model, dispersion and mixing within three-dimensional fracture networks were simulated. The result shows that, as hydraulic heterogeneity increased,	

ID (*gap)	Activity	2019 Score
	both longitudinal and traverse dispersion increases; the less mechanical dispersion observed in the structured network appears to be linked to the higher levels of connectivity than in the poorly connected random network; for moderate levels of hydraulic heterogeneity, fracture network structure is the principal control on transport times and dispersion within fracture networks. • The effect of spatial heterogeneity in Kd was evaluated, showing the effect is significant.	
R&&D Needed	• Future DFN simulations need to be performed on more realistic fracture networks. • Incorporate the effect of spatial heterogeneity in Kd into the GDSA model.	
C-14 *	*Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach*	M-H
Desc	As they move through the engineered barrier system and the natural system, radionuclides released from the engineered barrier will experience a complex set of physical and chemical interactions with the materials. Existing models generally assume that radionuclide retention in the natural system could be described with a linear, equilibrium Kd approach. The reality may be much more complex. Incorporation of interfacial reactions would be a much more flexible approach for GDSA as it allows for rational variation of retardation parameters based on a range of potential geochemical	
Type Codes	LT, PM/PA	
Elements	SC Element 4.2	
ISC Rationale	High The underlying processes are not fully understood	
SAL Rationale	4 Improved Representation • The effect of bentonite heating on U(VI) adsorption was investigated using bentonite samples from the FEBEX in situ experiment. The adsorption seems to decrease with the heating but the actual mechanism is not clear. • A new surface complexation model (SCM) was developed for U(VI) adsorption onto clay materials. The model specifically accounts for the 'spillover' of the electrostatic surface potential of basal cation exchange sites on the surface potential of neighboring edge sites. • Short-term (< 35 days) study of uranium sorption and diffusion in bentonite was conducted. The results indicate a relevance of so-called anion exclusion effects, the full or partial exclusion of anionic U(VI) solution species from clay interlayer spaces. • Long-term (6 years) study of uranium diffusion in bentonite was conducted. The Kd values obtained from the long-term experiment is one order of magnitude lower than those from batch sorption measurements. The apparent U(VI) diffusion coefficient determined from the long-term experiment is about two orders lower than obtained from short-term experiments, which may be attributed to a reduction of clay porosity. • A study of Pu sorption and desorption in bentonite was performed. The result suggests the importance of montmorillonite phases in controlling Pu sorption/desorption reactions on FEBEX bentonite. • Molecular and crystallographic behaviors of Pu associated with ferrihydrite and goethite iron oxide phases were also investigated. It was shown that the timing of Pu release and ferrihydrite corrosion product formation could lead to differences in Pu association: formation of PuO_2 versus coprecipitated Pu. • An analysis was performed to examine the consistency of macroscopic measurements, electrical double layer (EDL)-based models, and molecular-scale simulations of clay	

ID (*gap)	Activity	2019 Score
	media for adsorption and diffusion of trace levels of calcium (Ca2+), bromide (Br-), and tritiated water (HTO) in a loosely compacted, water-saturated Na-montmorillonite. • The concept of the control of nanopore confinement on radionuclide interaction with compacted clay materials was explored and applied to iodide sorption. The work shows	
R&&D Needed	• Further mechanistically understand a potential effect of heating on radionuclide adsorption on bentonite materials. • Better understand radionuclide interaction with clays and metal corrosion products, especially irreversible sorption and desorption processes. Radionuclide interaction with evolving engineered barrier system components (e.g. secondary mineral formation and EBS mineral alteration) will be exacerbated in thermal conditions associated with direct disposal of DPCs. • Test the model for other radionuclides. Incorporation of interfacial reactions would be a much more flexible approach for GDSA as it allows for rational variation of retardation parameters based on a range of potential geochemical conditions. conditions. that iodide can potentially interact with interlayer sites of a clay material.	
C-15 *	*Design improved backfill and seal materials*	H
Desc	This effort will focus on designing new buffer/backfill and seal materials for effective isolation of waste in a repository. The new design will fully take into account the capabilities of the materials as a hydrologic barrier (low permeability to a fluid flow) and a reactive barrier (high radionuclide sorption capacity). It will also consider the availability of the materials and their compatibility with repository environments. DPCs may require buffer materials engineered for high thermal conductivity. Relax thermal limit for buffer materials. This task will systematically examine the technical basis for the thermal limits of various disposal media (i.e., the maximum wall temperature allowed). Minimize erosion and colloid generation. Ensure self-sealing properties.	
Type Codes	LT	
Elements	SC Element 4.2	
ISC	High	
Rationale	Significantly impact on EBS design and performance.	
SAL Rationale	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both • The work on the development of next generation buffer materials was initiated and significant progress has been made. The work shows that the performance of the existing bentonite-based materials can be much improved using a material engineering technique. A technical advance is to be filed. • A thermal-hydrological-mechanical-chemical model was developed and applied to the analysis of coupled EBS processes in bentonite-backfilled repositories.	
R&&D Needed	• Continuing progress in materials science and technology opens new opportunities for buffer material design and improvement. • Development a subsystem model that can be used to evaluate the effectiveness of new buffer materials for waste isolation.	
C-16 *	*Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal*	H
Desc	Waste packages are an important layer of an engineered system for waste isolation,	

ID (*gap)	Activity	2019 Score
	especially for a repository in fractured crystalline rocks. This effort will include two parts: (1) new materials (e.g. coatings) and new concepts for waste package design and (2) improved models for predicting the long-term performance of waste packages in a crystalline repository. One aspect to be examined is the potential interactions of waste packages with buffer materials in the EBS. Cross cut to EBS (E-4).	
Type	LT, EA, PM, PA	
Codes		
Elements	SC Element 4.2	
ISC	High	
Rationale	These process models yet need to be developed and incorporated in GDSA.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Electrochemical test was initiated to measure the corrosion rates of metallic packaging materials.	
R&&D Needed	• Continue development of a waste package degradation model. • Incorporate the model into a GDSA model.	
C-17 *	*Model DFN evolution due to changes in stress field*	M-H
Desc	Fracture apertures and therefore the permeability of a fracture network change due to changes in stress field, which can be caused by excavation, waste emplacement, or glaciation/deglaciation.	
Type	PM, FT	
Codes		
Elements	SC Element 4.2	
ISC	High	
Rationale	Perhaps an important process to be accounted for glaciation effect on flow field.	
SAL	4 Improved Representation	
Rationale	Some work has been done internationally on DECOVALEX but has not been incorporated in SFWST DFN work.	
R&&D Needed	Incorporate the stress effect into the existing DFN model and study the effect on DRZ evolution and the impact of glaciation. Increased heating from DPC could also impact the local stress regime.	
D-01	*Probabilistic post-closure DPC criticality consequence analyses* *Task 1 - Scoping Phase* *Task 2 - Preliminary Analysis Phase* *Task 3 - Development Phase*	H
Desc	• Develop technical and regulatory strategy for low consequence analyses. Develop source term representing effects from criticality events, using coupled process modeling input. Identify appropriate criticality FEPs. Define key parameters and metrics.	
Type	PM, PA	
Codes	PFLOTRAN, other codes and scripts as applicable	
Elements	SC element 3.3.1, 3.3.2, 4.2b	
ISC	High	
Rationale	Consequence screening is a new approach, never attempted in an US or international	

ID (*gap)	Activity	2019 Score
	repository R&D program	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Criticality scenario development with source term and near-field changes specific to different types of criticality events, is needed to evaluate consequence screening. Contributing activities will coupled nuclear dynamics and thermal hydraulics. Other activities will contribute effects from mechanical/hydrologic/chemical/radiolytic changes in fuel/basket/canister performance. Regulatory strategy will be evaluated from system-level results.	
R&&D Needed	Development of generic models to represent repository performance with criticality events. Development of contributing process-level models for N-TH coupling, fuel/basket/envelope degradation, etc. that can be abstracted for PA. Development of technical and regulatory insights that can support recommendations for consequence	
D-02	*Maintain and populate DPC as-loaded database*	M
Desc	• Maintain UNF-ST&DARDS database; analyze baseline post-closure criticality responses	
Type	L, MA	
Codes	UNF-ST&DRDS Database; SCALE; etc.	
Elements	NA	
ISC	High	
Rationale	Compilation of SNF and DPC data is essential to managing disposal options.	
SAL	3 Improved Defensibility	
Rationale	Important data gathering activity for managing CSNF.	
R&&D Needed	Compilation of fuel characteristics (type, burnup profiles, etc.) and canister data (basket design, fuel loading schema, etc.) for all DPCs. Analysis (and re-analysis) of reactivity for stylized degradation cases, and for disposal environments (e.g., natural groundwaters, chloride brines).	
D-03	*DPC filler and neutron absorber degradation testing and analysis*	H
Desc	• Identify potential filler compositions, and test relevant behavior (injectability, radiolysis, material interactions, leachability). Follow the FY18 workplan (SFWD-SFWST-2018-000481) with appropriate modifications to focus on promising fillers. Test Boral and other absorber materials to check boron loss, and threshold humidity/temperature corrosion for filler interaction studies.	
Type	L, LT, MA	
Codes	Various	
Elements	SC elements 3.3.1, 3.3.2, 4.1, 4.2	
ISC	High	
Rationale	Preclude criticality Potential significant impact on EBS and near-field environment (argillite, crystalline) Retard transport of radionuclide (RNs)Potential changes to the wasteform	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Literature research and consultation with cement experts in FY18 identified several potentially effective filler materials including aqueous cement slurries, and molten metals, alloys, and low-temperature glasses. Fillers investigations are planned to continue in FY19, including initial mixing and handling. Screening of metals/alloys/glasses	

ID (*gap)	Activity	2019 Score
	for testing will be an important future step.	
R&&D Needed	Identify and test fillers for moderator displacement and neutron absorption in breached waste packages. Investigate durability in the disposal environment. Demonstrate injection of fillers into DPC fuel/basket geometry.	
D-04	*Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.*	H
Desc	• Analyze conditions inside and outside waste packages subjected to criticality events. Implement coupling between neutronics and thermal-hydraulics, and between corrosive/mechanical degradation and thermal-hydraulics and neutronics. Incorporate conditions external to waste packages (saturated and unsaturated repositories). Evaluate how more processes (e.g., chemical, radiolysis, aqueous transport), and disruptive events (seismic) can be incorporated in the modeling framework.	
Type	L, EA, PM	
Codes	Existing software (e.g., TOUGH-FLAC, FLAC3D-3DEC-PFC-TOUGH3, ORNL neutronics and CFD codes, others as applicable	
Elements	SC element 3.3.1, 3.3.2, 4.2e	
ISC	High	
Rationale	Process-level simulation of key parts of the criticality issue, including event dynamics, degradation, in-package and ex-package interaction	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Preliminary generic models have been demonstrated, but fidelity and validation are needed for all potential disposal host media and EBS concepts	
R&&D Needed	Support risk model with additional processes and couplings, and site-specific simulations: Multi-process, integrated, validated (within funding constraints) Modeling focus is on degradation of fuel configuration, especially basket degradation, and eventual re-configuration to a state that is subcritical.Defensible models of degradation (default state is undegraded fuel and basket configuration). Data for burnup credit assessment	
D-05	*Source term development with and without criticality*	H
Desc	Simulate fuel, basket and waste package envelope degradation (canister and overpack). Include degradation modes for cladding, unzipping, UO2 alteration/dissolution, basket corrosion and collapse, and canister/overpack breach evolution. Include interaction (heat, mass) with the near-field.	
Type	L, LT, EA, PM, PA	
Codes	GWB, PFLOTRAN, other codes as applicable	
Elements	SC element 3.3.1, 3.3.2, 4.2e	
ISC	High	
Rationale	Process-level simulation of source term behavior, and changes due to criticality events, which is the principal effect from criticality events in a repository.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Source term changes are the principal effect from criticality events, on repository performance. All previous models of waste form and in-package degradation have made assumptions and simplifications that are "conservative" wrt waste isolation, but are non-	

ID (*gap)	Activity	2019 Score
	conservative wrt the potential for criticality. A new generation of source term models is therefore needed to compare repository performance with/without the occurrence of criticality events.	
R&&D Needed	Support risk model with additional processes and couplings, and site-specific simulations: Modeling focus is on temperature and chemical environment dependent degradation of	
D-06	*Technical integration of DPC direct disposal*	L
Desc	Technical integration of DPC direct disposal solutions, considering concepts of operations, overpack concepts, engineering feasibility, cost analysis, and preclosure safety. Conduct periodic independent peer reviews.	
Type	NA (engineering review)	
Codes	NA	
Elements	SC Element 4.3e	
ISC Rationale		
SAL	2 Improved Confidence	
Rationale	Rely on literature and first-principles description of disposal solutions. Use engineering analysis.	
R&&D Needed	NA	
E-01	*SNF Degradation(& FMDM)*	M
Desc	• Implementation of FMDM (and/or other models) for spent fuel matrix degradation (including possible effect of Fe corrosion) • Radiolysis • Thermodynamics & stability of UO2 degradation phases (dehyd. schoepite, studtite, metastudtite) • Alternate electrochemical modeling for UO2 degradation	
Type	PM, MA, EA, PA	
Codes	PFLOTRAN/FMDM, VASP (DFT calcs) Zuzax/Cantera	
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures) - Note this source term model/testing is more important in crystalline case --SKB PA is sensitive to fuel degradation rate (particularly if they included high end under oxidizing conditions); less important in case of Salt concept AND NOT directly applicable in brine conditions	
SAL	3 Improved Defensibility	
Rationale	The parameter database for the FMD model was updated based on comparisons between model results and existing spent fuel and UO2 dissolution rate data. Electrochemical tests are in progress to support implementation of an improved steel passivation model in the FMD model by providing datasets with which the model can be calibrated for metals that will be present in the repository EBS and key environmental variables. Results from scoping experiments demonstrated a straightforward electrochemical	

ID (*gap)	Activity	2019 Score
	method that provides the electrokinetic information needed for model parameterization and validation. Model simulations using the FMDM V.4 agree with previous FMD model results showing the presence of metals that corrode at different rates can extend the time over which H2	
R&&D Needed	Continue work on FMDM model development and code optimization. Cross-reference with EBS/International From Roadmap: U.S. program evaluated the long-term behavior of LWR UOX in oxidizing environments. Other programs have evaluated and are modeling the degradation of UOX and MOX in reducing environments. Little information is available regarding the degradation/alteration of other UNF types. Model limitations: very high temperatures (> ~100C?), oxidizing conditions (?), solution compositional component variations complexation equilibria effects -many of these areas may be needed for DPC work	
E-02	*SNF Degradation testing activities*	M-H
Desc	• Degradation testing and integration of testing results into mixed potential model of spent fuel matrix degradation • Electrochemical experiments • SNF test plan development	
Type	L, EA, LT	
Codes		
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)- 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	Large uncertainties on alteration mechanisms and degradation rates under a wide range of conditions. Significant amount of SNF testing has been done.	
R&&D Needed	Work should address initially the delayed validation testing of the epsilon phase role in this process (cathodic and/or catalytic); potential gap is testing for surface area "obstruction"(long term effects)- need to assess testing results from literature to see if needed data exist for validation and/or plan for data collection.	
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	

ID (*gap)	Activity	2019 Score
	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.	
E-04 *	*Waste Package Degradation Model(mechanistic)*	M-H
Desc	• Degradation of waste packages and canisters • Degradation of WP internals • Carbon steel; stainless steel; copper waste packages • Should be tied to specific design concept (i.e., reference case) DPC - degradation of internals affects criticality	
Type	L, EA, MA, PA	
Codes	PFLOTRAN et al.	
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures) - Note this source term model/testing is more important in crystalline case--SKB PA is sensitive to fuel degradation rate (particularly if they included high end under oxidizing conditions); less important in case of Salt concept AND NOT directly applicable in brine conditions	
SAL	4 Improved Representation	
Rationale	Large international R&D on canister materials; also work done for preclosure corrosion on storage containers; Finland, SKB and YM developed defensible models for WP	
R&&D Needed	Key issues on mechanistic representation of corrosion at elevated temperatures and repository-relevant environmental solutions; Implementation of coupled waste package degradation processes in PA.	
E-05	*Corrosion Products - incorporation of radionuclides*	M
Desc	• Incorporation of radionuclides in corrosion products. Dependent on waste package	
Type	LT	
Codes		
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures);	

ID (*gap)	Activity	2019 Score
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	In FY18, molecular and crystallographic behaviors of Pu associated with ferrihydrite and goethite iron oxide phases were investigated. It was shown that the timing of Pu release and ferrihydrite corrosion product formation could lead to differences in Pu association: formation of PuO2 versus coprecipitated Pu. Alteration of amorphous ferrihydrite to a more crystalline goethite phase would retain Pu association with the solid phase. However, the nature of Pu association would be affected by the characteristics of Pu associated with the precursor ferrihydrite. The molecular nature of Pu association with iron oxide phases affects the leaching behavior of Pu. EXAFS and TEM data confirm that in Pu association with goethite as a surface precipitate is more labile than the coprecipitate. This has implications to the long-term stability of Pu associated with	
R&&D Needed	One of the key parameters controlling radionuclide release from the near field. In addition to physical processes, need to look at time-dependent changes in flow path due to mechanical processes. R&D issues are captured in FEP 2.2.01.01. Expand RN species to PA-relevant impact to the safety case	
E-06	*Waste Package Degradation Testing*	M-H
Desc	• Testing and experimental data for corrosion of carbon steel, stainless steel, and other potential waste package materials; borated stainless, aluminum,	
Type	LT	
Codes	N/A	
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)- Note this source term model/testing is more important in crystalline case; less important	
SAL	4 Improved Representation	
Rationale	Large international R&D on canister materials 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 periods. Interest in gas generation resulting from corrosion in some programs (Europe). Little information known about novel alloys with increased resistance to corrosion. Our experimental program for FY18 aims to 1) characterize how IEBS components (steel, Grimsel Granodiorite wall rock) react and change in the presence of Wyoming bentonite and 2) capture steel corrosion rates and interface mineralogy at reasonable high temperature (up to 250 °C, 150 bar) in-situ repository conditions. This chapter focused on the EBS Grimsel Granodiorite wall rock experiments IEBS-1 and IEBS-2. The following data on these samples have been acquired: 1) SEM images, 2) XRD (QXRD and clay determination) analyses, 3) electron microprobe data for major mineral phases, and 4) aqueous geochemistry data from both starting materials and the two experiments conducted to date.	
R&&D Needed	Key issues on mechanistic representation of corrosion at elevated temperatures and repository-relevant environmental solutions. NOTE that for NEW materials this SAL is a 5 (Crystalline); Initial focus should implement models from international literature on materials	

ID (*gap)	Activity	2019 Score
	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. High importance for overall confidence - primary isolation barrier. Medium importance	
E-07 *	*Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment*	M
Desc	• Testing and experimental data for corrosion of carbon steel, stainless steel, and other potential waste package materials in a salt repository. Mechanical damage from rock fall and drift collapse	
Type Codes	LT, FT N/A	
Elements	SC element 3.3.1, 4.2	
ISC Rationale	Medium	
SAL	4 Improved Representation	
Rationale	Some knowledge gaps exist regarding degradation modes for various alloys under various pre-closure conditions. Uncertainty in extrapolating short-term laboratory tests to long-time periods. Interest in gas generation resulting from corrosion in some programs (Europe). Pre-closure waste package containment issues are secondary, but the impacts of the waste package on the chemical and hydrological environment may have long-term performance impacts that need to be considered (see S-10 -- drift resaturation)	
R&&D Needed	Engineering evaluation needs to be conducted. Investigate the impacts of run-of-mine salt reconsolidation on waste packages.	
E-08	*Radionuclide Interaction w/ Buffer Materials*	M
Desc	• Sorption, diffusion, colloids, … smart Kds. Evolution with time?	
Type Codes	LT	
Elements	SC element 3.3.1, 4.2	
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; Q41; for Crystalline (3) as safety function of buffer is more related to protecting waste package and preventing advection.	
SAL	3 Improved Defensibility	
Rationale	A series of experiments were designed to test the effect of bentonite heating on U(VI) adsorption. U(VI) adsorption onto bentonite samples from the FEBEX in situ experiment, which were subjected to 18 years of heating at temperatures of 50-100 C, was compared to adsorption onto cold-zone FEBEX bentonite from the in situ experiment. The results from this study provide key information necessary for performance assessment of HLW disposal scenarios. The decreased adsorption observed in this study as a result of bentonite heating may impact the diffusion of U(VI) through engineered clay barriers. Because the decreased U(VI) adsorption was due to changes in the clay	

ID (*gap)	Activity	2019 Score
	mineral structure and not to aqueous U(VI) speciation, other radionuclides may be	
R&&D Needed	Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill. Crystalline gives this a Med (3) for the stated rationale.	
E-09	*Cement plug/liner degradation*	H
Desc	• Physical and chemical effects	
Type	PM	
Codes	PFLOTRAN	
Elements	SC element 3.3.1, 4.2	
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	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	• Important to seals / barrier chemical alteration This activity will entail thermodynamic modeling of waste package degradation to assess clay-metal-cement interactions and alteration of these materials. These efforts are key to the evaluation of thermal limits in a repository through characterization of barrier alteration products such as zeolite/clay transformations, and mineral/oxides growth at the metal interface. This also includes investigating the potential effects of mineral surface growth on metal interfaces.	
R&&D Needed	Methods for characterizing groundwater chemistry and models to predict water chemistry evolution in the near field need to be further improved. Need to define a generic chemistry for each geologic environment. Need to identify interactions with EBS materials (e.g., introduced fluids, alkaline plume from the near field). R&D to determine potential for identification of favorable and/or unfavorable	
E-10	*High-Temperature Behavior*	M-H
Desc	• Ability to apply PA model at temperatures up to 200C. (incorporate Hi temp experimental data) GDSA integration	
Type	PA, PM, EA, MA	
Codes	PFLOTRAN, CHNOSZ et al.	
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures); Crystalline relies on the buffer as a diffusion barrier and as protection for the WP, so not	
SAL	4 Improved Representation	
Rationale	• Chemical processes still under development, particularly at elevated temperature conditions The coupled THMC model has been improved by implementing a more mechanistic constitutive relationship for C-M coupling (RExM).	

ID (*gap)	Activity	2019 Score
	The model has been calibrated based on the results of laboratory tests. Ongoing analyses are evaluating the effects on bentonite buffer for "high T" cases.	
R&&D Needed	Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill. Need to address multiple or longer thermal pulse case	
E-11	*EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.*	H
Desc	• Lab experiments including Grimsel host, WY bentonite, steel coupons, and Grimsel groundwater. Bentonite: wall rock = 80/20, Water: rock = 9/1, Temp=250C, P=150 bar. Solution sampled weekly for cations and anions. Resultant reaction products characterized by SEM, XRD, QXRD, EMPA, and Raman.	
Type	LT, EA	
Codes	Incorporate experimental/ literature data into PFLOTRAN, CHNOSZ et al.	
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures); Crystalline relies on the buffer as a diffusion barrier and as protection for the WP, i.e., no advective pathway is highly important; DPC will tend to drive the Temp higher, specifically in the local EBS	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	• Chemical processes still under development, particularly at elevated temperature conditions This work has focused on evaluating the results of high-temperature, high pressure experiments conducted at the Grimsel URL. The impact that host rock, i.e. Grimsel Granodiorite, will have on the bentonite barrier and the interactions between bentonite and steel EBS components are evaluated.	
R&&D Needed	Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill. R&D (e.g., FEBEX) needs to take more data during the cooldown period (resaturation and other property changes).	
E-12	*Buffer/backfill dry-out and resaturation process*	M
Desc	1)Drift scale modelling to elucidate buffer/backfill evolution and multi-phase transport during thermal period 2) micro CT Lab tests to understanding permeability evolution and fracture propagation/healing during bentonite dry-out and resaturation	
Type	PM, LT, EA	
Codes	PFLOTRAN, TOUGH	
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures);	

ID (*gap)	Activity	2019 Score
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	• Chemical processes still under development, particularly at elevated temperature conditions A preliminary numerical thermal analysis was performed for disposal of 12 PWR SNF waste packages in a generic repository in crystalline host rock. For the simulations the numerical code TOUGH3 was used. The study was designed to investigate thermal behaviors due to the disposal of SNF waste with higher thermal power and related vapor migration. Limited sensitivity analyses were also conducted that investigated the effects of buffer thermal conductivity and contributions of adjacent waste packages to thermal effects. The results of the base case simulations showed that very high peak temperatures can be expected with the disposal of SNF. Sensitivity analyses investigated parameters that	
R&&D Needed	Flow in the EDZ is closely tied to the evolution of the EDZ. R&D related to FEP 2.2.01.01	
E-13 *	*HLW WF degradation (process model)*	M
Desc	This activity is a cross campaign integration activity to implement a glass degradation model that includes representation of Stage III rates (transition trigger and rate values) within the glass degradation model representation in PFLOTRAN for GDSA	
Type	PM; PA	
Codes	PFLOTRAN et al.	
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Primarily inventory is smaller than SNF inventory so less important to SC	
SAL	3 Improved Defensibility	
Rationale	The reactivity of silicate glasses and minerals is important to numerous engineering applications including nuclear waste disposal. Silicate dissolution exhibits complex temporal evolution and rich pattern formations. Observed complexity could emerge from a simple self-organizational mechanism: dissolution of the silica framework in a material could be catalyzed by the cations released from the reaction itself. This mechanism enables us to systematically predict many key features of a silicate dissolution process. The same mechanism could also lead to morphological instability of an alteration front, which, in combination with oscillatory dissolution, could potentially lead to a whole suite of patterning phenomena.	
R&&D Needed	A number of glass degradation models are implemented in GDSA from SAR; German program; and other European programs. This model would provide an explicit model representation of transition to Stage 3 degradation (higher rates than stage 2, but not as high as stage 1)	
E-14 *	*In-Package Chemistry*	H
Desc	• Fully coupled in-package chemistry model, as it impacts degradation, mobilization, and transport inside the WP -- similar in scope to YM modeling • Effect of canister/internal corrosion products on waste form degradation • In-package radionuclide solubilities DPC - effect of criticality on chemistry and source term (feed back loop)temperature effect of criticality temperature effect of criticality; effects of fillers on IPC	
Type	PM, LT	

ID (*gap)	Activity	2019 Score
Codes	PFLOTRAN et al.	
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures); source degradation high importance to Crystalline--directly affects WF	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	In-package chemistry – Modeling, experimental validation, and integration of the (spent) fuel matrix degradation model (FMDM) with GDSA-PA. Continuing development, optimization, experiments, and integration of the FMDM to evaluate the influence of H2 on UO2 degradation rate. Extend electrochemical modeling of UO2 corrosion in an aqueous environment based on thermodynamic calculations to compute fluid-solid chemical equilibria. Crystalline indicated "4" here	
R&&D Needed	Cross-cutting to EBS & International Improved understanding of solubility controls and dissolved concentration limits would lead to improved radionuclide transport models and better understanding of disposal system performance. Large knowledge gaps on radionuclide solubilities at elevated temperatures and in concentrated electrolyte solutions. Accurate redox speciation chemistry of important radionuclides such as Pu and Np are still a matter of investigation.	
E-15 *	*Cladding Degradation*	M
Desc	• Cladding degradation processes (e.g., HC)	
Type	M, T(mainly M)	
Codes	PFLOTRAN?	
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale		
R&&D Needed	Major GAP for DPC work	
E-16 *	*In-Package Flow*	M
Desc	• Modeling of flow and transport inside waste packages/canisters • Evolution of corrosion products	
Type	M, T M, T	
Codes	PFLOTRAN (mainly M)	
Elements	SC element 3.3.1, 4.2	
ISC	Medium	
Rationale	Argillite waste isolation is less reliant on the source term (e.g., low influence of fractures)	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale		
R&&D		

ID (*gap)	Activity	2019 Score
Needed		
E-17 *	*Buffer Material by Design*	H
Desc	• Development of new generation buffer materials (thermal management, resistance to erosion, limitation of chemical gradients/interactions)	
Type		
Codes		
Elements	SC element 3.3.1, 4.2	
ISC	High	
Rationale		
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Novel/new Materials	
R&&D Needed		
E-18 *	*Unbackfilled-Drift Thermal Radiation Model*	L
Desc	• For DPC waste packages, omit backfill in order to keep WP surface temperature lower • Need be able to model the thermal radiation process in PFLOTRAN and other codes in an unbackfilled drift	
Type	PA	
Codes	PFLOTRAN	
Elements	SC element 3.3.1, 4.2	
ISC		
Rationale		
SAL	4 Improved Representation	
Rationale	SAR has some bases	
R&&D Needed	Gap for DPC work, but could start with work from SAR	
E-19 *	*Other SNF/HLW Types*	L
Desc	Note that in the OWL/WF Characteristics work some additional degradation models are being evaluated/constrained for HIP Calcine and for TRISO particle fuels -- these are less important from an inventory standpoint than CSNF	
Type	L, PM, PA	
Codes		
Elements		
ISC		
Rationale		
SAL		
Rationale		
R&&D Needed		
E-20	*colloid source terms*	M-H

ID (*gap)	Activity	2019 Score
Desc	•	
Type		
Codes		
Elements		
ISC	High	
Rationale		
SAL	4 Improved Representation	
Rationale	Models exist in other programs, but have not been included as yet into SFWD work	
R&&D Needed		
I-01	*Radionuclide transport as pseudocolloids,Grimsel*	M
Desc	• Rates of radionuclide desorption from mineral colloids; input to PA, depending on type of model used in PA including irreversible desorption	
Type	LT,FT	
Codes	N/A	
Elements	SC elements 3.3 (Post-Closure Basis) & 4.2 (Post-Closure Safety Assessment)	
ISC	Medium	
Rationale	Colloid transport is relevant but perhaps less so than other transport mechanisms.	
SAL	3 Improved Defensibility	
Rationale	Significant work has been done at GTS, and much has been learned in the past year. A synthesis report by Paul Reimus summarizes the current state if the art nicely. DOE is not anymore a funding partner of the CFM Project at GTS, our activities are now less focused on colloids. Some parts of the puzzle need further attention, in particular for	
R&&D Needed	Moderate additional efforts on bentonite colloids are suggested.	
I-02	*FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling*	M-H
Desc	• Thermal, hydrological, mechanical and chemical alteration of bentonite backfilled EBS • Validation of coupled THMC model and PA model • Supply GDSA with the porosity, permeability, swelling pressure evolution and clay mineral alteration over the course of hydration • Input from high temperature experimental data, including lack of illitisation - dependent on bulk chemistry	
Type	FT, PM, LT, EA	
Codes	TOUGHREACT-FLAC3D	
Elements	SC elements 3.3.1, 4.2, and 4.3	
ISC	High	
Rationale	Argillite waste isolation is less reliant on engineered barrier than crystalline.	
SAL	4 Improved Representation	
Rationale	Expect SAL Level of 3 within a few years, because all data from FEBEX is collected, and so focus is now mainly on modeling and analysis.	
R&&D	A few more years of analysis and modeling of the valuable and complex FEBEX-DP data	

ID (*gap)	Activity	2019 Score
Needed	set is important. Additional work needs to be done to validate models against observations. Since the FEBEX-DP project has officially ended, this will be don under the auspices of the SKB Task Forces and the DECOVALEX project. Focus will shift over to HotBENT soon.	
I-03	*FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test*	M-H
Desc	• Evaluate post-test state of FEBEX barrier clay and interactions at EBS interfaces • Effects of dryout and mineral dehydration on backfill/buffer • Characterization (compositional, mineralogical) of FEBEX-DP (heated) bentonite and interactions with cement barrier • Experimental investigations on U sorption & diffusion in FEBEX-DP bentonite	
Type	LT, FT, PM, EA	
Codes	N/A	
Elements	SC elements 3.3.1, 4.2, and 4.3	
ISC	High	
Rationale	Argillite waste isolation is less reliant on engineered barrier than crystalline.	
SAL	4 Improved Representation	
Rationale	Expect SAL Level of 3 within a few years, because all data from FEBEX is collected, and so focus is now mainly on modeling and analysis.	
R&&D Needed	Limited amount of additional experimental work is suggested, e.g., to measure transport properties of FEBEX materials. Focus will shift over to HotBENT soon.	
I-04	*Experiment of bentonite EBS under high temperature, HotBENT*	H
Desc	• Thermal limit of crystalline and argillite repository with bentonite EBS. • Hydrological, mechanical and chemical alteration of various types of bentonite that backfilled EBS under high temperature (200 °C) • Validation of coupled THMC model • Supply GDSA with the porosity, permeability, swelling pressure, vapor pressure evolution and clay mineral alteration under high temperature • LANL should have input from experimental work • Cross-fertilize with THC processes in EBS and thermodynamic DB development	
Type	LT, FT, PM	
Codes	TOUGHREACT-FLAC3D	
Elements	SC elements 3.3 (Post-Closure Basis) & 4.2 (Post-Closure Safety Assessment)	
ISC	High	
Rationale	Argillite waste isolation is less reliant on engineered barrier than crystalline.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	HotBENT tackles a temperature regime of up to 200 degrees in a full-scale field heater test. This type of testing has never been done before; therefor SAL = 5.	
R&&D Needed	HotBENT is just starting and will run for several years.	
I-05	*Mont Terri FE (Full-scale Emplacement) Experiment*	M
Desc	• Thermally driven THM evolution in both the EBS components and the host-rock	

ID (*gap)	Activity	2019 Score
	behavior in argillaceous formations • Resaturation and swelling of the protective buffer around the waste package • Validation of coupled THM model of bentonite and clay host rocks • Supply GDSA with flow properties (e.g. porosity and permeability) evolution in the buffer, excavation disturbed zone and host rock • Inform GDSA related to local flow created by coupled THM processes.	
Type	FT, PM	
Codes	TOUGH-FLAC	
Elements	SC elements 3.3 (Post-Closure Basis) & 4.2 (Post-Closure Safety Assessment)	
ISC	High	
Rationale	Full scale heater test experiments are key to post-closure & pre-closure safety assessment	
SAL	3 Improved Defensibility	
Rationale	The FE heat test is a full-scale long-term Demonstration experiment which will not produce new fundamental science findings but rather should demonstrate that the waste emplacement can be engineered and predicted. As such, the experiment is mostly for improved defensibility.	
R&&D Needed	This is a long-running experiment; I makes sense to continue comparing our modeling predictions with actual measurements from FE, a relatively little effort. Continue modeling studies of field data for V&V	
I-06	*Mont Terri FS Fault Slip Experiment*	H
Desc	• Pressure-induced potential for fault reactivation and development of pathways for RN transport • Driving force for pressure buildup could be thermal pressurization, long-term hydrogen generation, or distant earthquakes • Validation of coupled THM models for fault slip and permeability evolution • Could supply GDSA with transient flow properties for faults	
Type	FT, PM	
Codes	TOUGH-FLAC, 3DEC	
Elements	SC elements 3.3 (Post-Closure Basis) & 4.2 (Post-Closure Safety Assessment)	
ISC	High	
Rationale	Fault(s) present a preferential pathway for flow	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	This is about the possibility of transport pathways generated from seismic slip of fault going through repository. Not much is know about the relation between fault slip and permeability change.	
R&&D Needed	Need for further analysis of existing experiment and future focus on new FS-B follow-up experiment.	
I-07	*DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.*	M-H
Desc	• Thermally driven THM evolution in both the EBS components and the host-rock behavior in argillaceous formations • Resaturation and swelling of the protective buffer around the waste package	

ID (*gap)	Activity	2019 Score
	• Validation of coupled THM model of bentonite and clay host rocks • Supply GDSA with flow properties (e.g. porosity and permeability) evolution in the buffer, excavation disturbed zone and host rock • Inform GDSA related to local flow created by coupled THM processes.	
Type	FT, PM	
Codes	TOUGH-FLAC	
Elements	Technical Bases: 3.3.1, 3.3.2; 4.2 Post-Closure Safety Assessment4.3 Confidence enhancement	
ISC	High	
Rationale	Heater test experiment is key to demonstrate scalability of process models - post-closure & pre-closure safety assessment	
SAL	4 Improved Representation	
Rationale	Task E of the DECOVALEX-2019 project involves the evaluation of upscaling of THM properties and processes from laboratory experiments, via in situ experiments, to a full repository scale. We have made a good progress in modeling of two experiments with good agreement of addressing thermal pressurization.	
R&&D Needed	Task E of DECOVALEX will end December 2019. Lessons learned will be summarized and guidance should be helpful for PA studies, where upscaling to repository scale is	
I-08	*DECOVALEX-2019 Task A: Advective gas flow in bentonite*	H
Desc	• Pressure buildup and gas migration in bentonite (important topic for bentonite backfill)	
Type	FT, PM	
Codes	TOUGH-FLACTOUGH-RBSN	
Elements	SC elements 3.3 (Post-Closure Basis) & 4.2 (Post-Closure Safety Assessment)	
ISC	High	
Rationale	EBS more important for Crystalline than for Argillite	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Complex gas transport behavior through bentonite has been observed in lab studies. It is not clear to date which conceptual models should be used for gas predictions.	
R&&D Needed	Further studies are important. Next step should be modeling of asn international field experiment, perhaps LASGIT. See Activity I-19.	
I-09	*DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan*	M-H
Desc	• Geochemistry: Evaluate groundwater chemistry in a crystalline repository and the effect of repository construction • Utilize fracture data for validation of fracture models in crystalline rock • Evaluate reactive transport processes at the filled CTD & cement interactions	
Type	FT, PM	
Codes	PFLOTRAN, EQ3/6, DFN, FCM	
Elements	SC element 3.3.2, 4.24.3 Confidence enhancement	
ISC	High	
Rationale	Field-scale experiment is relevant to geochemical evaluation of cement interactions - Important for model validation	
SAL	4 Improved Representation	

ID (*gap)	Activity	2019 Score
Rationale	This resaturation field experiment is used in the campaign in different ways. The main one is that data from shotcrete liner interactions are helping constrain 3D reactive transport models. There is more work to be done on this general topic but the specific GREET activity is will be completed by end of 2019.	
R&&D Needed	Activity will be completed by end of calendar year 2019. Follow-up activities need to be planned.	
I-10	*SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL*	M
Desc	• RN Transport: Examine diffusion and sorption processes in both matrix rock and a typical conductive fracture identified in a pilot borehole • Conduct discrete fracture modeling to assess impact of micro-fractures on transport	
Type	FT, PM	
Codes	LAGRIT, PFLOTRAN	
Elements	SC element 3.3.2, 4.24.3 Confidence enhancement	
ISC	High	
Rationale	Matrix diffusion (or absence of) can have major impact on dose.	
SAL	2 Improved Confidence	
Rationale	Much has been learned about matrix diffusion and the specific experimental data have been well explained.	
R&&D Needed	DECOVALEX activity will be completed by end of calendar year 2019. A follow-up activity would be to engage in a DFN transport validation exercise that includes matrix diffusion among other transport processes. This may be done in Task 10 of the SLB Task Forces.	
I-11	*Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies*	M
Desc	• Gas Transport: Hydrogen generation can result in long-term damage to bentonite and clay host rock • Microbial activity can lead to hydrogen uptake and reduced risk of damage; however, the transient activity of microbes in heated and pressurized bentonite/rock is not well understood	
Type	FT, PM	
Codes	TBD	
Elements	SC element 3.3.1, 3.3.2, 4.2, 4.3 Confidence enhancement	
ISC	Medium	
Rationale	Not sure of impact so leaving it at medium for now. (Possible to compact bentonite to point where microbes can't grow - Mont Terri)	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	It is important to understand sinks and sources for corrosion by-products and potential pathways that alter the characteristics and performance of engineered barrier materials.	
R&&D Needed	Microbial processes can be relevant for corrosion by-products uptake which in turn is important for gas transport assessment. This R&D effort is just starting and needs to be better defined.	
I-12	*TH and THM Process in Salt: German-US Collaborations (WEIMOS)*	H

ID (*gap)	Activity	2019 Score

Desc • Model Comparison studies with Germany on TM Benchmarking (WEIMOS)

Type FT, PM

Codes Sierra Mechanics

Elements 3.3.1 (Post-Closure Bases)

ISC High

Rationale International collaboration is a confidence enhancing activity, and this activity also contributes to the technical basis.

SAL 5 Fundamental Gaps in Method or Fundamental Data Needs, or Both

Rationale Thermo-mechanical simulations are an essential component of salt repository science. An excavated drift filled with nuclear waste (or other hazardous waste) will creep closed over the course of a few decades. WEIMOS seeks to improve thermo-mechanical simulations of salt repositories through enhancing rock salt constitutive models and general simulation techniques. The scope of work includes calibration of rock salt constitutive models against laboratory experiments, and then benchmarking the models against underground experiments. This process helps identify deficiencies in both the constitutive model and the methods used to simulate the complex experiments. Note that during the workshop the TH portion of this activity was rated SAL 3 and the THM portion of this activity was rated SAL 5. The overall activity has been assigned SAL 5.

R&&D Needed This specific activity is ending but continued collaboration with US/German program is important, in particular for THM process understanding and modeling. New activities are starting on both sides, see I-15 and I-16.

I-13 *TH and THM Process in Salt: German-US Collaborations (BENVASIM)* H

Desc • Model Comparison studies with Germany on THM Model Comparison (BENVASIM)

Type PM

Codes TOUGH-FLAC

Elements 4.2c (Post-Closure Safety Assessment)

ISC High

Rationale International collaboration is a confidence enhancing activity, and this activity also contributes to the technical basis.

SAL 5 Fundamental Gaps in Method or Fundamental Data Needs, or Both

Rationale BenVaSim is an international project designed to perform benchmarking and validation of numerical simulators used for analysis of long-term coupled processes associated with nuclear waste disposal in salt. The benchmarking of coupled THM models is important because simulations performed by different research groups using different constitutive models, assumptions, and simulators, may show large discrepancies, thus potentially contributing to a significant model uncertainty. Note that during the workshop the TH portion of this activity was rated SAL 3 and the THM portion of this activity was rated SAL 5. The overall activity has been assigned SAL 5.

R&&D Needed This specific activity needs to continue since it addresses THM modeling uncertainties in salt. These processes are not well understood.

I-14 *TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)* M-H

Desc • Model Comparison studies with Germany on granular salt reconsolidation (KOMPASS)

ID (*gap)	Activity	2019 Score
Type	PM, LT	
Codes	Sierra Mechanics	
Elements	4.2c (Post-Closure Safety Assessment)	
ISC	High	
Rationale	International collaboration is a confidence enhancing activity, which strongly impacts long-term performance	
SAL	4 Improved Representation	
Rationale	Although significant work related to the performance of salt repositories has been completed at WIPP, and internationally (particularly in Germany), initial modeling studies that have been completed show complex dependency on experimental technique. These make the existing body of work uncertain and more data and improved constitutive laws are needed.	
R&&D Needed	Continue collaboration with US/German program.	
I-15	*TH and THM Process in Salt: German-US Collaborations (RANGER)*	M
Desc	• Model Comparison studies with Germany on THM simulations regarding shaft and drift seals for salt repositories	
Type	PM	
Codes		
Elements	4.2c (Post-Closure Safety Assessment)	
ISC	Medium	
Rationale	International collaboration is a confidence enhancing activity, which contributes to the technical basis	
SAL	4 Improved Representation	
Rationale	While seal system design has been well-studied, new and emerging computational techniques and/or constitutive models (coupled THMC models) can be used to gain more confidence in evaluation of seal performance. Additionally, design bases should be revisited for these engineered barriers, taking into account advances in barrier technology and design concepts. This collaboration will bring together the institutional expertise from the nuclear waste programs in both Germany and the US, and will also integrate the next generation of researchers into this important subject area.	
R&&D Needed	Continue collaboration with US/German program.	
I-16 *	*New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling*	H
Desc	Comparative modeling of Borehole Heater Tests at WIPP on Coupled Processes: (1) Brine availability, transport, and chemistry in bedded salt formation, (2) Changes in permeability, porosity, and borehole closure during test, (3) Compare heated/unheated tests, (4) Collect data to validate numerical/constitutive models	
Type		
Codes		
Elements		
ISC	High	
Rationale		

ID (*gap)	Activity	2019 Score
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale		
R&&D Needed		
I-17 *	*New Activity: DECOVALEX Task on GDSA, PA, SA, UQ*	M
Desc	Multi-year benchmarking exercise of geologic repository performance assessment (PA) models and software, including sensitivity analysis (SA) methods for analyzing the effect of input uncertainties on output uncertainty. This exercise may also include, depending on interest, a subtask devoted to uncertainty quantification (UQ) methods.	
Type		
Codes		
Elements		
ISC	High	
Rationale		
SAL	3 Improved Defensibility	
Rationale		
R&&D Needed		
I-18 *	*New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport*	H
Desc	LASGIT: large-scale in situ bentonite column experiment at Aspo HRL, with testing of gas migration at several times during hydration and post-hydration phase (natural follow-up from lab-scale current task)	
Type		
Codes		
Elements		
ISC	High	
Rationale		
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale		
R&&D Needed		
I-19 *	*New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing*	M
Desc	ANDRA's Thermal Fracturing Task: Planned heater test at Bure to look at potential for thermal fracturing at the mid-point between heated emplacement holes	
Type		
Codes		
Elements		
ISC	Medium	
Rationale		

ID (*gap)	Activity	2019 Score
SAL	4 Improved Representation	
Rationale		
R&&D Needed		
I-20 *	*New Activity: New Mont Terri Task: Gas Transport in Host Rock*	M
Desc	ENSI's GT Experiment: Evaluation of gas transport models and of the behavior of clay rocks under gas pressure (gas migration in host rock)	
Type		
Codes		
Elements		
ISC	Medium	
Rationale		
SAL	4 Improved Representation	
Rationale		
R&&D Needed		
I-21 *	*New Activity: SKB Task 10 Validation of DFN Modeling*	M-H
Desc	Details to be developed b y SKB and partners. Logical next step for DFN modeling of flow and transport.	
Type		
Codes		
Elements		
ISC	High	
Rationale		
SAL	4 Improved Representation	
Rationale	Adds validation at the field scale	
R&&D Needed		
O-01	*Complete and Populate Online Waste Library (OWL)SF-17SN01050101*	L
Desc	• Develop/update a listing and inventory of DOE-managed HLW and SNF radioactive wastes which were assessed in the disposal options evaluation work and identify any additional wastes and/or waste forms to be added/updated • The On-Line Waste Library will be constructed for information on DOE-managed HLW, SNF, and other wastes that are potential candidates for deep geologic disposal, with links to supporting documents	
Type	L, LT, PM	
Codes	Web Develop	
Elements	SC element 3.3.1a	
ISC		
Rationale		
SAL		

ID (*gap)	Activity	2019 Score
Rationale	• Inventory for source term The construction of the next stage development of the Online Waste Library (OWL) capabilities for generating turn-key inventory output for generic storage/transportation and/or disposal studies will be a focus of FY19. The OWL will be augmented to include data sets for available cans/canisters/packages, including dimensional characteristics (inner and outer), masses, certification for usage and for which wastes/waste forms, material properties as appropriate, etc.	
R&&D Needed	Inventories have been estimated for UNF and HLW generated from different recycling processes. Additional data is needed for other fuel cycle scenarios under consideration by FCT program	
O-02	*GDSA Geologic Modeling*	M-H
Desc	• geologic and hydrologic conceptual framework for GDSA reference cases • data feeds to GDSA models (hydrologic parameters, stratigraphy, fractures) • Confidence in demonstrating understanding of the geologic environment • GIS analysis of site selection options	
Type	L, PA	
Codes	Rockworks, JewelSuite, ArcGIS	
Elements	SC element 3.3.2	
ISC Rationale	High	
SAL	4 Improved Representation	
Rationale	Develop 3D geologic framework modeling capability to support repository reference cases for alternative geologic media. The geologic framework model (GFM) will provide an integrated tool for visualization of the geologic and hydrologic environment. The GFM will integrate many of the key geologic inputs to the GDSA reference case including hydrostratigraphy, faults and fractures, lithology, hydrologic properties, physical rock properties.	
R&&D Needed	Many site characterization methods have been developed for repository and other related programs (EM, carbon sequestration). More refined methods can be developed to define flow paths (discontinuities, heterogeneities, fracture connectivity, and uncertainty quantification).	
O-03	*Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling*	M-H
Desc	• Web visualization and user interaction with geologic data and modeling to support GDSA reference cases and the Regional Geology GIS Database. • Development of 2D and 3D spatial data and web applications. • Addition of Global Survey of Deep Underground Facilities web application.	
Type	L, PA	
Codes	ArcGIS, Javascript	
Elements	SC element 3.3.2	
ISC Rationale	High	
SAL	4 Improved Representation	

ID (*gap)	Activity	2019 Score
Rationale	Support web visualization and user interaction with geologic data and modeling for the Regional Geologic Framework GIS Database and Global Survey web map applications and will continue support for web visualization and user interaction. Provide a hydrostratigraphic framework and hydrologic properties (e.g., permeability, porosity, pressure gradient) to support numerical modeling. Work with GDSA team to parameterize inputs into transport models. This task will support GDSA and PA activities through development of appropriate information feeds. Develop conceptual models for other geologic media if project priorities change.	
R&&D Needed	Many site characterization methods have been developed for repository and other related programs (EM, carbon sequestration). More refined methods can be developed to define flow paths (discontinuities, heterogeneities, fracture connectivity, and uncertainty quantification).	
O-04	*Thermodynamic and sorption database(s)*	M
Desc	• Probably in PA. Baseline safety assessment • Thermodynamic, surface complexation/ion-exchange databases • Update of thermodynamic data for clays, zeolites, & oxy-hydroxides - Barrier degradation at high T's • EoS for H2O (Liquid, vapor) revisiting	
Type	L, LT, PM	
Codes	H2OI95 --> IAPWS-95 H2O EoS Fortran code implementation	
Elements	ISC = Medium (for clay/shale)SC element 3.3.1c, 3.3.2b	
ISC Rationale	Medium	
SAL	3 Improved Defensibility	
Rationale	In FY19, LLNL will continue and expand our efforts in the development of thermodynamic databases in support of the Spent Fuel and Waste and Science Technology (SFWST) program. Thermodynamic models provide the basis for understanding the stability of solid phases and speciation of aqueous species and modeling the evolution of repository conditions. This effort will be performed in coordination with other US database development efforts.	
R&&D Needed	• Updates to key thermodynamic data on barrier chemical components and stable alteration phase assemblages • Sorption data analysis • Update H2O EoS - Geochemical & flow/transport codes	
O-05	*QA, V&V (documentation and tests)*	L
Desc	• V&V, benchmarking, and documentation of codes, including pre- and post-processors	
Type	PM, PA	
Codes	All software	
Elements		
ISC Rationale		
SAL		
Rationale	The thermal analysis presents conduction-based thermal simulations for the emplacement of nuclear wastein a geological repository in bedded salt. Benchmark	

ID (*gap)	Activity	2019 Score
	simulations were conducted to assess the validity ofsemi-analytical codes to perform thermal simulations. The investigation included use of the semi-analytical codeLinSour used at DBE Technology in Germany, a Mathcad 14-based semi-analytical code used at Sandia National Laboratories, and the numerical code FLAC3D. These codes were used to calculate thetemperature at the drift wall and waste package surface as a function of time for the two configurations.	
R&&D Needed		
O-06 *	*Natural/Anthropogenic Analogs for Radionuclide Transport*	L
Desc	• Site-dependent	
Type		
Codes		
Elements		
ISC	Low	
Rationale		
SAL	3 Improved Defensibility	
Rationale		
R&&D Needed		
O-07 *	*Full Biosphere Model*	L
Desc	• Detailed biosphere pathways, processes, and FEPs	
Type	PM, PA	
Codes	GDSA	
Elements		
ISC		
Rationale		
SAL		
Rationale		
R&&D Needed		
P-01	*CSNF repository argillite reference case*	M-H
Desc	• Revise properties, EBS/repository design, conceptual models, etc., as necessary • Include multiphase flow (e.g., buffer resaturation) • Assess need for M and THM coupled processes in PA • Assess need for C and THC coupled processes in PA (e.g., for buffer and DRZ) • Radionuclide solubilities	
Type	L, M, T(mainly L, M)	
Codes	GDSA, TOUGH-FLAC, TOUGH-RBSN	
Elements	3.3 Post Closure Bases, 4.2 Post Closure Safety Assessment	
ISC	High	

ID (*gap)	Activity	2019 Score
Rationale		
SAL	4 Improved Representation	
Rationale	Significant work related to the performance of argillite repositories has been completed internationally (particularly at the Mont Terri URL in Switzerland and the Meuse/Haute-Marne (MHM) URL in Bure, France). Initial modeling studies have been completed, and others are planned to further improve the inclusion of coupled THM models in GDSA.	
R&&D Needed	Continue work on THMC coupled process model development. Cross-reference with EBS/International.	
P-02	*CSNF repository crystalline reference case*	M-H
Desc	• Develop a modeling capability to capture main stages of repository evolution. • Revise properties, EBS/repository design, conceptual models, etc., as necessary • Refine spatial heterogeneity by including deformation zone and more realistic fracture sets (and associated connectivity • Include multiphase flow (e.g., buffer resaturation) • Dual/multi-continuum for transport granite • Radionuclide solubilities	
Type	L, M, T (mainly L, M)	
Codes	GDSA	
Elements	3.3 Post Closure Bases, 4.2 Post Closure Safety Assessment	
ISC	High	
Rationale		
SAL	4 Improved Representation	
Rationale	Significant work related to the performance of crystalline repositories has been completed internationally (e.g., the FEBEX experiment at the Grimsel site in Switzerland. Modeling studies have been conducted for nearly 20 years, completed, and others are planned to further improve the inclusion of coupled THMC models in GDSA. Multiple DOE labs are participating in the ongoing international effort.	
R&&D Needed	Continue work on fracture network modeling and fracture flow and transport modeling, and THMC coupled process model development (including colloid transport) at higher temperatures (e.g., the HOTBENT experiments being planned at Grimsel). Cross-reference with EBS/International Programs.	
P-03	*CSNF repository bedded salt reference case*	M
Desc	• Revise properties, EBS/repository design, conceptual models, etc., as necessary • Include multiphase flow, if needed (e.g., heat pipes) • Assess need for M and THM coupled processes in PA • Assess need for Pitzer model for C • Radionuclide solubilities	
Type	L, M, T (mainly L, M)	
Codes	GDSA	
Elements	3.3 Post Closure Bases, 4.2 Post Closure Safety Assessment	
ISC	High	
Rationale		
SAL	3 Improved Defensibility	

ID (*gap)	Activity	2019 Score
Rationale	Significant work related to the performance of salt repositories has been completed at WIPP, and internationally (particularly in Germany). Initial modeling studies have been completed, and others are planned to further improve the inclusion of coupled THMC models in GDSA. Unlike other media, in salt the regional groundwater flow in the geologic units next to the salt body can become complex due to the presence of the salt (i.e., free salinity-driven convection), which is more complex than typical "regional" groundwater flow	
R&&D Needed	Continue work on salt repository modeling, and THMC coupled process model development. Cross-reference with WIPP and EBS/International Programs.	
P-04	*CSNF repository unsaturated zone (alluvium) reference case*	M-H
Desc	• Define properties, EBS/repository design, conceptual models, etc., as necessary • Include multiphase flow (e.g., phase change due to waste package heat) • Assess need for M and THM coupled processes in PA (e.g. for backfill and DRZ) (not sure we care) • Assess need for C and THC coupled processes in PA (e.g., for backfill and DRZ) (not sure we care) • Determine dose-contributing radionuclides, solubilities, and sorption under oxidizing conditions	
Type	L, PA (PM?)	
Codes	GDSA	
Elements	3.3 Post Closure Bases, 4.2 Post Closure Safety Assessment	
ISC	High	
Rationale		
SAL	4 Improved Representation	
Rationale	Not associated with a supporting work package, so relies largely on the literature for concepts, processes, and parameters.	
R&&D Needed	Ensure modeling capability of processes important to the UZ, which may include multiphase flow w/ dry-out (heat pipe), dual-porosity/dual-permeability transport, representation of heterogeneous materials, gas phase transport, climatic forcing.	
P-05	*Disruptive events*	M
Desc	• PA processes initiated or dependent upon external events, such as human intrusion, glaciation, and seismicity. Also, include early WP failures.	
Type	L, M	
Codes	GDSA	
Elements	3.3 Post Closure Bases, 4.2 Post Closure Safety Assessment	
ISC	Medium	
Rationale		
SAL	4 Improved Representation	
Rationale	It may be difficult to further improve modeling of seismic events (and particularly their impact on the EDB and EBS components) for generic repositories because both the seismic effects (e.g., ground motion/displacement) and the damage to the EBS depend both on site specific geologic factors, and on the design of the EBS.	
R&&D	Development of a stylized human intrusion scenario	

ID (*gap)	Activity	2019 Score
Needed		
P-06	*(Pseudo) Colloid-Facilitated Transport Model*	M
Desc	• Formation, stability, and transport of pseudocolloids in the near field and far field	
Type	M	
Codes	PFLOTRAN	
Elements	SC element 3.3.2b	
ISC Rationale	High	
SAL Rationale	3 Improved Defensibility From Roadmap: Significant work has been done. But the puzzle is yet to be put together. Evidence suggests that Pu travels further than Kd models would predict.	
R&&D Needed	Couple LANL colloid model to GDSA Framework From Roadmap: Need improved models that can reproduce this observed behavior. Need improved techniques for in-situ characterization and quantification of colloids. Leverage info from NAGRA working group on colloids. Colloid formation - Better understand formation from clay materials, sorption/desorption (attachment/detachment). Colloid instability in high ionic strength environments. Colloid transport - Need to reduce uncertainty in infiltration. Need to better represent heterogeneous behavior of colloids. Need better understanding of colloid transport behavior in unsaturated environments to reduce conservatisms in current models. Multiple rate kinetics and irreversibility of radionuclide sorption onto colloids - better understand size dependence.	
P-07	*Intrinsic Colloid Model*	L
Desc	• Intrinsic Pu colloid formation, stability, and transport in the near and the far fields, as a function of T	
Type	M	
Codes	PFLOTRAN	
Elements	SC element 3.3.2b	
ISC Rationale	Low	
SAL Rationale	3 Improved Defensibility Topics 8, 11 and 12 in the Spent Fuel Disposition in Crystalline Rocks 2018 PR (Wang et al, 2018) document the progress in modeling colloid facilitated transport (CFT). A study of the dissolution of intrinsic colloids in the presence of montmorillonite at different T showed that kinetic constants for dissolution are lower than the apparent diffusion rates. Thus, dissolution was the rate-limiting step. The presence of clay tends to stabilize dissolved Pu species and drive intrinsic Pu colloid dissolution and the formation of more stable pseudo-colloids. A comprehensive review of CFT processes was completed, and a multiple site and multiple rate CFT model was developed and was applied to the data from the Grimsel Test Site. Batch and column transport experiments were conducted to assess the effects of colloid aging on CFT of 137Cs in granitic environments.	
R&&D Needed	Additional support and coordination with international efforts to develop and test improved models of CFT will continue to improve confidence and validate models. A method for the implementation of the colloid transport model in performance	

ID (*gap)	Activity	2019 Score
	assessment was proposed and will be implemented in PFLOTRAN.	
P-08 *	*Other missing FEPs (processes) in PA-GDSA*	M
Desc	• Gas generation and movement • Ongoing climatic effects • Neutron activation	
Type	M	
Codes	GDSA	
Elements	SC Element 3.3 (FEPS) 4.2 (PC Safety Assessment)	
ISC Rationale	Medium	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Significant improvements in the understanding of gas flow in clay and bentonite have resulted from LBNL modeling (using TOUGH-FLAC and TOUGH-RBSN) and coordination with international efforts at Mont Terri and DECOVALEX Task A (see Evaluation of UFD in Clay Bearing Rk 2018, SAND 2018 -12044 R)	
R&&D Needed	Await the outcome of R&D re-prioritization in Jan 19 workshop. Continued testing and modeling of gas flow experiments, particularly in cooperation with international efforts will significantly increase confidence in coupled THMC models including gas flow and transport, and support the development of validated models.	
P-09	*Surface processes and features*	L
Desc	• Develop model parameters for infiltration & surface discharge	
Type	L, M	
Codes	GDSA	
Elements	SC Element 3.3.2a	
ISC Rationale	Low	
SAL	4 Improved Representation	
Rationale	From 2012 Roadmap: Regional groundwater flow modeling is well understood. Could be opportunity for model improvements including surface recharge component, but such improvements would be more applicable to site specific models, not generic repositories.	
R&&D Needed	The quality of available regional groundwater flow and transport models is likely adequate for generic repository studies.	
P-10	*UA/SA*	M
Desc	• Standardized set of UQ/SA methods • Less common UQ/SA methods (re: PA license applications), such as variance based	
Type	L, M	
Codes	Dakota, etc.	
Elements	SC Element 3.3.2d, 4.2f,g	
ISC Rationale	High	
SAL	2 Improved Confidence	
Rationale	Recent GDSA annual reports (e.g., Advances in Geologic Disposal Safety Assessment and	

ID (*gap)	Activity	2019 Score
	an Unsaturated Alluvium Reference Case, SFWD-SFWST-2018-000509 SAND2018-11858 R) describe the progress made implementing uncertainty/sensitivity analysis techniques into the GDSA framework, coupling PFLOTRAN and Dakota, resulting in Improved Representation of UQ/SA.	
R&&D Needed	Continuing efforts and collaboration with international programs will result in further improvements and more confidence in validated models.	
P-11 *	*Pitzer model*	M-H
Desc	• Implement Pitzer activity coefficients (Wolery EQ3/6 version)	
Type	M	
Codes	PFLOTRAN	
Elements	SC element 3.3.2	
ISC Rationale	High	
SAL	4 Improved Representation	
Rationale	If we ever want to do full chemistry in a salt repository, or consider the effects of mixing brines (e.g., in a human intrusion scenario), this is required. From Roadmap (for FEP 2.1.09.01): Expected to be of high direct importance to long-term performance - effects potential degradation processes of engineered barriers and geochemistry inside the EBS, and solubility controls/limits. Expected to be of low importance to repository design and construction. Estimated at medium importance for overall confidence - demonstration of understanding of geochemical conditions.	
R&&D Needed	Pitzer models are well established in theory, but have not been implemented within the GDSA model. Would require additional geochemical modeling capability.	
P-12	*WP Degradation Model Framework*	H
Desc	• Degradation of WP outer barrier over time • Representation of GC breach area (e.g., patches) • Effect of other modes of corrosion (SCC, LC)	
Type	M	
Codes	PFLOTRAN	
Elements	3.3.1b WF/WP Technical Basis	
ISC Rationale	High	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Significant work related to the development and implementation of WP degradation models (as well as EBS degradation, and fuel matrix degradation (FMDM) models) including chemical processes has been completed both within the US, and internationally. However, direct incorporation of these process models into the GDSA model (PFLOTRAN) has not been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of	
R&&D Needed	Need to integrate WP degradation models (as well as FMDM and EBS degradation models) into PFLOTRAN	
P-13 *	*Full Representation of Chemical processes in PA*	M-H

ID (*gap)	Activity	2019 Score
Desc	• Linked to EBS in-package chemistry task • Effect of chemistry on near-field degradation and transport • Possibly a separate, “nested” model	
Type	PA	
Codes	PFLOTRAN	
Elements	SC element 3.3.1b	
ISC Rationale	High	
SAL Rationale	4 Improved Representation Significant work related to the development, testing and implementation of coupled models including chemical processes and thermodynamic databases has been completed both within the US (e.g. FMDM), and through US participation internationally (e.g., FEBEX, HOTBent, GREET). However, direct incorporation of the process models into the GDSA model (PFLOTRAN) has not yet been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of model confidence building and model validation.	
R&&D Needed	From 2012 Roadmap, Considerable work has been done in the U.S. and in other countries regarding radionuclide speciation and dissolved concentration limits. Improved understanding of solubility controls and dissolved concentration limits would lead to improved radionuclide transport models and better understanding of disposal system performance. Large knowledge gaps on radionuclide solubilities at elevated temperatures and in concentrated electrolyte solutions. Accurate redox speciation chemistry of important radionuclides such as Pu and Np are still a matter of investigation. Improved understanding of potential solubility-controlling phases for radionuclides with mixed compositions (i.e., not necessarily pure endmembers).	
P-14	*Generic Capability Development for PFLOTRAN*	M-H
Desc	• Certain constitutive models in other porous media codes (e.g., TOUGH-FLAC and FEHM) should be integrated into PFLOTRAN when needed, i.e., to avoid the use of surrogate models or lookup-tables/response surfaces.	
Type	M	
Codes	PFLOTRAN, FEHM, TOUGH-FLAC	
Elements	SC Element 4.2c,e	
ISC Rationale	High	
SAL Rationale	4 Improved Representation Recent GDSA annual reports (e.g., Advances in Geologic Disposal Safety Assessment and an Unsaturated Alluvium Reference Case, SFWD-SFWST-2018-000509 SAND2018-11858 R; Advances in Geologic Disposal System Modeling and Shale Reference Cases, SFWD-SFWST-2017-000044 SAND2017-10304 R) describe the progress made implementing PFLOTRAN for the analysis of generic repositories in unsaturated alluvium and shale. The reports also describe how uncertainty/sensitivity analysis techniques are integrated into the GDSA framework, coupling PFLOTRAN and Dakota.	
R&&D Needed	As necessary, features from FEHM and TOUGH-FLAC will be migrated to PFLTORAN (such as was done for WIPP PA). In addition, continuing efforts and collaboration with international programs will result in further improvements and more confidence in	

ID (*gap)	Activity	2019 Score

P-15 * *Species and element properties* **M-H**

Desc
- Solute-specific diffusivities
- Temperature-dependent solubilities

Type: M
Codes: PFLOTRAN
Elements: SC Element 4.2c,e
ISC Rationale: High

SAL: 4 Improved Representation

Rationale: Significant work related to the development, testing and implementation of coupled models including chemical processes and thermodynamic databases has been completed both within the US (e.g. FMDM), and through US participation internationally (e.g., FEBEX, HOTBent, GREET). However, direct incorporation of the process models into the GDSA model (PFLOTRAN) has not yet been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of model confidence building and model validation.

R&&D Needed: As appropriate and feasible, chemical process models and thermodynamic data will be linked to or integrated with PFLOTRAN. In addition, continuing efforts and collaboration with international programs will result in further improvements and more confidence in validated models.

P-16 * *Solid solution model* **M-H**

Desc
- Precipitation and dissolution of solid solutions

Type: M
Codes: PFLOTRAN
Elements: SC Element 4.2c,e
ISC Rationale: High

SAL: 4 Improved Representation

Rationale: Significant work related to the development, testing and implementation of coupled models including chemical processes and thermodynamic databases has been completed both within the US (e.g. FMDM), and through US participation internationally (e.g., FEBEX, HOTBent, GREET). However, direct incorporation of the process models into the GDSA model (PFLOTRAN) has not yet been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of model confidence building and model validation.

R&&D Needed: As appropriate and feasible, chemical process models and thermodynamic data will be linked to or integrated with PFLOTRAN. In addition, continuing efforts and collaboration with international programs will result in further improvements and more confidence in validated models.

P-17 * *Multi-Component Gas Transport* **M-H**

Desc
- Ability to model chemical species in the gas and liquid phases.

Type: M
Codes: PFLOTRAN

ID (*gap)	Activity	2019 Score
Elements	SC Element 4.2c,e	
ISC Rationale	High	
SAL	4 Improved Representation	
Rationale	Significant work related to the development, testing and implementation of coupled models including chemical processes and thermodynamic databases has been completed both within the US (e.g. FMDM), and through US participation internationally (e.g., FEBEX, HOTBent, GREET). However, direct incorporation of the process models into the GDSA model (PFLOTRAN) has not yet been accomplished, and it is not yet clear which modeling/simulation strategies will prove the most effective and efficient in terms of model confidence building and model validation.	
R&&D Needed	As appropriate and feasible, chemical process models and thermodynamic data will be linked to or integrated with PFLOTRAN. In addition, continuing efforts and collaboration with international programs will result in further improvements and more confidence in validated models.	
S-01	*Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)*	H
Desc	Excavation-induced mechanical damage (and resulting hydrologic properties) and creep-induced closure/healing, as influenced by temperature and brine content, including reconsolidation of run-of-mine salt. More data to parameterize constitutive models.	
Type	PM, PA, FT	
Codes	TOUGH-FLAC	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	Development and evolution (i.e., healing) of permeability and porosity around the drift, and in the run-of-mine salt backfill are very important to the safety case, specifically post-closure safety and confidence enhancement	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	Although extensive modeling of salt repositories at low temperature (e.g., WIPP) has been performed, significantly less work has been conducted for disposal of HLW/SNF at higher temperatures. Significant uncertainties remain regarding coupled THM processes, especially for the evolution of the EDZ and backfill. 2012-2019, implemented the state of the art constitutive models for behavior of salt (healing, damage, sealing) (SAL 4) . Still lacking in fundamental data to populate constitutive models for bedded salt (SAL 5).	
R&&D Needed	"R&D needed: Coupled model development and validation along with phased field tests, including EBS with crushed backfill and host rock. Critical for critical for better parametrization (parameters for creep and permeability evolution, back-fill compaction). Prioritize work for integration with PA (PFLOTRAN) including calculation of response surfaces for defined GDSA cases. From Roadmap (for FEP 2.2.01.01): Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to understand the coupled evolution of near-field host rock (EDZ) and backfill."	
S-02	*Salt Coupled THM processes, creep closure of excavations*	M-H
Desc	Interaction of creeping-closed excavations with materials inside the excavation (e.g.,	

ID (*gap)	Activity	2019 Score
	waste packages, rock bolts, bulkheads). More of a pre-closure, not so applicable to backfilled heat-generating waste, as in current salt disposal concept.	
Type	PM, LT	
Codes	Sierra Mechanics (WIPP)	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	Mine excavation evolution and creep closure are very important to the safety case, specifically post-closure safety and confidence enhancement	
SAL	4 Improved Representation	
Rationale	Although extensive modeling of salt repositories at low temperature (e.g., WIPP) has been performed, which makes this a 4, significantly less work has been conducted for disposal of HLW/SNF at higher temperatures. Significant uncertainties remain regarding coupled THM processes, especially for the evolution of the EDZ and backfill.	
R&&D Needed	"R&D needed: Coupled model development and validation along with phased field tests, including EBS with crushed backfill and host rock. Critical for critical for better parametrization (parameters for creep and permeability evolution, back-fill compaction). From Roadmap (for FEP 2.2.01.01): Need to know the evolution of the characteristics of the EDZ under the thermal-mechanical and wetting changes (clay and salt). Need to	
S-03	*Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt*	H
Desc	• Coupled thermal-hydrologic-chemical processes in a salt repository: specifically two-phase flow processes and material properties	
Type	PM, LT	
Codes	FEHM, PFLOTRAN, TOUGH	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	Redistribution of water around waste packages (i.e., dry-out around hot waste packages) is important for post-closure safety. Making detailed predictions of brine re-distribution in the drift around the waste package at early time (i.e., pre-closure) would be a confidence enhancement, but is not as important for pre-closure.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	From 2012 Roadmap (for FEP 2.2.08.01): Need to understand fracturing and healing in clays and salt. Water migration in salt is a unique process that needs to be better understood. Need to understand thermal and pressure gradients and gas generation and migration. 2012-2019, implemented the state of the art constitutive models for behavior of salt (relative permeability, capillary pressure, porosity change) (SAL 4) . Still lacking in fundamental data to populate constitutive models (SAL 5).	
R&&D Needed	FY18-19: Models will continue to be tested against all available laboratory/field data. Limited work was done in FY18 on integrating the new salt algorithms into PFOTRAN. This should become a priority moving forward. FY19-22. Prioritize salt algorithms necessary to include in PFLOTRAN and direct the necessary staff involved to make the code changes.	
S-04	*Coupled THC processes in Salt, Dissolution and precipitation of salt near heat*	H

ID (*gap)	Activity	2019 Score
	sources (heat pipes)	
Desc	• Coupled thermal-hydrologic-chemical processes in a salt repository: specifically dissolution and precipitation of saline rocks around waste packages	
Type	PM, PA, FT	
Codes	FEHM, PFLOTRAN, TOUGH-FLAC	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	Making detailed predictions of brine re-distribution in the drift around the waste package at early time (i.e., pre-closure) would be a confidence enhancement, but is not as important for pre-closure.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	From 2012 Roadmap (for FEP 2.2.08.01): Water migration in salt is a unique process that needs to be better understood. Need to understand thermal and pressure gradients and gas generation and migration. 2012-2019, implemented the state of the art constitutive models for behavior of salt (relative permeability, capillary pressure, porosity change) (SAL 4) . Still lacking in fundamental data to populate constitutive models (SAL 5).	
R&&D Needed	FY18-19: Models will continue to be tested against all available laboratory/field data. Limited work was done in FY18 on integrating the new salt algorithms into PFOTRAN. This should become a priority moving forward. FY19-22. Prioritize salt algorithms necessary to include in PFLOTRAN and direct the necessary staff involved to make the code changes.	
S-05	*Borehole-based Field Testing in Salt*	H
Desc	• Horizontal borehole test(s) in salt to verify: thermal, geochemical, geohydraulic, and geomechanical phenomena	
Type	FT,EA,MA	
Codes	PFLOTRAN, FEHM, TOUGH-FLAC	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	The field test focuses on assessment of brine availability (amount of brine in the salt, and its migration to excavations). Brine impacts waste package corrosion and radionuclide transport, which are both long-term performance assessment issues. The field test will also provide significant confidence building	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	From Roadmap (for FEP 2.2.08.06): Flow regimes and pathways are important factors for long-term performance assessments. Field scale heater testing and modeling is needed to develop confidence in coupled THMC models of HLW/SNF repositories.	
R&&D Needed	Shakedown field test being implemented in FY18. Field test being implemented in late FY18 and FY19 for new two boreholes (120C and ambient). 1) Instrumentation. 2) Logistics / training at WIPP. 3) Data collection 4) data interpretation 5) follow-on test design 6) troubleshooting. Additional heated temperatures, borehole configurations, and instrumentation will be used in follow-on tests in FY19 and beyond. 1) Instrumentation. 2) Logistics / training at WIPP. 3) Data collection 4) data interpretation 5) follow-on test design 6) troubleshooting. Field testing and associated analysis and modeling activities should contribute significantly to improving confidence in coupled THMC models of salt	

ID (*gap)	Activity	2019 Score
	behavior in a repository.	
S-06	*Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)*	M
Desc	• Coupled small-scale TH/THC/THM/THMC laboratory experiments that can be used to validate and parameterize coupled processes in salt. To investigate phenomena observed in field test, or to better interpret data collected during field test.	
Type	LT,EA,MA	
Codes	PFLOTRAN, FEHM, TOUGH-FLAC, EQ3/6 (Pitzer)	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	The laboratory tests will provide much-needed support to the field tests on assessment of brine availability (amount of brine in the salt, and its migration to excavations). This is important to post-closure safety assessment and confidence enhancement	
SAL	3 Improved Defensibility	
Rationale	Additional model validation related testing and analysis will result in improved process models, and increased confidence in the GDSA model.	
R&&D Needed	As needed laboratory tests will be scoped. Tests may be conceived to explain observations or process from field test, or from feedback in international interactions.	
S-07	*Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)*	M-H
Desc	• Analysis of brine composition from other salt sites beyond WIPP. Numerical modeling of brine composition during evaporation and dry-out. Most geochemistry modeling in brine has to do with actinide chemistry. To investigate phenomena observed in field test, or to better interpret data collected during field test. Explore using alternative thermodynamic databases.	
Type	L, LT, MA, FT	
Codes	PFLOTRAN, EQ3/6, DFN, FCM	
Elements	SC elements 3.3.1c & 4.2d	
ISC	High	
Rationale	Brine origin, chemistry, and composition data will provide much-needed support to the field tests. This is important to post-closure safety assessment and confidence	
SAL	4 Improved Representation	
Rationale	Testing, analysis and modeling of brine compositions is one part of THC coupled models for field scale borehole test program. The origins of different brines (intergranular, intragranular, hydrous minerals) will be evaluated, using stable isotopes and other chemical signals.	
R&&D Needed	Part of the borehole heater test program. Samples of brine will be collected from borehole. Numerical modeling of brine (Pitzer mode) will be use to predict liquid and solid components of brine during the test, and compared against observations. Investigate interaction between brine composition (chloride and boron) and waste package criticality (DPCs). Perform a broader literature survey on brine compositions in evaporites, beyond WIPP	
S-08	*Evolution of run-of-mine salt backfill*	M-H

ID (*gap)	Activity	2019 Score

Desc • Temporal, compositional, and textural evolution of 1) run-of-mine salt backfill, 2) salt with possible additives (e.g., clay, sand). Also constitutive models used to describe these processes. What are the uncertainties in using uncontrolled run-of-mine salt. Evolution of hydrologic (e.g., relative permeability, porosity, and capillary pressure curve) and mechanical (e.g., stiffness, backpressure during room closure) during

Type L, MA, FT
Codes TOUGH-FLAC, Sierra Mechanics, FEHM
Elements SC elements 3.3.1c & 4.2d
ISC High
Rationale Run-of-mine salt will be used in shaft seals, drift seals, and around waste packages, which makes it a critical component of the long-term safety case.

SAL 4 Improved Representation
Rationale Although significant work related to the performance of salt repositories has been completed at WIPP, and internationally (particularly in Germany), initial modeling studies that have been completed show complex dependency on experimental technique. These make the existing body of work uncertain and more data and improved constitutive laws are needed.

R&&D Needed Need to continue field scale testing and modeling of run-of-mine salt in the EBS and its relationship to the EDZ to develop improved models of RN F&T in a salt repository. Participation in internationals programs such as DECOVALEX and US/German partnerships, contributes to model improvement and increased confidence

S-09 *Numerical modeling of dryout in multiphase* M

Desc • Compare, validate, and benchmark the dryout and resaturation process in PFLOTRAN (compare TOUGH-REACT, FEHM, etc.).

Type MA
Codes PFLOTRAN, FEHM, TOUGH-FLAC
Elements SC elements 3.3.1c & 4.2d
ISC Medium
Rationale It is important that the PA model consider and implement the correct physics, but this is primarily a simulation issue.

SAL 3 Improved Defensibility
Rationale Although TOUGH and FEHM are well established models, coupled TH models in PFLOTRAN in salt at high temperatures needs to be further validated through testing.

R&&D Needed Perform code comparisons among PFLOTRAN, TOUGH, and FEHM on repository relevant simulations. Modeling will be calibrated on laboratory data and validated on field data.

S-10 * *Drift resaturation process in PA* M

Desc • Use TH(M) to simulate development of "initial conditions" used in long-term GDSA PA model. Especially with respect to the re-saturation of the DRZ. All media have some amount of increased porosity and decreased saturation in the DRZ surrounding the drift. In salt and clay, the re-hydration process is likely to be coupled with mechanical drift deformation and swelling/healing. The thermal conductivity and heat capacity of the buffer/backfill are very sensitive to the distribution of moisture. If the backfill or DRZ are dry, they will be more thermally insulating.

Type MA

ID (*gap)	Activity	2019 Score
Codes	PFLOTRAN, TOUGH-FLAC, FEHM	
Elements	SC element 3.3.1b, 3.3.1c	
ISC	Medium	
Rationale	Multiphase flow modeling of dryout and resaturation may only moderately or indirectly impact long-term performance assessment	
SAL	3 Improved Defensibility	
Rationale	Resaturation in process models is appropriately developed, but needs to be incorporated into PA models.	
R&&D Needed	PA models will be modified to include new representation of drift resaturation processes. Consider impacts of waste package corrosion (i.e., consumption of water in anoxic corrosion) on resaturation.	
S-11 *	*THMC effects of anhydrites, clays, and other non-salt components*	M-H
Desc	Improve representation of THMC effects due to non-salt components in bedded salt. These non-salt components may contribute water, impact brine movement (i.e., preferential pathways), and have a different mechanical response than salt.	
Type	PM, MA, LT, FT	
Codes	TOUGH-FLAC, Sierra Mechanics	
Elements		
ISC	High	
Rationale	The permeability and porosity of bedded salt is such that non-salt layers may provide significant pathways or sources of brine, which can impact long-term performance.	
SAL	4 Improved Representation	
Rationale	Bedded salt contains ubiquitous hydrous minerals that may impact both brine movement and mechanical behavior. Currently represented in a simplistic way, but could be more physically mechanistic. Dehydration of hydrous non-salt minerals can contribute water. Low-deviatoric stress state response of non-salt components may be	
R&&D Needed	Literature study on the contributions of non-salt components to THMC processes. Leverage ongoing DOE-EM shear-strength laboratory testing at WIPP, and incorporate new constitutive laws and observations into numerical models. Consider low-deviatoric stress state response of non-salt components in literature search.	
S-12	*Laboratory testing and modeling of fluid inclusions*	M
Desc	Improve representation of intragranular (i.e., fluid inclusions) brine migration in salt. Process model development and benchmarking against laboratory and field test data.	
Type	PM	
Codes	TOUGH-FLAC	
Elements		
ISC	Medium	
Rationale	Fluid inclusions may make up a significant proportion of the overall water content, but their contribution to overall brine availability and long-term performance is secondary.	
SAL	4 Improved Representation	
Rationale	Laboratory tests of fluid inclusions were performed by LANL. Modeling development of multi-continuum brine inclusion migration by TOUGH 2 is required. Intergranular and	

ID (*gap)	Activity	2019 Score
	intragranular brine migration currently handled independently, but model development will integrate them.	
R&&D Needed	Finish implementation of multicontinuum (inter- and intra-granular) brine migration in TOUGH-2. Compare this new implementation against laboratory and field data on fluid inclusions.	
S-13 *	*Acid gas generation, fate, and transport*	M
Desc	Collect field and laboratory data to elucidate possible issues related to HCl generation from hot brines and salt. Data will be used to improve and calibrate process models.	
Type	PM, LT, FT	
Codes	PFLOTRAN, EQ3/6	
Elements		
ISC	Medium	
Rationale	Acid gas generation may impact long-term performance in a secondary way.	
SAL	5 Fundamental Gaps in Method or Fundamental Data Needs, or Both	
Rationale	HCl generation when heating salt can lead to very low pH condensate. This may have implications for canister performance.	
R&&D Needed	Datasets (gases produced during heating salt) from FY19 field test will be analyzed to better understand the origin and significance of this possible mechanism.	

APPENDIX C: R&D ACTIVITY BREAKOUT SESSION

Activity	Name	DPC	EBS	Int	Arg	Crys	Salt
A-01	*Two-Part Hooke's Model(saturated)*				X		
A-02	*Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization*				X		
A-03	*Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS*				X		
A-04	*Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)*				X		
A-05	*THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)*				X		
A-06	*Diffusion of actinides through bentonite(including speciation)*				X	X	
A-07	*Analysis of clay hydration/dehydration and alteration under various environmental conditions*				X	X	X
A-08	*Evaluation of ordinary Portland cement (OPC)*				X	X	
C-01	*Discrete Fracture Network (DFN) Model*					X	
C-02	*Flow and Transport in Fractures - modeling approaches*					X	
C-03	*Fracture-Matrix Diffusion - Modeling approaches*					X	
C-04	*Lab and modeling study of EDZ - Crystalline*					X	
C-05	*Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization*					X	
C-06	*Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D*					X	
C-07	*Colloids in Fractures and Matrix*					X	
C-08	*Interaction of Buffer w/ Crystalline Rock*				X	X	
C-09	*Development of a centralized technical database for crystalline disposal system evaluation*					X	
C-10	*Collate data from International URLs*					X	
C-11	*Investigation of fluid flow and transport in low permeability media (clay materials).*					X	
C-12	*Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock*					X	

Activity	Name	DPC	EBS	Int	Arg	Crys	Salt
C-13	*Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport*					X	
C-14	*Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach*					X	
C-15	*Design improved backfill and seal materials*					X	
C-16	*Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal*					X	
C-17	*Model DFN evolution due to changes in stress field*					X	
D-01	*Probabilistic post-closure DPC criticality consequence analyses* *Task 1 - Scoping Phase* *Task 2 - Preliminary Analysis Phase* *Task 3 - Development Phase*	X					
D-02	*Maintain and populate DPC as-loaded database*	X					
D-03	*DPC filler and neutron absorber degradation testing and analysis*	X					
D-04	*Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.*	X					
D-05	*Source term development with and without criticality*	X					
D-06	*Technical integration of DPC direct disposal*	X					
E-01	*SNF Degradation(& FMDM)*		X		X	X	
E-02	*SNF Degradation testing activities*		X		X		
E-03	*THC processes in EBS*		X		X	X	
E-04	*Waste Package Degradation Model(mechanistic)*		X		X	X	
E-05	*Corrosion Products - incorporation of radionuclides*		X		X	X	
E-06	*Waste Package Degradation Testing*		X		X	X	
E-07	*Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment*		X				X
E-08	*Radionuclide Interaction w/ Buffer Materials*		X			X	X
E-09	*Cement plug/liner degradation*		X				
E-10	*High-Temperature Behavior*		X		X		X

Activity	Name	DPC	EBS	Int	Arg	Crys	Salt
E-11	*EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.*		X		X		
E-12	*Buffer/backfill dry-out and resaturation process*		X		X		X
E-13	*HLW WF degradation (process model)*		X		X	X	
E-14	*In-Package Chemistry*		X		X	X	
E-15	*Cladding Degradation*		X				
E-16	*In-Package Flow*		X				
E-17	*Buffer Material by Design*		X				
E-18	*Unbackfilled-Drift Thermal Radiation Model*		X				
E-19	*Other SNF/HLW Types*		X				
E-20	*colloid source terms*		X				
I-01	*Radionuclide transport as pseudocolloids,Grimsel*		X			X	
I-02	*FEBEX-DP Modeling: Dismantling phase of the long- term FEBEX heater test - Modeling*		X		X	X	
I-03	*FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test*		X		X		
I-04	*Experiment of bentonite EBS under high temperature, HotBENT*		X		X	X	
I-05	*Mont Terri FE (Full-scale Emplacement) Experiment*		X		X		
I-06	*Mont Terri FS Fault Slip Experiment*		X		X		
I-07	*DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.*		X		X		
I-08	*DECOVALEX-2019 Task A: Advective gas flow in bentonite*		X			X	
I-09	*DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan*		X		X	X	
I-10	*SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL*		X			X	
I-11	*Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies*		X			X	X
I-12	*TH and THM Process in Salt: German-US Collaborations (WEIMOS)*		X				X
I-13	*TH and THM Process in Salt: German-US Collaborations (BENVASIM)*		X				X
I-14	*TH and THM Process in Reconsolidating Salt: German- US Collaborations (KOMPASS)*		X				X
I-15	*TH and THM Process in Salt: German-US Collaborations (RANGER)*		X				X
I-16	*New Activity: DECOVALEX Task on Salt Heater Test and*		X				

Activity	Name	DPC	EBS	Int	Arg	Crys	Salt
	Coupled Modeling						
I-17	*New Activity: DECOVALEX Task on GDSA, PA, SA, UQ*			X			
I-18	*New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport*			X			
I-19	*New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing*			X			
I-20	*New Activity: New Mont Terri Task: Gas Transport in Host Rock*			X			
I-21	*New Activity: SKB Task 10 Validation of DFN Modeling*			X			
O-01	*Complete and Populate Online Waste Library (OWL)SF-17SN01050101*						
O-02	*GDSA Geologic Modeling*						
O-03	*Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling*						
O-04	*Thermodynamic and sorption database(s)*				X		X
O-05	*QA, V&V (documentation and tests)*						X
O-06	*Natural/Anthropogenic Analogs for Radionuclide Transport*						
O-07	*Full Biosphere Model*						
P-01	*CSNF repository argillite reference case*						
P-02	*CSNF repository crystalline reference case*						
P-03	*CSNF repository bedded salt reference case*						X
P-04	*CSNF repository unsaturated zone (alluvium) reference case*						
P-05	*Disruptive events*						
P-06	*(Pseudo) Colloid-Facilitated Transport Model*					X	
P-07	*Intrinsic Colloid Model*					X	
P-08	*Other missing FEPs (processes) in PA-GDSA*						
P-09	*Surface processes and features*						
P-10	*UA/SA*						
P-11	*Pitzer model*						X

Activity	Name	DPC	EBS	Int	Arg	Crys	Salt
P-12	*WP Degradation Model Framework*						
P-13	*Full Representation of Chemical processes in PA*				X		X
P-14	*Generic Capability Development for PFLOTRAN*						X
P-15	*Species and element properties*						
P-16	*Solid solution model*						
P-17	*Multi-Component Gas Transport*					X	
S-01	*Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)*						X
S-02	*Salt Coupled THM processes, creep closure of excavations*						X
S-03	*Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt*						X
S-04	*Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)*						X
S-05	*Borehole-based Field Testing in Salt*						X
S-06	*Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)*						X
S-07	*Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)*						X
S-08	*Evolution of run-of-mine salt backfill*						X
S-09	*Numerical modeling of dryout in multiphase*				X	X	X
S-10	*Drift resaturation process in PA*				X	X	X
S-11	*THMC effects of anhydrites, clays, and other non-salt components*						X
S-12	*Laboratory testing and modeling of fluid inclusions*						X
S-13	*Acid gas generation, fate, and transport*						X

APPENDIX D: R&D ACTIVITIES AND THEIR RELATED FEPS

Note: A FEP designated with a "*" in the Host Rock column means that it is not distinguished (or divided) by the host rock type (A=Argillite; C=Crystalline; S=Salt) in the 2012 UFD Roadmap. Also, a "P" after the FEP number indicates this is the "primary FEP" for that R&D Activity – see Section 3.3.3.

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
A-01	L	3	*Two-Part Hooke's Model(saturated)*						L
			2.2.07.01	P	A	Mechanical Effects on Host Rock		3.83	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.08.03		*	Flow in Backfill		2.76	
A-02	M	4	*Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization*						M
			2.2.07.01		A	Mechanical Effects on Host Rock		3.83	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01		*	Degradation of Seals		3.50	
			2.2.11.07		A	Thermal-Chemical Alteration of NBS		3.40	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.08.03		*	Flow in Backfill		2.76	
A-03	M	4	*Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS*						M
			2.2.07.01		A	Mechanical Effects on Host Rock		3.83	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01		*	Degradation of Seals		3.50	
			2.2.11.07		A	Thermal-Chemical Alteration of NBS		3.40	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.08.03		*	Flow in Backfill		2.76	
A-04	H	4	*Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)*						M-H
			2.2.01.01	P	A	Evolution of EDZ		8.00	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.2.11.06		A	Thermal-Mechanical Effects on NBS		3.40	
			2.2.08.04		A	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.07.02		A	Mechanical Effects on Other Geologic Units		3.10	
			2.2.11.01		A	Thermal Effects on Flow in NBS (Repository-Induced and Natural Geothermal)		3.10	
			2.2.11.02		A	Thermally-Driven Flow (Convection) in NBS		3.10	
			2.1.12.03		*	Gas Transport in EBS		1.02	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
A-05	M	4	*THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)*						M
			2.2.01.01	P	A	Evolution of EDZ		8.00	
			2.2.07.01		A	Mechanical Effects on Host Rock		3.83	
			2.2.05.01		A	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.2.08.04		A	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.08.03		*	Flow in Backfill		2.76	
A-06	M	4	*Diffusion of actinides through bentonite(including speciation)*						M
			2.1.09.13	P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.09.52		*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
A-07	M	5	*Analysis of clay hydration/dehydration and alteration under various environmental conditions*						M
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.08.06	P	A	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.09.51		*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.52		*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.2.08.07		A	Mineralogic Dehydration		2.82	
A-08	H	5	*Evaluation of ordinary Portland cement (OPC)*						H
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01	P	*	Degradation of Seals		3.50	
			2.1.08.04		*	Flow through Seals		2.80	
C-01	H	4	*Discrete Fracture Network (DFN) Model*						M-H

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.02.01		C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.08.02		C	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
C-02	H	3	*Flow and Transport in Fractures - modeling approaches*						M
			2.2.02.01		C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.08.02		C	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
C-03	H	3	*Fracture-Matrix Diffusion - Modeling approaches*						M
			2.2.02.01		C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
C-04	M	4	*Lab and modeling study of EDZ - Crystalline*						M
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.07.02		*	Drift Collapse		2.70	
C-05	H	3	*Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization*						M
			2.2.02.01		C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.06	P	C	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
C-06	H	4	*Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D*						M-H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
C-07	M	4	*Colloids in Fractures and Matrix*						M
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64	P	C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.08.04		C	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.09.62		C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.08.07		C	Mineralogic Dehydration		2.82	
			2.2.05.03		C	Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)		2.46	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
C-08	H	4	*Interaction of Buffer w/ Crystalline Rock*						M-H
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.2.08.04		C	Effects of Repository Excavation on Flow through the Host Rock		3.23	
C-09	M	3	*Development of a centralized technical database for crystalline disposal system evaluation*						M
			2.2.02.01	P	C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
C-10	M	3	*Collate data from International URLs*				*		M
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01	P	C	Flow through the Host Rock		3.65	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
C-11	H	4	*Investigation of fluid flow and transport in low permeability media (clay materials).*				*		M-H
			2.2.08.01	P	C	Flow through the Host Rock		3.65	
			2.1.08.01		*	Flow through the EBS		0.00	
C-12	M	4	*Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock*				*		M
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.52		C	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.54		C	Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.56		C	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.58		C	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.60		C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.1.09.51		*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.52		*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.53		*	Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.09.07		*	Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)		2.80	
			2.1.09.09	P	*	Chemical Effects at EBS Component Interfaces		2.61	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.06		C	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
			2.2.09.04		C	Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.10	
			2.1.09.54		*	Complexation in EBS		1.62	
			2.1.09.05		*	Chemical Interaction of Water with Corrosion Products (in Waste Packages, in Backfill, in Tunnels)		0.00	
			2.1.09.06		*	Chemical Interaction of Water with Backfill (on Waste Packages, in Backfill, in Tunnels)		0.00	
			2.1.09.08		*	Chemical Interaction of Water with Other EBS Components (in Waste Packages, in Tunnels)		0.00	
			2.1.09.62		*	Radionuclide Transport through Liners and Seals		0.00	
C-13	H	4	*Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport*				*		M-H
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55	P	C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
C-14	H	4	*Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach*				*		M-H
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55	P	C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.10.01		C	Microbial Activity in Host Rock		1.32	
C-15	H	5	*Design improved backfill and seal materials*				*		H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.09.07		*	Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)		2.80	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.03		*	Effects of Backfill on EBS Thermal Environment		2.22	
			2.1.08.05		*	Flow through Liner / Rock Reinforcement Materials in EBS		0.85	
			2.1.08.01		*	Flow through the EBS		0.00	
			2.1.08.06		*	Alteration and Evolution of EBS Flow Pathways		0.00	
			2.1.09.06		*	Chemical Interaction of Water with Backfill (on Waste Packages, in Backfill, in Tunnels)		0.00	
			2.1.09.08		*	Chemical Interaction of Water with Other EBS Components (in Waste Packages, in Tunnels)		0.00	
C-16	H	5	*Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal*				*		H
			2.1.03.02	P	*	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	
			2.1.07.05		*	Mechanical Impact on Waste Packages		2.76	
			2.1.03.06		*	Microbially Influenced Corrosion (MIC) of Waste Packages		0.00	
C-17	H	4	*Model DFN evolution due to changes in stress field*				*		M-H
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.05.03		C	Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)		2.46	
			1.2.03.02		*	Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)		2.34	
			1.3.05.01		*	Glacial and Ice Sheet Effects		1.85	
			2.2.07.01	P	C	Mechanical Effects on Host Rock		1.63	
			1.2.01.01		*	Tectonic Activity – Large Scale		1.44	
			1.2.04.02		*	Igneous Activity Impacts Geosphere (Host Rock, Other Geologic Units)		0.00	
D-01	H	5	*Probabilistic post-closure DPC criticality consequence analyses* *Task 1 - Scoping Phase* *Task 2 - Preliminary Analysis Phase* *Task 3 - Development Phase*						H
			2.1.02.06	P	*	SNF Cladding Degradation and Failure		3.62	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.1.07.05		*	Mechanical Impact on Waste Packages		2.76	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.1.03.08		*	Evolution of Flow Pathways in Waste Packages		1.96	
			2.1.13.02		*	Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)		1.73	
			2.1.14.01		*	Criticality In-Package		0.96	
			2.1.08.02		*	Flow in and through Waste Packages		0.86	
			2.1.01.02		*	Radioactive Decay and Ingrowth		0.00	
			2.1.13.01		*	Radiolysis (in Waste Package, in Backfill, and in Tunnel)		0.00	
D-02	H	3	*Maintain and populate DPC as-loaded database*						M
			2.1.01.01	P	*	Waste Inventory (Radionuclides and Non-Radionuclides)		2.05	
D-03	H	5	*DPC filler and neutron absorber degradation testing and analysis*						H
			2.1.02.06	P	*	SNF Cladding Degradation and Failure		3.62	
			2.1.07.05		*	Mechanical Impact on Waste Packages		2.76	
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.1.03.08		*	Evolution of Flow Pathways in Waste Packages		1.96	
			2.1.13.02		*	Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)		1.73	
			2.1.14.01		*	Criticality In-Package		0.96	
			2.1.08.02		*	Flow in and through Waste Packages		0.86	
			2.1.01.02		*	Radioactive Decay and Ingrowth		0.00	
			2.1.13.01		*	Radiolysis (in Waste Package, in Backfill, and in Tunnel)		0.00	
D-04	H	5	*Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.*						H
			2.1.02.06	P	*	SNF Cladding Degradation and Failure		3.62	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.1.07.05		*	Mechanical Impact on Waste Packages		2.76	
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.1.03.08		*	Evolution of Flow Pathways in Waste Packages		1.96	
			2.1.13.02		*	Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)		1.73	
			2.1.14.01		*	Criticality In-Package		0.96	
			2.1.08.02		*	Flow in and through Waste Packages		0.86	
			2.1.01.02		*	Radioactive Decay and Ingrowth		0.00	
			2.1.13.01		*	Radiolysis (in Waste Package, in Backfill, and in Tunnel)		0.00	
D-05	H	5	*Source term development with and without criticality*						H
			2.1.02.06	P	*	SNF Cladding Degradation and Failure		3.62	
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.1.03.08		*	Evolution of Flow Pathways in Waste Packages		1.96	
			2.1.13.02		*	Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)		1.73	
			2.1.14.01		*	Criticality In-Package		0.96	
			2.1.08.02		*	Flow in and through Waste Packages		0.86	
			2.1.01.02		*	Radioactive Decay and Ingrowth		0.00	
			2.1.13.01		*	Radiolysis (in Waste Package, in Backfill, and in Tunnel)		0.00	
D-06		2	*Technical integration of DPC direct disposal*						L
			2.1.14.01	P	*	Criticality In-Package		0.96	
E-01	M	3	*SNF Degradation(& FMDM)*						M
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.1.02.01	P	*	SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)		4.01	
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	
E-02	H	4	*SNF Degradation testing activities*						M-H
			2.1.02.01	P	*	SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)		4.01	
			2.1.02.06		*	SNF Cladding Degradation and Failure		3.62	

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.07.06	*	Mechanical Impact on SNF Waste Form		2.47	
			2.1.11.02	*	Exothermic Reactions in EBS		0.99	
E-03	H	4	*THC processes in EBS*					M-H
			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	
			2.1.03.04	*	Localized Corrosion of Waste Packages		4.34	
			2.2.09.61	A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61	C	Radionuclide Transport through EDZ		3.55	
			2.2.11.04	A	Thermal Effects on Chemistry and Microbial Activity in NBS		3.55	
			2.1.04.01 P	*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01	*	Degradation of Seals		3.50	
			2.1.09.07	*	Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)		2.80	
			2.2.09.61	S	Radionuclide Transport through EDZ		2.40	
			2.2.11.04	C	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.11.04	S	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
E-04	H	4	*Waste Package Degradation Model(mechanistic)*			*		M-H
			2.1.03.02 P	*	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	
E-05	M	5	*Corrosion Products - incorporation of radionuclides*					M
			2.1.09.51	*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.52	*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.53	*	Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.02 P	*	Chemical Characteristics of Water in Waste Packages		2.76	
E-06	H	4	*Waste Package Degradation Testing*					M-H

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.03.02	P	*	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	
E-07	M	4	*Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment*				*		M
			2.1.03.02	P	*	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	
			2.1.07.05		*	Mechanical Impact on Waste Packages		2.76	
E-08	H	3	*Radionuclide Interaction w/ Buffer Materials*						M
			2.2.01.01	P	A	Evolution of EDZ		8.00	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.09.51		*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.52		*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.53		*	Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.2.01.01		C	Evolution of EDZ		2.58	
			2.2.01.01		S	Evolution of EDZ		2.58	
			2.2.09.61		S	Radionuclide Transport through EDZ		2.40	
E-09	H	5	*Cement plug/liner degradation*						H
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.11.04		A	Thermal Effects on Chemistry and Microbial Activity in NBS		3.55	
			2.1.05.01		*	Degradation of Seals		3.50	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.03		A	Chemical Interactions and Evolution of Groundwater in Host Rock		3.10	
			2.1.06.01		*	Degradation of Liner / Rock Reinforcement Materials in EBS		2.62	
			2.2.09.61		S	Radionuclide Transport through EDZ		2.40	
			2.2.11.04		C	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.11.04		S	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
			2.2.09.03		S	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
E-10	H	4	*High-Temperature Behavior*						M-H
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.08.01		S	Flow through the Host Rock		7.73	
			2.2.08.01		A	Flow through the Host Rock		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		C	Evolution of EDZ		2.58	
			2.2.01.01	P	S	Evolution of EDZ		2.58	
E-11	H	5	*EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.*						H
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.08.01		S	Flow through the Host Rock		7.73	
			2.2.08.01		A	Flow through the Host Rock		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		C	Evolution of EDZ		2.58	
			2.2.01.01	P	S	Evolution of EDZ		2.58	
E-12	M	5	*Buffer/backfill dry-out and resaturation process*						M
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.08.06		S	Flow through EDZ		7.73	
			2.2.08.06	P	A	Flow through EDZ		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.09.51		*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.52		*	Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.09.53		*	Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		C	Evolution of EDZ		2.58	
			2.2.01.01		S	Evolution of EDZ		2.58	
E-13	M	3	*HLW WF degradation (process model)*				*		M
			2.1.02.02	P	*	HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)		0.00	
E-14	H	5	*In-Package Chemistry*				*		H
			2.1.09.02	P	*	Chemical Characteristics of Water in Waste Packages		2.76	
E-15	M	5	*Cladding Degradation*				*		M
			2.1.02.06		*	SNF Cladding Degradation and Failure		3.62	
E-16	M	5	*In-Package Flow*				*		M
			2.1.09.51	P	*	Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		3.06	
E-17	H	5	*Buffer Material by Design*				*		H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
E-18		4	*Unbackfilled-Drift Thermal Radiation Model*				*		L
			2.1.11.01	P	*	Heat Generation in EBS		2.59	
E-19			*Other SNF/HLW Types*				*		L
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.1.02.01	P	*	SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)		4.01	
			2.1.09.02		*	Chemical Characteristics of Water in Waste Packages		2.76	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.02.02		*	HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)		0.00	
E-20	H	4	*colloid source terms*						M-H
			2.1.09.55	P	*	Formation of Colloids in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		1.79	
I-01	M	3	*Radionuclide transport as pseudocolloids,Grimsel*						M
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.08.02		C	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64		A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64		C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.08.04		C	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.09.62		C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.08.07		C	Mineralogic Dehydration		2.82	
			2.2.05.03		C	Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)		2.46	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
I-02	H	4	*FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling*						M-H

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.07.02		*	Drift Collapse		2.70	
			2.1.07.09		*	Mechanical Effects at EBS Component Interfaces		2.56	
			2.1.11.04		*	Effects of Drift Collapse on EBS Thermal Environment		2.39	
			2.1.08.08		*	Capillary Effects in EBS		2.02	
			2.1.08.07		*	Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)		1.73	
I-03	H	4	*FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test*						M-H
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01	P	*	Degradation of Seals		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.2.08.07		A	Mineralogic Dehydration		2.82	
			2.2.08.07		C	Mineralogic Dehydration		2.82	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.07.02		*	Drift Collapse		2.70	
			2.1.07.09		*	Mechanical Effects at EBS Component Interfaces		2.56	
			2.1.11.04		*	Effects of Drift Collapse on EBS Thermal Environment		2.39	
			2.1.08.08		*	Capillary Effects in EBS		2.02	
			2.1.08.07		*	Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)		1.73	
I-04	H	5	*Experiment of bentonite EBS under high temperature, HotBENT*						H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.07.02		*	Drift Collapse		2.70	
			2.1.07.09		*	Mechanical Effects at EBS Component Interfaces		2.56	
			2.1.11.04		*	Effects of Drift Collapse on EBS Thermal Environment		2.39	
			2.1.08.08		*	Capillary Effects in EBS		2.02	
			2.1.08.07		*	Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)		1.73	

Act.	ISC	SAL	FEP	(P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
I-05	H	3	*Mont Terri FE (Full-scale Emplacement) Experiment*						M
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.07.01		A	Mechanical Effects on Host Rock		3.83	
			2.2.08.01		A	Flow through the Host Rock		3.65	
			2.2.08.02		A	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.2.08.04		A	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.07.02		A	Mechanical Effects on Other Geologic Units		3.10	
			2.2.08.07		A	Mineralogic Dehydration		2.82	
I-06	H	5	*Mont Terri FS Fault Slip Experiment*						H
			2.2.05.01	P	A	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.05.03		A	Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)		2.46	
I-07	H	4	*DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.*						M-H
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.05.01		*	Degradation of Seals		3.50	
			2.1.08.04		*	Flow through Seals		2.80	
			2.1.07.02		*	Drift Collapse		2.70	
			2.1.09.01		*	Chemistry of Water Flowing into the Repository		2.64	
			2.1.09.09		*	Chemical Effects at EBS Component Interfaces		2.61	
			2.1.07.09		*	Mechanical Effects at EBS Component Interfaces		2.56	
			2.1.07.08		*	Mechanical Impact on Other EBS Components (Seals, Liner / Rock Reinforcement Materials, Waste Package Support Materials)		2.16	
			2.1.08.08		*	Capillary Effects in EBS		2.02	
			2.1.08.09		*	Influx/Seepage into the EBS		1.89	
			2.1.08.07		*	Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)		1.73	
			2.1.09.03		*	Chemical Characteristics of Water in Backfill		1.47	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.08.05		*	Flow through Liner / Rock Reinforcement Materials in EBS		0.85	
I-08	H	5	*DECOVALEX-2019 Task A: Advective gas flow in bentonite*						H
			2.2.08.06	P	A	Flow through EDZ		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.64		A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64		C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.2.12.02		A	Effects of Gas on Flow through the NBS		2.18	
			2.1.08.08		*	Capillary Effects in EBS		2.02	
			2.1.08.07		*	Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)		1.73	
			2.2.12.02		C	Effects of Gas on Flow through the NBS		1.37	
			2.1.12.03		*	Gas Transport in EBS		1.02	
			2.1.12.01		*	Gas Generation in EBS		0.98	
			2.1.12.02		*	Effects of Gas on Flow through the EBS		0.98	
I-09	H	4	*DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan*						M-H
			2.2.01.01		A	Evolution of EDZ		8.00	
			2.2.07.01		A	Mechanical Effects on Host Rock		3.83	
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01	P	C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		A	Flow through the Host Rock		3.65	
			2.2.08.02		A	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
			2.2.08.06		A	Flow through EDZ		3.65	
			2.2.11.04		A	Thermal Effects on Chemistry and Microbial Activity in NBS		3.55	
			2.2.11.06		A	Thermal-Mechanical Effects on NBS		3.40	
			2.2.11.07		A	Thermal-Chemical Alteration of NBS		3.40	
			2.2.08.04		A	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.08.04		C	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.07.02		A	Mechanical Effects on Other Geologic Units		3.10	
			2.2.11.01		A	Thermal Effects on Flow in NBS (Repository-Induced and Natural Geothermal)		3.10	
			2.2.11.02		A	Thermally-Driven Flow (Convection) in NBS		3.10	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.08.07		A	Mineralogic Dehydration		2.82	
			2.2.11.03		A	Thermally-Driven Buoyant Flow / Heat Pipes in NBS		2.46	
			2.2.09.02		C	Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.11.05		A	Thermal Effects on Transport in NBS		0.00	
I-10	H	2	*SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL*						M
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.08.01		C	Flow through the Host Rock		3.65	
			2.2.08.06		C	Flow through EDZ		3.65	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64		C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.08.04		C	Effects of Repository Excavation on Flow through the Host Rock		3.23	
			2.2.09.62		C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.08.07		C	Mineralogic Dehydration		2.82	
			2.2.05.03		C	Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)		2.46	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
I-11	M	5	*Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies*						M
			2.2.11.04	P	A	Thermal Effects on Chemistry and Microbial Activity in NBS		3.55	
			2.2.12.03		S	Gas Transport in NBS		2.46	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.11.04		C	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.11.04		S	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.12.03		A	Gas Transport in NBS		1.66	
			2.2.12.03		C	Gas Transport in NBS		1.05	
I-12	H	5	*TH and THM Process in Salt: German-US Collaborations (WEIMOS)*						H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
I-13	H	5	*TH and THM Process in Salt: German-US Collaborations (BENVASIM)*						H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.08.03		*	Flow in Backfill		2.76	
I-14	H	4	*TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)*						M-H
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.08.03		*	Flow in Backfill		2.76	
I-15	M	4	*TH and THM Process in Salt: German-US Collaborations (RANGER)*						M
			2.1.04.01	P	*	Evolution and Degradation of Backfill		3.50	
			2.1.07.03		*	Mechanical Effects of Backfill		3.29	
			2.1.08.03		*	Flow in Backfill		2.76	
I-16	H	5	*New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling*				*		H
			2.2.08.06	P	S	Flow through EDZ		7.73	
I-17	H	3	*New Activity: DECOVALEX Task on GDSA, PA, SA, UQ*				*		M
			0.1.10.01	P	*	Model Issues		0.00	
I-18	H	5	*New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport*				*		H
			2.2.12.02	P	S	Effects of Gas on Flow through the NBS		3.23	
			2.2.12.02	P	A	Effects of Gas on Flow through the NBS		2.18	
			2.2.12.02	P	C	Effects of Gas on Flow through the NBS		1.37	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
I-19	M	4	*New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing*				*		M
			2.2.11.06	P	A	Thermal-Mechanical Effects on NBS		3.40	
			2.2.11.06	P	C	Thermal-Mechanical Effects on NBS		2.30	
			2.2.11.06	P	S	Thermal-Mechanical Effects on NBS		2.30	
I-20	M	4	*New Activity: New Mont Terri Task: Gas Transport in Host Rock*				*		M
			2.2.12.02	P	A	Effects of Gas on Flow through the NBS		2.18	
I-21	H	4	*New Activity: SKB Task 10 Validation of DFN Modeling*				*		M-H
			2.2.09.51	P	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
O-01			*Complete and Populate Online Waste Library (OWL)SF-17SN01050101*						L
			2.1.01.01	P	*	Waste Inventory (Radionuclides and Non-Radionuclides)		2.05	
O-02	H	4	*GDSA Geologic Modeling*						M-H
			2.2.02.01	P	A	Stratigraphy and Properties of Host Rock		3.74	
			2.2.02.01	P	C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.02.01	P	S	Stratigraphy and Properties of Host Rock		3.74	
			2.2.05.01		A	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.05.01		S	Fractures (Host Rock, and Other Geologic Units)		3.65	
O-03	H	4	*Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling*						M-H
			2.2.02.01	P	A	Stratigraphy and Properties of Host Rock		3.74	
			2.2.02.01	P	C	Stratigraphy and Properties of Host Rock		3.74	
			2.2.02.01	P	S	Stratigraphy and Properties of Host Rock		3.74	
			2.2.05.01		A	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.05.01		C	Fractures (Host Rock, and Other Geologic Units)		3.65	
			2.2.05.01		S	Fractures (Host Rock, and Other Geologic Units)		3.65	
O-04	M	3	*Thermodynamic and sorption database(s)*						M
			2.1.09.13	P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.11.04		A	Thermal Effects on Chemistry and Microbial Activity in NBS		3.55	
			2.1.05.01		*	Degradation of Seals		3.50	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.61		S	Radionuclide Transport through EDZ		2.40	
			2.2.11.04		C	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
			2.2.11.04		S	Thermal Effects on Chemistry and Microbial Activity in NBS		2.40	
O-05			*QA, V&V (documentation and tests)*						L
			N/A		*			0.00	
O-06	L	3	*Natural/Anthropogenic Analogs for Radionuclide Transport*				*		L
			N/A		*			0.00	
O-07			*Full Biosphere Model*				*		L
			N/A		*			0.00	
P-01	H	4	*CSNF repository argillite reference case*						M-H
			2.2.08.02		A	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
			2.2.03.01		A	Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.46	
			0.1.10.01	P	*	Model Issues		0.00	
P-02	H	4	*CSNF repository crystalline reference case*						M-H
			2.2.08.02		C	Flow through the Other Geologic Units (Confining Units and Aquifers)		3.65	
			2.2.03.01		C	Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.46	
			0.1.10.01	P	*	Model Issues		0.00	
P-03	H	3	*CSNF repository bedded salt reference case*						M
			2.2.08.02		S	Flow through the Other Geologic Units (Confining Units and Aquifers)		7.73	
			2.2.03.01		S	Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.46	
			0.1.10.01	P	*	Model Issues		0.00	
P-04	H	4	*CSNF repository unsaturated zone (alluvium) reference case*						M-H
			0.1.10.01	P	*	Model Issues		0.00	
P-05	M	4	*Disruptive events*						M
			1.2.03.01	P	*	Seismic Activity Impacts EBS and/or EBS Components		4.94	
			1.2.03.02		*	Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)		2.34	
P-06	H	3	*(Pseudo) Colloid-Facilitated Transport Model*						M

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.09.13		*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.61	P	A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61	P	C	Radionuclide Transport through EDZ		3.55	
			2.2.09.59		A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.60		A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.60		C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.61	P	S	Radionuclide Transport through EDZ		2.40	
			2.2.09.59		S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60		S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
P-07	L	3	*Intrinsic Colloid Model*						L
			2.2.09.61	P	A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61	P	C	Radionuclide Transport through EDZ		3.55	
			2.2.09.59		A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.60		A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.60		C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.61	P	S	Radionuclide Transport through EDZ		2.40	
			2.2.09.59		S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60		S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
P-08	M	5	*Other missing FEPs (processes) in PA-GDSA*				*		M
			2.2.12.02	P	S	Effects of Gas on Flow through the NBS		3.23	
			2.2.12.02	P	A	Effects of Gas on Flow through the NBS		2.18	
			1.3.01.01		*	Climate Change (Natural and Anthropogenic)		1.85	
			2.2.12.02	P	C	Effects of Gas on Flow through the NBS		1.37	
P-09	L	4	*Surface processes and features*						L
			2.3.08.02	P	*	Surface Runoff and Evapotranspiration		1.58	
			2.3.08.03		*	Infiltration and Recharge		1.58	
P-10	H	2	*UA/SA*						M
			N/A		*			0.00	
P-11	H	4	*Pitzer model*				*		M-H

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.1.09.13 P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.51	A	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.51	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.05	A	Radionuclide Speciation and Solubility in Host Rock		3.55	
			2.2.09.06	A	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52	A	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52	C	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.55	A	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55	C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.56	A	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.56	C	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.57	A	Complexation in Host Rock		3.55	
			2.2.09.57	C	Complexation in Host Rock		3.55	
			2.2.09.58	A	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.58	C	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.61	A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61	C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64	A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64	C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65	A	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.65	C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59	A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59	C	Colloidal Transport in Host Rock		3.29	
			2.2.09.60	A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.60	C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.62	A	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.62	C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	A	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.51	S	Advection of Dissolved Radionuclides in Host Rock		2.53	
			2.2.09.05	C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.05	S	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.06	C	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.06	S	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.52	S	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.55	S	Sorption of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.56	S	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.57	S	Complexation in Host Rock		2.40	
			2.2.09.58	S	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.61	S	Radionuclide Transport through EDZ		2.40	
			2.2.09.64	S	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		2.40	
			2.2.09.65	S	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		2.40	
			2.2.09.59	S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60	S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
			2.2.09.62	S	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		2.10	
			2.2.09.63	S	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		2.10	
P-12	H	5	*WP Degradation Model Framework*					H
			2.1.03.02 P	*	General Corrosion of Waste Packages		4.34	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			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	
P-13	H	4	*Full Representation of Chemical processes in PA*				*		M-H
			2.1.09.13	P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.51		A	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.01		A	Chemical Characteristics of Groundwater in Host Rock		3.55	
			2.2.09.02		A	Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.05		A	Radionuclide Speciation and Solubility in Host Rock		3.55	
			2.2.09.53		A	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.53		C	Diffusion of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		A	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.57		A	Complexation in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64		A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64		C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		A	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.03		A	Chemical Interactions and Evolution of Groundwater in Host Rock		3.10	
			2.2.09.04		A	Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.10	
			2.2.09.62		A	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.62		C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.63		A	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.51		S	Advection of Dissolved Radionuclides in Host Rock		2.53	
			2.2.09.01		C	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.01		S	Chemical Characteristics of Groundwater in Host Rock		2.40	
			2.2.09.02		C	Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.02		S	Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.05		S	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.53		S	Diffusion of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.55		S	Sorption of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.57		S	Complexation in Host Rock		2.40	
			2.2.09.61		S	Radionuclide Transport through EDZ		2.40	
			2.2.09.64		S	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		2.40	
			2.2.09.65		S	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		2.40	
			2.2.09.59		S	Colloidal Transport in Host Rock		2.22	
			2.2.09.03		C	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
			2.2.09.03		S	Chemical Interactions and Evolution of Groundwater in Host Rock		2.10	
			2.2.09.04		C	Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.10	
			2.2.09.04		S	Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.10	
			2.2.09.62		S	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		2.10	
			2.2.09.63		S	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		2.10	
P-14	H	4	*Generic Capability Development for PFLOTRAN*						M-H
			0.1.10.01	P	*	Model Issues		0.00	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
P-15	H	4	*Species and element properties*				*		M-H
			2.1.09.13	P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.51		A	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.05		A	Radionuclide Speciation and Solubility in Host Rock		3.55	
			2.2.09.06		A	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52		A	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52		C	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.55		A	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.56		A	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.56		C	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.57		A	Complexation in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.58		A	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.58		C	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64		A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64		C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		A	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.60	A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.60	C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.62	A	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.62	C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	A	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.51	S	Advection of Dissolved Radionuclides in Host Rock		2.53	
			2.2.09.05	C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.05	S	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.06	C	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.06	S	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.52	S	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.55	S	Sorption of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.56	S	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.57	S	Complexation in Host Rock		2.40	
			2.2.09.58	S	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.61	S	Radionuclide Transport through EDZ		2.40	
			2.2.09.64	S	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		2.40	
			2.2.09.65	S	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		2.40	
			2.2.09.59	S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60	S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
			2.2.09.62	S	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		2.10	
			2.2.09.63	S	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		2.10	

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
P-16	H	4	*Solid solution model*			*		M-H
			2.1.09.13 P	*	Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)		4.86	
			2.2.09.51	A	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.51	C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.05	A	Radionuclide Speciation and Solubility in Host Rock		3.55	
			2.2.09.06	A	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52	A	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52	C	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.55	A	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55	C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.56	A	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.56	C	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.57	A	Complexation in Host Rock		3.55	
			2.2.09.57	C	Complexation in Host Rock		3.55	
			2.2.09.58	A	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.58	C	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.61	A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61	C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64	A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64	C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65	A	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.65	C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59	A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59	C	Colloidal Transport in Host Rock		3.29	

Act.	ISC	SAL	FEP (P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.60	A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.60	C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.62	A	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.62	C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	A	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63	C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.51	S	Advection of Dissolved Radionuclides in Host Rock		2.53	
			2.2.09.05	C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.05	S	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.06	C	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.06	S	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.52	S	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.55	S	Sorption of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.56	S	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.57	S	Complexation in Host Rock		2.40	
			2.2.09.58	S	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.61	S	Radionuclide Transport through EDZ		2.40	
			2.2.09.64	S	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		2.40	
			2.2.09.65	S	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		2.40	
			2.2.09.59	S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60	S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
			2.2.09.62	S	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		2.10	
			2.2.09.63	S	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		2.10	

Act.	ISC	SAL	FEP	(P)	Host Rock	FEP Name	*Gap	2012 Score	2019 Score
P-17	H	4	*Multi-Component Gas Transport*				*		M-H
			2.2.09.51		A	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.51		C	Advection of Dissolved Radionuclides in Host Rock		3.74	
			2.2.09.05		A	Radionuclide Speciation and Solubility in Host Rock		3.55	
			2.2.09.06		A	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52		A	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.52		C	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.55		A	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.55		C	Sorption of Dissolved Radionuclides in Host Rock		3.55	
			2.2.09.56		A	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.56		C	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.57		A	Complexation in Host Rock		3.55	
			2.2.09.57		C	Complexation in Host Rock		3.55	
			2.2.09.58		A	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.58		C	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.55	
			2.2.09.61		A	Radionuclide Transport through EDZ		3.55	
			2.2.09.61		C	Radionuclide Transport through EDZ		3.55	
			2.2.09.64	P	A	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.64	P	C	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		3.55	
			2.2.09.65		A	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.65		C	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		3.55	
			2.2.09.59		A	Colloidal Transport in Host Rock		3.29	
			2.2.09.59		C	Colloidal Transport in Host Rock		3.29	
			2.2.09.60		A	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	
			2.2.09.60		C	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		3.29	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.09.62		A	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.62		C	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		A	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.63		C	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		3.10	
			2.2.09.51		S	Advection of Dissolved Radionuclides in Host Rock		2.53	
			2.2.09.05		C	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.05		S	Radionuclide Speciation and Solubility in Host Rock		2.40	
			2.2.09.06		C	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.06		S	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.52		S	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.55		S	Sorption of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.56		S	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.57		S	Complexation in Host Rock		2.40	
			2.2.09.58		S	Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
			2.2.09.61		S	Radionuclide Transport through EDZ		2.40	
			2.2.09.64	P	S	Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)		2.40	
			2.2.09.65		S	Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)		2.40	
			2.2.09.59		S	Colloidal Transport in Host Rock		2.22	
			2.2.09.60		S	Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.22	
			2.2.09.62		S	Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)		2.10	
			2.2.09.63		S	Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)		2.10	
S-01	H	5	*Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)*						H
			2.2.08.01		S	Flow through the Host Rock		7.73	
			2.2.08.06	P	S	Flow through EDZ		7.73	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.2.07.01		S	Mechanical Effects on Host Rock		3.83	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-02	H	4	*Salt Coupled THM processes, creep closure of excavations*						M-H
			2.2.07.01	P	S	Mechanical Effects on Host Rock		3.83	
			2.1.07.04		*	Mechanical Impact on Backfill		2.94	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-03	H	5	*Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt*						H
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.2.07.01		S	Mechanical Effects on Host Rock		3.83	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
			2.2.09.53		S	Diffusion of Dissolved Radionuclides in Host Rock		2.40	
			2.2.09.54		S	Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)		2.40	
S-04	H	5	*Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)*						H
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.2.07.01		S	Mechanical Effects on Host Rock		3.83	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-05	H	5	*Borehole-based Field Testing in Salt*						H
			2.2.08.01		S	Flow through the Host Rock		7.73	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-06	H	3	*Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)*						M
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-07	H	4	*Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)*						M-H
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-08	H	4	*Evolution of run-of-mine salt backfill*						M-H
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-09	M	3	*Numerical modeling of dryout in multiphase*						M
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	

Act.	ISC	SAL	FEP (P)		Host Rock	FEP Name	*Gap	2012 Score	2019 Score
S-10	M	3	*Drift resaturation process in PA*				*		M
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.04		S	Effects of Repository Excavation on Flow through the Host Rock		7.10	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.1.04.01		*	Evolution and Degradation of Backfill		3.50	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
			2.1.08.03		*	Flow in Backfill		2.76	
			2.1.11.01		*	Heat Generation in EBS		2.59	
			2.2.01.01		S	Evolution of EDZ		2.58	
S-11	H	4	*THMC effects of anhydrites, clays, and other non-salt components*				*		M-H
			2.2.08.01		S	Flow through the Host Rock		7.73	
			2.2.08.06	P	S	Flow through EDZ		7.73	
			2.2.08.07		S	Mineralogic Dehydration		6.49	
			2.2.12.02		S	Effects of Gas on Flow through the NBS		3.23	
S-12	M	4	*Laboratory testing and modeling of fluid inclusions*						M
			2.2.08.01	P	S	Flow through the Host Rock		7.73	
			2.2.08.06		S	Flow through EDZ		7.73	
S-13	M	5	*Acid gas generation, fate, and transport*				*		M
			2.2.12.02	P	S	Effects of Gas on Flow through the NBS		3.23	

APPENDIX E: FEPS AND THEIR RELATED ACTIVITIES

Note: A FEP designated with a "*" in the Host Rock column means that it is not distinguished (or divided) by the host rock type (A=Argillite; C=Crystalline; S=Salt) in the 2012 UFD Roadmap.

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
0.1.10.01 *Model Issues*								
	P-01	*	M-H	0.00	H	4		CSNF repository argillite reference case
	P-02	*	M-H	0.00	H	4		CSNF repository crystalline reference case
	P-04	*	M-H	0.00	H	4		CSNF repository unsaturated zone (alluvium) reference case
	P-14	*	M-H	0.00	H	4		Generic Capability Development for PFLOTRAN
	I-17	*	M	0.00	H	3	*	New Activity: DECOVALEX Task on GDSA, PA, SA, UQ
	P-03	*	M	0.00	H	3		CSNF repository bedded salt reference case
1.2.01.01 *Tectonic Activity – Large Scale*								
	C-17	*	M-H	1.44	H	4	*	Model DFN evolution due to changes in stress field
1.2.03.01 *Seismic Activity Impacts EBS and/or EBS Components*								
	P-05	*	M	4.94	M	4		Disruptive events
1.2.03.02 *Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)*								
	C-17	*	M-H	2.34	H	4	*	Model DFN evolution due to changes in stress field
	P-05	*	M	2.34	M	4		Disruptive events
1.2.04.02 *Igneous Activity Impacts Geosphere (Host Rock, Other Geologic Units)*								
	C-17	*	M-H	0.00	H	4	*	Model DFN evolution due to changes in stress field
1.3.01.01 *Climate Change (Natural and Anthropogenic)*								
	P-08	*	M	1.85	M	5	*	Other missing FEPs (processes) in PA-GDSA
1.3.05.01 *Glacial and Ice Sheet Effects*								
	C-17	*	M-H	1.85	H	4	*	Model DFN evolution due to changes in stress field
2.1.01.01 *Waste Inventory (Radionuclides and Non-Radionuclides)*								
	D-02	*	M	2.05	H	3		Maintain and populate DPC as-loaded database
	O-01	*	L	2.05				Complete and Populate Online Waste Library (OWL)SF-17SN01050101

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.1.01.02 *Radioactive Decay and Ingrowth*								
	D-01	*	H	0.00	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	0.00	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	0.00	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	0.00	H	5		Source term development with and without criticality
2.1.02.01 *SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)*								
	E-02	*	M-H	4.01	H	4		SNF Degradation testing activities
	E-01	*	M	4.01	M	3		SNF Degradation(& FMDM)
	E-19	*	L	4.01			*	Other SNF/HLW Types
2.1.02.02 *HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)*								
	E-13	*	M	0.00	M	3	*	HLW WF degradation (process model)
	E-19	*	L	0.00			*	Other SNF/HLW Types
2.1.02.06 *SNF Cladding Degradation and Failure*								
	D-01	*	H	3.62	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	3.62	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	3.62	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	3.62	H	5		Source term development with and without criticality
	E-02	*	M-H	3.62	H	4		SNF Degradation testing activities
	E-15	*	M	3.62	M	5	*	Cladding Degradation

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.1.03.02 *General Corrosion of Waste Packages*								
	C-16	*	H	4.34	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
	P-12	*	H	4.34	H	5		WP Degradation Model Framework
	E-03	*	M-H	4.34	H	4		THC processes in EBS
	E-04	*	M-H	4.34	H	4	*	Waste Package Degradation Model (mechanistic)
	E-06	*	M-H	4.34	H	4		Waste Package Degradation Testing
	E-07	*	M	4.34	M	4	*	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment
2.1.03.03 *Stress Corrosion Cracking (SCC) of Waste Packages*								
	C-16	*	H	4.34	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
	P-12	*	H	4.34	H	5		WP Degradation Model Framework
	E-04	*	M-H	4.34	H	4	*	Waste Package Degradation Model (mechanistic)
	E-06	*	M-H	4.34	H	4		Waste Package Degradation Testing
	E-07	*	M	4.34	M	4	*	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment
2.1.03.04 *Localized Corrosion of Waste Packages*								
	C-16	*	H	4.34	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
	P-12	*	H	4.34	H	5		WP Degradation Model Framework
	E-03	*	M-H	4.34	H	4		THC processes in EBS
	E-04	*	M-H	4.34	H	4	*	Waste Package Degradation Model (mechanistic)
	E-06	*	M-H	4.34	H	4		Waste Package Degradation Testing
	E-07	*	M	4.34	M	4	*	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment
2.1.03.05 *Hydride Cracking of Waste Packages*								
	C-16	*	H	4.34	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
	P-12	*	H	4.34	H	5		WP Degradation Model Framework
	E-04	*	M-H	4.34	H	4	*	Waste Package Degradation Model (mechanistic)

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	E-06	*	M-H	4.34	H	4		Waste Package Degradation Testing
	E-07	*	M	4.34	M	4	*	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment
2.1.03.06 *Microbially Influenced Corrosion (MIC) of Waste Packages*								
	C-16	*	H	0.00	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
2.1.03.08 *Evolution of Flow Pathways in Waste Packages*								
	D-01	*	H	1.96	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	1.96	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	1.96	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	1.96	H	5		Source term development with and without criticality
2.1.04.01 *Evolution and Degradation of Backfill*								
	A-08	*	H	3.50	H	5		Evaluation of ordinary Portland cement (OPC)
	C-15	*	H	3.50	H	5	*	Design improved backfill and seal materials
	D-01	*	H	3.50	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-04	*	H	3.50	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	E-11	*	H	3.50	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
	E-17	*	H	3.50	H	5	*	Buffer Material by Design
	I-04	*	H	3.50	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-08	*	H	3.50	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-12	*	H	3.50	H	5		TH and THM Process in Salt: German-US Collaborations (WEIMOS)
	I-13	*	H	3.50	H	5		TH and THM Process in Salt: German-US Collaborations (BENVASIM)
	A-04	*	M-H	3.50	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	C-06	*	M-H	3.50	H	4		Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D
	C-08	*	M-H	3.50	H	4		Interaction of Buffer w/ Crystalline Rock
	E-03	*	M-H	3.50	H	4		THC processes in EBS
	E-10	*	M-H	3.50	H	4		High-Temperature Behavior
	I-02	*	M-H	3.50	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	3.50	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-07	*	M-H	3.50	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	I-14	*	M-H	3.50	H	4		TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)
	S-08	*	M-H	3.50	H	4		Evolution of run-of-mine salt backfill
	A-02	*	M	3.50	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	*	M	3.50	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	A-05	*	M	3.50	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	A-06	*	M	3.50	M	4		Diffusion of actinides through bentonite (including speciation)
	A-07	*	M	3.50	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	C-04	*	M	3.50	M	4		Lab and modeling study of EDZ - Crystalline
	C-05	*	M	3.50	H	3		Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization
	E-08	*	M	3.50	H	3		Radionuclide Interaction w/ Buffer Materials
	E-12	*	M	3.50	M	5		Buffer/backfill dry-out and resaturation process
	I-05	*	M	3.50	H	3		Mont Terri FE (Full-scale Emplacement) Experiment

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-15	*	M	3.50	M	4		TH and THM Process in Salt: German-US Collaborations (RANGER)
	S-09	*	M	3.50	M	3		Numerical modeling of dryout in multiphase
	S-10	*	M	3.50	M	3	*	Drift resaturation process in PA
2.1.05.01 *Degradation of Seals*								
	A-08	*	H	3.50	H	5		Evaluation of ordinary Portland cement (OPC)
	E-09	*	H	3.50	H	5		Cement plug/liner degradation
	E-03	*	M-H	3.50	H	4		THC processes in EBS
	I-03	*	M-H	3.50	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-07	*	M-H	3.50	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	A-02	*	M	3.50	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	*	M	3.50	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	O-04	*	M	3.50	M	3		Thermodynamic and sorption database(s)
2.1.06.01 *Degradation of Liner / Rock Reinforcement Materials in EBS*								
	E-09	*	H	2.62	H	5		Cement plug/liner degradation
2.1.07.02 *Drift Collapse*								
	I-04	*	H	2.70	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-02	*	M-H	2.70	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.70	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-07	*	M-H	2.70	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	C-04	*	M	2.70	M	4		Lab and modeling study of EDZ - Crystalline
2.1.07.03 *Mechanical Effects of Backfill*								
	I-04	*	H	3.29	H	5		Experiment of bentonite EBS under high temperature, HotBENT

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-12	*	H	3.29	H	5		TH and THM Process in Salt: German-US Collaborations (WEIMOS)
	I-13	*	H	3.29	H	5		TH and THM Process in Salt: German-US Collaborations (BENVASIM)
	I-02	*	M-H	3.29	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	3.29	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-14	*	M-H	3.29	H	4		TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)
	I-15	*	M	3.29	M	4		TH and THM Process in Salt: German-US Collaborations (RANGER)
2.1.07.04 *Mechanical Impact on Backfill*								
	D-01	*	H	2.94	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-04	*	H	2.94	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	I-04	*	H	2.94	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	S-01	*	H	2.94	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	I-02	*	M-H	2.94	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.94	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	S-02	*	M-H	2.94	H	4		Salt Coupled THM processes, creep closure of excavations
2.1.07.05 *Mechanical Impact on Waste Packages*								
	C-16	*	H	2.76	H	5	*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
	D-01	*	H	2.76	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	D-03	*	H	2.76	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	2.76	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	E-07	*	M	2.76	M	4	*	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment
2.1.07.06 *Mechanical Impact on SNF Waste Form*								
	E-02	*	M-H	2.47	H	4		SNF Degradation testing activities
2.1.07.08 *Mechanical Impact on Other EBS Components (Seals, Liner / Rock Reinforcement Materials, Waste Package Support Materials)*								
	I-07	*	M-H	2.16	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.07.09 *Mechanical Effects at EBS Component Interfaces*								
	I-04	*	H	2.56	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-02	*	M-H	2.56	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.56	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-07	*	M-H	2.56	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.08.01 *Flow through the EBS*								
	C-15	*	H	0.00	H	5	*	Design improved backfill and seal materials
	C-11	*	M-H	0.00	H	4	*	Investigation of fluid flow and transport in low permeability media (clay materials).
2.1.08.02 *Flow in and through Waste Packages*								
	D-01	*	H	0.86	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	D-03	*	H	0.86	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	0.86	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	0.86	H	5		Source term development with and without criticality
2.1.08.03 *Flow in Backfill*								
	C-15	*	H	2.76	H	5	*	Design improved backfill and seal materials
	I-04	*	H	2.76	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-08	*	H	2.76	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-13	*	H	2.76	H	5		TH and THM Process in Salt: German-US Collaborations (BENVASIM)
	S-01	*	H	2.76	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	*	H	2.76	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	*	H	2.76	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	I-02	*	M-H	2.76	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.76	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-14	*	M-H	2.76	H	4		TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)
	S-08	*	M-H	2.76	H	4		Evolution of run-of-mine salt backfill
	A-02	*	M	2.76	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	*	M	2.76	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	A-05	*	M	2.76	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	I-15	*	M	2.76	M	4		TH and THM Process in Salt: German-US Collaborations (RANGER)
	S-09	*	M	2.76	M	3		Numerical modeling of dryout in multiphase

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	S-10	*	M	2.76	M	3	*	Drift resaturation process in PA
	A-01	*	L	2.76	L	3		Two-Part Hooke's Model(saturated)

2.1.08.04 *Flow through Seals*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	A-08	*	H	2.80	H	5		Evaluation of ordinary Portland cement (OPC)
	C-15	*	H	2.80	H	5	*	Design improved backfill and seal materials
	I-07	*	M-H	2.80	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	A-02	*	M	2.80	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	*	M	2.80	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	A-05	*	M	2.80	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	A-01	*	L	2.80	L	3		Two-Part Hooke's Model(saturated)

2.1.08.05 *Flow through Liner / Rock Reinforcement Materials in EBS*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-15	*	H	0.85	H	5	*	Design improved backfill and seal materials
	I-07	*	M-H	0.85	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.

2.1.08.06 *Alteration and Evolution of EBS Flow Pathways*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-15	*	H	0.00	H	5	*	Design improved backfill and seal materials

2.1.08.07 *Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-04	*	H	1.73	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-08	*	H	1.73	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-02	*	M-H	1.73	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	1.73	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-07	*	M-H	1.73	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.08.08 *Capillary Effects in EBS*								
	I-04	*	H	2.02	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-08	*	H	2.02	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-02	*	M-H	2.02	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.02	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-07	*	M-H	2.02	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.08.09 *Influx/Seepage into the EBS*								
	I-07	*	M-H	1.89	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.09.01 *Chemistry of Water Flowing into the Repository*								
	I-07	*	M-H	2.64	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.09.02 *Chemical Characteristics of Water in Waste Packages*								
	D-01	*	H	2.76	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	2.76	H	5		DPC filler and neutron absorber degradation testing and analysis

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	D-04	*	H	2.76	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	2.76	H	5		Source term development with and without criticality
	E-14	*	H	2.76	H	5	*	In-Package Chemistry
	E-01	*	M	2.76	M	3		SNF Degradation(& FMDM)
	E-05	*	M	2.76	M	5		Corrosion Products - incorporation of radionuclides
	E-19	*	L	2.76			*	Other SNF/HLW Types
2.1.09.03 *Chemical Characteristics of Water in Backfill*								
	I-07	*	M-H	1.47	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
2.1.09.05 *Chemical Interaction of Water with Corrosion Products (in Waste Packages, in Backfill, in Tunnels)*								
	C-12	*	M	0.00	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.06 *Chemical Interaction of Water with Backfill (on Waste Packages, in Backfill, in Tunnels)*								
	C-15	*	H	0.00	H	5	*	Design improved backfill and seal materials
	C-12	*	M	0.00	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.07 *Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)*								
	C-15	*	H	2.80	H	5	*	Design improved backfill and seal materials
	E-03	*	M-H	2.80	H	4		THC processes in EBS
	C-12	*	M	2.80	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.08 *Chemical Interaction of Water with Other EBS Components (in Waste Packages, in Tunnels)*								
	C-15	*	H	0.00	H	5	*	Design improved backfill and seal materials

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-12	*	M	0.00	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.09 *Chemical Effects at EBS Component Interfaces*								
	I-07	*	M-H	2.61	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	C-12	*	M	2.61	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.13 *Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*								
	A-08	*	H	4.86	H	5		Evaluation of ordinary Portland cement (OPC)
	E-09	*	H	4.86	H	5		Cement plug/liner degradation
	E-03	*	M-H	4.86	H	4		THC processes in EBS
	I-07	*	M-H	4.86	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	P-11	*	M-H	4.86	H	4	*	Pitzer model
	P-13	*	M-H	4.86	H	4	*	Full Representation of Chemical processes in PA
	P-15	*	M-H	4.86	H	4	*	Species and element properties
	P-16	*	M-H	4.86	H	4	*	Solid solution model
	A-06	*	M	4.86	M	4		Diffusion of actinides through bentonite (including speciation)
	E-01	*	M	4.86	M	3		SNF Degradation(& FMDM)
	O-04	*	M	4.86	M	3		Thermodynamic and sorption database(s)
	P-06	*	M	4.86	H	3		(Pseudo) Colloid-Facilitated Transport Model
	E-19	*	L	4.86			*	Other SNF/HLW Types
2.1.09.51 *Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*								
	A-07	*	M	3.06	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	C-12	*	M	3.06	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	E-05	*	M	3.06	M	5		Corrosion Products - incorporation of radionuclides
	E-08	*	M	3.06	H	3		Radionuclide Interaction w/ Buffer Materials
	E-12	*	M	3.06	M	5		Buffer/backfill dry-out and resaturation process
	E-16	*	M	3.06	M	5	*	In-Package Flow
2.1.09.52 *Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*								
	A-06	*	M	3.06	M	4		Diffusion of actinides through bentonite (including speciation)
	A-07	*	M	3.06	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	C-12	*	M	3.06	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	E-05	*	M	3.06	M	5		Corrosion Products - incorporation of radionuclides
	E-08	*	M	3.06	H	3		Radionuclide Interaction w/ Buffer Materials
	E-12	*	M	3.06	M	5		Buffer/backfill dry-out and resaturation process
2.1.09.53 *Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*								
	C-12	*	M	3.06	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	E-05	*	M	3.06	M	5		Corrosion Products - incorporation of radionuclides
	E-08	*	M	3.06	H	3		Radionuclide Interaction w/ Buffer Materials
	E-12	*	M	3.06	M	5		Buffer/backfill dry-out and resaturation process
2.1.09.54 *Complexation in EBS*								
	C-12	*	M	1.62	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.09.55 *Formation of Colloids in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*								
	E-20	*	M-H	1.79	H	4		colloid source terms
2.1.09.62 *Radionuclide Transport through Liners and Seals*								

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-12	*	M	0.00	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.1.11.01 *Heat Generation in EBS*								
	D-01	*	H	2.59	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	2.59	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	2.59	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	2.59	H	5		Source term development with and without criticality
	E-11	*	H	2.59	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
	S-01	*	H	2.59	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	*	H	2.59	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	*	H	2.59	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-05	*	H	2.59	H	5		Borehole-based Field Testing in Salt
	E-10	*	M-H	2.59	H	4		High-Temperature Behavior
	S-07	*	M-H	2.59	H	4		Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)
	S-08	*	M-H	2.59	H	4		Evolution of run-of-mine salt backfill
	E-12	*	M	2.59	M	5		Buffer/backfill dry-out and resaturation process
	S-06	*	M	2.59	H	3		Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)
	S-09	*	M	2.59	M	3		Numerical modeling of dryout in multiphase
	S-10	*	M	2.59	M	3	*	Drift resaturation process in PA
	E-18	*	L	2.59		4	*	Unbackfilled-Drift Thermal Radiation Model

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.1.11.02 *Exothermic Reactions in EBS*								
	E-02	*	M-H	0.99	H	4		SNF Degradation testing activities
2.1.11.03 *Effects of Backfill on EBS Thermal Environment*								
	C-15	*	H	2.22	H	5	*	Design improved backfill and seal materials
2.1.11.04 *Effects of Drift Collapse on EBS Thermal Environment*								
	I-04	*	H	2.39	H	5		Experiment of bentonite EBS under high temperature, HotBENT
	I-02	*	M-H	2.39	H	4		FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling
	I-03	*	M-H	2.39	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
2.1.12.01 *Gas Generation in EBS*								
	I-08	*	H	0.98	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
2.1.12.02 *Effects of Gas on Flow through the EBS*								
	I-08	*	H	0.98	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
2.1.12.03 *Gas Transport in EBS*								
	I-08	*	H	1.02	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	A-04	*	M-H	1.02	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
2.1.13.01 *Radiolysis (in Waste Package, in Backfill, and in Tunnel)*								
	D-01	*	H	0.00	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
	D-03	*	H	0.00	H	5		DPC filler and neutron absorber degradation testing and analysis
	D-04	*	H	0.00	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
	D-05	*	H	0.00	H	5		Source term development with and without criticality

FEP		Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.1.13.02	*Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)*								
		D-01	*	H	1.73	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
		D-03	*	H	1.73	H	5		DPC filler and neutron absorber degradation testing and analysis
		D-04	*	H	1.73	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
		D-05	*	H	1.73	H	5		Source term development with and without criticality
2.1.14.01	*Criticality In-Package*								
		D-01	*	H	0.96	H	5		Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
		D-03	*	H	0.96	H	5		DPC filler and neutron absorber degradation testing and analysis
		D-04	*	H	0.96	H	5		Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
		D-05	*	H	0.96	H	5		Source term development with and without criticality
		D-06	*	L	0.96		2		Technical integration of DPC direct disposal
2.2.01.01	*Evolution of EDZ*								
		E-11	A	H	8.00	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
		E-11	C	H	2.58	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
		E-11	S	H	2.58	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	S-01	S	H	2.58	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	S	H	2.58	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	S	H	2.58	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-05	S	H	2.58	H	5		Borehole-based Field Testing in Salt
	A-04	A	M-H	8.00	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	E-10	A	M-H	8.00	H	4		High-Temperature Behavior
	E-10	C	M-H	2.58	H	4		High-Temperature Behavior
	E-10	S	M-H	2.58	H	4		High-Temperature Behavior
	I-07	A	M-H	8.00	H	4		DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.
	I-09	A	M-H	8.00	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-02	S	M-H	2.58	H	4		Salt Coupled THM processes, creep closure of excavations
	S-07	S	M-H	2.58	H	4		Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)
	S-08	S	M-H	2.58	H	4		Evolution of run-of-mine salt backfill
	A-05	A	M	8.00	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	A-07	A	M	8.00	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	E-08	A	M	8.00	H	3		Radionuclide Interaction w/ Buffer Materials
	E-08	C	M	2.58	H	3		Radionuclide Interaction w/ Buffer Materials
	E-08	S	M	2.58	H	3		Radionuclide Interaction w/ Buffer Materials
	E-12	A	M	8.00	M	5		Buffer/backfill dry-out and resaturation process
	E-12	C	M	2.58	M	5		Buffer/backfill dry-out and resaturation process
	E-12	S	M	2.58	M	5		Buffer/backfill dry-out and resaturation process
	I-05	A	M	8.00	H	3		Mont Terri FE (Full-scale Emplacement) Experiment

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	S-06	S	M	2.58	H	3		Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)
	S-09	S	M	2.58	M	3		Numerical modeling of dryout in multiphase
	S-10	S	M	2.58	M	3	*	Drift resaturation process in PA
2.2.02.01 *Stratigraphy and Properties of Host Rock*								
	C-01	C	M-H	3.74	H	4		Discrete Fracture Network (DFN) Model
	O-02	A	M-H	3.74	H	4		GDSA Geologic Modeling
	O-02	C	M-H	3.74	H	4		GDSA Geologic Modeling
	O-02	S	M-H	3.74	H	4		GDSA Geologic Modeling
	O-03	A	M-H	3.74	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	O-03	C	M-H	3.74	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	O-03	S	M-H	3.74	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	C-02	C	M	3.74	H	3		Flow and Transport in Fractures - modeling approaches
	C-03	C	M	3.74	H	3		Fracture-Matrix Diffusion - Modeling approaches
	C-05	C	M	3.74	H	3		Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization
	C-09	C	M	3.74	M	3		Development of a centralized technical database for crystalline disposal system evaluation
2.2.03.01 *Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*								
	P-01	A	M-H	2.46	H	4		CSNF repository argillite reference case
	P-02	C	M-H	2.46	H	4		CSNF repository crystalline reference case
	P-03	S	M	2.46	H	3		CSNF repository bedded salt reference case
2.2.05.01 *Fractures (Host Rock, and Other Geologic Units)*								
	I-06	A	H	3.65	H	5		Mont Terri FS Fault Slip Experiment
	C-01	C	M-H	3.65	H	4		Discrete Fracture Network (DFN) Model
	C-17	C	M-H	3.65	H	4	*	Model DFN evolution due to changes in stress field
	I-09	C	M-H	3.65	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	O-02	A	M-H	3.65	H	4		GDSA Geologic Modeling

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	O-02	C	M-H	3.65	H	4		GDSA Geologic Modeling
	O-02	S	M-H	3.65	H	4		GDSA Geologic Modeling
	O-03	A	M-H	3.65	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	O-03	C	M-H	3.65	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	O-03	S	M-H	3.65	H	4		Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling
	A-05	A	M	3.65	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	C-02	C	M	3.65	H	3		Flow and Transport in Fractures - modeling approaches
	C-03	C	M	3.65	H	3		Fracture-Matrix Diffusion - Modeling approaches
	C-05	C	M	3.65	H	3		Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization
	C-07	C	M	3.65	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.65	M	3	*	Collate data from International URLs
	I-01	C	M	3.65	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.65	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
2.2.05.03 *Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)*								
	I-06	A	H	2.46	H	5		Mont Terri FS Fault Slip Experiment
	C-17	C	M-H	2.46	H	4	*	Model DFN evolution due to changes in stress field
	C-07	C	M	2.46	M	4		Colloids in Fractures and Matrix
	I-01	C	M	2.46	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	2.46	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
2.2.07.01 *Mechanical Effects on Host Rock*								
	S-01	S	H	3.83	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	S	H	3.83	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	S-04	S	H	3.83	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	C-17	C	M-H	1.63	H	4	*	Model DFN evolution due to changes in stress field
	I-09	A	M-H	3.83	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-02	S	M-H	3.83	H	4		Salt Coupled THM processes, creep closure of excavations
	A-02	A	M	3.83	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	A	M	3.83	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	A-05	A	M	3.83	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	I-05	A	M	3.83	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	A-01	A	L	3.83	L	3		Two-Part Hooke's Model(saturated)
2.2.07.02 *Mechanical Effects on Other Geologic Units*								
	A-04	A	M-H	3.10	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	I-09	A	M-H	3.10	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	I-05	A	M	3.10	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
2.2.08.01 *Flow through the Host Rock*								
	E-11	A	H	3.65	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
	E-11	C	H	3.65	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
	E-11	S	H	7.73	H	5		EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
	S-01	S	H	7.73	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	S-05	S	H	7.73	H	5		Borehole-based Field Testing in Salt
	C-01	C	M-H	3.65	H	4		Discrete Fracture Network (DFN) Model
	C-11	C	M-H	3.65	H	4	*	Investigation of fluid flow and transport in low permeability media (clay materials).
	C-17	C	M-H	3.65	H	4	*	Model DFN evolution due to changes in stress field
	E-10	A	M-H	3.65	H	4		High-Temperature Behavior
	E-10	C	M-H	3.65	H	4		High-Temperature Behavior
	E-10	S	M-H	7.73	H	4		High-Temperature Behavior
	I-09	A	M-H	3.65	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-11	S	M-H	7.73	H	4	*	THMC effects of anhydrites, clays, and other non-salt components
	C-02	C	M	3.65	H	3		Flow and Transport in Fractures - modeling approaches
	C-07	C	M	3.65	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.65	M	3	*	Collate data from International URLs
	I-01	C	M	3.65	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-05	A	M	3.65	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	I-10	C	M	3.65	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	S-12	S	M	7.73	M	4		Laboratory testing and modeling of fluid inclusions

2.2.08.02 *Flow through the Other Geologic Units (Confining Units and Aquifers)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-01	C	M-H	3.65	H	4		Discrete Fracture Network (DFN) Model
	I-09	A	M-H	3.65	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	P-01	A	M-H	3.65	H	4		CSNF repository argillite reference case
	P-02	C	M-H	3.65	H	4		CSNF repository crystalline reference case
	C-02	C	M	3.65	H	3		Flow and Transport in Fractures - modeling approaches
	I-01	C	M	3.65	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-05	A	M	3.65	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	P-03	S	M	7.73	H	3		CSNF repository bedded salt reference case

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.2.08.04 *Effects of Repository Excavation on Flow through the Host Rock*								
	S-03	S	H	7.10	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	S	H	7.10	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-05	S	H	7.10	H	5		Borehole-based Field Testing in Salt
	A-04	A	M-H	3.23	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	C-08	C	M-H	3.23	H	4		Interaction of Buffer w/ Crystalline Rock
	I-09	A	M-H	3.23	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	I-09	C	M-H	3.23	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-08	S	M-H	7.10	H	4		Evolution of run-of-mine salt backfill
	A-05	A	M	3.23	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	C-07	C	M	3.23	M	4		Colloids in Fractures and Matrix
	I-01	C	M	3.23	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-05	A	M	3.23	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	I-10	C	M	3.23	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	S-06	S	M	7.10	H	3		Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)
	S-09	S	M	7.10	M	3		Numerical modeling of dryout in multiphase
	S-10	S	M	7.10	M	3	*	Drift resaturation process in PA
2.2.08.06 *Flow through EDZ*								
	E-09	A	H	3.65	H	5		Cement plug/liner degradation
	E-09	C	H	3.65	H	5		Cement plug/liner degradation
	E-09	S	H	7.73	H	5		Cement plug/liner degradation
	I-08	A	H	3.65	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-08	C	H	3.65	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-16	S	H	7.73	H	5	*	New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling
	S-01	S	H	7.73	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	S	H	7.73	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	S	H	7.73	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-05	S	H	7.73	H	5		Borehole-based Field Testing in Salt
	C-08	C	M-H	3.65	H	4		Interaction of Buffer w/ Crystalline Rock
	I-09	A	M-H	3.65	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-07	S	M-H	7.73	H	4		Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)
	S-08	S	M-H	7.73	H	4		Evolution of run-of-mine salt backfill
	S-11	S	M-H	7.73	H	4	*	THMC effects of anhydrites, clays, and other non-salt components
	A-02	A	M	3.65	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	A	M	3.65	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
	A-05	A	M	3.65	M	4		THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)
	A-07	A	M	3.65	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	C-04	C	M	3.65	M	4		Lab and modeling study of EDZ - Crystalline
	C-05	C	M	3.65	H	3		Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization
	C-07	C	M	3.65	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.65	M	3	*	Collate data from International URLs
	E-12	A	M	3.65	M	5		Buffer/backfill dry-out and resaturation process
	E-12	C	M	3.65	M	5		Buffer/backfill dry-out and resaturation process
	E-12	S	M	7.73	M	5		Buffer/backfill dry-out and resaturation process
	I-01	C	M	3.65	M	3		Radionuclide transport as pseudocolloids, Grimsel

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-05	A	M	3.65	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	I-10	C	M	3.65	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	S-06	S	M	7.73	H	3		Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)
	S-09	S	M	7.73	M	3		Numerical modeling of dryout in multiphase
	S-10	S	M	7.73	M	3	*	Drift resaturation process in PA
	S-12	S	M	7.73	M	4		Laboratory testing and modeling of fluid inclusions
	A-01	A	L	3.65	L	3		Two-Part Hooke's Model(saturated)
2.2.08.07 *Mineralogic Dehydration*								
	S-01	S	H	6.49	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	S	H	6.49	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	S	H	6.49	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-05	S	H	6.49	H	5		Borehole-based Field Testing in Salt
	I-03	A	M-H	2.82	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-03	C	M-H	2.82	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-03	S	M-H	6.49	H	4		FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test
	I-09	A	M-H	2.82	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	S-07	S	M-H	6.49	H	4		Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)
	S-08	S	M-H	6.49	H	4		Evolution of run-of-mine salt backfill
	S-11	S	M-H	6.49	H	4	*	THMC effects of anhydrites, clays, and other non-salt components
	A-07	A	M	2.82	M	5		Analysis of clay hydration/dehydration and alteration under various environmental conditions
	C-07	C	M	2.82	M	4		Colloids in Fractures and Matrix

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-01	C	M	2.82	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-05	A	M	2.82	H	3		Mont Terri FE (Full-scale Emplacement) Experiment
	I-10	C	M	2.82	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	S-06	S	M	6.49	H	3		Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)
	S-09	S	M	6.49	M	3		Numerical modeling of dryout in multiphase
	S-10	S	M	6.49	M	3	*	Drift resaturation process in PA
2.2.09.01 *Chemical Characteristics of Groundwater in Host Rock*								
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	C-07	C	M	2.40	M	4		Colloids in Fractures and Matrix
	C-09	C	M	2.40	M	3		Development of a centralized technical database for crystalline disposal system evaluation
	C-10	C	M	2.40	M	3	*	Collate data from International URLs
	I-01	C	M	2.40	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	2.40	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
2.2.09.02 *Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*								
	I-09	C	M-H	2.40	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
2.2.09.03 *Chemical Interactions and Evolution of Groundwater in Host Rock*								
	E-09	A	H	3.10	H	5		Cement plug/liner degradation
	E-09	C	H	2.10	H	5		Cement plug/liner degradation
	E-09	S	H	2.10	H	5		Cement plug/liner degradation
	P-13	A	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-07	C	M	2.10	M	4		Colloids in Fractures and Matrix
	C-12	C	M	2.10	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	2.10	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	2.10	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.04 *Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-13	A	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA
	C-12	C	M	2.10	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock

2.2.09.05 *Radionuclide Speciation and Solubility in Host Rock*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	2.40	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	2.40	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	2.40	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	2.40	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	2.40	M	4		Colloids in Fractures and Matrix
	C-09	C	M	2.40	M	3		Development of a centralized technical database for crystalline disposal system evaluation
	C-12	C	M	2.40	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-01	C	M	2.40	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	2.40	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
2.2.09.06 *Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*								
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	2.40	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	2.40	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	2.40	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	2.40	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-12	C	M	2.40	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.2.09.51 *Advection of Dissolved Radionuclides in Host Rock*								
	C-01	C	M-H	3.74	H	4		Discrete Fracture Network (DFN) Model
	C-08	C	M-H	3.74	H	4		Interaction of Buffer w/ Crystalline Rock
	C-13	C	M-H	3.74	H	4	*	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport
	C-14	C	M-H	3.74	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
	I-09	C	M-H	3.74	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	I-21	C	M-H	3.74	H	4	*	New Activity: SKB Task 10 Validation of DFN Modeling
	P-11	A	M-H	3.74	H	4	*	Pitzer model
	P-11	C	M-H	3.74	H	4	*	Pitzer model
	P-11	S	M-H	2.53	H	4	*	Pitzer model
	P-13	A	M-H	3.74	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.74	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.53	H	4	*	Full Representation of Chemical processes in PA

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-15	A	M-H	3.74	H	4	*	Species and element properties
	P-15	C	M-H	3.74	H	4	*	Species and element properties
	P-15	S	M-H	2.53	H	4	*	Species and element properties
	P-16	A	M-H	3.74	H	4	*	Solid solution model
	P-16	C	M-H	3.74	H	4	*	Solid solution model
	P-16	S	M-H	2.53	H	4	*	Solid solution model
	P-17	A	M-H	3.74	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.74	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.53	H	4	*	Multi-Component Gas Transport
	C-02	C	M	3.74	H	3		Flow and Transport in Fractures - modeling approaches
	C-03	C	M	3.74	H	3		Fracture-Matrix Diffusion - Modeling approaches
	C-04	C	M	3.74	M	4		Lab and modeling study of EDZ - Crystalline
	C-07	C	M	3.74	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.74	M	3	*	Collate data from International URLs
	C-12	C	M	3.74	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	3.74	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.74	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.52 *Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.2.09.53 *Diffusion of Dissolved Radionuclides in Host Rock*								
	S-03	S	H	2.40	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	C-13	C	M-H	3.55	H	4	*	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport
	C-14	C	M-H	3.55	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
2.2.09.54 *Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*								
	S-03	S	H	2.40	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.2.09.55 *Sorption of Dissolved Radionuclides in Host Rock*								
	C-13	C	M-H	3.55	H	4	*	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport
	C-14	C	M-H	3.55	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.55	M	3	*	Collate data from International URLs
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.56 *Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock

2.2.09.57 *Complexation in Host Rock*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-14	C	M-H	3.55	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	C-09	C	M	3.55	M	3		Development of a centralized technical database for crystalline disposal system evaluation
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.58 *Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*

	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
2.2.09.59 *Colloidal Transport in Host Rock*								
	C-14	C	M-H	3.29	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
	P-11	A	M-H	3.29	H	4	*	Pitzer model
	P-11	C	M-H	3.29	H	4	*	Pitzer model
	P-11	S	M-H	2.22	H	4	*	Pitzer model
	P-13	A	M-H	3.29	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.29	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.22	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.29	H	4	*	Species and element properties
	P-15	C	M-H	3.29	H	4	*	Species and element properties
	P-15	S	M-H	2.22	H	4	*	Species and element properties
	P-16	A	M-H	3.29	H	4	*	Solid solution model
	P-16	C	M-H	3.29	H	4	*	Solid solution model
	P-16	S	M-H	2.22	H	4	*	Solid solution model
	P-17	A	M-H	3.29	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.29	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.22	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.29	M	4		Colloids in Fractures and Matrix
	C-07	C	M	3.29	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.29	M	3	*	Collate data from International URLs
	C-12	C	M	3.29	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	I-01	C	M	3.29	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.29	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	P-06	A	M	3.29	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	C	M	3.29	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	S	M	2.22	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-07	A	L	3.29	L	3		Intrinsic Colloid Model
	P-07	C	L	3.29	L	3		Intrinsic Colloid Model
	P-07	S	L	2.22	L	3		Intrinsic Colloid Model

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity

2.2.09.60 *Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*

	P-11	A	M-H	3.29	H	4	*	Pitzer model
	P-11	C	M-H	3.29	H	4	*	Pitzer model
	P-11	S	M-H	2.22	H	4	*	Pitzer model
	P-15	A	M-H	3.29	H	4	*	Species and element properties
	P-15	C	M-H	3.29	H	4	*	Species and element properties
	P-15	S	M-H	2.22	H	4	*	Species and element properties
	P-16	A	M-H	3.29	H	4	*	Solid solution model
	P-16	C	M-H	3.29	H	4	*	Solid solution model
	P-16	S	M-H	2.22	H	4	*	Solid solution model
	P-17	A	M-H	3.29	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.29	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.22	H	4	*	Multi-Component Gas Transport
	C-12	C	M	3.29	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	P-06	A	M	3.29	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	C	M	3.29	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	S	M	2.22	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-07	A	L	3.29	L	3		Intrinsic Colloid Model
	P-07	C	L	3.29	L	3		Intrinsic Colloid Model
	P-07	S	L	2.22	L	3		Intrinsic Colloid Model

2.2.09.61 *Radionuclide Transport through EDZ*

	E-09	A	H	3.55	H	5		Cement plug/liner degradation
	E-09	C	H	3.55	H	5		Cement plug/liner degradation
	E-09	S	H	2.40	H	5		Cement plug/liner degradation
	E-03	A	M-H	3.55	H	4		THC processes in EBS
	E-03	C	M-H	3.55	H	4		THC processes in EBS
	E-03	S	M-H	2.40	H	4		THC processes in EBS
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	C-10	C	M	3.55	M	3	*	Collate data from International URLs
	C-12	C	M	3.55	M	4	*	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock
	E-08	A	M	3.55	H	3		Radionuclide Interaction w/ Buffer Materials
	E-08	C	M	3.55	H	3		Radionuclide Interaction w/ Buffer Materials
	E-08	S	M	2.40	H	3		Radionuclide Interaction w/ Buffer Materials
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL
	O-04	A	M	3.55	M	3		Thermodynamic and sorption database(s)
	O-04	C	M	3.55	M	3		Thermodynamic and sorption database(s)
	O-04	S	M	2.40	M	3		Thermodynamic and sorption database(s)
	P-06	A	M	3.55	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	C	M	3.55	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-06	S	M	2.40	H	3		(Pseudo) Colloid-Facilitated Transport Model
	P-07	A	L	3.55	L	3		Intrinsic Colloid Model
	P-07	C	L	3.55	L	3		Intrinsic Colloid Model
	P-07	S	L	2.40	L	3		Intrinsic Colloid Model
2.2.09.62 *Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)*								
	P-11	A	M-H	3.10	H	4	*	Pitzer model
	P-11	C	M-H	3.10	H	4	*	Pitzer model
	P-11	S	M-H	2.10	H	4	*	Pitzer model
	P-13	A	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.10	H	4	*	Species and element properties
	P-15	C	M-H	3.10	H	4	*	Species and element properties
	P-15	S	M-H	2.10	H	4	*	Species and element properties
	P-16	A	M-H	3.10	H	4	*	Solid solution model
	P-16	C	M-H	3.10	H	4	*	Solid solution model

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-16	S	M-H	2.10	H	4	*	Solid solution model
	P-17	A	M-H	3.10	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.10	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.10	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.10	M	4		Colloids in Fractures and Matrix
	I-01	C	M	3.10	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.10	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.63 *Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)*

Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
P-11	A	M-H	3.10	H	4	*	Pitzer model
P-11	C	M-H	3.10	H	4	*	Pitzer model
P-11	S	M-H	2.10	H	4	*	Pitzer model
P-13	A	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
P-13	C	M-H	3.10	H	4	*	Full Representation of Chemical processes in PA
P-13	S	M-H	2.10	H	4	*	Full Representation of Chemical processes in PA
P-15	A	M-H	3.10	H	4	*	Species and element properties
P-15	C	M-H	3.10	H	4	*	Species and element properties
P-15	S	M-H	2.10	H	4	*	Species and element properties
P-16	A	M-H	3.10	H	4	*	Solid solution model
P-16	C	M-H	3.10	H	4	*	Solid solution model
P-16	S	M-H	2.10	H	4	*	Solid solution model
P-17	A	M-H	3.10	H	4	*	Multi-Component Gas Transport
P-17	C	M-H	3.10	H	4	*	Multi-Component Gas Transport
P-17	S	M-H	2.10	H	4	*	Multi-Component Gas Transport
C-07	C	M	3.10	M	4		Colloids in Fractures and Matrix
I-01	C	M	3.10	M	3		Radionuclide transport as pseudocolloids, Grimsel
I-10	C	M	3.10	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.64 *Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)*

Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
I-08	A	H	3.55	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
I-08	C	H	3.55	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
P-11	A	M-H	3.55	H	4	*	Pitzer model
P-11	C	M-H	3.55	H	4	*	Pitzer model
P-11	S	M-H	2.40	H	4	*	Pitzer model
P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	I-01	A	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

2.2.09.65 *Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)*

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	P-11	A	M-H	3.55	H	4	*	Pitzer model
	P-11	C	M-H	3.55	H	4	*	Pitzer model
	P-11	S	M-H	2.40	H	4	*	Pitzer model
	P-13	A	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	C	M-H	3.55	H	4	*	Full Representation of Chemical processes in PA
	P-13	S	M-H	2.40	H	4	*	Full Representation of Chemical processes in PA
	P-15	A	M-H	3.55	H	4	*	Species and element properties
	P-15	C	M-H	3.55	H	4	*	Species and element properties
	P-15	S	M-H	2.40	H	4	*	Species and element properties
	P-16	A	M-H	3.55	H	4	*	Solid solution model
	P-16	C	M-H	3.55	H	4	*	Solid solution model
	P-16	S	M-H	2.40	H	4	*	Solid solution model
	P-17	A	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	C	M-H	3.55	H	4	*	Multi-Component Gas Transport
	P-17	S	M-H	2.40	H	4	*	Multi-Component Gas Transport
	C-07	C	M	3.55	M	4		Colloids in Fractures and Matrix
	I-01	C	M	3.55	M	3		Radionuclide transport as pseudocolloids, Grimsel
	I-10	C	M	3.55	H	2		SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
2.2.10.01 *Microbial Activity in Host Rock*								
	C-14	C	M-H	1.32	H	4	*	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach
2.2.11.01 *Thermal Effects on Flow in NBS (Repository-Induced and Natural Geothermal)*								
	A-04	A	M-H	3.10	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	I-09	A	M-H	3.10	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
2.2.11.02 *Thermally-Driven Flow (Convection) in NBS*								
	A-04	A	M-H	3.10	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	I-09	A	M-H	3.10	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
2.2.11.03 *Thermally-Driven Buoyant Flow / Heat Pipes in NBS*								
	I-09	A	M-H	2.46	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
2.2.11.04 *Thermal Effects on Chemistry and Microbial Activity in NBS*								
	E-09	A	H	3.55	H	5		Cement plug/liner degradation
	E-09	C	H	2.40	H	5		Cement plug/liner degradation
	E-09	S	H	2.40	H	5		Cement plug/liner degradation
	E-03	A	M-H	3.55	H	4		THC processes in EBS
	E-03	C	M-H	2.40	H	4		THC processes in EBS
	E-03	S	M-H	2.40	H	4		THC processes in EBS
	I-09	A	M-H	3.55	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	I-11	A	M	3.55	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies
	I-11	C	M	2.40	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-11	S	M	2.40	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies
	O-04	A	M	3.55	M	3		Thermodynamic and sorption database(s)
	O-04	C	M	2.40	M	3		Thermodynamic and sorption database(s)
	O-04	S	M	2.40	M	3		Thermodynamic and sorption database(s)
2.2.11.05 *Thermal Effects on Transport in NBS*								
	I-09	A	M-H	0.00	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
2.2.11.06 *Thermal-Mechanical Effects on NBS*								
	A-04	A	M-H	3.40	H	4		Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)
	I-09	A	M-H	3.40	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	I-19	A	M	3.40	M	4	*	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing
	I-19	C	M	2.30	M	4	*	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing
	I-19	S	M	2.30	M	4	*	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing
2.2.11.07 *Thermal-Chemical Alteration of NBS*								
	I-09	A	M-H	3.40	H	4		DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan
	A-02	A	M	3.40	M	4		Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization
	A-03	A	M	3.40	M	4		Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS
2.2.12.02 *Effects of Gas on Flow through the NBS*								
	I-08	A	H	2.18	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-08	C	H	1.37	H	5		DECOVALEX-2019 Task A: Advective gas flow in bentonite
	I-18	A	H	2.18	H	5	*	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	I-18	C	H	1.37	H	5	*	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport
	I-18	S	H	3.23	H	5	*	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport
	S-01	S	H	3.23	H	5		Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
	S-03	S	H	3.23	H	5		Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
	S-04	S	H	3.23	H	5		Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
	S-11	S	M-H	3.23	H	4	*	THMC effects of anhydrites, clays, and other non-salt components
	I-20	A	M	2.18	M	4	*	New Activity: New Mont Terri Task: Gas Transport in Host Rock
	P-08	A	M	2.18	M	5	*	Other missing FEPs (processes) in PA-GDSA
	P-08	C	M	1.37	M	5	*	Other missing FEPs (processes) in PA-GDSA
	P-08	S	M	3.23	M	5	*	Other missing FEPs (processes) in PA-GDSA
	S-09	S	M	3.23	M	3		Numerical modeling of dryout in multiphase
	S-10	S	M	3.23	M	3	*	Drift resaturation process in PA
	S-13	S	M	3.23	M	5	*	Acid gas generation, fate, and transport
2.2.12.03 *Gas Transport in NBS*								
	I-11	A	M	1.66	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies
	I-11	C	M	1.05	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies
	I-11	S	M	2.46	M	5		Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies
2.3.08.02 *Surface Runoff and Evapotranspiration*								
	P-09	*	L	1.58	L	4		Surface processes and features
2.3.08.03 *Infiltration and Recharge*								
	P-09	*	L	1.58	L	4		Surface processes and features
N/A								
	P-10	*	M	0.00	H	2		UA/SA

FEP	Act.	Host Rock	2019 Score	2012 Score	ISC	SAL	Gap	Activity
	O-05	*	L	0.00				QA, V&V (documentation and tests)
	O-06	*	L	0.00	L	3	*	Natural/Anthropogenic Analogs for Radionuclide Transport
	O-07	*	L	0.00			*	Full Biosphere Model

APPENDIX F: FEPS AND THEIR ARGILLITE-RELATED ACTIVITIES

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.01.01	*Evolution of EDZ*						8.00
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	E-10	H	4	High-Temperature Behavior		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
1.2.03.01	*Seismic Activity Impacts EBS and/or EBS Components*						4.94
	P-05	M	4	Disruptive events		M	
2.1.09.13	*Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						4.86
	A-08	H	5	Evaluation of ordinary Portland cement (OPC)		H	
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	A-06	M	4	Diffusion of actinides through bentonite (including speciation)		M	
	E-01	M	3	SNF Degradation (& FMDM)		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	E-19			Other SNF/HLW Types	*	L	
2.1.03.02	*General Corrosion of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.03	*Stress Corrosion Cracking (SCC) of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.04	*Localized Corrosion of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.05	*Hydride Cracking of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.02.01	*SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)*						4.01
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-01	M	3	SNF Degradation (& FMDM)		M	
	E-19			Other SNF/HLW Types	*	L	
2.2.07.01	*Mechanical Effects on Host Rock*						3.83
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
	A-01	L	3	Two-Part Hooke's Model(saturated)		L	
2.2.02.01	*Stratigraphy and Properties of Host Rock*						3.74
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
2.2.09.51	*Advection of Dissolved Radionuclides in Host Rock*						3.74
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.05.01	*Fractures (Host Rock, and Other Geologic Units)*						3.65
	I-06	H	5	Mont Terri FS Fault Slip Experiment		H	
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
2.2.08.01	*Flow through the Host Rock*						3.65
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
2.2.08.02	*Flow through the Other Geologic Units (Confining Units and Aquifers)*						3.65
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	P-01	H	4	CSNF repository argillite reference case		M-H	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.08.06	*Flow through EDZ*						3.65
	E-09	H	5	Cement plug/liner degradation		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
	A-01	L	3	Two-Part Hooke's Model(saturated)		L	
2.1.02.06	*SNF Cladding Degradation and Failure*						3.62
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-15	M	5	Cladding Degradation	*	M	
2.2.09.01	*Chemical Characteristics of Groundwater in Host Rock*						3.55
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.02	*Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.05	*Radionuclide Speciation and Solubility in Host Rock*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.06	*Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.52	*Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.53	*Diffusion of Dissolved Radionuclides in Host Rock*						3.55
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.55	*Sorption of Dissolved Radionuclides in Host Rock*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.56	*Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.57	*Complexation in Host Rock*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.09.58	*Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.61	*Radionuclide Transport through EDZ*						3.55
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.64	*Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)*						3.55
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
2.2.09.65	*Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.11.04	*Thermal Effects on Chemistry and Microbial Activity in NBS*						3.55
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.1.04.01	*Evolution and Degradation of Backfill*						3.50
	A-08	H	5	Evaluation of ordinary Portland cement (OPC)		H	
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-17	H	5	Buffer Material by Design	*	H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	E-03	H	4	THC processes in EBS		M-H	
	E-10	H	4	High-Temperature Behavior		M-H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	A-06	M	4	Diffusion of actinides through bentonite(including speciation)		M	
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.1.05.01	*Degradation of Seals*						3.50
	A-08	H	5	Evaluation of ordinary Portland cement (OPC)		H	
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.2.11.06	*Thermal-Mechanical Effects on NBS*						3.40
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	I-19	M	4	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing	*	M	
2.2.11.07	*Thermal-Chemical Alteration of NBS*						3.40
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.07.03	*Mechanical Effects of Backfill*						3.29
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.2.09.59	*Colloidal Transport in Host Rock*						3.29
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.60	*Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.29
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.08.04	*Effects of Repository Excavation on Flow through the Host Rock*						3.23
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.07.02	*Mechanical Effects on Other Geologic Units*						3.10
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
2.2.09.03	*Chemical Interactions and Evolution of Groundwater in Host Rock*						3.10
	E-09	H	5	Cement plug/liner degradation		H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.04	*Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.10
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.62	*Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)*						3.10
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.63	*Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)*						3.10
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.11.01	*Thermal Effects on Flow in NBS (Repository-Induced and Natural Geothermal)*						3.10
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
2.2.11.02	*Thermally-Driven Flow (Convection) in NBS*						3.10
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
2.1.09.51	*Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	E-16	M	5	In-Package Flow	*	M	
2.1.09.52	*Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	A-06	M	4	Diffusion of actinides through bentonite(including speciation)		M	
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.09.53	*Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.07.04	*Mechanical Impact on Backfill*						2.94
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.08.07	*Mineralogic Dehydration*						2.82
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	A-07	M	5	Analysis of clay hydration/dehydration and alteration under various environmental conditions		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
2.1.08.04	*Flow through Seals*						2.80
	A-08	H	5	Evaluation of ordinary Portland cement (OPC)		H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	A-01	L	3	Two-Part Hooke's Model(saturated)		L	
2.1.09.07	*Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)*						2.80
	E-03	H	4	THC processes in EBS		M-H	
2.1.07.05	*Mechanical Impact on Waste Packages*						2.76
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.08.03	*Flow in Backfill*						2.76
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	A-02	M	4	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization		M	
	A-03	M	4	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS		M	
	A-05	M	4	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)		M	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
	A-01	L	3	Two-Part Hooke's Model(saturated)		L	
2.1.09.02	*Chemical Characteristics of Water in Waste Packages*						2.76
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-14	H	5	In-Package Chemistry	*	H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-19			Other SNF/HLW Types	*	L	
2.1.07.02	*Drift Collapse*						2.70
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.09.01	*Chemistry of Water Flowing into the Repository*						2.64
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.06.01	*Degradation of Liner / Rock Reinforcement Materials in EBS*						2.62
	E-09	H	5	Cement plug/liner degradation		H	
2.1.09.09	*Chemical Effects at EBS Component Interfaces*						2.61
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.11.01	*Heat Generation in EBS*						2.59
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	E-18		4	Unbackfilled-Drift Thermal Radiation Model	*	L	
2.1.07.09	*Mechanical Effects at EBS Component Interfaces*						2.56
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.07.06	*Mechanical Impact on SNF Waste Form*						2.47
	E-02	H	4	SNF Degradation testing activities		M-H	
2.2.03.01	*Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.46
	P-01	H	4	CSNF repository argillite reference case		M-H	
2.2.05.03	*Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)*						2.46
	I-06	H	5	Mont Terri FS Fault Slip Experiment		H	
2.2.11.03	*Thermally-Driven Buoyant Flow / Heat Pipes in NBS*						2.46
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
2.1.11.04	*Effects of Drift Collapse on EBS Thermal Environment*						2.39
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
1.2.03.02	*Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)*						2.34
	P-05	M	4	Disruptive events		M	
2.2.12.02	*Effects of Gas on Flow through the NBS*						2.18
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-18	H	5	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport	*	H	
	I-20	M	4	New Activity: New Mont Terri Task: Gas Transport in Host Rock	*	M	
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	
2.1.07.08	*Mechanical Impact on Other EBS Components (Seals, Liner / Rock Reinforcement Materials, Waste Package Support Materials)*						2.16

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.01.01	*Waste Inventory (Radionuclides and Non-Radionuclides)*						2.05
	D-02	H	3	Maintain and populate DPC as-loaded database		M	
	O-01			Complete and Populate Online Waste Library (OWL) SF-17SN01050101		L	
2.1.08.08	*Capillary Effects in EBS*						2.02
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.03.08	*Evolution of Flow Pathways in Waste Packages*						1.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.08.09	*Influx/Seepage into the EBS*						1.89
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
1.3.01.01	*Climate Change (Natural and Anthropogenic)*						1.85
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.09.55	*Formation of Colloids in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						1.79
	E-20	H	4	colloid source terms		M-H	
2.1.08.07	*Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)*						1.73
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.13.02	*Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)*						1.73
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.2.12.03	*Gas Transport in NBS*						1.66
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and		M	
2.3.08.02	*Surface Runoff and Evapotranspiration*						1.58
	P-09	L	4	Surface processes and features		L	
2.3.08.03	*Infiltration and Recharge*						1.58
	P-09	L	4	Surface processes and features		L	
2.1.09.03	*Chemical Characteristics of Water in Backfill*						1.47
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.12.03	*Gas Transport in EBS*						1.02
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	A-04	H	4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)		M-H	
2.1.11.02	*Exothermic Reactions in EBS*						0.99
	E-02	H	4	SNF Degradation testing activities		M-H	
2.1.12.01	*Gas Generation in EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
2.1.12.02	*Effects of Gas on Flow through the EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
2.1.14.01	*Criticality In-Package*						0.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	D-06		2	Technical integration of DPC direct disposal		L	
2.1.08.02	*Flow in and through Waste Packages*						0.86
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.08.05	*Flow through Liner / Rock Reinforcement Materials in EBS*						0.85

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
0.1.10.01	*Model Issues*						0.00
	P-01	H	4	CSNF repository argillite reference case		M-H	
	P-02	H	4	CSNF repository crystalline reference case		M-H	
	P-04	H	4	CSNF repository unsaturated zone (alluvium) reference case		M-H	
	P-14	H	4	Generic Capability Development for PFLOTRAN		M-H	
	I-17	H	3	New Activity: DECOVALEX Task on GDSA, PA, SA, UQ	*	M	
	P-03	H	3	CSNF repository bedded salt reference case		M	
2.1.01.02	*Radioactive Decay and Ingrowth*						0.00
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.02.02	*HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)*						0.00
	E-13	M	3	HLW WF degradation (process model)	*	M	
	E-19			Other SNF/HLW Types	*	L	
2.1.13.01	*Radiolysis (in Waste Package, in Backfill, and in Tunnel)*						0.00
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.11.05	*Thermal Effects on Transport in NBS*						0.00
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	

APPENDIX G: FEPS AND THEIR CRYSTALLINE-RELATED ACTIVITIES

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
1.2.03.01	*Seismic Activity Impacts EBS and/or EBS Components*						4.94
	P-05	M	4	Disruptive events		M	
2.1.09.13	*Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						4.86
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	E-19			Other SNF/HLW Types	*	L	
2.1.03.02	*General Corrosion of Waste Packages*						4.34
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.03	*Stress Corrosion Cracking (SCC) of Waste Packages*						4.34
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.04	*Localized Corrosion of Waste Packages*						4.34
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.05	*Hydride Cracking of Waste Packages*						4.34
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.02.01	*SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)*						4.01
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	E-19			Other SNF/HLW Types	*	L	
2.2.02.01	*Stratigraphy and Properties of Host Rock*						3.74
	C-01	H	4	Discrete Fracture Network (DFN) Model		M-H	
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
	C-02	H	3	Flow and Transport in Fractures - modeling approaches		M	
	C-03	H	3	Fracture-Matrix Diffusion - Modeling approaches		M	
	C-05	H	3	Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization		M	
	C-09	M	3	Development of a centralized technical database for crystalline disposal system evaluation		M	
2.2.09.51	*Advection of Dissolved Radionuclides in Host Rock*						3.74

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	C-01	H	4	Discrete Fracture Network (DFN) Model		M-H	
	C-08	H	4	Interaction of Buffer w/ Crystalline Rock		M-H	
	C-13	H	4	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport	*	M-H	
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	I-21	H	4	New Activity: SKB Task 10 Validation of DFN Modeling	*	M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-02	H	3	Flow and Transport in Fractures - modeling approaches		M	
	C-03	H	3	Fracture-Matrix Diffusion - Modeling approaches		M	
	C-04	M	4	Lab and modeling study of EDZ - Crystalline		M	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.05.01	*Fractures (Host Rock, and Other Geologic Units)*						3.65
	C-01	H	4	Discrete Fracture Network (DFN) Model		M-H	
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
	C-02	H	3	Flow and Transport in Fractures - modeling approaches		M	
	C-03	H	3	Fracture-Matrix Diffusion - Modeling approaches		M	
	C-05	H	3	Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization		M	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.08.01	*Flow through the Host Rock*						3.65
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	C-01	H	4	Discrete Fracture Network (DFN) Model		M-H	
	C-11	H	4	Investigation of fluid flow and transport in low permeability media (clay materials).	*	M-H	
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
	E-10	H	4	High-Temperature Behavior		M-H	
	C-02	H	3	Flow and Transport in Fractures - modeling approaches		M	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.08.02	*Flow through the Other Geologic Units (Confining Units and Aquifers)*						3.65
	C-01	H	4	Discrete Fracture Network (DFN) Model		M-H	
	P-02	H	4	CSNF repository crystalline reference case		M-H	
	C-02	H	3	Flow and Transport in Fractures - modeling approaches		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
2.2.08.06	*Flow through EDZ*						3.65
	E-09	H	5	Cement plug/liner degradation		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	C-08	H	4	Interaction of Buffer w/ Crystalline Rock		M-H	
	C-04	M	4	Lab and modeling study of EDZ - Crystalline		M	
	C-05	H	3	Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization		M	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.1.02.06	*SNF Cladding Degradation and Failure*						3.62
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-15	M	5	Cladding Degradation	*	M	
2.2.09.52	*Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.2.09.53	*Diffusion of Dissolved Radionuclides in Host Rock*						3.55
	C-13	H	4	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport	*	M-H	
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.54	*Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.2.09.55	*Sorption of Dissolved Radionuclides in Host Rock*						3.55
	C-13	H	4	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport	*	M-H	
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.56	*Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.2.09.57	*Complexation in Host Rock*						3.55
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-09	M	3	Development of a centralized technical database for crystalline disposal system evaluation		M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.58	*Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.2.09.61	*Radionuclide Transport through EDZ*						3.55
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.64	*Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)*						3.55
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.65	*Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)*						3.55
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.1.04.01	*Evolution and Degradation of Backfill*						3.50
	C-15	H	5	Design improved backfill and seal materials	*	H	
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-17	H	5	Buffer Material by Design	*	H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	C-06	H	4	Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D		M-H	
	C-08	H	4	Interaction of Buffer w/ Crystalline Rock		M-H	
	E-03	H	4	THC processes in EBS		M-H	
	E-10	H	4	High-Temperature Behavior		M-H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	C-04	M	4	Lab and modeling study of EDZ - Crystalline		M	
	C-05	H	3	Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.1.05.01	*Degradation of Seals*						3.50
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.1.07.03	*Mechanical Effects of Backfill*						3.29
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.2.09.59	*Colloidal Transport in Host Rock*						3.29
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-10	M	3	Collate data from International URLs	*	M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.60	*Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						3.29
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.08.04	*Effects of Repository Excavation on Flow through the Host Rock*						3.23
	C-08	H	4	Interaction of Buffer w/ Crystalline Rock		M-H	
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.62	*Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)*						3.10
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.63	*Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)*						3.10
	P-11	H	4	Pitzer model	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.1.09.51	*Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	E-16	M	5	In-Package Flow	*	M	
2.1.09.52	*Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.09.53	*Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.07.04	*Mechanical Impact on Backfill*						2.94
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
2.2.08.07	*Mineralogic Dehydration*						2.82
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.1.08.04	*Flow through Seals*						2.80
	C-15	H	5	Design improved backfill and seal materials	*	H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.09.07	*Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)*						2.80
	C-15	H	5	Design improved backfill and seal materials	*	H	
	E-03	H	4	THC processes in EBS		M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.07.05	*Mechanical Impact on Waste Packages*						2.76
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.08.03	*Flow in Backfill*						2.76
	C-15	H	5	Design improved backfill and seal materials	*	H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.1.09.02	*Chemical Characteristics of Water in Waste Packages*						2.76
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-14	H	5	In-Package Chemistry	*	H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-19			Other SNF/HLW Types	*	L	
2.1.07.02	*Drift Collapse*						2.70
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	C-04	M	4	Lab and modeling study of EDZ - Crystalline		M	
2.1.09.01	*Chemistry of Water Flowing into the Repository*						2.64
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.06.01	*Degradation of Liner / Rock Reinforcement Materials in EBS*						2.62
	E-09	H	5	Cement plug/liner degradation		H	
2.1.09.09	*Chemical Effects at EBS Component Interfaces*						2.61
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.11.01	*Heat Generation in EBS*						2.59
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	E-18		4	Unbackfilled-Drift Thermal Radiation Model	*	L	
2.2.01.01	*Evolution of EDZ*						2.58
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.07.09	*Mechanical Effects at EBS Component Interfaces*						2.56
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.07.06	*Mechanical Impact on SNF Waste Form*						2.47
	E-02	H	4	SNF Degradation testing activities		M-H	
2.2.03.01	*Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.46
	P-02	H	4	CSNF repository crystalline reference case		M-H	
2.2.05.03	*Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)*						2.46
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.01	*Chemical Characteristics of Groundwater in Host Rock*						2.40
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-09	M	3	Development of a centralized technical database for crystalline disposal system evaluation		M	
	C-10	M	3	Collate data from International URLs	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.02	*Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	I-09	H	4	DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan		M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.05	*Radionuclide Speciation and Solubility in Host Rock*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-09	M	3	Development of a centralized technical database for crystalline disposal system evaluation		M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.06	*Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.2.11.04	*Thermal Effects on Chemistry and Microbial Activity in NBS*						2.40
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.1.11.04	*Effects of Drift Collapse on EBS Thermal Environment*						2.39
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
1.2.03.02	*Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)*						2.34
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
	P-05	M	4	Disruptive events		M	
2.2.11.06	*Thermal-Mechanical Effects on NBS*						2.30
	I-19	M	4	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing	*	M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.11.03	*Effects of Backfill on EBS Thermal Environment*						2.22
	C-15	H	5	Design improved backfill and seal materials	*	H	
2.1.07.08	*Mechanical Impact on Other EBS Components (Seals, Liner / Rock Reinforcement Materials, Waste Package Support Materials)*						2.16
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.2.09.03	*Chemical Interactions and Evolution of Groundwater in Host Rock*						2.10
	E-09	H	5	Cement plug/liner degradation		H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	C-07	M	4	Colloids in Fractures and Matrix		M	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
	I-01	M	3	Radionuclide transport as pseudocolloids,Grimsel		M	
	I-10	H	2	SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL		M	
2.2.09.04	*Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.10
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.01.01	*Waste Inventory (Radionuclides and Non-Radionuclides)*						2.05
	D-02	H	3	Maintain and populate DPC as-loaded database		M	
	O-01			Complete and Populate Online Waste Library (OWL)SF-17SN01050101		L	
2.1.08.08	*Capillary Effects in EBS*						2.02
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.03.08	*Evolution of Flow Pathways in Waste Packages*						1.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.08.09	*Influx/Seepage into the EBS*						1.89
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
1.3.01.01	*Climate Change (Natural and Anthropogenic)*						1.85
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	
1.3.05.01	*Glacial and Ice Sheet Effects*						1.85
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
2.1.09.55	*Formation of Colloids in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						1.79
	E-20	H	4	colloid source terms		M-H	
2.1.08.07	*Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)*						1.73
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.13.02	*Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)*						1.73
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.2.07.01	*Mechanical Effects on Host Rock*						1.63
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
2.1.09.54	*Complexation in EBS*						1.62
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.3.08.02	*Surface Runoff and Evapotranspiration*						1.58
	P-09	L	4	Surface processes and features		L	
2.3.08.03	*Infiltration and Recharge*						1.58
	P-09	L	4	Surface processes and features		L	
2.1.09.03	*Chemical Characteristics of Water in Backfill*						1.47
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
1.2.01.01	*Tectonic Activity – Large Scale*						1.44
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
2.2.12.02	*Effects of Gas on Flow through the NBS*						1.37
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
	I-18	H	5	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport	*	H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	
2.2.10.01	*Microbial Activity in Host Rock*						1.32
	C-14	H	4	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach	*	M-H	
2.2.12.03	*Gas Transport in NBS*						1.05
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies		M	
2.1.12.03	*Gas Transport in EBS*						1.02
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
2.1.11.02	*Exothermic Reactions in EBS*						0.99
	E-02	H	4	SNF Degradation testing activities		M-H	
2.1.12.01	*Gas Generation in EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
2.1.12.02	*Effects of Gas on Flow through the EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in bentonite		H	
2.1.14.01	*Criticality In-Package*						0.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	D-06		2	Technical integration of DPC direct disposal		L	
2.1.08.02	*Flow in and through Waste Packages*						0.86
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.08.05	*Flow through Liner / Rock Reinforcement Materials in EBS*						0.85
	C-15	H	5	Design improved backfill and seal materials	*	H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
0.1.10.01	*Model Issues*						0.00
	P-01	H	4	CSNF repository argillite reference case		M-H	
	P-02	H	4	CSNF repository crystalline reference case		M-H	
	P-04	H	4	CSNF repository unsaturated zone (alluvium) reference case		M-H	
	P-14	H	4	Generic Capability Development for PFLOTRAN		M-H	
	I-17	H	3	New Activity: DECOVALEX Task on GDSA, PA, SA, UQ	*	M	
	P-03	H	3	CSNF repository bedded salt reference case		M	
1.2.04.02	*Igneous Activity Impacts Geosphere (Host Rock, Other Geologic Units)*						0.00
	C-17	H	4	Model DFN evolution due to changes in stress field	*	M-H	
2.1.01.02	*Radioactive Decay and Ingrowth*						0.00
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.02.02	*HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)*						0.00
	E-13	M	3	HLW WF degradation (process model)	*	M	
	E-19			Other SNF/HLW Types	*	L	
2.1.03.06	*Microbially Influenced Corrosion (MIC) of Waste Packages*						0.00
	C-16	H	5	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal	*	H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.08.01	*Flow through the EBS*						0.00
	C-15	H	5	Design improved backfill and seal materials	*	H	
	C-11	H	4	Investigation of fluid flow and transport in low permeability media (clay materials).	*	M-H	
2.1.08.06	*Alteration and Evolution of EBS Flow Pathways*						0.00
	C-15	H	5	Design improved backfill and seal materials	*	H	
2.1.09.05	*Chemical Interaction of Water with Corrosion Products (in Waste Packages, in Backfill, in Tunnels)*						0.00
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.09.06	*Chemical Interaction of Water with Backfill (on Waste Packages, in Backfill, in Tunnels)*						0.00
	C-15	H	5	Design improved backfill and seal materials	*	H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.09.08	*Chemical Interaction of Water with Other EBS Components (in Waste Packages, in Tunnels)*						0.00
	C-15	H	5	Design improved backfill and seal materials	*	H	
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.09.62	*Radionuclide Transport through Liners and Seals*						0.00
	C-12	M	4	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock	*	M	
2.1.13.01	*Radiolysis (in Waste Package, in Backfill, and in Tunnel)*						0.00
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	O-05			QA, V&V (documentation and tests)		L	
	O-06	L	3	Natural/Anthropogenic Analogs for Radionuclide Transport	*	L	
	O-07			Full Biosphere Model	*	L	

APPENDIX H: FEPS AND THEIR SALT-RELATED ACTIVITIES

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.08.01	*Flow through the Host Rock*						7.73
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	S-11	H	4	THMC effects of anhydrites, clays, and other non-salt components	*	M-H	
	S-12	M	4	Laboratory testing and modeling of fluid inclusions		M	
2.2.08.02	*Flow through the Other Geologic Units (Confining Units and Aquifers)*						7.73
	P-03	H	3	CSNF repository bedded salt reference case		M	
2.2.08.06	*Flow through EDZ*						7.73
	E-09	H	5	Cement plug/liner degradation		H	
	I-16	H	5	New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling	*	H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	S-07	H	4	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	S-11	H	4	THMC effects of anhydrites, clays, and other non-salt components	*	M-H	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	S-06	H	3	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
	S-12	M	4	Laboratory testing and modeling of fluid inclusions		M	
2.2.08.04	*Effects of Repository Excavation on Flow through the Host Rock*						7.10

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	S-06	H	3	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
2.2.08.07	*Mineralogic Dehydration*						6.49
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	S-07	H	4	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	S-11	H	4	THMC effects of anhydrites, clays, and other non-salt components	*	M-H	
	S-06	H	3	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
1.2.03.01	*Seismic Activity Impacts EBS and/or EBS Components*						4.94
	P-05	M	4	Disruptive events		M	
2.1.09.13	*Radionuclide Speciation and Solubility in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						4.86
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	E-19			Other SNF/HLW Types	*	L	
2.1.03.02	*General Corrosion of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.03	*Stress Corrosion Cracking (SCC) of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.04	*Localized Corrosion of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.03.05	*Hydride Cracking of Waste Packages*						4.34
	P-12	H	5	WP Degradation Model Framework		H	
	E-04	H	4	Waste Package Degradation Model(mechanistic)	*	M-H	
	E-06	H	4	Waste Package Degradation Testing		M-H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.02.01	*SNF (Commercial, DOE) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Radionuclide Release)*						4.01
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	E-19			Other SNF/HLW Types	*	L	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.07.01	*Mechanical Effects on Host Rock*						3.83
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-02	H	4	Salt Coupled THM processes, creep closure of		M-H	
2.2.02.01	*Stratigraphy and Properties of Host Rock*						3.74
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
2.2.05.01	*Fractures (Host Rock, and Other Geologic Units)*						3.65
	O-02	H	4	GDSA Geologic Modeling		M-H	
	O-03	H	4	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling		M-H	
2.1.02.06	*SNF Cladding Degradation and Failure*						3.62
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-02	H	4	SNF Degradation testing activities		M-H	
	E-15	M	5	Cladding Degradation	*	M	
2.1.04.01	*Evolution and Degradation of Backfill*						3.50
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	E-17	H	5	Buffer Material by Design	*	H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	E-03	H	4	THC processes in EBS		M-H	
	E-10	H	4	High-Temperature Behavior		M-H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	I-05	H	3	Mont Terri FE (Full-scale Emplacement) Experiment		M	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
2.1.05.01	*Degradation of Seals*						3.50
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.1.07.03	*Mechanical Effects of Backfill*						3.29

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-12	H	5	TH and THM Process in Salt: German-US Collaborations (WEIMOS)		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
2.2.12.02	*Effects of Gas on Flow through the NBS*						3.23
	I-18	H	5	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport	*	H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-11	H	4	THMC effects of anhydrites, clays, and other non-salt components	*	M-H	
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
	S-13	M	5	Acid gas generation, fate, and transport	*	M	
2.1.09.51	*Advection of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	E-16	M	5	In-Package Flow	*	M	
2.1.09.52	*Diffusion of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.1.09.53	*Sorption of Dissolved Radionuclides in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						3.06
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
2.1.07.04	*Mechanical Impact on Backfill*						2.94
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	S-02	H	4	Salt Coupled THM processes, creep closure of		M-H	
2.1.08.04	*Flow through Seals*						2.80
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.09.07	*Chemical Interaction of Water with Liner / Rock Reinforcement and Cementitious Materials in EBS (in Backfill, in Tunnels)*						2.80
	E-03	H	4	THC processes in EBS		M-H	
2.1.07.05	*Mechanical Impact on Waste Packages*						2.76
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	E-07	M	4	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment	*	M	
2.1.08.03	*Flow in Backfill*						2.76
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-13	H	5	TH and THM Process in Salt: German-US Collaborations (BENVASIM)		H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-14	H	4	TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	I-15	M	4	TH and THM Process in Salt: German-US Collaborations (RANGER)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
2.1.09.02	*Chemical Characteristics of Water in Waste Packages*						2.76
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-14	H	5	In-Package Chemistry	*	H	
	E-01	M	3	SNF Degradation(& FMDM)		M	
	E-05	M	5	Corrosion Products - incorporation of radionuclides		M	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	E-19			Other SNF/HLW Types	*	L	
2.1.07.02	*Drift Collapse*						2.70
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.09.01	*Chemistry of Water Flowing into the Repository*						2.64
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.06.01	*Degradation of Liner / Rock Reinforcement Materials in EBS*						2.62
	E-09	H	5	Cement plug/liner degradation		H	
2.1.09.09	*Chemical Effects at EBS Component Interfaces*						2.61
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.11.01	*Heat Generation in EBS*						2.59
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	S-07	H	4	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	S-06	H	3	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
	E-18		4	Unbackfilled-Drift Thermal Radiation Model	*	L	
2.2.01.01	*Evolution of EDZ*						2.58
	E-11	H	5	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry		H	
	S-01	H	5	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)		H	
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	S-04	H	5	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)		H	
	S-05	H	5	Borehole-based Field Testing in Salt		H	
	E-10	H	4	High-Temperature Behavior		M-H	
	S-02	H	4	Salt Coupled THM processes, creep closure of		M-H	
	S-07	H	4	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)		M-H	
	S-08	H	4	Evolution of run-of-mine salt backfill		M-H	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	E-12	M	5	Buffer/backfill dry-out and resaturation process		M	
	S-06	H	3	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)		M	
	S-09	M	3	Numerical modeling of dryout in multiphase		M	
	S-10	M	3	Drift resaturation process in PA	*	M	
2.1.07.09	*Mechanical Effects at EBS Component Interfaces*						2.56
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.2.09.51	*Advection of Dissolved Radionuclides in Host Rock*						2.53
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.1.07.06	*Mechanical Impact on SNF Waste Form*						2.47
	E-02	H	4	SNF Degradation testing activities		M-H	
2.2.03.01	*Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.46
	P-03	H	3	CSNF repository bedded salt reference case		M	
2.2.12.03	*Gas Transport in NBS*						2.46
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies		M	
2.2.09.01	*Chemical Characteristics of Groundwater in Host Rock*						2.40
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.02	*Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.05	*Radionuclide Speciation and Solubility in Host Rock*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.06	*Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.52	*Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-11	H	4	Pitzer model	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.53	*Diffusion of Dissolved Radionuclides in Host Rock*						2.40
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.54	*Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	S-03	H	5	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in		H	
2.2.09.55	*Sorption of Dissolved Radionuclides in Host Rock*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.56	*Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.57	*Complexation in Host Rock*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.58	*Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.61	*Radionuclide Transport through EDZ*						2.40

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	E-08	H	3	Radionuclide Interaction w/ Buffer Materials		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.64	*Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.65	*Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)*						2.40
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.11.04	*Thermal Effects on Chemistry and Microbial Activity in NBS*						2.40
	E-09	H	5	Cement plug/liner degradation		H	
	E-03	H	4	THC processes in EBS		M-H	
	I-11	M	5	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies		M	
	O-04	M	3	Thermodynamic and sorption database(s)		M	
2.1.11.04	*Effects of Drift Collapse on EBS Thermal Environment*						2.39
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
1.2.03.02	*Seismic Activity Impacts Geosphere (Host Rock, Other Geologic Units)*						2.34
	P-05	M	4	Disruptive events		M	
2.2.11.06	*Thermal-Mechanical Effects on NBS*						2.30
	I-19	M	4	New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing	*	M	
2.2.09.59	*Colloidal Transport in Host Rock*						2.22
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.2.09.60	*Colloidal Transport in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.22
	P-11	H	4	Pitzer model	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
	P-06	H	3	(Pseudo) Colloid-Facilitated Transport Model		M	
	P-07	L	3	Intrinsic Colloid Model		L	
2.1.07.08	*Mechanical Impact on Other EBS Components (Seals, Liner / Rock Reinforcement Materials, Waste Package Support Materials)*						2.16
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.2.09.03	*Chemical Interactions and Evolution of Groundwater in Host Rock*						2.10
	E-09	H	5	Cement plug/liner degradation		H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
2.2.09.04	*Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*						2.10
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.2.09.62	*Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)*						2.10
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.2.09.63	*Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)*						2.10
	P-11	H	4	Pitzer model	*	M-H	
	P-13	H	4	Full Representation of Chemical processes in PA	*	M-H	
	P-15	H	4	Species and element properties	*	M-H	
	P-16	H	4	Solid solution model	*	M-H	
	P-17	H	4	Multi-Component Gas Transport	*	M-H	
2.1.01.01	*Waste Inventory (Radionuclides and Non-Radionuclides)*						2.05
	D-02	H	3	Maintain and populate DPC as-loaded database		M	
	O-01			Complete and Populate Online Waste Library (OWL) SF-17SN01050101		L	
2.1.08.08	*Capillary Effects in EBS*						2.02
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.03.08	*Evolution of Flow Pathways in Waste Packages*						1.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.08.09	*Influx/Seepage into the EBS*						1.89
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
1.3.01.01	*Climate Change (Natural and Anthropogenic)*						1.85
	P-08	M	5	Other missing FEPs (processes) in PA-GDSA	*	M	
2.1.09.55	*Formation of Colloids in EBS (in Waste Form, in Waste Package, in Backfill, in Tunnel)*						1.79
	E-20	H	4	colloid source terms		M-H	
2.1.08.07	*Condensation Forms in Repository (on Tunnel Roof/Walls, on EBS Components)*						1.73
	I-04	H	5	Experiment of bentonite EBS under high temperature, HotBENT		H	
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
	I-02	H	4	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling		M-H	
	I-03	H	4	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test		M-H	
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.13.02	*Radiation Damage to EBS Components (in Waste Form, in Waste Package, in Backfill, in Other EBS Components)*						1.73
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
2.3.08.02	*Surface Runoff and Evapotranspiration*						1.58
	P-09	L	4	Surface processes and features		L	
2.3.08.03	*Infiltration and Recharge*						1.58
	P-09	L	4	Surface processes and features		L	
2.1.09.03	*Chemical Characteristics of Water in Backfill*						1.47
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
2.1.12.03	*Gas Transport in EBS*						1.02
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
2.1.11.02	*Exothermic Reactions in EBS*						0.99
	E-02	H	4	SNF Degradation testing activities		M-H	
2.1.12.01	*Gas Generation in EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
2.1.12.02	*Effects of Gas on Flow through the EBS*						0.98
	I-08	H	5	DECOVALEX-2019 Task A: Advective gas flow in		H	
2.1.14.01	*Criticality In-Package*						0.96
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
	D-06		2	Technical integration of DPC direct disposal		L	
2.1.08.02	*Flow in and through Waste Packages*						0.86
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.08.05	*Flow through Liner / Rock Reinforcement Materials in EBS*						0.85
	I-07	H	4	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.		M-H	
0.1.10.01	*Model Issues*						0.00
	P-01	H	4	CSNF repository argillite reference case		M-H	
	P-02	H	4	CSNF repository crystalline reference case		M-H	
	P-04	H	4	CSNF repository unsaturated zone (alluvium) reference case		M-H	
	P-14	H	4	Generic Capability Development for PFLOTRAN		M-H	
	I-17	H	3	New Activity: DECOVALEX Task on GDSA, PA, SA, UQ	*	M	
	P-03	H	3	CSNF repository bedded salt reference case		M	
2.1.01.02	*Radioactive Decay and Ingrowth*						0.00
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	
2.1.02.02	*HLW (Glass, Ceramic, Metal) Degradation (Alteration/Phase Separation, Dissolution/Leaching, Cracking, Radionuclide Release)*						0.00
	E-13	M	3	HLW WF degradation (process model)	*	M	
	E-19			Other SNF/HLW Types	*	L	
2.1.13.01	*Radiolysis (in Waste Package, in Backfill, and in Tunnel)*						0.00

FEP	Act.	ISC	SAL	Activity	*Gap	2019 Score	2012 Score
	D-01	H	5	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase		H	
	D-03	H	5	DPC filler and neutron absorber degradation testing and analysis		H	
	D-04	H	5	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.		H	
	D-05	H	5	Source term development with and without criticality		H	

APPENDIX I: HIGH- AND MEDIUM-SCORING FEPS WITHOUT CURRENT ACTIVITIES

FEP	FEP Title	Host Rock	2012 Score
2.2.05.03	*Alteration and Evolution of NBS Flow Pathways (Host Rock and Other Geologic Units)*		
		S	2.46
2.2.07.02	*Mechanical Effects on Other Geologic Units*		
		S	3.10
2.2.09.01	*Chemical Characteristics of Groundwater in Host Rock*		
		A	3.55
		S	2.40
2.2.09.02	*Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		S	2.40
2.2.09.04	*Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.10
2.2.09.05	*Radionuclide Speciation and Solubility in Host Rock*		
		A	3.55
		S	2.40
2.2.09.06	*Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		C	2.40
		S	2.40
2.2.09.51	*Advection of Dissolved Radionuclides in Host Rock*		
		A	3.74
		S	2.53
2.2.09.52	*Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		C	3.55
		S	2.40
2.2.09.53	*Diffusion of Dissolved Radionuclides in Host Rock*		
		A	3.55
2.2.09.54	*Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		C	3.55

FEP	FEP Title	Host Rock	2012 Score
2.2.09.55	*Sorption of Dissolved Radionuclides in Host Rock*		
		A	3.55
		S	2.40
2.2.09.56	*Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		C	3.55
		S	2.40
2.2.09.57	*Complexation in Host Rock*		
		A	3.55
		S	2.40
2.2.09.58	*Complexation in Other Geologic Units (Non-Host-Rock) (Confining Units and Aquifers)*		
		A	3.55
		C	3.55
		S	2.40
2.2.09.62	*Dilution of Radionuclides in Groundwater (Host Rock and Other Geologic Units)*		
		A	3.10
2.2.09.63	*Dilution of Radionuclides with Stable Isotopes (Host Rock and Other Geologic Units)*		
		A	3.10
2.2.09.64	*Radionuclide Release from Host Rock (Dissolved, Colloidal, and Gas Phase)*		
		S	2.40
2.2.09.65	*Radionuclide Release from Other Geologic Units (Dissolved, Colloidal, Gas Phase)*		
		A	3.55
		S	2.40

Note: A FEP designated with a "*" in the Host Rock column means that it is not distinguished (or divided) by the host rock type (A=Argillite; C=Crystalline; S=Salt) in the 2012 UFD Roadmap

APPENDIX J: EVOLUTION OF STATE-OF-THE-ART KNOWLEDGE

This appendix provides a comparison between the consensus SAL descriptive values (see Table 3-2) developed in the 2019 Update Workshop (as documented in Appendix B) with the comparable "State-of-the-Art" assignments in the 2012 Roadmap (DOE 2012, App. A) – see Section 3.3.3 above for more information.

Table J-1. Comparison of 2012 "State-of-the-Art" with 2019 SAL Values.

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
A-1	Two-Part Hooke's Model (saturated)	2.2.07.01 Mechanical Effects on Host Rock (Clay/Shale)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
A-2	Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
A-3	Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
A-4	Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)	2.2.01.01 Evolution of EDZ (clay/shale)	Fundamental Data Needs	Improved Representation
A-5	THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)	2.2.01.01 Evolution of EDZ (clay/shale)	Fundamental Data Needs	Improved Representation
A-6	Diffusion of actinides through bentonite (including speciation)	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Representation
A-7	Analysis of clay hydration/dehydration and alteration under various environmental conditions	2.2.08.06 Flow through EDZ (clay/shale)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
A-8	Evaluation of ordinary Portland cement (OPC)	FEP 2.1.05.01 Degradation of Seals	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
C-1	Discrete Fracture Network (DFN) Model	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-2	Flow and Transport in Fractures - modeling approaches	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
C-3	Fracture-Matrix Diffusion - Modeling approaches??	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
C-4	Lab and modeling study of EDZ - Crystalline	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-5	Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization	2.2.08.06 Flow thru EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
C-6	Buffer Erosion (is this a gap in our program?) is it too site specific for generic R&D	2.1.04.01 Evolution/Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-7	Colloids in Fractures and Matrix	2.2.09.64 Radionuclide Release from Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-8	Interaction of Buffer w/ Crystalline Rock	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
C-9	Development of a centralized technical database for crystalline disposal system evaluation	2.2.02.01 Stratigraphy and Properties of Host Rock (crystalline)	Fundamental Gaps in Method	Improved defensibility
C-10	Collate data from International URLs **(GAP)**	2.2.08.01 Flow through the Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
C-11	Investigation of fluid flow and transport in low permeability media (clay materials). **(GAP)**	2.2.08.01 Flow through the Host Rock (clay)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-12	Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock **(GAP)**	2.1.09.09 Chemical Effects at EBS Component Interfaces	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-13	Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport **(GAP)**	2.2.09.55 Sorption of Dissolved Radionuclides in Host Rock	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-14	Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach **(GAP)**	2.2.09.55 Sorption of Dissolved Radionuclides in Host Rock	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
C-15	Design improved backfill and seal materials **(GAP)**	2.1.04.01 Evolution/Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
C-16	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal **(GAP)**	2.1.03.02 General Corrosion of Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
C-17	Model DFN evolution due to changes in stress field **(GAP)**	2.2.07.01 Mechanical Effects on Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved representation
D-1	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase	2.1.02.06 SNF Cladding Degradation and Failure	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
D-2	Maintain and populate DPC as-loaded database	2.1.01.01 Waste Inventory	Fundamental Data Needs	Improved Defensibility
D-3	DPC filler and neutron absorber degradation testing and analysis	2.1.02.06 SNF Cladding Degradation and Failure	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
D-4	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.	2.1.02.06 SNF Cladding Degradation and Failure	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
D-5	Source term development with and without criticality	2.1.02.06 SNF Cladding Degradation and Failure	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
D-6	Technical integration of DPC direct disposal	2.1.14.01 Criticality in Package	Fundamental Data Needs	Improved Confidence
E-1	SNF Degradation (& FMDM)	2.1.02.01 SNF Degradation	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
E-2	SNF Degradation testing activities	2.1.02.01 SNF Degradation	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
E-3	THC processes in EBS	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
E-4	Waste Package Degradation Model (mechanistic) **(GAP)**	2.1.03.02 General Corrosion of Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
E-5	Corrosion Products - incorporation of radionuclides	2.1.09.02 Chemical Characteristics of Water in Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both/

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
E-6	Waste Package Degradation Testing	2.1.03.02 General Corrosion of Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
E-7	Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment **(GAP)**	2.1.03.02 General Corrosion of Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
E-8	Radionuclide Interaction w/ Buffer Materials	2.2.01.01Evolution of EDZ (clay/shale)	Fundamental Data Needs	Improved Defensibility
E-9	Cement plug/liner degradation	2.2.08.06 Flow through EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-10	High-Temperature Behavior	2.2.01.01 Evolution of EDZ (clay/shale)	Fundamental Data Needs	Improved Representation
E-11	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.	2.2.01.01 Evolution of EDZ (clay/shale)	Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-12	Buffer/backfill dry-out and resaturation process	2.2.08.06 Flow through EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-13	HLW WF degradation (process model) (this Activity has been assigned to another DOE Campaign; 2012 & 2019 evaluations here are derived from E-1 and E-2) **<u>(Partial GAP)</u>**	2.1.02.02 HLW Degradation	Not Evaluated	Improved Defensibility
E-14	In-Package Chemistry **<u>(Partial GAP)</u>**	2.1.09.02 Chemical Characteristics of Water in Waste Packages	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-15	Cladding Degradation **<u>(GAP)</u>**	2.1.02.06 SNF Cladding Degradation and Failure	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-16	In-Package Flow **<u>(GAP)</u>**	2.1.09.51 Advection of Dissolved Radionuclides in EBS	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-17	Buffer Material by Design **<u>(GAP)</u>**	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
E-18	Unbackfilled-Drift Thermal Radiation Model **(GAP)**	2.1.11.01 Heat Generation in EBS	Fundamental Data Needs	Improved Representation
E-19	Other SNF/HLW Types **(partial GAP)**	2.1.02.01 SNF Degradation	Fundamental Gaps in Method, Fundamental Data Needs	Not Evaluated
E-20	**Colloid source terms**	2.1.09.55 Formation of Colloids in EBS	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-1	Radionuclide transport as pseudo-colloids, Grimsel	2.2.09.64 Radionuclide Release from Host Rock (crystalline or clay/shale/salt)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
I-2	FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-3	FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-4	Experiment of bentonite EBS under high temperature, HotBENT	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-5	Mont Terri FE (Full-scale Emplacement) Experiment	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
I-6	Mont Terri FS Fault Slip Experiment	2.2.05.01 Fractures (argillite)	Fundamental Gaps in Method	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-7	DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in	2.1.04.01 Evolution and Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
	Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.			
I-8	DECOVALEX-2019 Task A: Advective gas flow in bentonite	2.2.08.06 Flow through EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-9	DECOVALEX-2019 Task C: GREET (Groundwater REcovery Experiment in Tunnel) at Mizunami URL, Japan	2.2.05.01 Fractures (crystalline)	Fundamental Gaps in Method	Improved Representation
I-10	SKB GWFTS Task Force: Longterm Diffusion Experiment LTDE-SD at the Äspö HRL	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Confidence
I-11	Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies	2.2.11.04 Thermal Effects on Chemistry and Microbial Activity in Geosphere (clay/shale)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-12	TH and THM Processs in Salt: German-US Collaborations (WEIMOS)	2.1.04.01 Evolution and degradation of Backfill/Buffer	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-13	TH and THM Processs in Salt: German-US Collaborations (BENVASIM)	2.1.04.01 Evolution and degradation of Backfill/Buffer	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-14	TH and THM Processs in Reconsolidating Salt: German-US Collaborations (KOMPASS)	2.1.04.01 Evolution and degradation of Backfill/Buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-15	TH and THM Processs in Salt: German-US Collaborations (RANGER)	2.1.04.01 Evolution and degradation of Backfill/Buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-16	**New Activity:** DECOVALEX Task on Salt Heater Test and Coupled Modeling **(GAP)**	2.2.08.06 Flow through EDZ (Salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-17	**New Activity:** DECOVALEX Task on GDSA, PA, SA, UQ **(GAP)**	FEP (0.1.10.01 Model Issues) not explicitly scored, but “Disposal System Modeling” rated as a “High” priority “Cross-Cutting” issue in 2012	Not Evaluated	Improved Defensibility
I-18	**New Activity**: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport **(GAP)**	2.2.12.02 Effects of Gas on Flow Through the Geosphere	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
I-19	**New Activity:** Other potential DECOVALEX Tasks of Interest: Thermal Fracturing **(GAP)**	2.2.11.06 Thermal-Mechanical Effects on Geosphere	Fundamental Data Needs	Improved Representation
I-20	**New Activity:** New Mont Terri Task: Gas Transport in Host Rock **(GAP)**	2.2.12.02 Effects of Gas on Flow Through the Geosphere (Clay/Shale)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
I-21	**New Activity:** SKB Task 10 Validation of DFN Modeling **(GAP)**	2.2.09.51 Advection of Dissolved Radionuclides in Host Rock (crystalline)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
O-1	Complete and Populate Online Waste Library (OWL) SF-17SN01050101	2.1.01.01 Waste Inventory	Fundamental Data Needs	Not evaluated during the workshop
O-2	GDSA Geologic Modeling	2.2.02.01 Stratigraphy and Properties of Host Rock	Fundamental Gaps in Method	Improved Representation
O-3	Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling	2.2.02.01 Stratigraphy and Properties of Host Rock	Fundamental Gaps in Method	Improved Representation
O-4	Thermodynamic and sorption database(s)	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Defensibility
O-5	QA, V&V (documentation and tests)	FEP not explicitly scored, but “Disposal System Modeling” rated as a “High” priority “Cross-Cutting” issue in 2012	N/A	N/A
O-6	Natural/Anthropogenic Analogs for Radionuclide Transport **(GAP)**	No assigned FEP	Not Evaluated	Improved Defensibility
O-7	Full Biosphere Model **(GAP)**	Biosphere FEPs score low (<1), but this is needed eventually to satisfy regulations	Not Evaluated	Not Evaluated

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
P-1	CSNF repository argillite reference case	FEP (0.1.10.01 Model Issues) not explicitly scored, but "Disposal System Modeling" rated as a "High" priority "Cross-Cutting" issue in 2012	Not Evaluated	Improved Representation
P-2	CSNF repository crystalline reference case	FEP (0.1.10.01 Model Issues) not explicitly scored, but "Disposal System Modeling" rated as a "High" priority "Cross-Cutting" issue in 2012	Not Evaluated	Improved Representation
P-3	CSNF repository bedded salt reference case	FEP (0.1.10.01 Model Issues) not explicitly scored, but "Disposal System Modeling" rated as a "High" priority "Cross-Cutting" issue in 2012	Not Evaluated	Improved Defensibility
P-4	CSNF repository unsaturated zone (alluvium) reference case	FEP (0.1.10.01 Model Issues) not explicitly scored, but "Disposal System Modeling" rated as a "High" priority "Cross-Cutting" issue in 2012	Not Evaluated	Improved Representation
P-5	Disruptive events	1.2.03.01 (Seismic Activity Impacts EBS	Improved Representation	Improved Representation
P-6	(Pseudo) Colloid-Facilitated Transport Model	2.2.09.61 Radionuclide Transport thru EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
P-7	Intrinsic Colloid Model	2.2.09.61 Radionuclide Transport thru EDZ	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
P-8	Other missing FEPs (processes) in PA-GDSA **(GAP)**	2.2.12.02 Effects of Gas on Flow through the Geosphere (Salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method Fundamental Data Needs
P-9	Surface processes and features	2.3.08.02 Runoff and Evapotranspiration	Improved Representation	Improved Representation
P-10	Uncertainty Quantification and Sensitivity Analysis (UQ/SA)	FEP 0.1.10.01 Model Issues and FEP 0.1.10.02 Data Issues (the latter should include UQ/SA) were not scored separately in 2012.	Not Evaluated	Improved Confidence
P-11	Pitzer model **(GAP)**	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Representation
P-12	WP Degradation Model Framework	2.1.03.02 General Corrosion of Waste Package	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
P-13	Full Representation of Chemical processes in PA **(GAP)**	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Representation
P-14	Generic Capability Development for PFLOTRAN	FEP (0.1.10.01 Model Issues) not explicitly scored in 2012, but "Disposal System Modeling" rated as a "High" priority "Cross-Cutting" issue	Not Evaluated	Improved Representation
P-15	Species and element properties **(GAP)**	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Representation
P-16	Solid solution model **(GAP)**	2.1.09.13 Radionuclide Speciation and Solubility in EBS	Improved Representation	Improved Representation
P-17	Multi-Component Gas Transport **(GAP)**	2.2.09.64 Radionuclide Release from Host Rock	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
S-1	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)	2.2.08.06 Flow thru the EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
S-2	Salt Coupled THM processes, creep closure of excavations	2.2.07.01 Mechanical Effects on Host Rock (Salt)	Fundamental Gaps in Method Fundamental Data Needs	Improved Representation
S-3	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt	2.2.08.06 Flow through EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
S-4	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)	2.2.08.06 Flow through EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both
S-5	Borehole-based Field Testing in Salt	2.2.08.06 Flow through EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both

R&D Activity #	R&D Activity Name	Primary FEP	2012 Roadmap "State of the Art" (for the Primary FEP)	2019 Roadmap Update "State of the Art" Level (SAL)
S-6	Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)	2.2.08.06 Flow through EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
S-7	Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)	2.2.08.06 Flow through EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
S-8	Evolution of run-of-mine salt backfill	2.1.04.01 Evolution/Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
S-9	Numerical modeling of dryout in multiphase	2.1.04.01 Evolution/Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
S-10	Drift resaturation process in PA **(GAP)**	2.1.04.01 Evolution/Degradation of Backfill/buffer	Fundamental Gaps in Method, Fundamental Data Needs	Improved Defensibility
S-11	THMC effects of anhydrites, clays, and other non-salt components **(GAP)**	2.2.08.06 Flow thru EDZ (salt)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
S-12	Laboratory testing and modeling of fluid inclusions	2.2.08.01 Flow Through the Host Rock (Salt)	Fundamental Gaps in Method, Fundamental Data Needs	Improved Representation
S-13	Acid gas generation, fate, and transport **(GAP)**	2.2.12.02 Effects of Gas on Flow Through the Geosphere (Salt)	Fundamental Gaps in Method, Fundamental Data Needs	Fundamental Gaps in Method or Fundamental Data Needs, or Both

APPENDIX K: ADDITIONAL INFORMATION ON ACTIVITIES AND INTEGRATION

Activity	Name / Comments	*Gap Activity
A-01	*Two-Part Hooke's Model(saturated)* • Used to calculate the permeability/porosity evolution of EBS in clay formation using a continuum approach •Used to calculate displacements in clay rock damage zones. •Response surface suggested (permeability, porosity, stress). •Cross-cuts with EBS integration needed	
A-02	*Simplified Representation of THMC processes in EBS and host rock, e.g., clay illitization* • Response surface suggested (permeability, porosity, cation exchange capacity, swelling stress). • Chemical processes still under development (see A-3) • Cross-cuts with EBS & GDSA integration needed	
A-03	*Clay mineral alteration & experimental data re: Simplified Representation of THMC processes in EBS* • Clay phase transformation in response to temperature could cause inhomogeneous swelling throughout the clay barrier • Response surface suggested (permeability, porosity, cation exchange capacity, swelling stress) • Cross-cuts with EBS integration needed	
A-04	*Argillite Coupled THM processes modeling including host rock, EBS, and EDZ (TOUGH-FLAC)* • Response surface suggested (permeability and porosity fields/surfaces for EDZ and backfill).	
A-05	*THM discrete Fracture Modeling using Rigid-Body-Spring-Network (RBSN)* ROM or response surface suggested (fracture property response surface). A coupled version of RBSN requires dynamic input (T, p, s). Could also be used for upscaling from discrete fracture network to continuum properties for TOUGH-FLAC • Cross-cuts with EBS & GDSA integration needed	
A-06	*Diffusion of actinides through bentonite(including speciation)* • Direct implementation in PFLOTRAN suggested (but not clear if this is a model or just a data-gathering experiment for Fick's Law). Data gathering time frame up to 6 years. (Need to review Joseph et al. 2016 for implementation suggestions.) • Cross-cuts with EBS & GDSA integration needed	

Activity	Name / Comments	*Gap Activity

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

• Development of saturation and pressure initial conditions (or possibly start time, when a fully saturated domain is justified), including the effects of chemistry and two-phase flow and transport.
• The THC (no mechanical, with reactive chemistry) assessment of resaturation could be carried out with PFLOTRAN. This would be a first step to explore the dependence of the full chemistry on the resaturation on the . Performing a full chemistry simulation at the drift scale (rather than the GDSA PA scale of several km), will illustrate how resaturation slows down some chemical processes and may speed up others. Dry early-time conditions in the DRZ and backfill may slow down canister corrosion.
• Cross-cuts with EBS & GDSA integration needed

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

Implementation through PFLOTRAN to GDSA-PA should be captured in the reactive transport model. Still, model validation is needed to assess knowledge gaps in the prediction of solubilities, changes in water chemistry, and secondary phase formation.
• Cross-cuts with EBS, GDSA, & international integration needed

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

DFNWorks maps to ECPM; flow and transport can be simulated w/ either DFN or ECPM in PFLOTRAN. Further integration would require:
1. additional development of DFNWorks for generation of more realistic fracture networks
2. pflotran and/or mesh development for dual continuum (porosity and or permeability) for realistic fracture networks,
3. transient particle tracker (alternative model to reactive transport that could provide

C-02 *Flow and Transport in Fractures - modeling approaches*

Complete comparison of modeling approaches.
If graph representation of DFN is beneficial requires code integration.
ECPM is complete.
Steady state particle tracking works; transient needs to be developed.
Embed fractures in octree mesh requires additional development of gridding software, and pflotran development to use octree.

C-03 *Fracture-Matrix Diffusion - Modeling approaches*

Incorporate lessons learned (e.g. upscaled parameters) into PA simulations.

C-04 *Lab and modeling study of EDZ - Crystalline*

Incorporate lessons learned (e.g. upscaled parameters) into PA simulations.

C-05 *Development and demonstration of geophysical, geochemical, and hydrological techniques for site characterization*

Activity	Name / Comments	*Gap Activity
	Use results to inform conceptual and numerical models used in PA (and process modeling)	
C-06	*Buffer Erosion (is this a gap in our program?)is it too site specific for generic R&D* Develop mechanistic model for buffer erosion and associated colloid transport. How to incorporate in PA depends on model, possibility of representing with upscaled buffer parameters or probability distribution on wp failure (?) in PA.	
C-07	*Colloids in Fractures and Matrix* Implement Reimus colloid model in pflotran. Use Grimsel results for model validation and to inform parameter choices for generic reference case.	
C-08	*Interaction of Buffer w/ Crystalline Rock* Sections 3.4, 3.5 and 6.5.2 of the 2018 International Activities Report describe International modeling of the coupled EBS-THMC processes Process models (e.g. buffer erosion, colloid generation) need to be developed. Use results from international community to inform conceptual and numerical models in PA and process modeling. Importance of this task increases if direct disposal of DPCs is	
C-09	*Development of a centralized technical database for crystalline disposal system evaluation* Much of the information contained in this database may also be relevant for other host rock disposal options.	
C-10	*Collate data from International URLs*	*
C-11	*Investigation of fluid flow and transport in low permeability media (clay materials).*	*
C-12	*Model validation: Evolution of groundwater chemistry and radionuclide transport in fractured rock*	*
C-13	*Evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport* This could be linked into current ECPM fracture representation with appropriate upscaling of spatial heterogeneous Kds. Would benefit from concurrent consideration of spatial heterogeneity in permeability within fractures. Changes in grid block size with upscaling may mask some effects of important processes that occur within fractures - thus these upscaling studies will need to conduct sensitivity studies on gridding approaches.	*

Activity	Name / Comments	*Gap Activity
C-14	*Radionuclide sorption and incorporation by natural and engineered materials: Beyond a simple Kd approach* A variety of Kd models were considered during Yucca Mountain - perhaps these past approaches could be reviewed and evaluated	*
C-15	*Design improved backfill and seal materials* Perhaps some of these materials could be incorporated in the HOTBENT experiment	*
C-16	*Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal*	*
C-17	*Model DFN evolution due to changes in stress field*	*
D-01	*Probabilistic post-closure DPC criticality consequence analyses* *Task 1 - Scoping Phase* *Task 2 - Preliminary Analysis Phase* *Task 3 - Development Phase* Different media require different approaches. Reference cases are currently in shale and alluvium, but other media are under consideration. Cross cuts with PA	
D-02	*Maintain and populate DPC as-loaded database*	
D-03	*DPC filler and neutron absorber degradation testing and analysis* • Cross cuts with EBS	
D-04	*Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.* • Cross-cuts with EBS	
D-05	*Source term development with and without criticality*	
D-06	*Technical integration of DPC direct disposal* Customer directed	
E-01	*SNF Degradation(& FMDM)* • Direct implementation in PFLOTRAN under way - model coupling completed and now at the testing stage.	

Activity	Name / Comments	*Gap Activity
	• Additional development and more efficient coding suggested-- this is under development with PFLOTRAN recoding of model • Parking Lot: Further discussion needed based on gaps: thermal, etc., this should be tied to work for DPC going forward	
E-02	*SNF Degradation testing activities* • Further testing needed on other SNF types • Integration with models	
E-03	*THC processes in EBS* • No model linkage to GDSA yet. • PFLOTRAN can handle reactive transport (RT) but computational resources may limit its process representation for a large grid and/or multiple realizations • Modeling of alteration phase paragenesis & mechanisms (in progress); also need to cross integrate with buffer erosion (C-6).	
E-04	*Waste Package Degradation Model(mechanistic)* • Direct implementation in PFLOTRAN suggested (1D model), similar to SNF degradation • Currently evaluating development of thermodynamic relations for high T 316 SS corrosion phase assemblage (e.g., chromite, magnetite) • Need process model development	*
E-05	*Corrosion Products - incorporation of radionuclides* • Integration plan for process model development & GDSA implementation; data collection and simple model such as smart Kd	
E-06	*Waste Package Degradation Testing* • Support for modeling efforts • Integration plan for process model development & GDSA implementation	
E-07	*Pre-Closure Chemical and Mechanical Waste Package Degradation Salt environment* No credit is typically taken (e.g., at WIPP) for waste packages. Mechanical integrity of waste packages may be relevant to criticality for certain waste types (e.g., Pu). May be most relevant in early post-closure time frame (before room closes in first few hundred years). In a dry salt repository (i.e., very hot), the waste packages may survive better. Canisters may have a rind of dry salt deposited on them during dry-out. Run-of-mine salt backfill can be used for shielding of waste packages during emplacement and operational	*
E-08	*Radionuclide Interaction w/ Buffer Materials* Need Integration plan for parameters for GDSA implementation	
E-09	*Cement plug/liner degradation* • “Cross-cutting” issue with barrier degradation at high T's; Need Integration plan for	

Activity	Name / Comments	*Gap Activity
	model development & parametric GDSA implementation	
E-10	*High-Temperature Behavior* • "Cross-cutting" issue with barrier degradation at high T's • Integration plan for process model development & GDSA implementation	
E-11	*EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.* • "Cross-cutting" issue with barrier degradation at high T's • Integration plan for process model development & GDSA implementation	
E-12	*Buffer/backfill dry-out and resaturation process* • Development of saturation and pressure initial conditions (or possibly start time, when a fully saturated domain is justified), including the effects of chemistry and two-phase flow and transport. • The THC (no mechanical, with reactive chemistry) assessment of resaturation could be carried out with PFLOTRAN. This would be a first step to explore the dependence of the full chemistry on the resaturation on the . Performing a full chemistry simulation at the drift scale (rather than the GDSA PA scale of several km), will illustrate how resaturation slows down some chemical processes and may speed up others. Dry early-time conditions in the DRZ and backfill may slow down canister corrosion. • Need to have plan for approach and implementation with integration	
E-13	*HLW WF degradation (process model)* • Requires integration with Waste Form Campaign • Integration plan for process model development & GDSA implementation	*
E-14	*In-Package Chemistry* • High fidelity electrochemistry coupled with transport • Cross-reference with Tasks E-3, E-12, and A-7 • Integration plan for process model development & GDSA implementation; suggest 0-D or 1-D nested model similar to FMDM	*
E-15	*Cladding Degradation* • Cross-reference with Tasks E-3 and E-4	*
E-16	*In-Package Flow* • Requires development of a tractable conceptual model • Cross-reference with Tasks E-3, E-12, and A-7	*
E-17	*Buffer Material by Design*	*
E-18	*Unbackfilled-Drift Thermal Radiation Model*	*

Activity	Name / Comments	*Gap Activity
E-19	*Other SNF/HLW Types*	*
E-20	*colloid source terms*	
I-01	*Radionuclide transport as pseudocolloids,Grimsel* • Basic model has been developed in the last couple of years and will be improved upon (redox effect) in the next 3 years. • Response surface suggested (permeability, porosity, cation exchange capacity, swelling stress). • Chemical processes still under development -account for data from new experiments at Grimsel? -revisit future use of CFM data for validation in pFlotran	
I-02	*FEBEX-DP Modeling: Dismantling phase of the long-term FEBEX heater test - Modeling* • The THMC model was developed and tested against THM data, model validation with chemical data is ongoing • Response surface suggested (permeability, porosity, cation exchange capacity, swelling stress). • Chemical processes still under development • Linked to Tasks S-1, A-2, S-8, and E-12 Integrate results of LANL lab test w/ LBNL modeling	
I-03	*FEBEX-DP Experimental Work: Dismantling phase of the long-term FEBEX heater test* • Analysis of FEBEX-DP samples will provide insights on clay buffer degradation and interactions at EBS interfaces to inform modeling approaches. • Linked to Tasks A-1 and A-2	
I-04	*Experiment of bentonite EBS under high temperature, HotBENT* • The test was proposed in FY15, is planned to start in FY17 and will last for 5 years. • Linked to Tasks A-1 and A-2	
I-05	*Mont Terri FE (Full-scale Emplacement) Experiment* • The Mont Terri FE Experiment will be one of the largest and longest running heater tests worldwide. Heating started in 2015 and will go on for at least 15 years • Linked to Tasks A-2, A-4, and A-5	
I-06	*Mont Terri FS Fault Slip Experiment* • Related to concerns about thermal pressurization. early on and gas pressure buildup at later stages. Aims at understanding (i) the conditions for slip activation and stability of clay faults, and (ii) the evolution of the coupling between fault slip, pore pressure and fluids migration. Results obtained by the experiment are crucial in defining mechanisms of natural and induced earthquakes, their precursors and risk assessment, and the loss of	

Activity	Name / Comments	*Gap Activity

integrity of natural low permeability barriers. Fault slip can lead to radionuclide pathways.
• Linked to Task P-5

I-07 *DECOVALEX-2019 Task E: Upscaling of modeling results from small scale to one-to-one scale based in heater test data in Callovo-Oxfordian claystone (COx) at MHM underground research laboratory in France.*

• The purpose of Task E is upscaling THM modeling from small size experiments (some cubic meters) to real scale emplacement cells (some ten cubic meters) all the way to scale of a waste repository (cubic kilometers). The task is aligned with the French repository program, which focuses its R&D on the Callovo-Oxfordian claystone (COx) formation near Bure in the east of France.
• Linked to Tasks A-2, A-4, and A-5

I-08 *DECOVALEX-2019 Task A: Advective gas flow in bentonite*

• The DECOVALEX-2019 project will provide extensive experimental and field test results on the behavior of gas generation and pressurization in bentonite and clay stone, including dilation and fracture formation.
• Linked to Tasks P-6 and P-15

I-09 *DECOVALEX-2019 Task C: GREET (Groundwater Recovery Experiment in Tunnel) at Mizunami URL, Japan*

• The DECOVALEX-2019 project Task C will provide comprehensive geochemical and fracture characterization of host-rock at various locations and times.
• Experimental and field test results (groundwater recovery, monitoring) will provide key information about groundwater chemical evolution.
• Modeling hydro-mechanical-chemical-biological processes during groundwater recovery in crystalline rock.
• Linked to Tasks C-1 and A-2
• Work done in argillite WP to evaluate cement/shotcrete interaction in CTD testconstrain properties of generic reference case

I-10 *SKB GWFTS Task Force: Long-term Diffusion Experiment LTDE-SD at the Äspö HRL*

• Obtain data on sorption properties and processes of individual radionuclides, and their effect on natural fracture surfaces and internal surfaces in the rock matrix.
• Investigate the magnitude and extent of diffusion into matrix rock from a natural fracture in situ under natural rock stress conditions and hydraulic pressure and groundwater chemical conditions provide parameters for PA

I-11 *Microbial Processes Affecting Hydrogen Generation and Uptake: FEBEX-DP and Mont Terri Studies*

• The fate of repository gases generated over long periods from corrosion of metallic materials under anoxic conditions and related formation of hydrogen can result in long-term damage to bentonite and clay host rock.

Activity	Name / Comments	*Gap Activity
	Future incorporation into models depends on results of experiments.	
I-12	*TH and THM Process in Salt: German-US Collaborations (WEIMOS)*	
I-13	*TH and THM Process in Salt: German-US Collaborations (BENVASIM)*	
I-14	*TH and THM Process in Reconsolidating Salt: German-US Collaborations (KOMPASS)*	
I-15	*TH and THM Process in Salt: German-US Collaborations (RANGER)*	
I-16	*New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling*	*
I-17	*New Activity: DECOVALEX Task on GDSA, PA, SA, UQ*	*
I-18	*New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport*	*
I-19	*New Activity: Other potential DECOVALEX Tasks of Interest: Thermal Fracturing*	*
I-20	*New Activity: New Mont Terri Task: Gas Transport in Host Rock*	*
I-21	*New Activity: SKB Task 10 Validation of DFN Modeling*	*
O-01	*Complete and Populate Online Waste Library (OWL)SF-17SN01050101*	
O-02	*GDSA Geologic Modeling*	
O-03	*Web Visualization of Geologic Conceptual Framework for GDSA Geologic Modeling*	

Activity	Name / Comments	*Gap Activity
O-04	*Thermodynamic and sorption database(s)* • Thermodynamic, surface complexation/ion-exchange databases, used as input to process models • Surface complexation unlikely to be represented in PA • The current H2O EoS in PFLOTRAN (IFC-67) is considered obsolete, although it may still be adequate	
O-05	*QA, V&V (documentation and tests)* • PFLOTRAN wiki already has significant regression testing, but this is an ongoing task in all phases of repository development	
O-06	*Natural/Anthropogenic Analogs for Radionuclide Transport*	*
O-07	*Full Biosphere Model* • This should probably wait until there are actual candidate sites • Needs to consider the various biosphere FEPs in the UFDC list (3.3.XX.YY)	*
P-01	*CSNF repository argillite reference case*	
P-02	*CSNF repository crystalline reference case*	
P-03	*CSNF repository bedded salt reference case*	
P-04	*CSNF repository unsaturated zone (alluvium) reference case* End-member case for consequence analysis of DPC criticality FEP.	
P-05	*Disruptive events* • Requires stylized scenarios and regulations for generic repositories and for site-screening activities • Should remain on hold for some types of events (e.g., igneous!!) until there are candidate sites, but probably requires development for human intrusion	
P-06	*(Pseudo) Colloid-Facilitated Transport Model* • Direct implementation in PFLOTRAN suggested, with perhaps some simplification of the conceptual model.	
P-07	*Intrinsic Colloid Model* • Direct implementation in PFLOTRAN, with perhaps some simplification of the conceptual	

Activity	Name / Comments	*Gap Activity
	model.	
P-08	*Other missing FEPs (processes) in PA-GDSA* • Gas generation/ movement might be important with regard to corrosion processes and buffer stability	*
P-09	*Surface processes and features* • Consider processes such as precipitation, evapotranspiration, surface runoff, streams, lakes, etc.	
P-10	*UA/SA* • We already have the various methods in Dakota • What other methods need to be added (e.g., CUSONORO)?	
P-11	*Pitzer model* We prefer the Wolery, rather than the Felmy, implementation. Important for reposities in salt.	*
P-12	*WP Degradation Model Framework*	
P-13	*Full Representation of Chemical processes in PA* •Different equations in different domains? •Loose coupling using different processes in different domains? •Compare loose coupling with tight coupling? • Integration plan for process model development & GDSA implementation	*
P-14	*Generic Capability Development for PFLOTRAN*	
P-15	*Species and element properties* • Probably only a second order effect.	*
P-16	*Solid solution model* • A simpler version (ignoring molar volumes) may be implemented sooner.	*
P-17	*Multi-Component Gas Transport* • We assume equilibrium between the gas and liquid phases; so the number of reactive transport degrees of freedom does not increase	*
S-01	*Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)* • Response surface suggested for integration of THM coupling into PA (permeability and	

Activity	Name / Comments	*Gap Activity
	porosity fields/surfaces for EDZ and backfill)	
S-02	*Salt Coupled THM processes, creep closure of excavations* Response surface suggested for integration of THM coupling into PA.	
S-03	*Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt* • Important constitutive relationships still needed in PFLOTRAN include (Kuhlman): - Crushed salt thermal conductivity dependence on porosity and temperature, - Salt solubility in brine as a function of temperature, - Changes in salt porosity including precipitation and dissolution of salt, - Water vapor diffusion coefficient as a function of pressure, temperature, and porosity, - Power-law permeability-porosity relationship, - Water vapor pressure as a function of brine strength and temperature, and - Temperature-dependent clay dehydration source term.	
S-04	*Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)* • Important constitutive relationships still needed in PFLOTRAN include (Kuhlman): - Salt solubility in brine as a function of temperature, - Changes in salt porosity including precipitation and dissolution of salt, - Water vapor diffusion coefficient as a function of pressure, temperature, and porosity, - Power-law permeability-porosity relationship, - Water vapor pressure as a function of brine strength and temperature	
S-05	*Borehole-based Field Testing in Salt* • Modeling before and after field experiments. Test plans to be developed in FY17, execution in FY19. • Highest priority activity in Salt R&D	
S-06	*Laboratory Experiments to Validate Coupled Process models in Salt (in support of field test S-5)* These laboratory activities support the field test, and may not directly link into GDSA.	
S-07	*Brine Origin, Chemistry, and Composition in Salt (in support of field test S-5)* These laboratory activities support the field test, and may not directly link into GDSA.	
S-08	*Evolution of run-of-mine salt backfill* This work describes THM processes in salt (e.g., permeability, porosity, stiffness), which are important to process models and feeds into PA models through a lookup table.	
S-09	*Numerical modeling of dryout in multiphase* This effort appears to be focused on the incorporation of dryout and resaturation models in PFLOTRAN.	

Activity	Name / Comments	*Gap Activity
S-10	*Drift resaturation process in PA* • Development of saturation and pressure initial conditions (or possibly start time, when a fully saturated domain is justified). • The TH (no mechanical) assessment of resaturation could be carried out with PFLOTRAN. This would be a first step to explore the dependence of the resaturation on the vadose zone parameters (i.e., van Genuchten parameters), and the sensitivity of the resaturation to these parameters, and related back to the uncertainty of these parameters. Even though these processes may never be included in the GDSA PA model, they should be explored at an appropriate scale and dimension (e.g., a 2D cross-section through a drift).	*
S-11	*THMC effects of anhydrites, clays, and other non-salt components* •Not entirely sure of how to represent these things in PA, since they are small-scale heterogeneities. A generic salt reference case may include some effects of stylized non-salt layers. A process-modeling approach is required to determine whether these features and their effects are important at repository time/length scales	*
S-12	*Laboratory testing and modeling of fluid inclusions* A process-modeling approach is required to determine whether these features and their effects are important at repository time/length scales.	
S-13	*Acid gas generation, fate, and transport* A process-modeling and laboratory experimental approach is required to determine whether these features and their effects are important at repository time/length scales.	*

APPENDIX L: SUMMARY OF R&D ACTIVITIES AND ACTIVITY GROUPS

This appendix provides additional detail on the discussions and interactions that took place during the breakout sessions but is mostly a high-level summary of the various individual R&D Activities in all eight R&D Activity Groups.

Argillite

Integration across R&D Activity Groups is important for Argillite because all Argillite Activities are related to EBS Activities and most depend on data from International URL Activities. Developing representations of processes (e.g., surrogate models, response surfaces) to couple with the PA system model (*GDSA Framework*) is an important issue. Progress since the 2012 Roadmap is documented in improved SAL values for the 2019 evaluation of nearly all Activities. Continuing work includes expanding the applicability of coupled process models to elevated temperatures and integration of DPC-relevant information.

Three Activities, i.e. A-2, A-3, and A-7, involve expanding the applicability of EBS coupled process models to elevated temperatures. The integration challenge for PA is determining the best method to pass information from the process modeling to *GDSA Framework*, both in the short term and the long term. In the short term, one option is to develop response surfaces (e.g., for permeability, porosity, cation exchange capacity, swelling stress). Plans need to be formalized for developing reduced order/simplified model outputs for the complex Argillite process models. An example is A-2, which involves developing a simplified representation of THMC coupled processes in EBS. A-1, A-2, A-4, and A-5 are all cross-cutting Argillite Activities that require integration with International Activities.

The Argillite R&D Activities are summarized briefly here, with more information provided in Appendix B. Activity A-1 involves application of the Two-Parts Hooke's constitutive model to, among other things, EDZ evolution (how permeability, porosity and stiffness varies) and displacements in damage zones. Activity A-2 will develop a simplified representation of THMC processes in the EBS and host rock, e.g., clay illitization. Activity A-3 will conduct R&D needed to better understand processes associated with backfill/buffer interactions with EBS materials at elevated temperatures. Activity A-4 will develop a coupled THM process model, for the EBS and EDZ. Activity A-5 will continue discrete fracture modeling of gas migration experiments from the DECOVALEX-2019 project and validation of anisotropic, layered shale strength and elastic properties against laboratory data from the Opalinus Clay and other shales. Activity A-6 will develop improved understanding of solubility controls and dissolved concentration limits to improve radionuclide transport models and support a better understanding of disposal system performance. Activity A-7 will develop an improved understanding of bentonite buffer "dry-out" and clay hydration under various environmental conditions. Activity A-8 will baseline the chemical reactions of a shotcrete liner in contact with engineered barrier materials. As part of the new scope, the emphasis will be on the characterization of (secondary) cementitious phases in response to hydrothermal alteration. This will include steel corrosion measurements, which will provide data revealing if corrosion is inhibited in the presence of cement. None of the identified Argillite R&D Activities are considered to be Gap Activities; however, a number of EBS Gap Activities are directly relevant to a repository in argillite host rock.

Based on 2012 Roadmap FEP ("Issue") scores, one Argillite Activity (A-6) would be evaluated as SAL 4 (Improved Representation) and the rest would be evaluated as SAL 5 (Fundamental Gaps in Method or Fundamental Data Needs, or Both). Now in 2019, based on R&D over the intervening seven years, one Activity (A-1) was evaluated as SAL 3 (Improved Defensibility) and Activities A-2 through A-6 were evaluated as SAL 4 (Improved Representation). Activities A-7 (Analysis of clay hydration/dehydration and alteration at high temperatures) and A-8 (Evaluation of ordinary Portland cement (OPC)), which is new work scope, were evaluated as SAL 5. Evaluation of all eight argillite Activities resulted in 2019 SAL scores of SAL 5 (two Activities), SAL 4 (five Activities), and SAL 3 (one Activity).

Crystalline

The Crystalline R&D Activity Group has a significant focus on opportunities to improve model representations of the most significant processes to repository performance. Buffer erosion is a good example of an instance in which a new mechanistic representation can be developed, building on work that has already been done in Europe. Hydrologic properties of the EDZ represent another opportunity for improved representation. Flow and transport in fractures, including matrix diffusion, are an ongoing focus. Overall, modeling a repository in crystalline rocks involves more issues than other rock types, so there is a need for more R&D Activities and more emphasis on longer range research planning.

Crystalline R&D Activities cover a wide range of topics. Activity C-1 is focused on discrete fracture modeling and improvement of models of radionuclide flow and transport in fractured media by simulation of field scale and laboratory testing programs, particularly in coordination with international programs in crystalline rock. Activity C-2 addresses modeling approaches and will focus on understanding the uncertainty in fluid flow and radionuclide transport associated with different modeling approaches. Fracture-matrix diffusion modeling is addressed by C-3 and will include column and field scale testing on matrix diffusion and upscaling modeling as needed. It will also incorporate modeling advances from international work. Activity C-4 will simulate laboratory-observed EDZ development using the rigid body spring network (RBSN) model and predict the development of an EDZ and its associated hydro-mechanical properties. Activity C-5 will continue development and demonstration of geophysical techniques for site characterization. Activity C-6 will address the development of mechanistic model for buffer erosion for inclusion in PA, if needed. Activity C-7 will continue to improve models to simulate colloid transport and improve techniques for *in situ* characterization and quantification of colloids. Activity C-8 involves participation in multinational programs analyzing potential repositories in crystalline rocks as an excellent and cost-effective way to develop improved, validated THMC models that could be directly applicable to the US program. As an example, HotBENT could provide highly relevant experimental validation of important repository processes at high temperature. Activity C-9 involves the development of a centralized technical database for crystalline disposal system evaluation.

The remainder of the Crystalline R&D Activities are considered to be Gap Activities, with some of them of decades-long duration. C-10 involves collating data from International URLs. C-11 will investigate fluid flow and transport in low permeability media (clay materials). C-12 is focused on model validation, specifically the evolution of groundwater chemistry and radionuclide transport in fractured rock. C-13 will address evaluation and upscaling of the effects of spatial heterogeneity on radionuclide transport. The focus of C-14 will be radionuclide sorption and incorporation by natural and engineered materials. C-15 will be a multi-year (or multi-decade) effort to design improved backfill and seal materials. C-16 will have a broad scope involving development of new waste package concepts and models for evaluation of waste package performance for long-term disposal. C-17 will incorporate stress effects into existing DFN models and study the effect on DRZ evolution.

Based on the 2012 FEP ("Issue") scores, all 2019 Crystalline R&D Activities would be evaluated as SAL 5 (Fundamental Gaps in Method or Fundamental Data Needs, or Both). Now in 2019, based on R&D over the intervening seven years, ten Activities (C-1, C-4, C-6, C-7, C-8, C-11, C-12, C-13, C-14, and C-17) were evaluated as SAL 4 (Improved Representation), and five Activities (C-2, C-3, C-5, C-9, and C-10) were evaluated as SAL 3 (Improved Defensibility). Two Activities (C-15 and C-16) involve new work on waste package design and backfill and seal materials and have values of SAL 5. Evaluation of all seventeen crystalline Activities resulted in 2019 SAL scores of SAL 5 (two Activities), SAL 4 (ten Activities), and SAL 3 (five Activities).

Salt

R&D Activities are focused on a few issues. Reconsolidation of granular salt is a focus because of its role in the evolution of the excavation damaged/disturbed zone (EDZ). Coupled geomechanical, i.e. coupled hydro-mechanical, modeling is needed to understand flow and transport issues. Drift resaturation processes in salt are significantly different from the processes in other rock types and as such require specific R&D Activities. In-situ testing at the Waste Isolation Pilot Plant (WIPP) is the driver for most salt R&D Activities.

The Salt Team is currently working 13 R&D Activities. Activities (S-1 to S-4) are broad modeling Activities that involve different aspects of coupled thermal-hydrologic-mechanical (THM) and thermal-hydrologic-chemical (THC) processes, based on field test data. A common thread running through these Activities is the need to understand how higher temperatures impact these coupled processes. This need is one of the reasons for S-5, which consists of borehole-based heater testing. This major field test is supported by laboratory testing (S-6, experiments to validate and parameterize coupled process models) and includes data gathering activities during the field test (S-7, experiments on brine samples collected from boreholes). S-8 pertains to the evolution of run-of-mine salt backfill, with testing and modeling components as well as continued use of international collaboration. This R&D Activity includes research on the evolution of hydrologic and mechanical properties during reconsolidation. While it is understood that reconsolidation will occur, there is some uncertainty about the timeframes involved, what the actual evolution will look like, or how it will affect the EDZ. S-9 seeks to compare, validate, and benchmark the dryout and resaturation processes using the PA code, PFLOTRAN. S-12 involves improving the process model representation of intragranular brine (i.e., fluid inclusion) migration in salt. There will be model development and benchmarking against laboratory and field test data, including the results of laboratory testing on fluid inclusions by LANL. The final additional Activity, S-13, addresses acid gas generation, fate, and transport. This R&D Activity emphasizes collecting field and laboratory data that can be used to improve and calibrate process models.

S-10 and S-11 are currently considered to be Gap Activities. S-10 specifically addresses the issue of incorporating drift resaturation into the *GDSA Framework* PA model. Process models have already been developed to include drift resaturation processes, which are significantly different in salt compared to other rock types. While there is an EBS Activity for resaturation processes as well, that Activity focuses on the resaturation of bentonite. S-11 is designed to improve the modeling representation of thermal-hydrologic-mechanical-chemical (THMC) effects of anhydrites, clays, and other non-salt components. The effort leverages ongoing DOE–Office of Environmental Management (DOE–EM) testing at WIPP.

Based on 2012 FEP ("Issue") scores, all 2019 Salt R&D Activities would be evaluated as SAL 5 (Fundamental Gaps in Method or Fundamental Data Needs, or Both). Now in 2019, based on R&D over the intervening seven years, five Activities (S-2, S-7, S-8, S-11, and S-12) were evaluated as SAL 4 (Improved Representation), and three Activities (S-6, S-9, and S-10) were evaluated as SAL 3 (Improved Defensibility). Much of the change in the State of the Art between 2012 and 2019 was due to the increased understanding of salt behavior in unheated conditions. The evaluation of all thirteen salt Activities resulted in 2019 SAL scores of SAL 5 (five Activities), SAL 4 (five Activities), and SAL 3 (three Activities).

DPC

All testing and modeling R&D Activities in this area are rated SAL 5 and ISC 5 because direct disposal of DPC is an issue that has only recently emerged into prominence. Because direct disposal is a relatively new issue the identification of information gaps and integration issues is a major focus of current Activities. There has also been an effort to identify new issues that may result from the direct disposal of DPCs.

Several new DPC-specific Activities have been defined. Activity D-1 will focus on criticality scenario development with source term and near-field changes specific to different types of criticality events, to be used for consequence screening. Activity D-2 will maintain and populate a DPC "as-loaded" database. Activity D-3 will identify potential filler compositions, and test related behavior (injectability, radiolysis, material interactions, leachability). Activity D-4 will analyze conditions inside and outside waste packages subjected to criticality events. Activity D-5 will simulate fuel, basket and waste package envelope degradation (canister and overpack), including degradation modes for cladding, unzipping, UO_2 alteration/dissolution, basket corrosion and collapse, and canister/overpack breach evolution. Activity D-6 will provide technical integration of DPC direct disposal solutions, considering concepts of operations, overpack concepts, engineering feasibility, cost analysis, and pre-closure safety.

Criticality is an issue that has been screened out from past performance assessments because of low probability, but it may require re-evaluation when considering direct disposal of DPCs. An analysis was completed (Hardin et al. 2015) to see if it was possible to predict which DPCs might go critical versus those that would not. The analysis of currently loaded DPCs shows that they can be divided into three categories: (1) DPCs that will not go critical if disposed directly in a geologic repository, (2) DPCs that may go critical but do not require mitigation, and (3) DPCs that may go critical but do require mitigation. For this third group, various types of filler materials that can be injected into ports on top of the DPC are being investigated. It takes water to degrade a DPC and support a criticality event. A repository in salt host rock is beneficial in this regard because the chlorine in the salt brine is a thermal neutron absorber that tends to quench potential criticality events. The working assumption is that 70% to 90% of the DPCs could be directly disposed in salt without having to resort to some form of criticality mitigation fillers.

An evaluation of possible gap activities during the DPC breakout session yielded three items, all of which are R&D Activities represented in other R&D Activity groups. The first is development of a waste package failure model (E-04) that includes breach geometry details, especially as they relate to evaluation of criticality. The criticality process is very sensitive to the geometry of the waste package breach. A model that is adequate for criticality assessment would also need to allow for cyclic wetting, dryout, and rewetting behavior. Thus, in the development and pursuit of EBS Activity E-04, considerations related to criticality initiation need to be considered. The second potential gap activity related to DPCs is the transport of short-lived fission products. In the past, there has not been much attention paid to short-lived products for post-closure because they decayed before any waste package breach and were not significant to PA performance. However, the work needs to be done to prove this point one way or the other. This potential gap should be investigated as part of PA Activity P-08. The third potential gap activity is the development of a repository-scale system model for DPC disposal. This is currently being developed in conjunction with the *GDSA Framework* reference cases (P-01, P-02, P-03, P-04).

EBS

EBS R&D Activities support all three host-rock R&D Activity groups but the specific EBS information needs differ between groups. The Salt group is focused on testing and modeling to improve understanding of THM effects on the EDZ and granular salt backfill evolution. EBS research supporting the Argillite group includes testing and modeling of buffer evolution, including coupled THMC processes. Safety cases in crystalline rock place more emphasis on the EBS than models of repositories in argillite or salt. Consequently, the Crystalline host-rock R&D Activity group has more information needs, including testing and modeling of waste form and waste package behavior, and the diffusion barrier in the buffer/backfill.

EBS Activities address a wide range of topics. Activity E-1 will focus on implementation of FMDM (and/or other models) for spent fuel matrix degradation (including possible effect of Fe corrosion). Activity E-2 includes degradation testing and integration of testing results into a mixed potential model of spent fuel matrix degradation. Activity E-3 addresses a variety of THC processes related to the EBS. Activity E-4 will focus on development of a mechanistic waste package degradation model that will include DPC relevant parameters, including those that affect criticality. Activity E-5 will focus on incorporation of radionuclides in corrosion products. Activity E-6 will include testing and experimental data for corrosion of carbon steel, stainless steel, and other potential waste package materials. Activity E-7 will include testing and experimental data for corrosion of carbon steel, stainless steel, and other potential waste package materials in a salt repository as well as mechanical damage from rock fall and drift collapse. Activity E-8 addresses radionuclide interactions with buffer materials. Activity E-9 will address cement plug/liner degradation. Activity E-10 will address the ability to apply PA models at temperatures up to 200°C. Activity E-11 will focus on EBS high-temperature experimental data collection to evaluate high-temperature mineralogy /geochemistry changes. Activity E-12 will include testing and modeling to evaluate buffer/backfill dry-out and resaturation processes.

The remainder of the EBS Activities are Gap Activities. Activity E-13 is a "cross-campaign" integration activity (i.e., between different offices in DOE) to implement a glass degradation model that includes representation of Stage III rates (transition trigger and rate values) within the glass degradation model representation in PFLOTRAN. Activity E-14 will develop a fully coupled in-package chemistry model, as it impacts degradation, mobilization, and transport inside the waste package. Activity E-15 will model cladding degradation processes (e.g., hydride cracking). Activity E-16 will model flow and transport inside waste packages/canisters and the evolution of corrosion products. Activity E-17 will evaluate the development of new generation buffer materials (thermal management, resistance to erosion, limitation of chemical gradients/interactions). Activity E-18 will develop an unbackfilled-drift thermal radiation model for DPC waste packages. Activity E-19 will develop or consider additional waste-form degradation models for minor inventory sources such as HIP Calcine and TRISO particle fuels. Activity E-20 addresses colloid source terms but is not clearly defined as yet.

Buffer/backfill Activities are an EBS R&D priority. These studies include the evaluation of dry-out and re-saturation processes and the potential impacts on barrier performance, i.e. E-10 and E-12. These studies involve both laboratory and field data from the Grimsel URL, i.e. E-11. The evaluation of new, i.e. novel, buffer materials has been identified as a Gap Activity, i.e. E-17.

The potential future direct disposal of DPCs in a geologic repository is an important factor driving EBS Activities. New information needs are created because of the physical characteristics of the DPCs. These information needs include evaluating the impacts of higher heat loading from DPCs and developing waste package damage models for evaluation of potential criticality events. There are also other information needs related to criticality events involving DPCs, including changes to radionuclide inventory and source term effects, as well as impacts of heat generated from the events. Several EBS Activities are addressing these needs, but gaps have also been identified.

International

International Activities are well integrated with other project Activities but are also unique in some ways. For example, International Activities are unique in that the United States usually does not have the final say in determining what tests are conducted. Several topical areas have already greatly benefitted from international work and have seen improved State-of-the-Art Levels. In addition to importance for Post-closure Safety Evaluation (Safety Case Element 4.2 in Figure 3-2), International Activities are also important for Confidence Building (Safety Case Element 4.3 in Figure 3-2) via international consensus or comparison. Testing data from international URLs are being incorporated in modeling Activities for all host-rock R&D groups. Consequently, when International Activities are evaluated, it is important to include decision metrics that go beyond those used to evaluate other Activities, e.g., (a) what data and collaborations are existing and available; (b) a small investment in existing URL studies may yield a large return; (c) or, on the other hand, various international URL studies may be too site-specific to be valuable for the U.S. generic program. Data from tests being conducted in these URLs is being used for a variety of tasks by SFWST personnel. Multiple new opportunities exist in the international arena that may lead to new Activities in 2020 and beyond. Six of these have been identified as GAP Activities (I-16 to I-21) in Appendix B.

Activity I-1 will use data from the CFM project at the Grimsel Test Site to evaluate bentonite colloids. Activity I-2 will continue laboratory analysis and modeling of the complex FEBEX-DP data set. Activity I-3 will conduct a limited amount of additional experimental work to measure transport properties of FEBEX materials. Activity I-4 will evaluate results from HotBENT which will tackle a temperature regime of up to 200°C in a full-scale field heater test. Activity I-5 will support the Mont Terri FE heater test, which is a full-scale long-term demonstration experiment that should demonstrate that waste emplacement can be engineered and predicted. Activity I-6 will evaluate results from the Mont Terri Fault Slip experiment. Activity I-7 will support Task E of the DECOVALEX-2019 project that involves the evaluation of upscaling of THM properties and processes from laboratory experiments, via *in situ* experiments, to a full repository scale. Activity I-8 will address complex gas transport behavior through bentonite that has been observed in lab studies. Activity I-9 supports DECOVALEX-2019 Task C: GREET (Groundwater REcovery Experiment in Tunnel) at the Mizunami URL in Japan. This resaturation field experiment is used in the SFWST Campaign in different ways. The main one is that data from shotcrete liner interactions are helping constrain 3-D reactive transport models. Activity I-10 supports the SKB GWFTS Task Force Long-term Diffusion Experiment (LTDE-SD) at the Äspö URL in Sweden (also called an HRL or hard-rock laboratory). Activity I-11 will evaluate microbial processes affecting hydrogen generation and uptake using FEBEX-DP and Mont Terri studies. Activity I-12 supports WEIMOS collaboration, which seeks to improve thermo-mechanical simulations of salt host-rock repositories through enhancing rock salt constitutive models and general simulation techniques. Activity I-13 supports BenVaSim, which is an international project designed to perform benchmarking and validation of numerical simulators used for analysis of long-term coupled processes associated with nuclear waste disposal in salt. Activity I-14 will evaluate TH and THM processes in reconsolidating salt as part of the German-US collaborations (KOMPASS). Activity I-15 will conduct THM model comparison studies with Germany regarding shaft and drift seal evolution in salt repositories.

The remainder of the International R&D Activities are considered to be Gap Activities. Activity I-16 will include comparative modeling of Borehole Heater Tests at WIPP for coupled processes. Activity I-17 is a proposed DECOVALEX task consisting of a multi-year benchmarking exercise of geologic repository performance assessment (PA) models and software, including sensitivity analysis (SA) methods for analyzing the effect of input uncertainties on output uncertainty. Activity I-18 will support LASGIT, a large-scale in situ bentonite column experiment at the Äspö URL, with testing of gas migration at several times during the hydration and post-hydration phases. Activity I-19 will support ANDRA's Thermal Fracturing Task, a planned heater test at Bure, France to look at potential for thermal fracturing at the mid-point between heated emplacement holes. Activity I-20 will support ENSI's Gas Transport Experiment, an evaluation of gas transport models and of the behavior of clay rocks under gas pressure (gas migration in host rock). Activity I-21 will support SKB Task 10 involving validation of DFN modeling.

PA-GDSA

The workshop did not include a breakout session that specifically evaluated PA (GDSA) R&D Activities. However, PA R&D Activities were identified as a High-priority Cross-Cutting R&D Issue in the 2012 Roadmap (see Table 2-4 above). Thus, R&D in the SFWST (formerly UFD) Campaign has had an important focus on developing generic PA reference cases and PA software, which has been used to help integrate other R&D being conducted within the Campaign—as shown by the integration focus of the 2016, 2017, and 2018 Annual Working Group meetings for the Campaign (e.g., see https://energyworkshops.sandia.gov/nuclear/2018-sfwst-rd-team-meeting/).

The current 2019 Roadmap Update effort has included the evaluation and prioritization of seventeen PA-GDSA R&D Activities. Activity P-1 is the continued development of the Generic CSNF repository Argillite reference case. Activity P-2 is the continued development of the Generic CSNF Repository Crystalline Reference Case. Activity P-3 is the continued development of the Generic CSNF Repository Bedded Salt Reference Case. Activity P-4 will develop a Generic CSNF Repository Unsaturated Zone (Alluvium) Reference Case. Activity P-5 investigates PA processes initiated or dependent upon external disruptive events, such as human intrusion, glaciation, and seismicity, but also internal disruptive events, such as early WP failures. Activity P-6 is focused on modeling formation, stability, and transport of pseudo-colloids in the near field and far field. Activity P-7 is focused on intrinsic Pu colloid formation, stability, and transport in the near and the far fields, as a function of temperature. Activity P-9 will develop model parameters for infiltration and surface discharge. Activity P-10 will implement a standardized set of UQ/SA methods for PA-GDSA. Activity P-12 will focus on a waste package degradation model framework for PA-GDSA. Activity P-14 focuses on generic capability development for PFLOTRAN.

P-08, P-11, P-13, P-15, P-16, and P-17 are currently considered to be PA Gap Activities. Activity P-8 is a catch-all activity for FEPs that are currently missing from the generic PA-GDSA reference cases and models. Activity P-11 will implement Pitzer activity coefficients (Wolery EQ3/6 version). Activity P-13 will develop a full representation of chemical processes in PA-GDSA. Activity P-15 focuses on species and element properties for use in the PA-GDSA models. Activity P-16 will model precipitation and dissolution of solid solutions. Activity P-17 will address multi-component gas transport.

Other

The workshop did not include a session that discussed or evaluated the activities in the Other R&D Activity group. These are R&D Activities that provide general support to SFWST work, such as database development and implementation, or do not fit clearly into other categories. Examples include GDSA geologic modeling, natural analogues, and biosphere. These R&D Activities are clearly important, and many were recognized as such in the 2012 Roadmap as indicated by the State-of-the-Art descriptions in Appendix J for Activities O-1 through O-4. Others are important for reasons besides generic R&D that might be needed, e.g., a complete biosphere model (O-7) will, undoubtedly, be a regulatory requirement for any repository project. In general, evaluation of Other R&D Activities includes factors, such as general support requirements, that are not directly applicable to the mainstream R&D activities evaluated in the Update Workshop.

There are seven activities included in the Other R&D Activity group. Activity O-1 is the On-Line Waste Library which will include information on DOE-managed HLW, SNF, and other wastes that are potential candidates for deep geologic disposal, with links to supporting documents. Activity O-2 is GDSA Geologic Model which will provide a geologic and hydrologic conceptual framework for GDSA reference cases (Activities P-1 to P-4) and data feeds to GDSA models (hydrologic parameters, stratigraphy, fractures). Activity O-3 is developing a web visualization of a geologic conceptual framework for GDSA Geologic Modeling. Activity O-4 is developing and implementing thermodynamic and sorption databases, which has a significant international collaboration aspect. Activity O-5 is a general QA (quality assurance) Activity that will, among other things, provide V&V (verification and validation), benchmarking, and documentation of software codes, including pre- and post-processors. Activity O-6 will investigate both natural and anthropogenic analogs to improve understanding of radionuclide transport and repository performance. Activity O-7 will develop a full biosphere model including detailed biosphere pathways, processes, and FEPs.