U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Performance Confirmation

Presented to:
Nuclear Waste Technical Review Board

Presented by:

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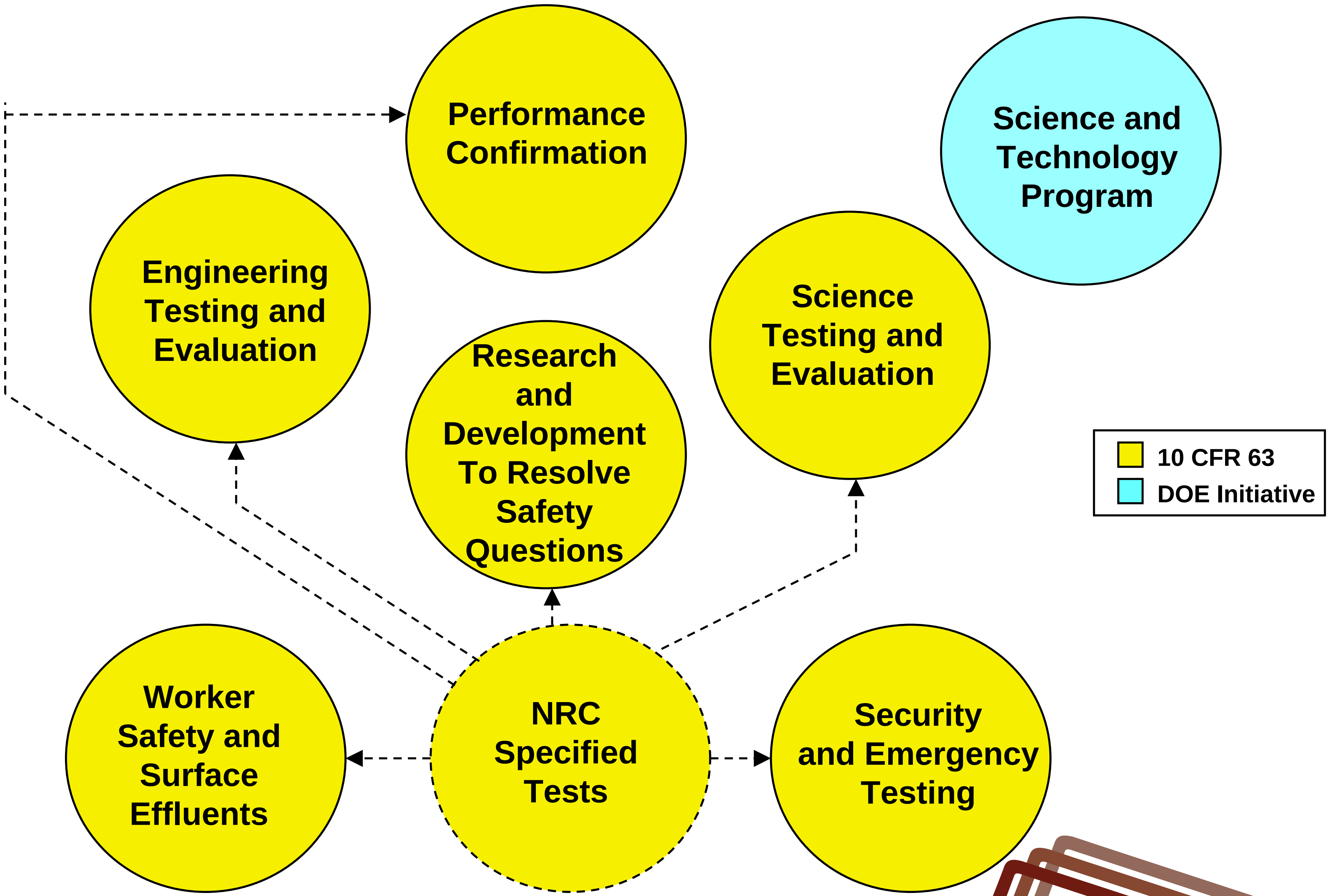
Outline of Presentation

- Vision of the Program
- Process used to select activities for inclusion into the program
- Description of the selected program and its key components
- Further development of the performance confirmation program

Testing and Monitoring Categories



Performance Confirmation versus Other Testing and Monitoring Programs

- **Performance confirmation program focuses on**
  - **Activities specifically designed to confirm the technical basis for the licensing decision**
  - **Testing the functionality of the barriers and total system performance**
- **Other testing and monitoring programs focus on**
  - **Increasing confidence**
  - **Meeting other regulatory requirements**

Role and Requirements for Performance Confirmation

- **The NRC requires a performance confirmation plan as part of a License Application for the Yucca Mountain repository**
  - **"Performance confirmation means the program of tests, experiments, and analyses that is conducted to evaluate the adequacy of the information used to demonstrate compliance with the performance objectives …" (10 CFR 63.2)**
- **Performance confirmation program should demonstrate that the system and the sub-system components (i.e., barriers) are operating as predicted**
  - **"The performance confirmation program must provide data that indicate, where practicable, whether natural and engineered systems and components required for repository operation, and that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated" (10 CFR 63.131(a)(2))**

Motivation to Update the Performance Confirmation Plan

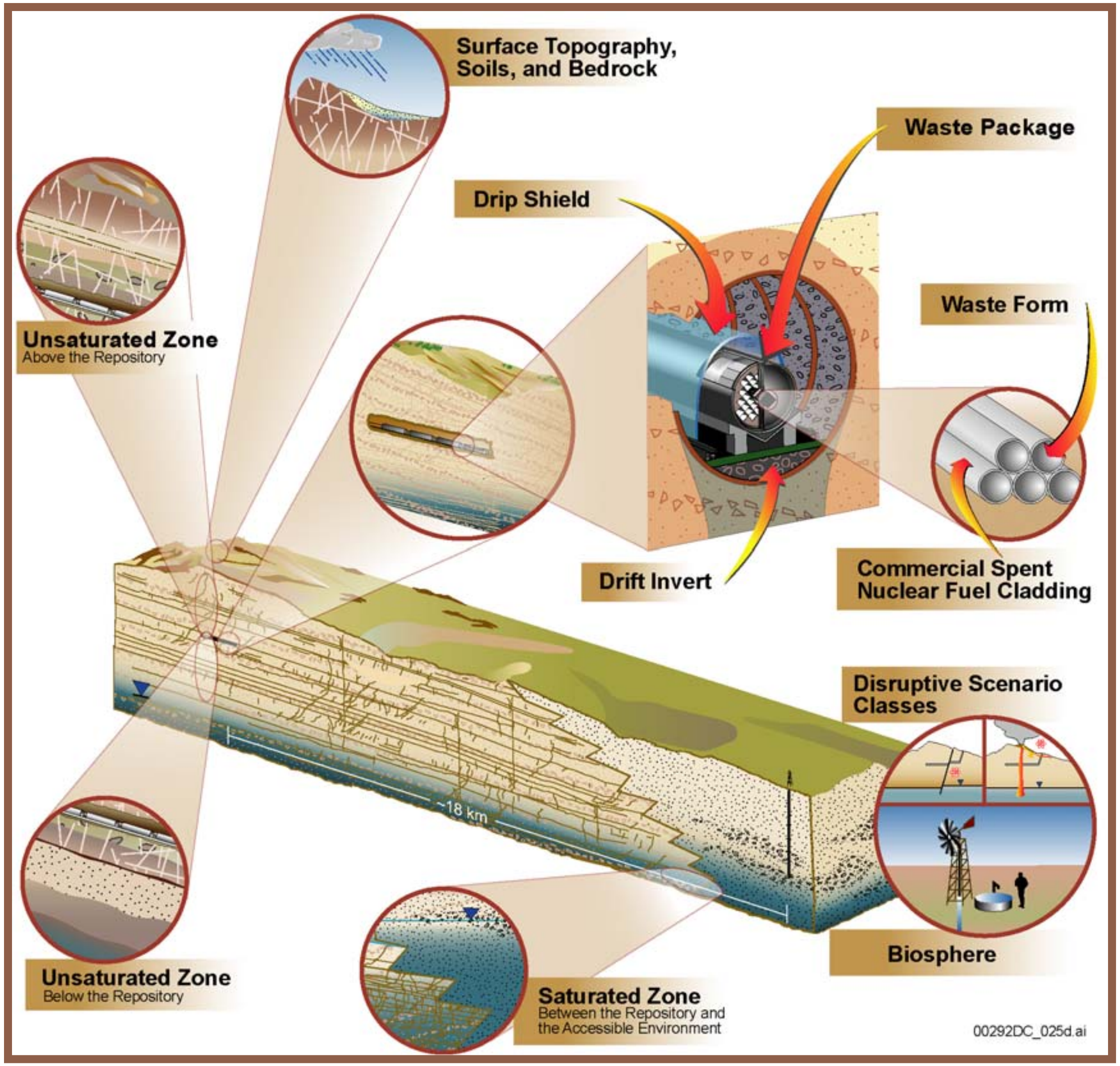
- **Address requirements in the finalized 10 CFR 63**
  - **Also address expectations laid out in the *Yucca Mountain Review Plan***
  - **Reflect the barriers important to waste isolation**
  - **Use a risk-informed performance-based process to determine how to confirm each barrier's performance**
- **Ensure performance confirmation program is consistent and compatible with repository operations**

Elements of a Performance Confirmation Vision

- Based on 10 CFR 63 requirements and *Yucca Mountain Review Plan* expectations
- Provides a comprehensive and thorough look at critical aspects of the overall system and the barriers
- Uses a risk-informed performance-based approach to determine the complexity, extent, and number of activities to include for testing a parameter's effect on total system performance or a particular barrier functionality
- Confirms operations rather than imposing substantial design requirements (i.e., does not drive facility design)
- Supports a License Amendment for closure

Decision Analysis Process Used to Develop a Performance Confirmation Program

Decision Analysis Based on Performance Assessment



- **Performance assessment barriers and scenario classes were the basis of the decision analysis**
- **Performance assessment technical staff provided technical judgments**
- **Performance assessment manager provided management value judgments**
- **Performance assessment includes process abstraction and total system model**

Decision Analysis Approach

- Provides a consistent, logical, defensible basis for evaluating and comparing activities considered for inclusion in the performance confirmation program
- Explicitly acknowledges that tradeoffs among different objectives and goals may be necessary
- Uses a formal multi-attribute utility analysis as the technical basis
  - A technically sound mathematical approach for evaluating alternatives where more than one objective is important
  - Has been used by DOE, other federal agencies, and private companies since the late 1970s to evaluate complex decision problems

Terminology

- ***Parameters*** **are "things that can be measured or observed"**
- ***Data acquisition methods*** **are the means to measure parameter(s)**

Parameter	Data acquisition method
Temperature and relative humidity of the waste packages	Monitor temperature and relative humidity of the air in the emplacement drifts
Temperature and relative humidity of the waste packages	Use a remotely operated vehicle to take physical measurements on the waste package surface in the emplacement drifts
Composition of the drift invert materials	Testing of invert material in the drifts prior to emplacement of waste

- **Each combination of a parameter and data acquisition method is a** ***performance confirmation activity***
- **A** ***portfolio*** **is a complete set of performance confirmation activities which could form the basis for the performance confirmation program**
- **The** ***performance confirmation program*** **is the selected set of performance confirmation activities**

Approach

Phase 1: Activity evaluation → **Phase 2: Portfolio development and evaluation** → **Phase 3: Portfolio selection and refinement**

Management value judgments

Technical judgments

- Define activity evaluation criteria
- Define and describe candidate performance confirmation activities
- Assign management value judgments to criteria
- Evaluate activities (technical judgments using evaluation criteria)
- Combine technical activity evaluation and management value judgments to get overall utility for each candidate activity

In each phase all scenario classes and barriers were explicitly considered

Activity Evaluation Criteria

- **At an initial workshop (August 26, 2002), three criteria were defined, to be used in estimating the potential impact of a performance confirmation activity on the performance confirmation program:**
  - **Barrier capability and system performance sensitivity to the parameter**
  - **Confidence in the current representation of the parameter**
  - **Accuracy with which the proposed activity measures or estimates the parameter**
- **Workshop participants included:**
  - **Technical investigators with various areas of expertise**
  - **Performance assessment analysts and managers**
  - **DOE staff**

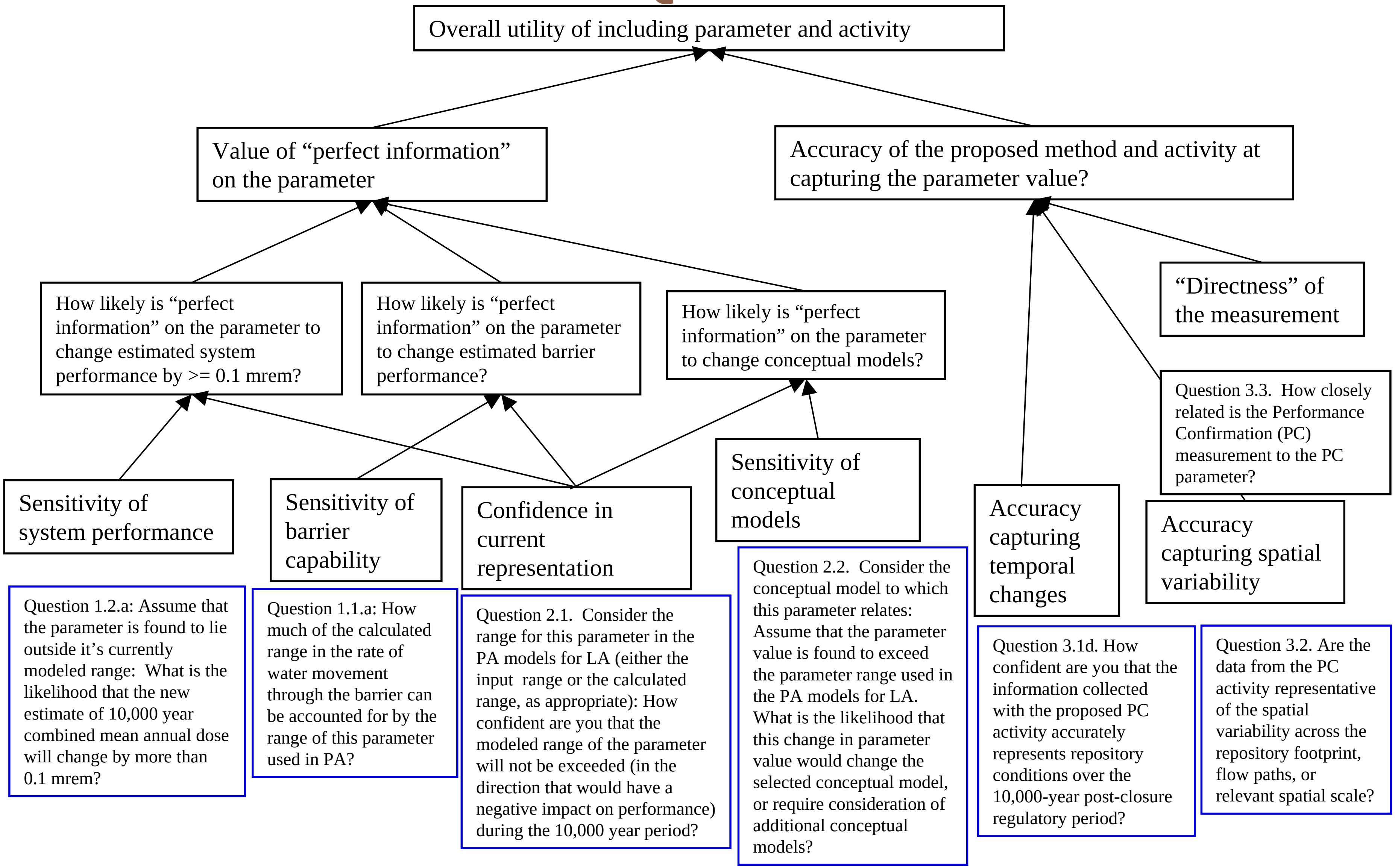
A Detailed Set of Questions was Developed Around Each Criterion

Technical judgments

- The goal of the questionnaire was to elicit technical input on how well proposed parameters and activities meet the three criteria
- The goal of the questionnaire was to improve consistency across model areas
- Workshops were held in September 2002 with each group of technical experts
- During the workshops
  - Each group developed a comprehensive list of parameters to be considered
  - For each parameter identified, the group defined one or more data acquisition methods that could be implemented to provide information on that parameter
  - Several activities were evaluated in each workshop by the group, using the questionnaire

Technical Judgments: Use of the Questionnaire

Technical judgments



Performance Assessment Managers Provided the Necessary Management Value Judgments

Management value judgments

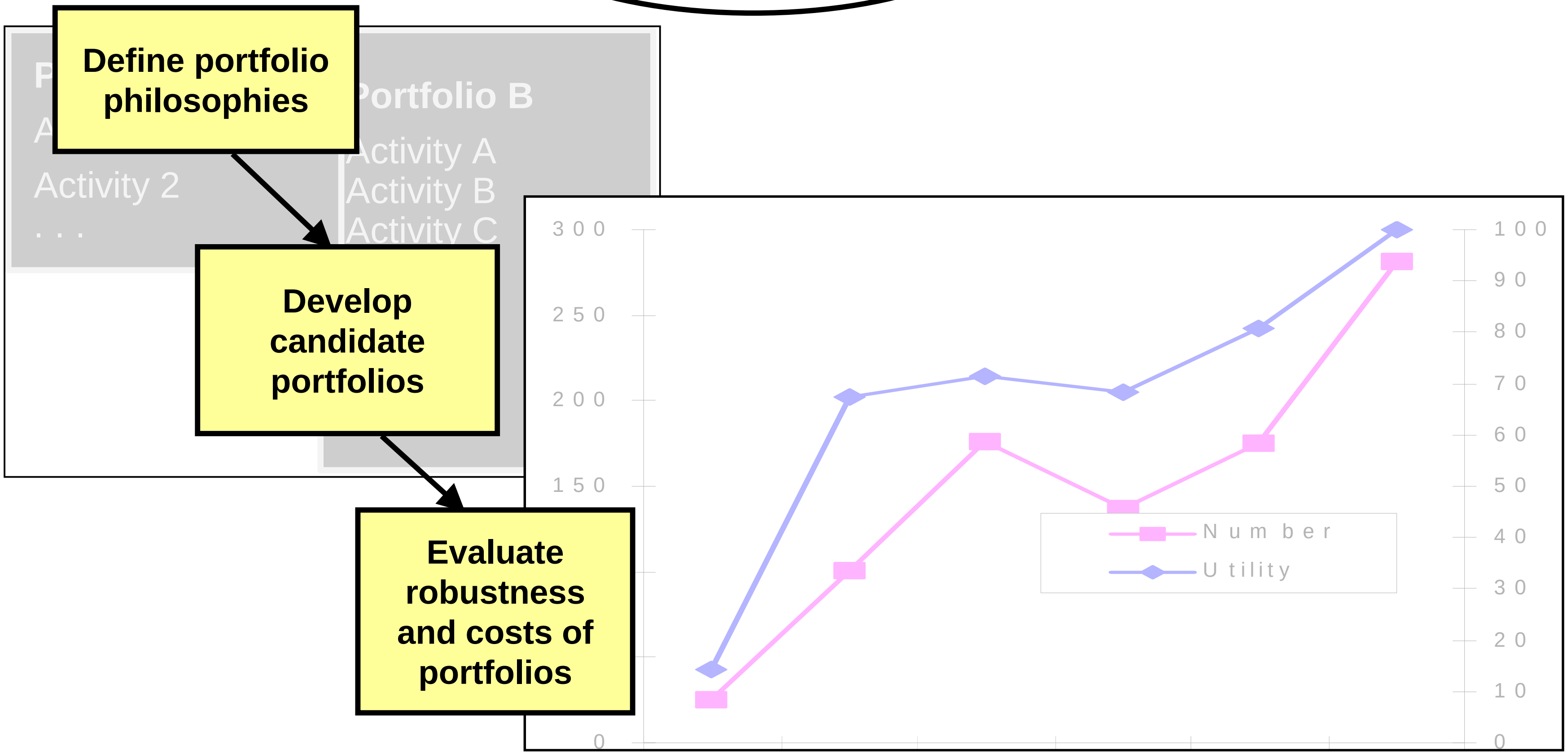
- BSC Managers reviewed the overall process and endorsed the specific criteria being used to evaluate activities
- Managers answered a series of tradeoff questions, designed around the technical questions used in the questionnaire, to establish management value judgments about the relative importance of the criteria
- Management value judgment used in conjunction with the technical judgments to establish the overall utility for each activity
- Participants included the manager of the performance assessment project and the manager and/or deputy for related subprojects: natural systems, engineered systems, performance assessment strategy and scope, and the performance confirmation manager

Phase 1 Summary

- 237 parameters and a total of 360 activities initially identified
- After discussion, evaluation, and consolidation, 204 parameters and 287 total activities remained
- A review meeting was held with representatives of the technical experts
  - In the few instances in which the utility ranking did not agree with the overall opinions of the technical experts, an alternative ranking was considered during portfolio development in Phase 2
- Costs were estimated for each activity for consideration in developing portfolios

Approach

Phase 1: Activity evaluation → **Phase 2: Portfolio development and evaluation** → **Phase 3: Portfolio selection and refinement**



Rationale for Portfolios

- **Each candidate activity contributes to demonstrating compliance with one or more regulatory requirements**
- **The best portfolio does not necessarily result from ranking activities by utility, cost, or the ratio of utility to cost**
  - **Some regulatory requirements are not captured by the technical judgments and management value judgments input to the utility**
  - **Activity evaluations do not account for potential synergies**
- **Some costs cannot be assigned to individual activities (e.g., observation drift construction and remotely operated vehicle development)**
- **Portfolios of performance confirmation activities can be evaluated for regulatory compliance and for total cost**

Philosophy for Portfolio Development

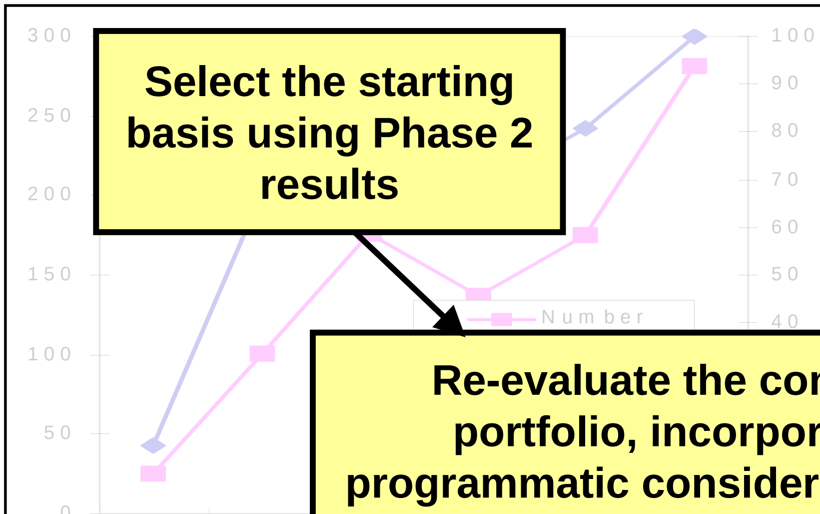
- **Each portfolio addresses the performance confirmation requirements of 10 CFR 63**
- **Eleven portfolios were developed**
  - **Spanned a range of scope, costs, and robustness**
  - **Included portfolios that emphasized cost-benefit and hypothesis testing philosophies**
  - **Included portfolios that emphasized off-site work or on-site work**
- **Six of these portfolios were evaluated in detail**
  - **Scope, costs, robustness**

Portfolio Evaluation Criteria

- Activities were mapped to the regulatory requirements in 10 CFR 63 Subpart F
  - Some activities support multiple requirements
- Attributes were totaled across the activities in each portfolio
  - Activity count
  - Total utility
  - Total operating plus capital cost
- Activity utilities were summed for each regulatory requirement in 10 CFR 63 Subpart F, within each portfolio
- A subjective assessment was made against each regulatory requirement in 10 CFR 63 Subpart F, for each portfolio
  - This added "coverage" as a subjective subcriterion

Approach

Phase 1: Activity evaluation → **Phase 2: Portfolio development and evaluation** → **Phase 3: Portfolio selection and refinement**



Select the starting basis using Phase 2 results

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Re-evaluate the complete portfolio, incorporating programmatic considerations and management judgment

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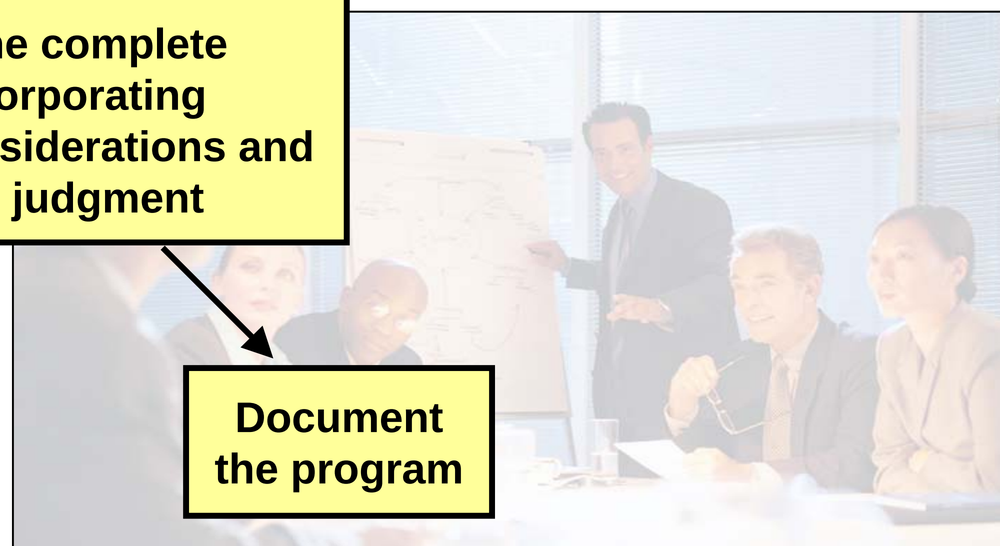
Document the program



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Starting Basis

- The BSC Manager of Projects and senior advisors
  - Reviewed all eleven portfolios, and the detailed evaluation of six
  - Selected one of the portfolios as the starting basis for the performance confirmation program
- They directed several changes to that basis
  - Activities were to be added to increase the robustness of the portfolio with respect to aspects of the regulation where it was judged relatively weaker than some other portfolios
  - Activities in the portfolio were described in terms of their relationship to the specific paragraphs of the regulatory requirement (10 CFR 63, Subpart F)

Portfolio Refinement

- **In a series of meetings, BSC senior management reviewed every activity in the modified basis portfolio, and made adjustments to the portfolio based on management judgment and programmatic considerations**
- **Of the initial activities:**
  - **26 were removed from the portfolio because they were more logical candidates for other testing programs**
  - **1 was deleted because it addressed a phenomonom conservatively treated in the performance assessment**
  - **3 were combined with other activities in the program based on the judgment that the combined activities were a more logical unit to consider**
  - **3 activities were retained in principle but modified in scope**
  - **2 new activities were added**

**** The Performance Confirmation Plan, Rev. 02 includes a description of the rationale for changes to the portfolio made during management discussions***

Elements of the Yucca Mountain Performance Confirmation Program

Activity Group Sequence

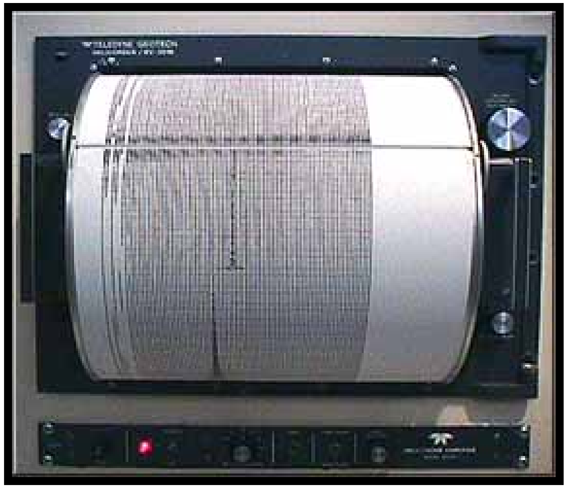
- Activities related to disruptive scenario classes (with highest risk scenario class first)
  - Igneous activity scenario class
  - Seismic activity scenario class
- Biosphere-related activities "downstream" of the nine barriers
  - These may apply to multiple scenario classes
- Nominal scenario class (which is lower risk than the disruptive scenario classes)
  - Waste package and drip shield
  - Preemplacement environment
  - Surface topography, soils, and bedrock; and the unsaturated zone (both above and below the repository)
  - Coupled thermal processes
  - Saturated zone
  - Cladding, waste form, and invert

Igneous Activity Scenario Class

- **Probability** of occurrence of igneous events
  - Drilling of aeromagnetic anomalies (180a)
    - Improved data set
  - Updated probability estimate (181a)
    - Incorporate improved data set
- **Consequences** of igneous events
  - Number of waste packages hit by magma (185a)
    - Calculations and analog studies
  - Behavior of contaminated ash (191a, 192a, 193a, 207a, 214a, 215a, 216a, 217a)
    - Ash loading, resuspension, redistribution, stabilization, and weathering
    - Radionuclide partition, sorption, dissolution/migration
    - Modeling, analogs, lab testing
  - Updated expert elicitation (182a)
    - Incorporate improved data set
- **Precursor conditions**
  - Satellite monitoring of regional extensional tectonics (221a)
    - Ongoing activity

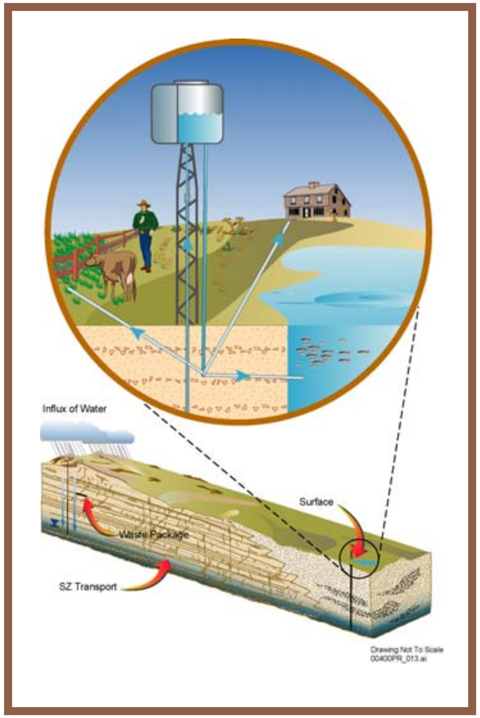
Seismic Activity Scenario Class

- Rock and soil dynamic properties at higher strains associated with major seismic events (173a)
  - Extend existing lower strain data set
- Regional seismic activity and near-field strong ground motions (167a)
  - Monitor for seismic activity and its consequences
  - Ongoing activity
- Inspection of surface and underground fault displacement in drifts if strong ground motion occurs (170a)
  - Contingency activity, using remotely operated vehicle

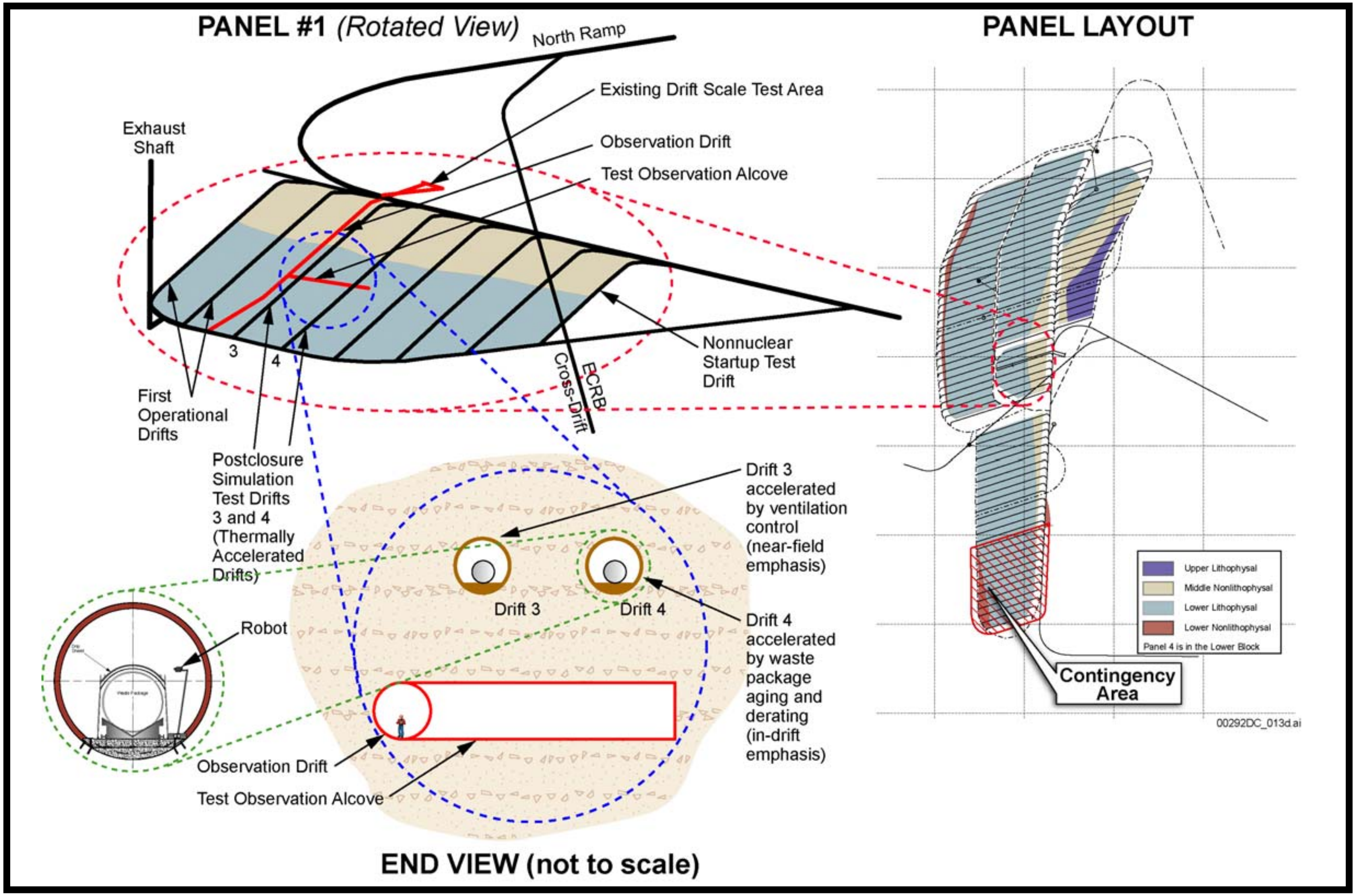


Biosphere-Related Activities “Downstream” of the Nine Barriers

- **Periodic survey of *reasonably maximally exposed individual* characteristics and of occupational dust levels (162a)**
  - **Ongoing activity**
- **Natural analog study of the movement of radionuclides added to soil and their migration back to the water table, where they may be pumped back to the surface (166b)**
  - **Nominal and disruptive scenario classes**
- **Radionuclide movement to humans via plants (204a, 205a, 206a)**
  - **Nominal and disruptive scenario classes**
- **Radionuclide movement to humans through soil ingestion (direct or via animals) (208a)**
  - **Nominal and disruptive scenario classes**

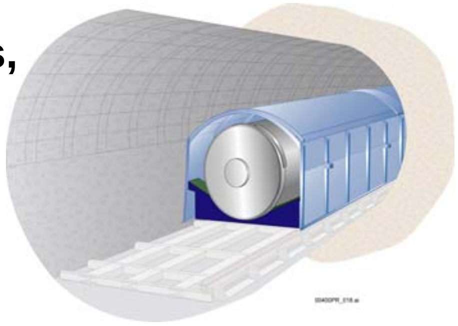


Dedicated Performance Confirmation Drifts With an Accelerated Thermal Cycle



Waste Package and Drip Shield Combined Activities

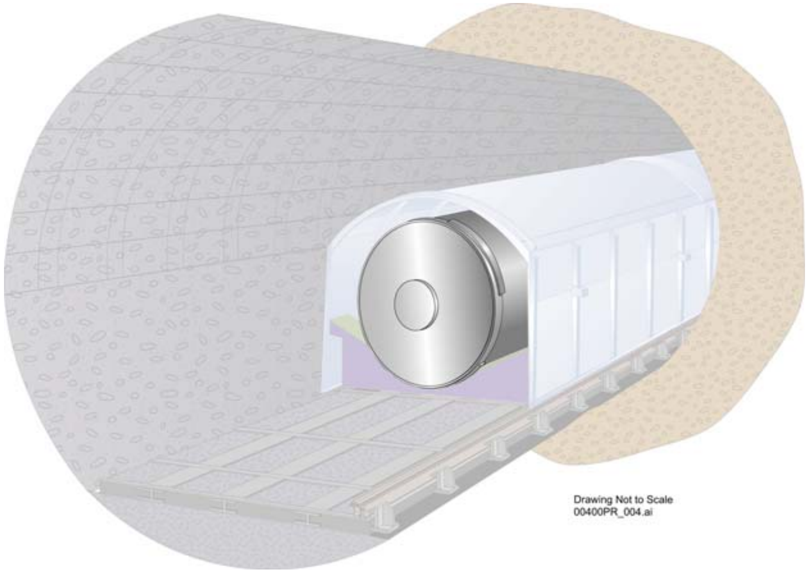
- **Mechanistic details of waste package and drip shield corrosion (68a, 69a, 70a, 71a, 72a, 73a, 74a, 75a, 76a)**
  - General corrosion, phase stability of Alloy 22, localized corrosion, microbial corrosion
  - Ongoing activities
  - Strengthen extrapolation to 10,000 years
- **Laboratory tests on mock-ups to confirm stress sources on the waste package and drip shield (79a)**
  - Consequence of rockfall and seismic activity
- **Waste package and drip shield environments (51a, 52a, 53a, 54e, 56e, 57a, 58e)**
  - In thermally accelerated drifts, using drift-end instruments, in-drift samples, and the remotely operated vehicle
  - Includes temperature, humidity, dust composition, gas composition, pressure, radiolysis effects, condensate chemistry, thin film chemistry, and microbes
  - Temperature, humidity, and dust measurements include all emplacement drifts



Waste Package

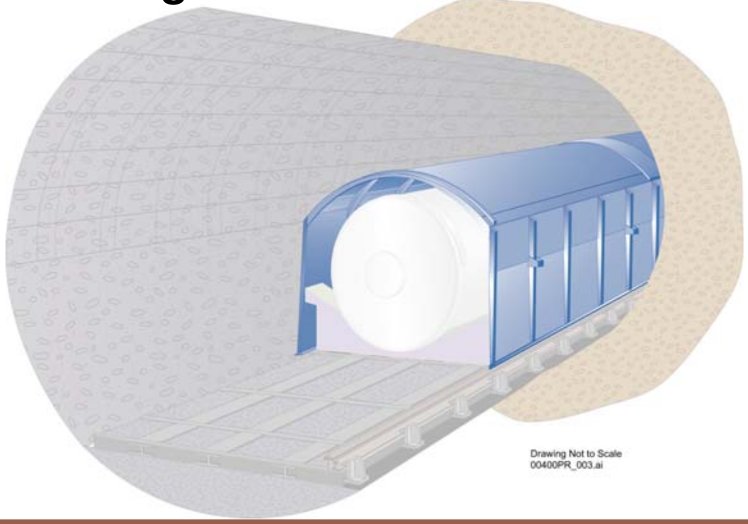
- **Monitoring radionuclides in exhaust air (251a)**
  - **Measure at the end of each drift in a sensor module that also measures temperature and humidity**
- **Pressure seal of all waste packages (83a)**
  - **Measure with the remotely operated vehicle, imaging internal mechanical sensors that respond to equilibration of internal and external pressures**

Both activities provide direct measures of overall waste package performance



Drip Shield

- Rockfall detection using acoustic/seismic tomography (59a1)
  - Concept demonstrated by an existing university grant program
- Inspection of drifts using the remotely operated vehicle (59a2)
  - Drift 4 will include drip shields after about 5 years
  - Other drifts will be inspected for ground support integrity
- Drift shape monitoring using the remotely operated vehicle in the thermally accelerated drifts (60b)
  - Several concepts being considered

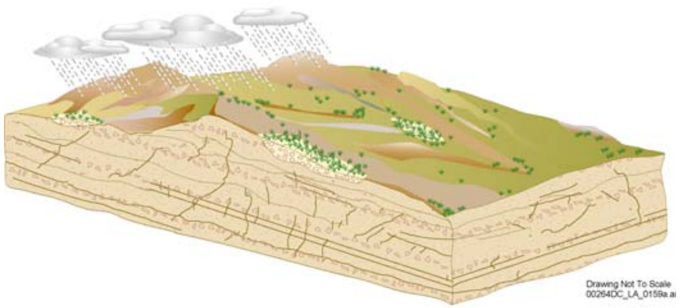


Preemplacement Environment

- Mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics (105a, 106a, 107a, 108a)
  - Three-pass construction
    - Excavate with light ground support
    - Remove Tunnel Boring Machine and map
    - Install permanent ground support
- Hydrologic properties of significant fractures and faults (109a, 111b)
  - No characterization boreholes will be located over emplaced waste packages (gaps will be used, or characterization will use alcoves)
- Chemistry and age of pore water, using chloride mass balance and isotope chemistry (119a, 120a)

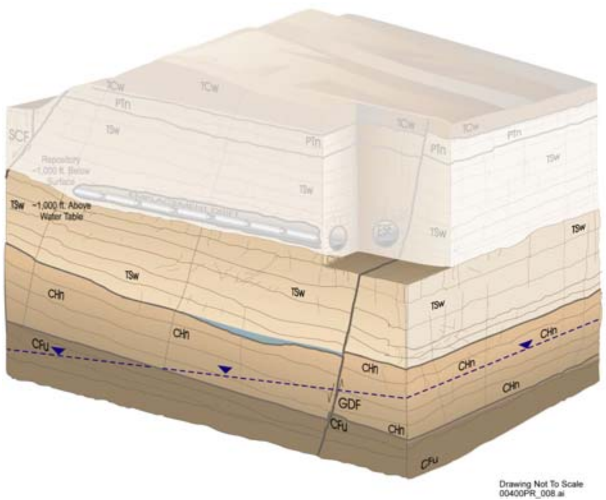
The Surface and the Unsaturated Zone Above the Repository

- **Seepage into bulkheaded, low temperature alcoves (133b)**
  - **The situation most typical of the 10,000-year postclosure period**
- **Thermal seepage into an unventilated, thermally accelerated drift (51a, 133c1)**
  - **Detected by humidity change in the nearly stagnant, but slowly moving, air. Investigated using the remotely operated vehicle**
  - **Plausible because of the absence of ventilation, but unlikely due to elevated temperature**
- **Thermal seepage into ventilated heated drifts (51a, 133c2)**
  - **Detected by ventilation humidity change and investigated by the remotely operated vehicle**
  - **Unlikely due to ventilation and thermal effects**
- **Precipitation monitoring (84b)**
  - **To place seepage data in context**
- **Infiltration from rare high-intensity and long-duration storms (96b)**
  - **To place seepage data in context**
- **Seal performance (200a)**
  - **Seals prevent hydrologic short circuits**
  - **Lab test prior to emplacement**



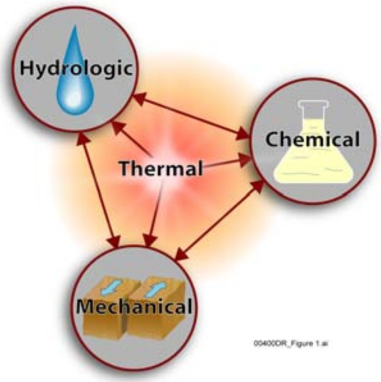
The Unsaturated Zone Below the Repository

- **Monitoring for radionuclides in deep boreholes near the footprint (151a)**
  - **Monitors unsaturated zone characteristics**
- **In situ test of transport and sorption properties of the unsaturated zone (137a)**
  - **In a drift, prior to emplacement**



Coupled Thermal Processes

- **Lower lithophysal drift scale test prior to emplacement (220a)**
  - **In the cross drift that was excavated by a tunnel boring machine**
  - **Thermal and thermal-mechanical processes are primary objectives; thermal-hydrologic and thermal-chemical processes are secondary objectives**
- **Drift 3, thermally accelerated by ventilation control (125a, 128a, 129b, 131a)**
  - **Near-field focus, uses an observation drift rather than in-drift boreholes**
  - **Fracture permeability, rock saturation, temperature, and water chemistry**
- **Drift 4, thermally accelerated by waste package aging and derating (51a, 52a, 54e, 56e, 58e)**
  - **Engineered barrier environment focus using the remotely operated vehicle**
  - **Includes drip shields and termination of ventilation at 5 years**



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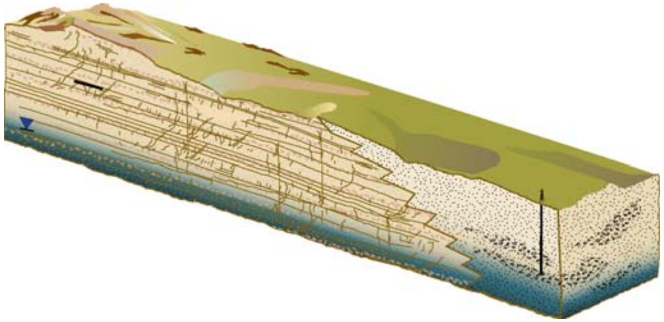
Saturated Zone

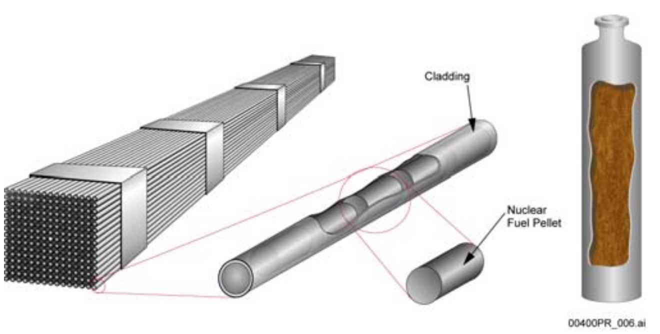
- **Monitoring for radionuclides in deep boreholes downstream from the footprint (151a)**
  - **Monitors unsaturated and saturated zone characteristics**
- **Saturated zone chemistry and water levels (150a)**
  - **Chemistry affects retardation**
  - **Water levels are diagnostic of flow paths and rates**
- **Saturated zone colloids (153a)**
  - **Laboratory studies using field samples**

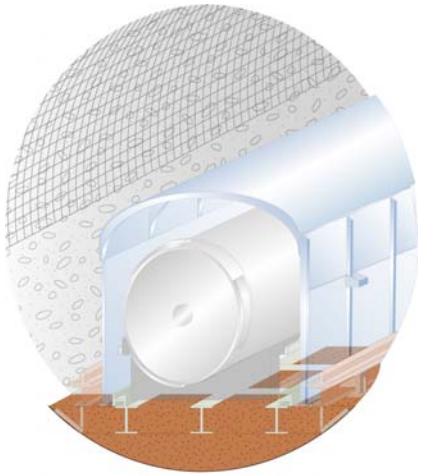


- **Saturated zone fault zone hydrology (159a)**
  - **Deep borehole tests**
  - **Faults affect flow paths and rates**

Cladding, Waste Form, and Invert

- **Radionuclide inventory (199a)**
  - **From waste acceptance documents**
- **Sorption coefficients for waste form colloids (16a)**
  - **Laboratory tests**
- **Monitor cladding studies (1a)**
  - **From dry storage facilities**
  - **From academic and industrial research**
- **Measure invert tuff gravel sorption coefficients (36a)**
  - **Laboratory tests**

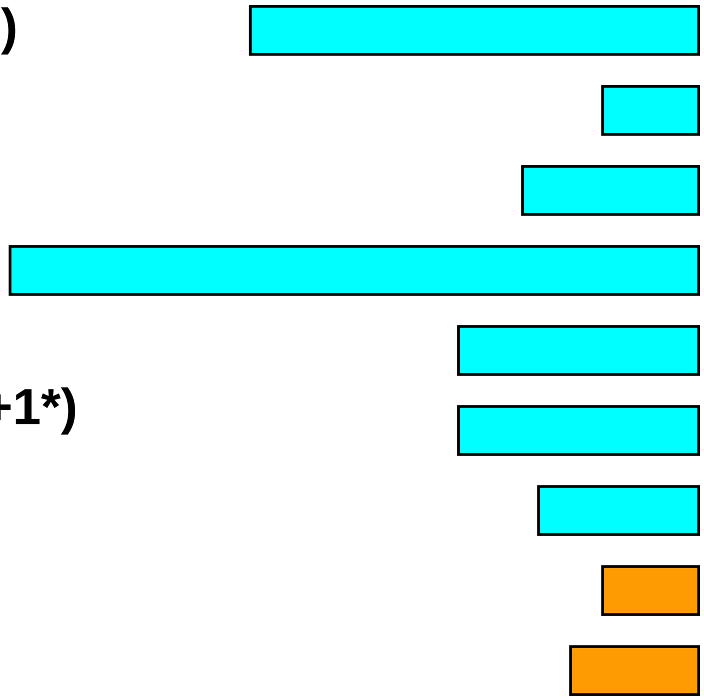




The Performance Confirmation Program Focuses on Importance to Waste Isolation

Number of Activities

- **Igneous activity scenario class (13 activities)**
- **Seismic activity scenario class (3)**
- **Biosphere-related activities (6)**
- **Waste package and drip shield (22)**
- **Preemplacement environment (8)**
- **Surface barrier and the unsaturated zone (8+1*)**
- **Coupled thermal processes (5+7*)**
- **Saturated zone (3+1*)**
- **Cladding, waste form, and invert (4)**



Scenario classes that contribute most to risk are well represented in the performance confirmation program

Barriers that contribute most to risk are well represented

Barriers that contribute least to risk are represented minimally

Caveat: The 72 activities have varying degrees of scope complexity and cost
*** The second number indicates activities included in a prior group**

Documentation and Further Development of the Performance Confirmation Program

Path Forward - Revision 3

- Revision 3 of the *Performance Confirmation Plan* is scheduled for spring of 2004
  - Define activities (what, when, where, and how)
  - Establish expected baseline for performance confirmation activities
  - Develop graded approach to establish allowable bounds and tolerances for parameters
  - Management and administration
  - Identify needed test plans
  - Define process for reporting variances to the NRC and describe the appropriate corrective action steps

Path Forward - Revision 3

(Continued)

- Provide design requirements and further details on:
  - Accelerated drift tests
    - Drift scale test in the lower lithophysal unit
    - Thermally accelerated drift focused on near-field coupled processes
    - Thermally accelerated drift focused on in-drift coupled processes
  - Exhaust mains instrumentation/monitoring systems
  - Seepage/H_2O collection system
  - Rockfall monitoring system

Technology Development Areas

- **Several performance confirmation activities require feasibility evaluation and/or technology adaptation/development**
  - **Remotely operated vehicle (with reduced dependence on infrastructure)**
  - **Radionuclide sensors with increased sensitivity (e.g., measuring in the exhaust mains)**
  - **Seepage detection via humidity spikes**
  - **Rockfall or engineered barrier system collapse detection via acoustic/ seismic tomography**
  - **Fast, effective mapping**
  - **Automated monitoring of drift deformation**
- **The performance confirmation staff is currently pursuing each of these areas**
  - **Some activities may be deleted and replaced as a result**

Path Forward - Implementation

- Implement *Performance Confirmation Plan*
  - Monitor, test, and collect data (including ongoing tests)
  - Analyze and evaluate data (including site characterization baseline)
  - Take corrective actions should significant variances arise

Summary

- A multi-attribute utility analysis (decision analysis) was employed to select activities for inclusion in the Performance Confirmation Program:
  - Phase 1: Technical judgments and performance assessment management value judgments
  - Phase 2: Portfolio development and evaluation
  - Phase 3: Senior management review
- Activities have been categorized into risk-level groups, such as igneous activities and waste package performance, that contribute most to risk are the emphasis of the Performance Confirmation Program
- Revision 3 of the Performance Confirmation Plan (scheduled for spring of 2004) will further develop the PC program by:
  - Further defining activities, establishing expected baselines for activities and defining the process for reporting variances

Backup

Backup Contents

- Questionnaire (Phase 1)
  - 5 Pages
- Other Management Value Judgments (Phase 1)
  - 3 Pages
- Portfolio Descriptions (Phase 2)
  - 8 Pages
- Modifications to Portfolios (Phase 3)
  - 2 Pages
- List of Performance Confirmation Activities
  - 2 Pages
- Mapping of Performance Confirmation Activities to Regulatory Requirements
  - 2 Pages

Phase 1: Questionnaire (1 of 5)

PC Parameter Evaluation Questionnaire
(updated 9/26/02)

NOTE: This questionnaire is intended for use by subject matter experts who have participated in the interactive PC Parameter Evaluation workshops September 18, 20, 24, and 25, 2002 at the BSC offices in Summerlin, Nevada. It is not meant as a stand-alone document, and can not be used effectively without the accompanying verbal discussion and group interaction planned at the meetings. Some revisions and refinements have been made to the questionnaire in response to comments received during those workshops. Future documentation will expand the detailed discussion of each of these questions.

Developing a list of candidate PC parameters and methods

The first step in this process is to identify the candidate PC parameters, and the potential PC methods and activities associated with those parameters. The first goal of the meetings in late September is to develop a list of candidate parameters.

For the purposes of these workshops, *parameters* are "things that can be measured or observed" which are candidates for inclusion in the PC program (e.g., they can be model inputs, model outputs, intermediate results, etc…). *PC methods or activities* are the individual monitoring or testing activities, focused on a specific parameter (or parameters). Every PC method or activity is expected to fall roughly into one of the following five categories:

- Pre-emplacement mapping, sampling, and inspection
- Continuous monitoring of preclosure evolution
- Dedicated thermal drift with accelerated thermal cycle
- Mobile-based monitoring (e.g., remotely operated vehicle)
- Off-footprint testing and monitoring (i.e., laboratory testing of corrosion rate and monitoring of industry trends for reported cladding condition).

A matrix of candidate parameters and potential PC methods was compiled during each of the meetings in late September – the final version of that matrix from each meeting has been distributed to the workshop participants. Every parameter/method combination on that matrix is to be evaluated using this questionnaire. Note that in some workshops, only the parameter lists were discussed in detail, without a complete set of associated methods or activities. Participants will need to identify one or more activities suitable for those parameters where activities were not yet identified.

During the evaluation process, if you find you need to make changes, refinements, or clarifications to either the parameter definition or the specification of the PC activity, please document that change.

Purpose of the questionnaire

The "value" of including a specific parameter/method in the PC Program is a function of

- The *sensitivity* of barrier capability and system performance to the parameter
- The level of *confidence* you have in the current parameter representation
- The *accuracy* of the proposed PC method at measuring or estimating the parameter value
- The *cost* of implementing the PC method

The questions herein ask you to evaluate each parameter and method according to these four attributes. Those evaluations will be combined with managerial value judgements about the importance of each of those attributes to determine the overall technical value of using the PC method/activity to measure or estimate the parameter. However, these are not the only things that are important or that will be considered in developing that Program; a number of other higher level criteria have been and are being identified that are important to consider when developing the PC Program. For example, tests explicitly mentioned in 10 CFR 63 must be included, at least one method to address each barrier will be included, and so on. Ultimately, the technical value defined by the answers to these questions will be combined with the higher-level criteria to develop the PC program.

Instructions for completing the questionnaire

The questions below are organized in the manner of a "flow chart," so that you are guided to answer only those questions that are relevant for the parameter/method being considered. At the back of this form is an "Evaluation summary sheet" for recording your answers to the questions.

The questions are organized so that questions about the parameter come first (Part A) and questions about the PC activity come second (Part B). It is much easier to answer the questions if you are very clear about what parameter and what PC activity you are evaluating. If there are several viable and promising PC activities that could address a specific parameter, you can answer the questions in Part B several times, once for each PC activity. Use as many summary sheets as you need to.

If after completing the evaluation you feel that the questionnaire and your answers do not accurately reflect the potential value of including a PC parameter, please add any text comments that you believe are relevant to the value of including the parameter. You can use the back of the evaluation summary sheet or a separate document.

Phase 1: Questionnaire (2 of 5)

Part A. Questions about the parameter

What parameter is being considered? (fill in on summary sheet)

For disruptive events, skip to question A2.

A1. What barrier(s) does the parameter relate to?

1	Surficial Soils and Topography
2	Unsaturated Rock Units Above the Repository
3	Unsaturated Rock Units Below the Repository
4	Saturated Zone Rock Units
5	Drip Shield
6	Waste Package
7	Cladding
8	Waste Form
9	Invert
10	Parameter does not relate to a barrier → Go to A2

A2. If the parameter does not relate to a specific barrier, does it relate to any of the following?

A	Biosphere
B	Igneous activity
C	Seismic activity
D	Radionuclide inventory

Section 1. Sensitivity of barrier capability and system performance to the parameter

For disruptive events, skip to Question 1.2.a.

1.1. Does the candidate parameter relate to the capability of a specific barrier to limit movement of water or radionuclides?

- ❑ No → Go to Question 1.2
- ❑ Yes → Continue below

Each question on the following page asks you to think about the impact of the candidate parameter on one of the fundamental capabilities of a barrier. The questions ask how much of the current uncertainty in barrier capability can be tied to uncertainty or variability in the candidate parameter.

The following table provides a guideline to help determine which questions are relevant for each barrier; use this table to determine which questions you need to answer.

10 CFR 63.102(h) requires natural and engineered barriers

10 CFR 63.2 defines barrier attributes	**Natural Barrier**	**Engineered Barrier**
Substantially reduce water flow (Question 1.1.a.)	Surficial Soils UZ Above UZ Below SZ	Drip Shield Waste Package Cladding
Substantially reduce rad. transport (Question 1.1.b)	UZ Below SZ	Waste Package Cladding Invert
Substantially reduce rad. release rate (Question 1.1.c.)	UZ Above (chemistry set by rock minerals)	Cladding Waste Form

Phase 1: Questionnaire (3 of 5)

Use the scale to the right to answer whichever of the following three questions is relevant (from the table on the previous page). If the question does not apply to the parameter, enter a score of "A" on the Evaluation Summary Sheet or leave it blank.

1.1.a. How much of the calculated range in the rate of water movement through the barrier[1] can be accounted for by the range of this parameter[2] used in PA[3]?

1.1.b. Consider the retardation of radionuclide movement within this barrier: How much of the calculated range in the rate of radionuclide movement *relative to water movement*[4] through the barrier can be accounted for by the range of this parameter[2] used in PA[3]? (i.e., the range in the calculated retardation factor)

1.1.c. How much of the calculated range in the radionuclide release rate[5] can be accounted for by the range of this parameter[2] used in PA[3]?

Scale for recording the sensitivity of barrier capability to the parameter

A	NA or no change (parameter is not related to the barrier capability)
B	90% to 100% of the full calculated range in PA
C	About 75% of the full calculated range in PA
D	About 50% of the full calculated range in PA
E	About 25% of the full calculated range in PA
F	10% or less of the full calculated range in PA

[1] Water flow at the barrier exit integrated over a time step and spatial grid block in the TSPA.
[2] For bounded parameters, the parameter range is the full range used in PA; for unbounded parameters (e.g., Normal or other distribution) the parameter range is defined as the 5th to 95th percentiles.
[3] PA includes all the performance assessment models, and for the purposes of this questionnaire, refers to the PA models that will be used to support the license application.
[4] Transit time across the barrier for a significant fraction of the radionuclides divided by transit time of a significant fraction of the water.
[5] For a significant fraction (in terms of dose potential) of the radionuclides. Include dose potential of radionuclides that would contribute dose if they were not retained by the barrier.

1.2.a. *Assume the parameter value is found to lie outside it's currently modeled range*. Use the scale below to estimate the likelihood that the new estimate of 10,000-year combined (nominal plus disruptive) mean annual dose changes **more than 0.1 mrem**.

Note: For disruptive events, estimate the likelihood that changes in the value of the candidate parameter could result in an increase in the estimated 10,000-year combined mean annual dose of more than 0.1 mrem.

A	More than 1 chance in 10
B	Between 1 chance in 100 and 1 chance in 10
C	Between 1 chance in 1000 and 1 chance in 100
D	Between 1 chance in 10,000 and 1 chance in 1000
E	Between 1 chance in 100,000 and 1 chance in 10,000
F	Less than 1 chance in 100,000

Section 2. Confidence in parameter representation

2.1 Consider the range for this parameter in the PA models for LA (either the input range or the calculated range, as appropriate): How confident are you that the modeled range of the parameter will not be exceeded (in the direction that would have a negative impact on performance) during the 10,000-year period?

A	<10% confident
B	<50% confident, but >10% confident
C	<90% confident, but >50% confident
D	>90% confident

2.2. Consider the conceptual model(s) to which this parameter relates*: Assume the parameter value is found to exceed the parameter range used in the PA models for LA*: what is the likelihood that this change in the parameter value would change the selected conceptual model, or require consideration of additional conceptual models?

A	More than 1 chance in 5
B	Between 1 chance in 10 and 1 chance in 5
C	Between 1 chance in 100 and 1 chance in 10
D	Between 1 chance in 1000 and 1 chance in 100
E	Between 1 chance in 10000 and 1 chance in 1000
F	Less than 1 chance in 10000

Phase 1: Questionnaire (4 of 5)

Part B. Questions about the PC activity/method for this parameter

If there is more than one potential PC activity that addresses this parameter, answer the questions in Part B separately for each activity. Use additional evaluation summary sheets as needed.

***Briefly* describe the proposed PC activity being evaluated? (on the summary sheet)**

B1. What is the degree of ease of obtaining relevant data using this approach?

A	Can be obtained in a single measurement, in a shirtsleeve environment
B	Can be obtained by automated equipment accessible in a shirtsleeve environment
C	Can be obtained in intermittent long-term measurements, in a shirtsleeve environment
D	Can be obtained in a single measurement, by humans wearing PPE
E	Can be obtained by automated equipment accessible by humans wearing PPE
F	Can be obtained in intermittent long-term measurements, by humans wearing PPE
G	Can be obtained by ROV using current instrumentation technology
H	Can be obtained by ROV using instrumentation to be developed during the PC program
I	Cannot be obtained using existing technologies

B2. How long will the proposed PC activity take? For PC activities that involve several iterations of a test or measurement over a time period, we need two estimates (using the same scale).

B2a. How long will a single test or measurement take?

B2b. Over what time period will the testing/measuring continue?

For example a PC activity that involves taking simple measurements annually over the entire performance confirmation period would be evaluated as an "A" for the first part and "E" for the second part.

For PC activities where a single test or measurement continues for the entire duration of the activity, the answers to these two questions will be the same.

A	Less than 6 months
B	6 months to 1 year
C	1 to 3 years
D	3 to 10 years
E	more than 10 years

Section 3. Accuracy of the proposed method in verifying the parameter

3.1. The four questions below ask about the temporal evolution of the parameter and the ability of the proposed activity to track and/or predict that evolution.

3.1.a. How is the parameter value expected to change or vary over the pre-closure period (due to natural evolution or characterization, construction, operations, or emplacement of wastes)?

A	Parameter is static during the pre-closure period → Go to Question 3.1.c.
B	Parameter is expected to evolve during the pre-closure period due to natural evolution alone→ Continue below
C	Parameter is expected to evolve during the pre-closure period due to repository activities alone → Continue below
D	Parameter is expected to evolve during the pre-closure period due to both natural evolution and repository activities → Continue below

3.1.b. Will the proposed PC activity track the changes in the parameter value during the pre-closure period?

- ❑ No
- ❑ Yes

3.1.c. How is the parameter value expected to change or vary during the 10,000 year post-closure period (due to natural evolution or characterization, construction, operations, or the presence of wastes)?

A	Parameter is static during the 10,000 year post-closure regulatory period → Go to Question 3.2
B	Parameter is expected to evolve during the 10,000 year post-closure regulatory period due to natural evolution alone→ Continue below
C	Parameter is expected to evolve during the 10,000 year post-closure regulatory period due to repository activities alone→ Continue below
D	Parameter is expected to evolve during the 10,000 year post-closure regulatory period due to both natural evolution and repository activities→ Continue below

Phase 1: Questionnaire (5 of 5)

3.1.d. How confident are you that the information collected with the proposed PC activity accurately represents repository conditions over the 10,000-year post-closure regulatory period?

A	We have *high confidence* that relevant time-dependent processes for the repository are captured in the measurement. Examples that would indicate high confidence include: (a) the PC measurement captures data from a closely related analogue system over time frames on the order of 10,000 years, (b) the PC measurement estimates the parameter changes by accelerating the time history, and that acceleration captures the relevant changes.
B	We have *moderate confidence* that relevant time-dependent processes for the repository are captured in the measurement. Examples that would indicate moderate confidence include: (a) the PC measurement captures data from loosely related analogue systems over time frames on the order of 10,000 years, (b) the PC measurement captures data from a closely related analogue system, but over time frames much greater than or much less than 10,000 years, (c) the PC measurement estimates the parameter changes by accelerating the time history, which causes the candidate parameter to change in a similarly representative manner to how it is expected to evolve in the repository environment.
C	We have *weak confidence* that relevant time-dependent processes for the repository are captured in the measurement. Examples that would indicate weak confidence include: (a) the PC measurement captures data from loosely related analogue system over time frames not representative of the 10,000 regulatory period, (b) the PC measurement estimates the parameter changes by accelerating time history, which causes the candidate parameter to change significantly differently than it is expected to evolve in the repository environment.
D	The PC measurement is designed to estimate post-closure changes through simple extrapolation of pre-closure measurement.

3.1.Is the parameter value expected to vary over the repository footprint, the SZ flow paths, or other relevant spatial scale?

- ❑ No → Go to question 3.3
- ❑ Yes → Continue below

3.2.a. Are the data from the PC activity representative of the spatial variability across the repository footprint, flow paths, or relevant spatial scale?

A	The data measure a parameter over all locations across the relevant spatial scale.
B	The data measure a parameter over representative locations we are *highly confident* represent the spatial variability across the relevant spatial scale.
C	The data measure a parameter over representative locations we are *moderately confident* represent the spatial variability across the relevant spatial scale.
D	The data measure a parameter over representative locations we are *weakly confident* represent the spatial variability across the relevant spatial scale.
E	The measurement give no information on the known spatial variability of the parameter across the relevant spatial scale and only measures a single (or non-representative few) location(s)

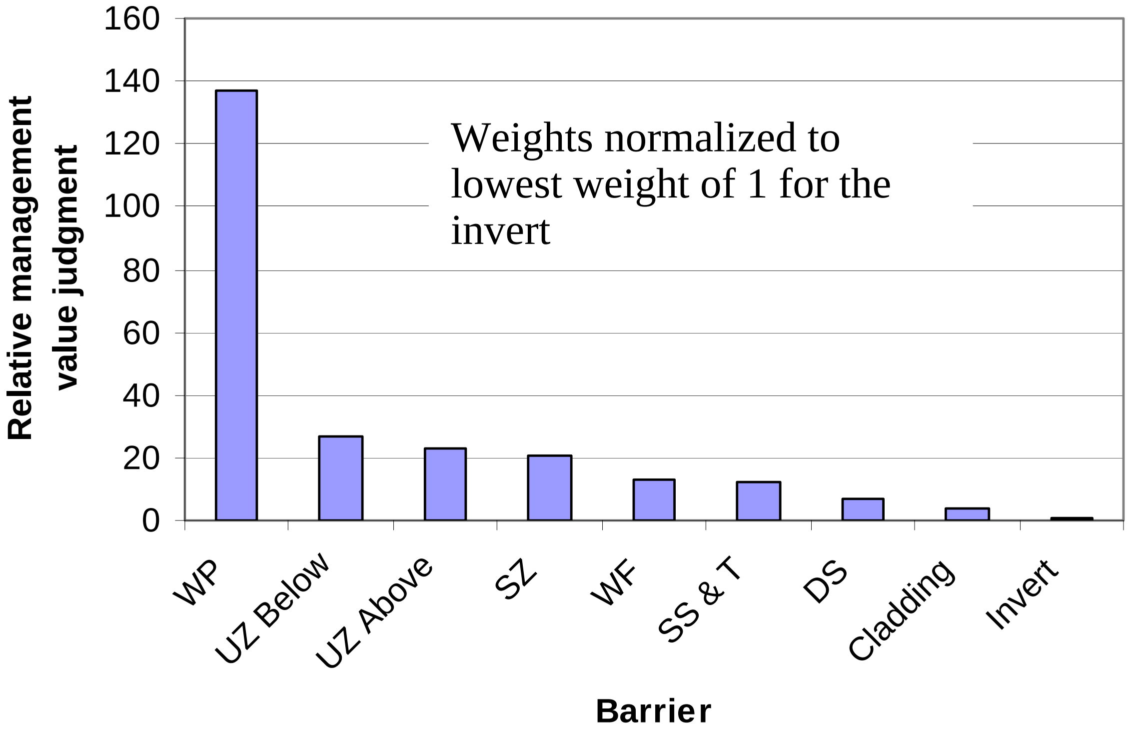
3.2.How closely related is the PC measurement to the PC parameter?

A	The proposed measurement directly measures the parameter
B	The proposed measurement is a widely-accepted and accurate surrogate for the parameter. Small uncertainties, noise, or errors in the measurement lead to an equally small range in the calculated parameter value.
C	The proposed measurement is closely related to the parameter of interest. Small uncertainties, noise, or errors in the measurement lead to a somewhat larger range in the estimated parameter value.
D	The proposed measurement is indirectly related to the parameter, and is several calculations removed from the parameter of interest. Small uncertainties, noise, or errors in the measurement lead to a large range in the calculated parameter value.

Management Value Judgments Related to Barrier Capability

Management value judgments

- **The contribution of "sensitivity to barrier capability" to total utility depends in part on the relative value assigned to each of the nine barriers**
- **Performance assessment managers assigned weights to each of the barriers, based on judgment:**

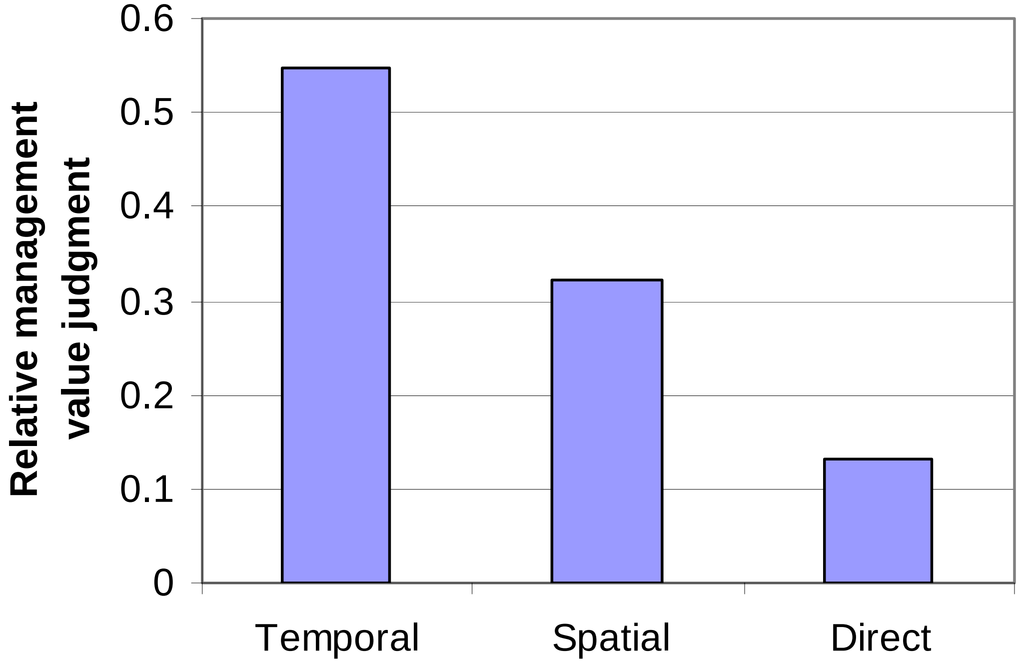


  - **Informed by the risk prioritization report and the "one on" analyses**
  - **Informed by discussions of barrier capability**

Example Management Value Judgment Accuracy

Management value judgments

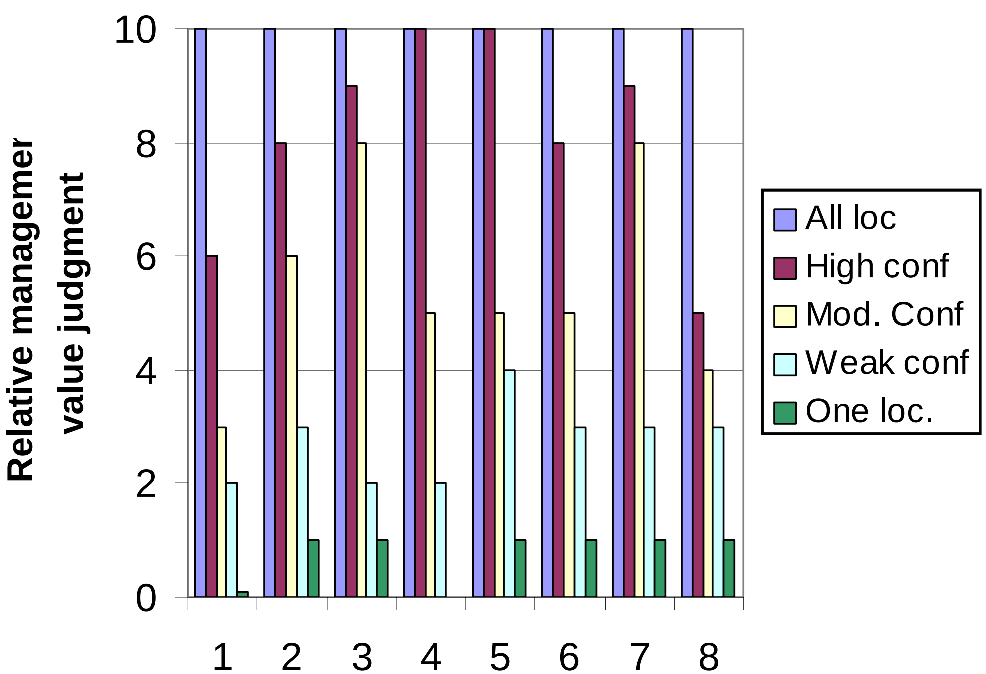
- **"Value of perfect information" on a parameter was scaled by the estimated accuracy of the activity**
- **The three technical judgment aspects of accuracy were weighted by the management value judgments shown below:**

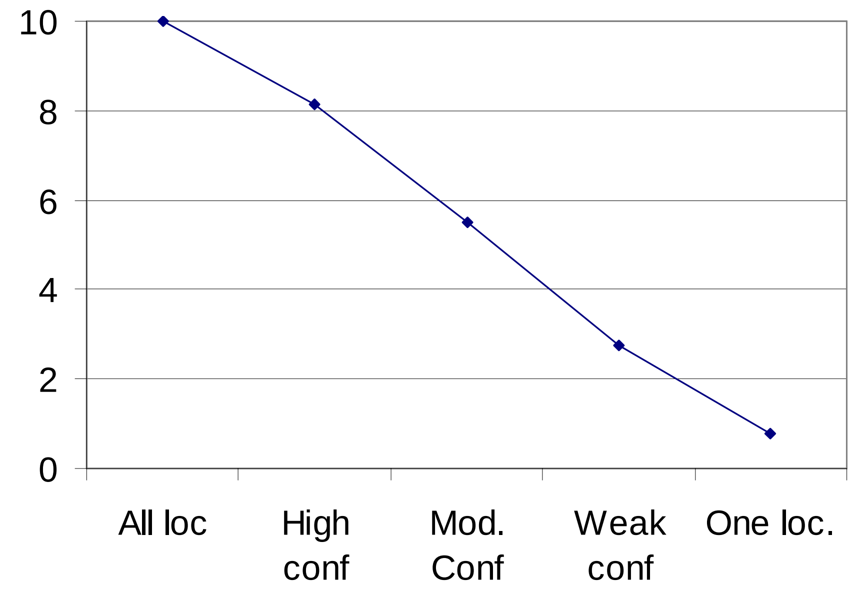


Example Management Value Judgment for the Technical Judgment Question on Spatial Variability

Management value judgments

- **Participants discussed the scale and assigned each of the five levels a weight indicative of relative accuracy of the measurement**
- **8 participants**
- **Rankings highly consistent**
- **Average of the relative weights of the 8 participants used**



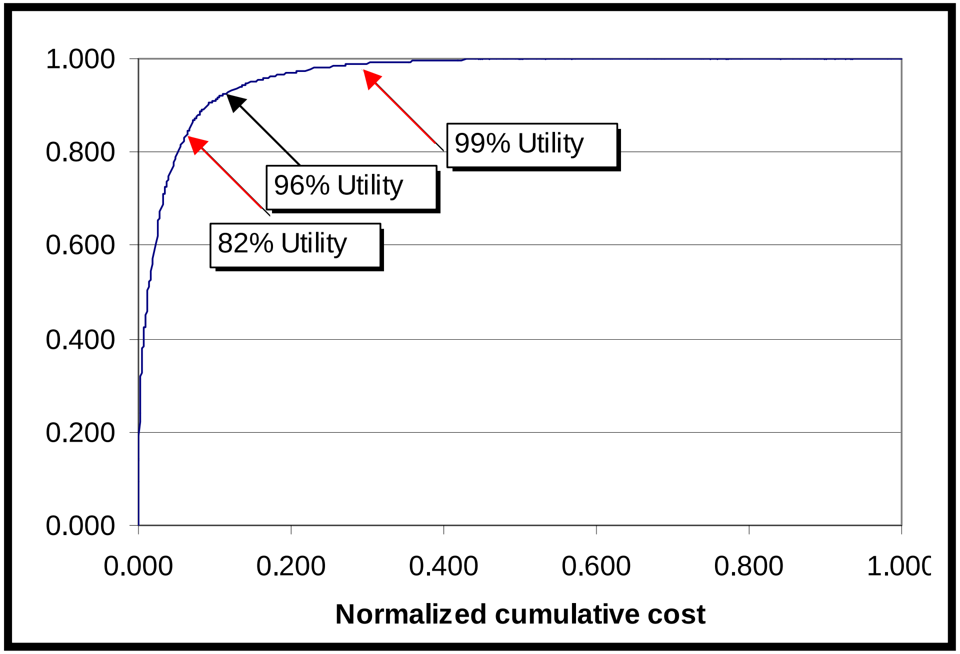


Two Bounding Portfolios Were Developed

- **All inclusive portfolio (K)**
  - **Includes all activities identified by the technical experts and evaluated as having positive benefit (ignoring costs)**
- **Minimum cost portfolio (A)**
  - **Least-cost set of activities that addresses the performance confirmation requirements of 10 CFR 63**
  - **The degree of activity for each 10 CFR 63 requirement is small, to achieve minimum cost**
- **These bounding portfolios were evaluated in detail**
- **A reduced version of the "all-inclusive" portfolio was developed, consisting of every parameter identified, but including only the most valuable activity associated with measuring that parameter (B)**
  - **This portfolio was not evaluated in detail**

Cost Effectiveness Portfolios

- **Three portfolios were developed**
  - **All activities were ranked by utility-to-cost ratio**
  - **"Threshold" utility-to-cost ratios were set for alternative portfolios (C, D, E)**
  - **Activities that met the threshold were included in the portfolio**
  - **Reviewed for cost synergies among activities**
- **Portfolios capturing 99 percent and 82 percent of the total potential utility were evaluated in detail**



Hypothesis Testing Portfolios

- Two portfolios were defined around the notion of "hypothesis testing"
  - A set of performance "hypotheses" was developed at the barrier and total system level
  - Activities were identified as
    - Providing a direct test of an hypothesis
    - Providing an indirect test of an hypothesis (e.g., testing "inputs" to the hypothesis)
  - Example:
    - The surficial barrier will limit infiltration to less than nn percent of precipitation, averaged over the footprint and one year
- One hypothesis testing portfolio included only direct tests of the hypotheses (F)
- A second hypothesis testing portfolio included both direct and indirect tests of the hypotheses (G)
- Both portfolios were evaluated in detail

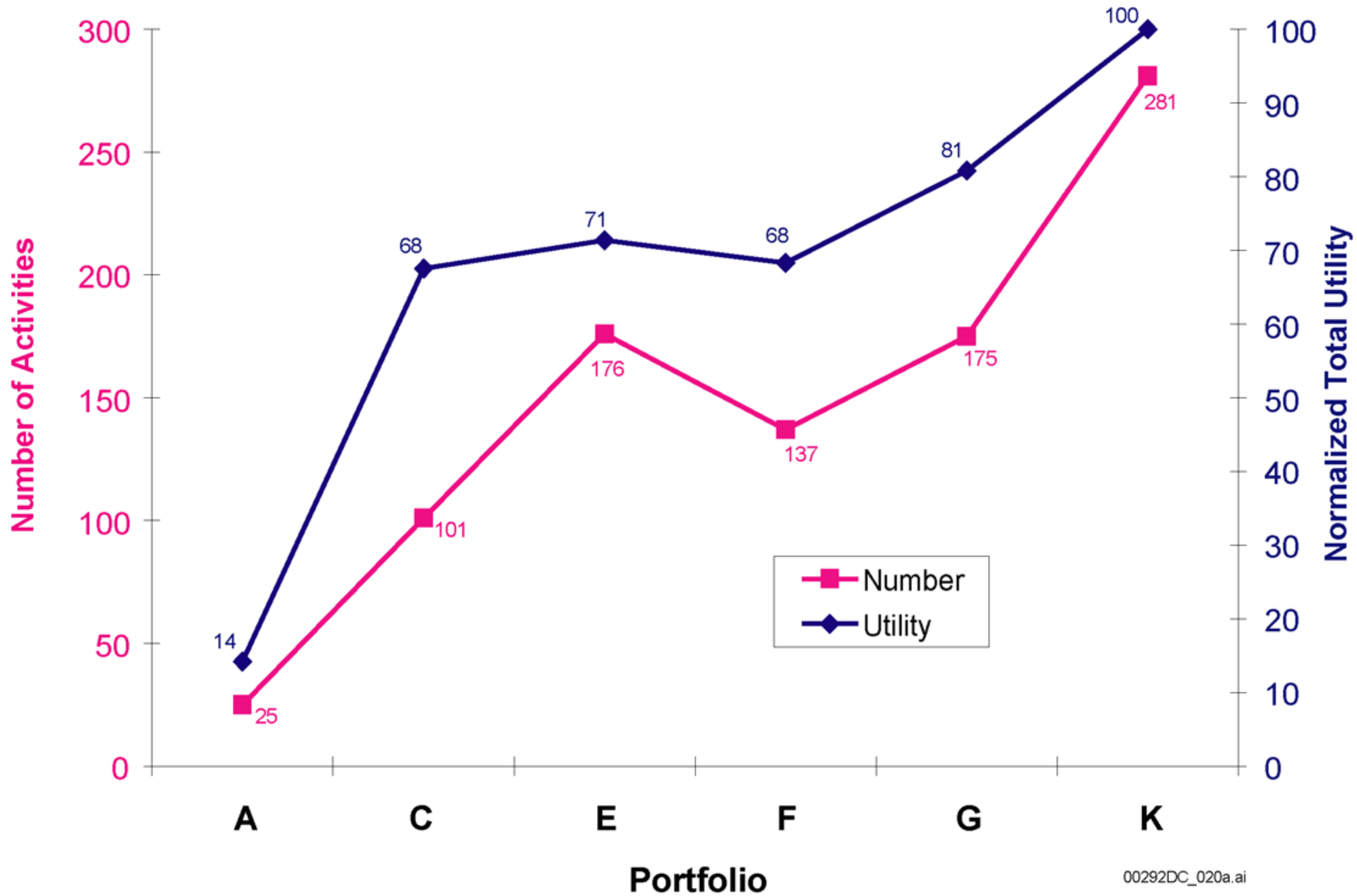
Type or Location Portfolios

- Three portfolios were developed that focus on either the type or the location of performance confirmation activities
  - Maximize use of a thermally accelerated emplacement drift (H)
    - Assumes a thermally accelerated drift will be included in the program; includes primarily activities making use of that drift
  - Maximize use of off-footprint testing (I)
    - Designed to keep worker risks as low as possible, and minimize interference of the program with activities in the Geologic Repository Operations Area
  - Maximize use of existing data, activities in existing facilities, and pre-emplacement activities (J)
    - Using data already collected or being collected in the Cross Drift Thermal Test and the Drift Scale Test
- These portfolios were not evaluated in detail
  - Did not provide significant additional benefit over other portfolios

Six Portfolios Were Evaluated in Detail

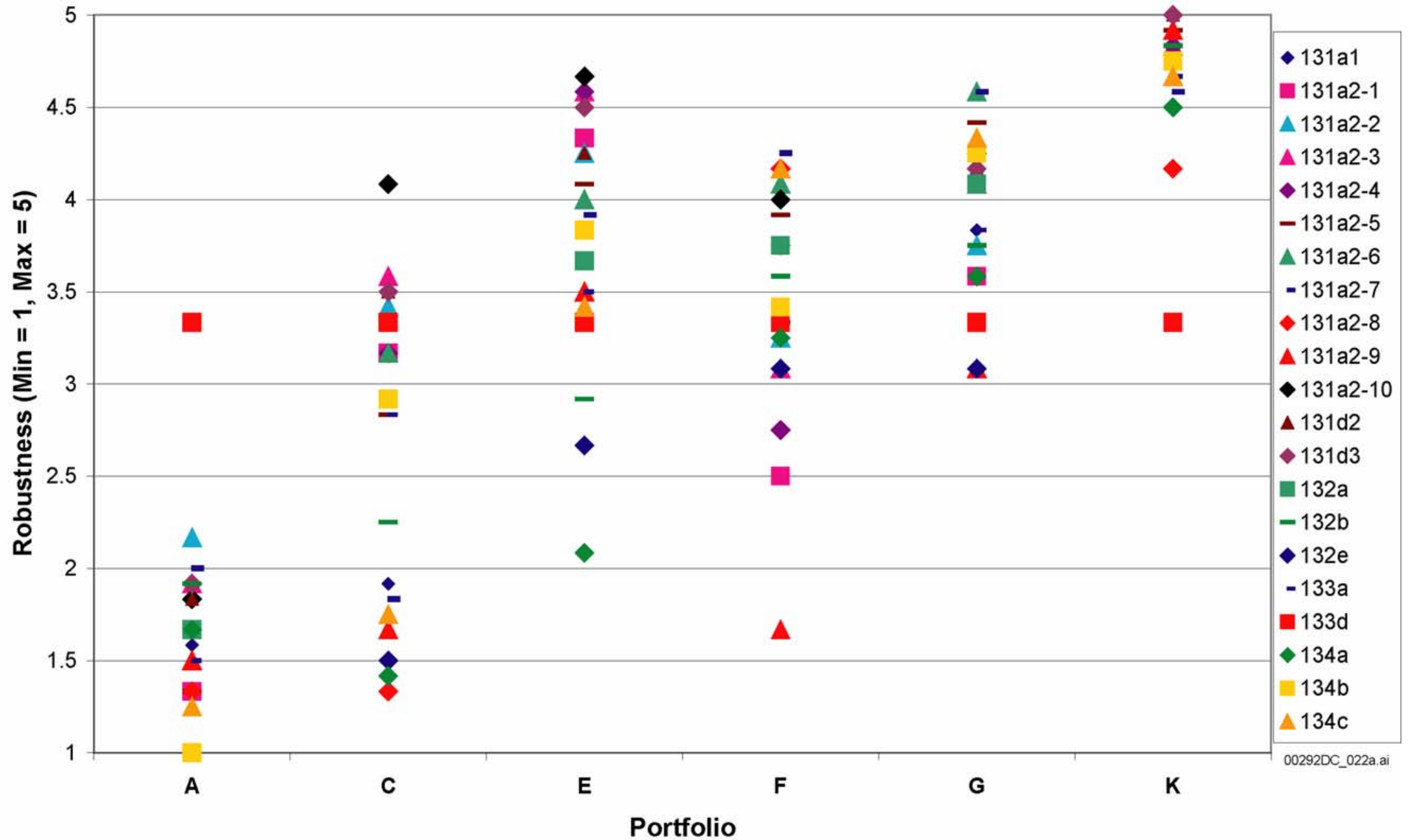
- **Minimum cost (Portfolio A)**
- **Cost effective - 82 percent total utility (Portfolio C)**
- **Cost effective - 99 percent total utility (Portfolio E)**
- **Hypothesis testing - Direct (Portfolio F)**
- **Hypothesis testing - Direct and indirect (Portfolio G)**
- **All inclusive (Portfolio K)**

Phase 2: Portfolio Comparison Activity Count and Summed Utility

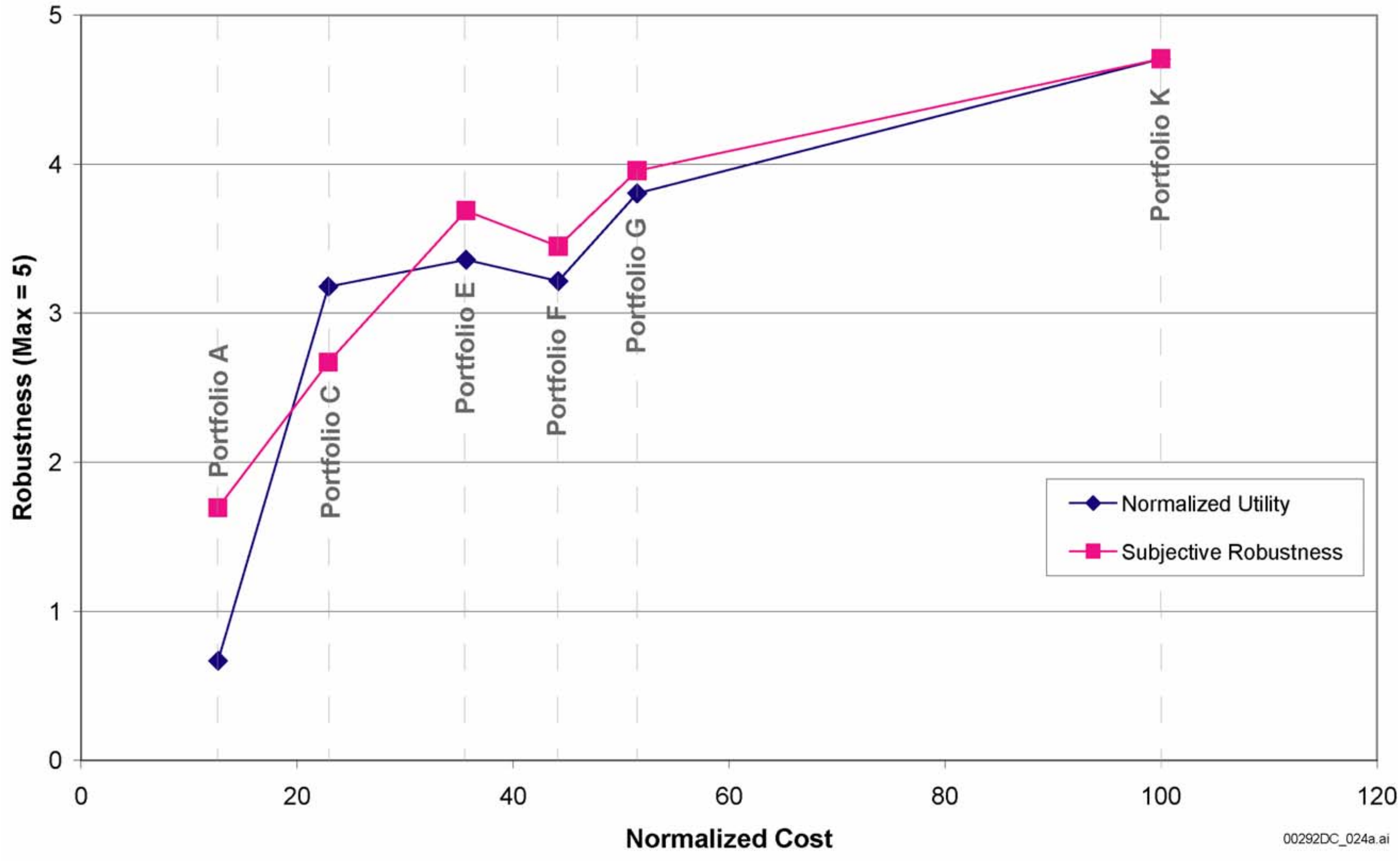


YUCCA MOUNTAIN PROJECT

Phase 2: Portfolio Comparison Subjective Assessment of Robustness



Phase 2: Portfolio Comparison Relative Costs and Subjective Robustness



Phase 3: Modifications Made to Portfolio (1 of 2)

Final Revised Portfolio Action	Activity Identifier Number	Activities	Rationale for Addition, Modification, or Removal
Modified Activities	96b	Moisture content and/or potential in soil—in situ measurements with tensiometers, time domain reflectometry and neutron probes, continuous monitoring.	Scope reduced: to be done only after significant rainfall events.
	159a	Fault zone hydrologic and transport characteristics (including anisotropy)—fault hydraulic testing at 2 sites.	Scope increased: to include transport testing.
	185a	Number of waste packages hit in Zone 1—modeling, analogue studies.	Scope reduced: originally proposed for Zones 1 and 2, reduced to apply to Zone 1 only.
Added Items	220a	Drift Scale Test in the lower lithophysal unit.	Added to provide a test prior to construction authorization. Test not yet fully defined.
	221a	Geodetic monitoring of extensional tectonics in the Yucca Mountain region using global positioning system satellite monitoring as a potential indicator of future igneous activity.	Added to provide additional indicator of igneous activity.
Removed Items	62a	Flow splitting and/or flow paths on all engineered barrier system surfaces—preemplacement test in drift with heat.	More appropriate for the Scientific Testing and Evaluation Program.
Removed Items (Continued)	63a	Crack plugging (Note: this parameter significantly reduces water movement through drip shield and waste package and radionuclide movement through waste package)—laboratory testing under controlled environment.	More appropriate for the Scientific Testing and Evaluation Program.
	64a	Pit plugging (Note: this parameter significantly reduces water movement through drip shield and waste package and radionuclide movement through waste package)—laboratory testing under controlled environment.	More appropriate for the Scientific Testing and Evaluation Program.
	65b	Water flow rate through breaches in the engineered barrier system components—laboratory test with heat.	More appropriate for the Scientific Testing and Evaluation Program.
	78a	Flaws (including manufacturing flaws, and size, orientation, number)—laboratory testing under controlled environment of specimens from manufacturing mockups and laboratory-prepared specimens.	More appropriate for the Engineering Test and Evaluation Program.
	81b	Critical stress (K_{ISCC} and stress threshold)—laboratory testing under controlled environment of laboratory-prepared specimens and specimens from manufacturing mockups.	More appropriate for either the Scientific Testing and Evaluation Program or the Engineering Test and Evaluation Program.
	95a	Physical and/or hydrological properties of soil—core samples for measuring density, porosity and permeability.	More appropriate for the Scientific Testing and Evaluation Program.
	98a	Matrix, fracture, or bulk physical and/or hydro properties—core samples for measuring density, porosity and permeability.	More appropriate for the Scientific Testing and Evaluation Program.

Final Revised Portfolio Action	Activity Identifier Number	Activities	Rationale for Addition, Modification, or Removal
	114b	Hydrologic and mineralogical properties of the PTn—evaluation in alcoves from the shafts (mapping, core samples, laboratory testing).	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	134c	Laboratory analysis of chemistry of water samples from seepage in alcoves, in the thermally accelerated drift, or in emplacement drifts.	Combined with activities to collect water samples (133b, 133c1, 133c2).
	135b	Hydrologic conditions beneath drift (drift shadow)—analogue studies, natural caves, and old mines.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
Removed Items (Continued)	138a	Field hydrologic properties of the CHn (and interface with TSw3)—several shafts designed to connect atmosphere with repository level should be extended deeper to allow access to CHn. Two or more representative locations should be chosen. Shafts equipped with typical mining elevators. Side alcoves can be drilled where needed so testing and monitoring is possible. One side alcove will be in CHn so several tests can be performed regarding hydrologic properties (matrix, fracture mapping and properties, air-permeability, etc.). In addition to shafts, tunneling into CHn can provide more extensive access for performance confirmation observation testing activities and instrumented for long-term monitoring of repository-induced perturbations.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	139a	Hydrologic conditions CHn—the deep shafts with side alcoves in the CHn (and drifts into CHn) will also serve as test site for measuring hydrologic conditions of the CHn (potential, saturation, temperature, etc.). Liquid release tests can help to identify if fast fracture flow (by passing the matrix) is possible in this unit.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	140a	Field sorptive characteristics of the CHn (including K_d)—the deep shafts with side alcoves in the CHn (and drifts into CHn) will also serve to perform tracer tests (sorbing and nonsorbing) to identify and confirm the sorptive characteristics in the CHn.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	152a	K_d—laboratory testing of rock matrix samples and alluvium samples.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	154a	Recharge rates: regional model domain—modeling and new field work (U.S. Geologic Survey regional model).	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	156a	Flux at site-scale model boundaries—use the coupled site and/or regional models to evaluate measured fluxes across boundaries—borehole dilution tests (concentration as a function of depth in the borehole, monitored over time).	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.

Phase 3: Modifications Made to Portfolio (2 of 2)

Final Revised Portfolio Action	Activity Identifier Number	Activities	Rationale for Addition, Modification, or Removal
Removed Items (Continued)	175b	Engineered barrier system behavior under ground motion—offsite shake table.	More appropriate for either the Scientific Testing and Evaluation Program or the Engineering Test and Evaluation Program.
	176a	Alloy 22 failure criterion (determine residual stress for accelerated stress corrosion cracking of cold-worked metal)—perform laboratory experiments on specimens of Alloy 22 with a range of residual stresses due to cold working/surficial damage.	More appropriate for either the Scientific Testing and Evaluation Program or the Engineering Test and Evaluation Program.
	177a	Titanium Grade 7 failure criterion (determine residual stress for accelerated stress corrosion cracking of cold-worked metal)—perform laboratory experiments on specimens of Titanium Grade 7 with a range of residual stresses due to cold working or surficial damage.	More appropriate for either the Scientific Testing and Evaluation Program or the Engineering Test and Evaluation Program.
	183a	Dike system geometry—analogues: mapping of exposed dike geometries, some drilling of dikes.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program
	184a	Conduit system geometry—field measurements, analogue studies.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	186a	Updated modeling and laboratory experiments of damage to waste package resulting from an igneous event.	No longer needed—performance models now treat waste package hit with magma as destroyed.
	188a	Ashplume: Incorporation ratio—models and analogues, field studies.	More appropriate for the Scientific Testing and Evaluation Program.
	189a	Ashplume: waste particle size—models and analogues.	More appropriate for the Scientific Testing and Evaluation Program.
	195a	Proportion of eruptive styles—models and analogues, field and laboratory measurements.	Rolled into activity definition in 196a.
	196a	Distribution of magma type downdrift—models and analogues.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	197a	Distance magma travels downdrift—models and analogues.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	198a	Distribution of physical environment downdrift—models and analogues.	More appropriate as candidate for Office of Civilian Radioactive Waste Management's Science and Technology Program.
	213a	Dust levels by occupational activity.	Combined with activity 162a.

Selected Performance Confirmation Activities
(1 of 2)

Activity Number	Activity Description
1a	Monitoring the literature regarding commercial spent nuclear fuel cladding during the preclosure period, including tracking empirical data on cladding failure in dry storage facilities as well as academic and industrial research on mechanistic processes affecting cladding degradation.
16a	Laboratory testing of sorption coefficients (K_ds) for waste form colloids.
36a	Laboratory testing of invert chemistry and sorption coefficients (K_ds).
51a	Monitoring of the air temperature and relative humidity at the exit of all emplacement drifts.
52a	Monitoring and laboratory testing of quantity and composition of dust on engineered barrier surfaces in a thermally accelerated emplacement drift.
53a	Monitoring and laboratory testing of the quantity and composition of dust in the air in the emplacement drifts.
54e	Monitoring of gas composition, pressure, and radiolysis effects within a thermally accelerated emplacement drift using a remotely operated vehicle.
56e	Monitoring, sampling, and laboratory testing of condensation water quantities, composition, and ionic characteristics, including microbial effects, from a thermally accelerated emplacement drift.
57a	Laboratory testing of water conditions, including thin films, on engineered barrier system components.
58e	Monitoring, sampling, and laboratory testing of microbial types and amounts on engineered barrier surfaces in a thermally accelerated emplacement drift.
59a1	Rockfall monitoring and aboveground motion sensing throughout the underground facility using acoustic or seismic tomography with sensors located in accessible areas, which can also measure strong ground motion.
59a2	Inspection of the underground facility, waste package and other engineered components, with a remotely operated vehicle, when indicated by the results of the acoustic or seismic monitoring of the underground facility.
60b	Monitoring drift shape, drift degradation, waste package, and drift components of a thermally accelerated emplacement drift with a remotely operated vehicle.
68a	Laboratory testing of passive current density on Alloy 22 and Titanium Grade 7.
69a	Laboratory testing of the weight loss rate of Alloy 22 and Titanium Grade 7.
70a	Laboratory testing of surface dissolution of Alloy 22 and Titanium Grade 7.
71a	Laboratory testing of surface composition and passive film of Alloy 22 and Titanium Grade 7 coupons from a thermally accelerated emplacement drift.
72a	Laboratory testing of the mechanical properties of passive film on Alloy 22 and Titanium Grade 7 coupons from a thermally accelerated emplacement drift.
73a	Laboratory testing and analysis of phase transformations of Alloy 22 coupons from a thermally accelerated emplacement drift.
74a	Laboratory testing and analysis of the open circuit potential of Alloy 22 and Titanium Grade 7.
75a	Laboratory testing and analysis of the critical potential of Alloy 22 and Titanium Grade 7.
76a	Laboratory testing and analysis of the critical ionic concentration, both abiotic and biotic, on Alloy 22 and Titanium Grade 7.
79a	Laboratory analysis of waste package and drip shield stress sources using Alloy 22 and Titanium Grade 7 specimens and manufacturing mockups.

Activity Number	Activity Description
83a	Monitoring the internal pressure of the waste packages using mobile radiation detectors to detect the shadow of pressure-sensitive internal sensors.
84b	Precipitation monitoring and analysis of precipitation composition.
96b	Measurements of moisture content and potential in surface soils after significant rainfall events.
105a	Mapping of fracture characteristics in all drifts and shafts during repository construction.
106a	Mapping of fault zone characteristics in all drifts and shafts during repository construction.
107a	Mapping of stratigraphic contacts of geologic units in all drifts and shafts during repository construction, including revisiting the geologic framework model if necessary.
108a	Mapping of lithophysal characteristics in all drifts and shaft walls within the lithophysal host rock units during repository construction.
109a	Evaluation of the hydrologic properties of fractures using a combination of gas and liquid tracer tests as well as laboratory testing of moisture retention properties of the fractures.
111b	Evaluation of the hydrologic properties of any previously undetected faults found during repository construction.
119a	Laboratory analysis of chloride mass balance, based on samples taken throughout the underground facility.
120a	Laboratory analysis of isotope chemistry (U, Sr, O, H, ^{36}Cl, ^{3}H, C) within the unsaturated zone, based on samples taken throughout the underground facility.
125a	Monitoring of rock-mass moisture content in boreholes in the near-field rock of a thermally accelerated emplacement drift.
128a	Air permeability testing to measure fracture permeability in the near-field rock of a thermally accelerated emplacement drift.
129b	Monitoring of temperatures and thermal gradients in the near-field rock of a thermally accelerated emplacement drift.
131a	Collection and laboratory analysis of water chemistry in the near-field rock of a thermally accelerated emplacement drift.
133b	Monitoring, collection, and laboratory analysis of seepage water from bulkheaded alcoves on the intake side of the repository.
133c1	Monitoring, collection, and laboratory analysis of seepage water from a thermally accelerated drift, using a remotely operated vehicle.
133c2	Monitoring, collection, and laboratory analysis of seepage water from emplacement drifts, using a remotely operated vehicle.
137a	Testing of transport properties and field sorptive properties of the crystal-poor member of the Topopah Spring Tuff (Tptp).
150a	Monitoring, sampling, and analyzing saturated zone water from Nye County and site wells for water levels, Eh, and pH.
151a	Monitoring, sampling, and analyzing saturated zone water from Nye County and site wells for radionuclide concentrations.

Selected Performance Confirmation Activities
(2 of 2)

Activity Number	Activity Description
159a	Hydraulic testing of fault zone hydrologic characteristics, including anisotropy, in the saturated zone.
162a	Periodic surveys of the habitats and characteristics of the reasonably maximally exposed individual and dust levels associated with occupational activity.
166b	Natural analogue studies of the fraction of radionuclides from the soil captured by the water table.
167a	Monitoring regional seismic activity, if such data are not available through other programs.
170a	Observation of subsurface and surface faults displacement after significant local or regional seismic events.
173a	Laboratory testing of rock and soil dynamic properties using higher strains than have been tested during site characterization.
180a	Drilling of aeromagnetic anomalies for volcanic event count modeling.
181a	Update probability estimates for volcanic intrusion by updating the probabilistic volcanic hazard analysis.
182a	Update estimated consequences of an igneous intrusion using expert elicitation.
185a	Updated modeling and analogue studies of the number of waste packages hit from igneous events.
191a	Updated modeling and analogue studies of initial mass loading of ash.
192a	Field measurements of the resuspension and redistribution of volcanic ash in analogues.
193a	Experimental and analogue studies of the resuspension and redistribution of ash resulting from human activities (e.g., plowing).
199a	Monitoring of average codisposal and commercial spent nuclear fuel waste package radionuclide inventory by tracking the waste stream receipt certification.
200a	Laboratory testing of effectiveness of ramp, borehole, and shaft seals prior to submitting a license amendment to receive and possess waste.
204a	Laboratory testing and literature review of radionuclide transfer factors, root uptake.
205a	Laboratory testing and literature review of radionuclide foliar translocation factor.
206a	Laboratory testing and literature review of radionuclide foliar interception factor.
207a	Laboratory testing of sorption coefficients (K_ds) for ash particles in soils.
208a	Laboratory testing for inadvertent soil intake containing radionuclides by humans and animals.
214a	Laboratory testing for radionuclide activity partition by ash and soil particle size.
215a	Laboratory testing and literature review of airborne volcanic ash level stabilization.
216a	Laboratory testing for waste particle dissolution and migration in ash and soil.
217a	Analysis of ash particles for dimensional changes due to weathering.
220a	Drift Scale Test in the Lower Lithophysal Unit.
221a	Geodetic monitoring of extensional tectonics in the Yucca Mountain region using global positioning system satellite monitoring as a potential indicator of future igneous activity.
251a	Monitoring of ventilation system exhaust gas for radionuclides.

Mapping of Performance Confirmation to Regulatory Requirements (1 of 2)

Regulation Subparagraph	Regulation Paragraph Text	Activities Supporting the Regulation
131(a)(1)	"The performance confirmation program must provide data that indicate, where practicable, whether: Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review"	51a, 52a, 53a, 54e, 56e, 58e, 59a1, 59a2, 60b, 105a, 106a, 107a, 108a, 109a, 111b, 119a, 120a, 125a, 128a, 129b, 131a, 133b, 133c1, 133c2
131(a)(2)—Total system performance, nominal scenario class	Directly affects total system performance, not through a barrier: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	83a, 151a, 251a
131(a)(2)—Surface barrier	Surficial soils and topography: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	51a, 84b, 96b, 133b, 133c1, 133c2
131(a)(2)—Unsaturated zone above the repository barrier	Unsaturated zone above : "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	51a, 105a, 106a, 107a, 108a, 109a, 111b, 119a, 120a, 125a, 128a, 129b, 131a, 133b, 133c1, 133c2, 220a
131(a)(2)—Unsaturated zone below the repository barrier	Unsaturated zone below: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	105a, 106a, 107a, 108a, 109a, 111b, 119a, 120a, 125a, 128a, 131a, 137a, 151a, 220a
131(a)(2)—Saturated zone barrier	Saturated zone: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	150a, 151a, 153a, 159a
131(a)(2)—Drip shield barrier	Drip shield: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	53a, 54e, 56e, 57a, 59a1, 59a2, 60b, 68a, 69a, 70a, 74a, 75a, 76a, 79a

Regulation Subparagraph	Regulation Paragraph Text	Activities Supporting the Regulation
131(a)(2)—Waste package barrier	Waste package: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	51a, 52a, 53a, 54e, 56e, 57a, 58e, 59a1, 59a2, 68a, 69a, 70a, 71a, 72a, 73a, 74a, 75a, 76a, 79a, 129b. 133b, 133c1, 133c2
131(a)(2)—Cladding barrier	Cladding: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	1a
131(a)(2)—Waste form barrier	Waste form: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	16a, 199a
131(a)(2)—Invert barrier	Invert: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	36a
131(a)(2)—Total system performance, disruptive scenario classes	Directly affects system performance, not through a barrier: "The performance confirmation program must provide data that indicate, where practicable, whether: ...Natural and engineered systems and components required for repository operation, and that are...assumed to operate as barriers after permanent closure, are functioning as intended and anticipated"	162a, 166b, 167a, 170a, 173a, 180a, 181a, 182a, 185a, 191a, 192a, 193a, 204a, 205a, 206a, 207a, 208a, 214a, 215a, 216a, 217a, 221a
131(d)(2)	"The program must be implemented so that: It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities"	51a, 52a, 53a, 54e, 56e, 58e, 59a1, 59a2, 60b, 96b, 105a, 106a, 107a, 108a, 109a, 111b, 119a, 120a, 125a, 128a, 129b, 131a, 133b, 133c1, 133c2, 150a, 151a
131(d)(3)	"The program must be implemented so that: It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository"	51a, 52a, 53a, 54e, 56e, 58e, 59a1, 59a2, 60b, 84b, 96b, 105a, 106a, 107a, 108a, 109a, 111b, 119a, 120a, 125a, 128a, 129b, 131a, 133b, 133c1, 133c2, 150a, 151a, 167a, 170a
132(a)	"During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping must be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken..."	51a, 52a, 53a, 54e, 56e, 58e, 59a1, 59a2, 60b, 105a, 106a, 107a, 108a, 125a, 128a, 129b, 131a, 133b, 133c1, 133c2, 167a, 170a, 173a

Mapping of Performance Confirmation to Regulatory Requirements
(2 of 2)

Regulation Subparagraph	Regulation Paragraph Text	Activities Supporting the Regulation
132(b)	"Subsurface conditions must be monitored and evaluated against design assumptions"	51a, 52a, 53a 54e, 56e, 58e, 59a1, 59a2, 60b, 125a, 129b, 131a, 133b, 133c1, 133c2
132(e)	"In situ monitoring of the thermomechanical response of the underground facility must be conducted until permanent closure, to ensure that the performance of the geologic and engineering features is within design limits"	51a, 59a1, 59a2, 60b, 129b, 220a
133(a)	"During the early or developmental stages of construction, a program for testing of engineered systems and components used in the design, such as, for example, borehole and shaft seals, backfill, and drip shields, as well as the thermal interaction effects of the waste packages, backfill, drip shields, rock, and unsaturated zone and saturated zone, must be conducted"	1a, 16a, 36a, 51a, 52a, 53a, 54e, 56e, 57a, 58e, 59a1, 59a2, 60b, 68a, 69a, 70a, 71a, 72a, 73a, 74a, 75a, 76a, 79a, 125a, 128a, 129b, 131a, 133c1, 133c2, 167a, 170a, 199a, 200a, 220a
133(d)	"Tests must be conducted to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale operation proceeds to seal boreholes, shafts, and ramps"	200a
134(a)	"A program must be established at the geologic repository operations area for monitoring the condition of the waste packages. Waste packages chosen for the program must be representative of those to be emplaced in the underground facility"	83a, 151a, 251a
134(b)	"Consistent with safe operation at the geologic repository operations area, the environment of the waste packages [chosen for the program] must be representative of the environment in which wastes are to be emplaced"	51a, 52a, 53a, 54e, 56e, 57a, 58e, 59a1, 59a2, 133b, 133c1, 133c2
134(c)	"The waste package monitoring program must include laboratory experiments that focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste…must be duplicated in the laboratory experiments"	1a, 16a, 69a, 71a, 72a, 73a