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Office of
Science and Technology and International

Science and Technology Program Plan

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OST&I
OCRWM Office of Science and Technology and International

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, D.C.

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Introduction

This program plan articulates the five-year goals and objectives for the Science and Technology (S&T) Program within the Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM). The S&T Program is intended to reduce the cost of the proposed Yucca Mountain repository and enhance the understanding of the processes affecting its performance through the application of new scientific understanding and technology. While the design for the proposed repository will provide a safe and effective disposition of spent nuclear fuel (SNF) and high-level waste (HLW), it is unreasonable to assume the science and technology supporting the repository today will remain unchanged over the more than 50 years that the repository will be in operation. In fact, continuous improvement in operations and enhanced knowledge of the disposal process is expected of a Nuclear Regulatory Commission (NRC) license holder. Therefore, it is prudent to support an effort within OCRWM to assure that the proposed repository will be able to use advanced technology that becomes available in the future to reduce cost to the taxpayer and utility ratepayer. As a separate office within OCRWM, the S&T Program supports the proposed Yucca Mountain repository operations and transportation activities; together these are henceforth referred to as the Repository System.

The Office of Science and Technology and International (OST&I) has been intentionally established external to the other OCRWM projects so that its investigations will not be construed as a deviation from the current approach being pursued by the Repository System, but as pursuit of significant improvements and advances. Furthermore, it is recognized that the forward-looking S&T activities are not generally compatible with the very structured and legalistic environment demanded by the NRC regulatory process under which the repository system is managed. This separation creates an effective barrier allowing S&T to perform investigations in a way that should not be perceived internally or externally as affecting the regulatory process. However, this barrier also creates a complication in that the S&T activities potentially may not be as closely associated with the Repository System as would normally be the case for a mission-driven S&T program. Coordination between S&T and the Repository System to properly integrate across this barrier is paramount to success. Figure 1 broadly defines the coordination and differences between scientific investigations sponsored by OST&I and the Repository System.

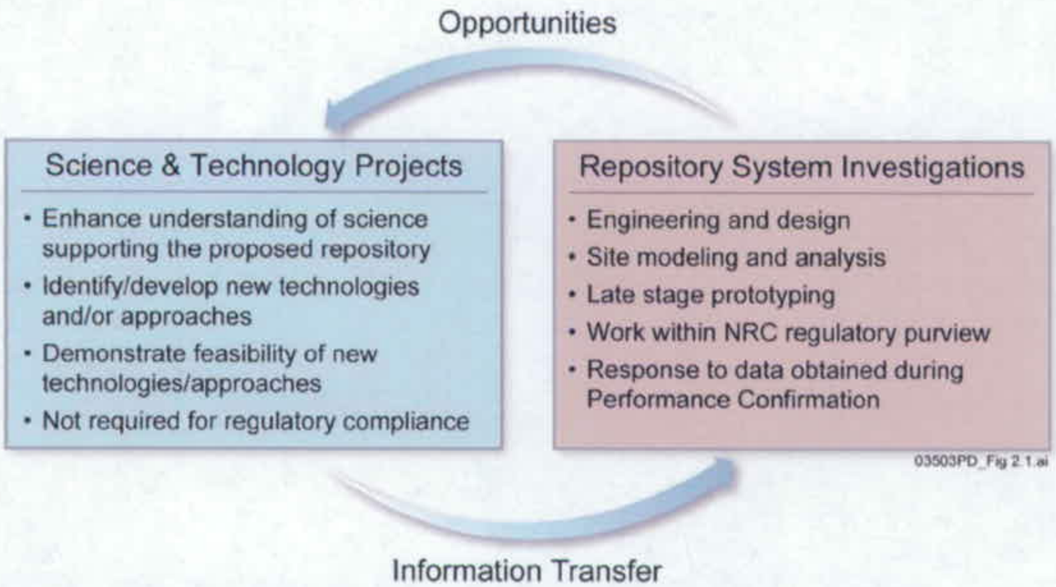
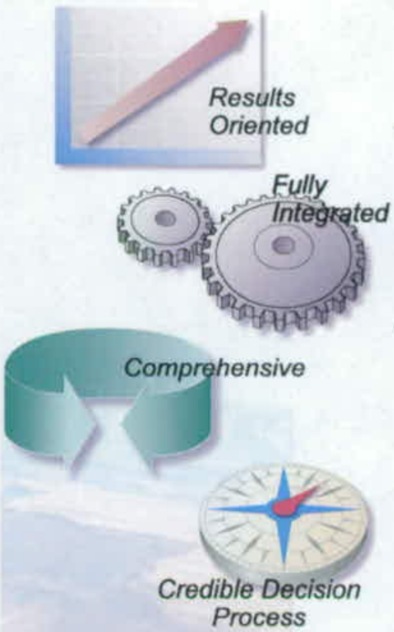


Figure 1 Differences Between S&T Projects and Repository System Investigations

OST&I will focus its investments in S&T on investigations enhancing understanding of the post closure performance of the proposed repository at Yucca Mountain and on seeking newer, better and time or cost-saving practices resulting from innovation. This approach will keep OCRWM current with the best practices in the nuclear industry, while allowing the technical resources of the Repository System to focus on operations and interactions with regulatory authorities.

Strategic Approach

The strategy for implementing the S&T Program was outlined by the Director in the OCRWM Science and Technology Program Strategic Plan (DOE/RW-0574): "To be of value to OCRWM, science and technology activities must be results-oriented, provide new knowledge or tools, and demonstrate partnership with the Repository System at every level" and stressed the steps necessary to achieve this as follows:



The role of S&T is to invest in technical activities that are longer-term in nature than the typically near-term activities supported by the Repository System.

- Focus only on OCRWM goals – The projects supported will meet at least one of the following three critical criteria established for the program:
  - Reduce the costs and schedule of the repository system.
  - Enhance understanding of the processes related to waste isolation at the repository.
  - Keep OCRWM current with best practices in the nuclear industry.
- Fully Integrate with the Repository System – Activities will be identified based on the technology roadmaps and schedules directly linked to repository system goals. Technology roadmaps will be prepared for the highest-priority areas to provide a robust and credible basis for the S&T Program investment portfolio. Financial responsibility for the projects will transition from S&T funding to the Repository System as technologies are deemed ready for use.
- Employ Sound Business Practices –
  - Selection Criteria Focused Toward Line Program Acceptance: To ensure the greatest impact to the OCRWM mission in terms of risk and cost reduction, projects are selected using a set of criteria focused on the integration of improved technology into existing practices.
  - Project Management Practices Enforced: Performance measures, milestones and decision points are established for each project prior to initiation and will be reviewed annually.
  - Relevance and Technical Merit are Both Required: Regular reviews will be held to ensure all projects meet quality requirements, are of the highest technical merit and continue to be relevant to the Repository System requirements and schedule.
  - Defined Project Completion Point: Project requirements and technology insertion points are defined prior to project initiation, and if successful, each S&T project will be: 1) evaluated for benefit to the Repository System, and 2) provided to decision makers and could potentially be incorporated into the baseline at a future time.
- Co-Fund Prototype Testing – For projects beyond development, work should generally be co–funded with the repository and must meet relevant OCRWM quality assurance requirements.

Management Approach

Management of the S&T program is structured in a way that the technical management of the work is done by recognized experts while the programmatic management is done by the Headquarters staff (Figure 2). Headquarters is responsible for policy development, establishing overall program direction and priorities, budget and reporting performance. Integrated project teams, called Thrust Teams are responsible for planning, managing and reviewing the technical activities within a specific technical area as well as coordinating the research with the Repository System to ensure relevancy.

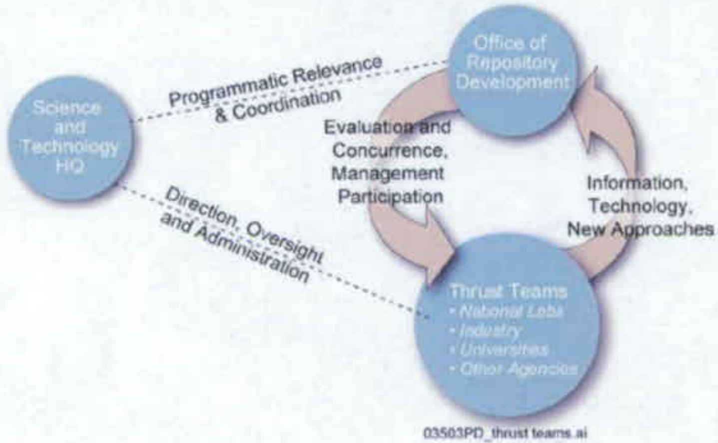


Figure 2 Relationship between Office of Repository Development and the S&T Thrust Teams

The Thrust Teams are lead by recognized experts in the specific technical area assigned to that team. By placing the authority for technical management of the program with the Thrust Team Leader, projects can be managed in a flexible manner that is expected to maintain high technical merit and focus. In establishing and managing individual projects the Thrust Teams will use the following approach:

- Promote Expert Collaboration – Thrust Teams will manage and coordinate projects within each major S&T program area in a fair and open way, encouraging participation by the technical community at large. Thrust Team leaders are encouraged to publish the results of the research and coordinate the work, where appropriate, with others who are working in the field to elicit comments and "peer review".
- Fully Integrate with the Scientific and Vendor Community – Technology development and demonstration activities will be planned with and carried out by, private industry, Department of Energy (DOE) laboratories, universities and other federal agencies leveraging work where appropriate with other relevant programs, both foreign and domestic. For technologies to be demonstrated through the commercial market, potential vendors will be identified early and may even become partners for implementation in the Repository System.
- Select Technology Providers Using Methods Appropriate to the Maturity of the Activity – Scientific activities will generally be competed, on a periodic basis, among the DOE laboratories, universities, or other federal agencies, while more mature requirements will be solicited to private industry. Industry procurements will use a phased approach allowing multiple concepts to be competitively developed and evaluated prior to selection.
- Conduct Frequent Reviews – Peer review will be performed on all projects periodically to ensure the projects are meeting the OCRWM quality assurance requirements, are of high technical merit and are meeting program needs and schedules.

Science and Technology Initiatives

OCRWM S&T Initiatives will be directly aligned with those areas defined as Investment Areas in the S&T Strategic Plan (Nov. 2004), high-cost centers in the Total System Life Cycle Cost model (TSLCC) (Figure 3) or as elements with significant conservatism or large uncertainties from the Total System Performance Assessment (TSPA). The Initiatives are typically identified from the analysis of OCRWM systems models, by the knowledge developed by experts in the normal course of their work, or by outsiders familiar with the OCRWM mission. Initiatives may have a very broad scope and be long term in nature - such as the scientific investigations whose goals are to better understand repository performance, or very narrowly focused, such as those in the Advanced Technologies Thrust whose goal is to introduce new technology or approach into the Repository System.

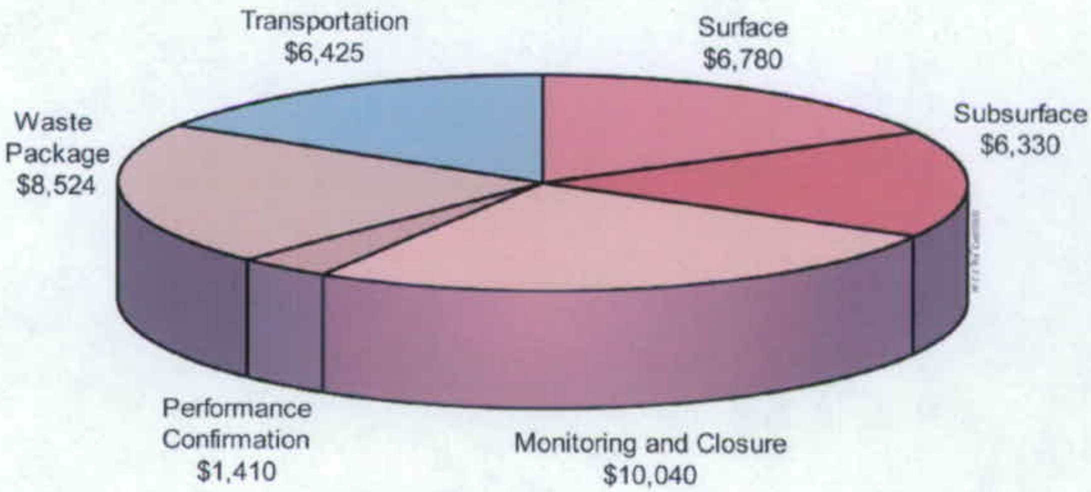


Figure 3 Estimated Life-Cycle Cost for the Proposed Yucca Mountain Repository
Billions of dollars
Source: 2000 TSLCC dated May 2001 Pg B-2

While there is a broad acknowledgment of the value of bringing new technology to the high-cost-center activities within the program, the value of advancing science (such as providing new knowledge to better understand processes like waste-form performance or natural barriers) is often less well understood (see text box inside back cover). The goal is to achieve a sustainable balance of investments between these two types of activities. The distribution of investments will vary annually. Activities which require long-term study, such as waste-form performance or natural barriers, will be maintained annually at an appropriate level to insure the understanding of the systems associated with the proposed repository continues to grow, and the increased understanding can, over the longer term enable important technological advances. It should be noted that an important element of the "nuclear culture" encouraged by the NRC, and expected of an NRC licensee, is a strong technical program driving continuous improvement in operations and enhanced knowledge of the disposal process.

The relationship of the 2005 through 2010 S&T Initiatives to the Investment Areas is described in the following section. A description of each Initiative along with a defined set of goals and objectives can be found in Appendix A.

Waste Packages

Approximately 11,000 waste packages are to be fabricated in order to dispose of the 70,000 metric tons of waste to be emplaced in the proposed repository. Each of these waste packages will be made of a structural stainless steel inner container surrounded by an outer shell made of a highly corrosion-resistant metal alloy. The fabrication of these waste packages requires precision machining, welding and precise alignment of two concentric metal containers and three lids. As a result of the expense of materials and complex fabrication, the estimated-cost of each waste package is over $600,000, leading to a total of over $8 billion in life-cycle costs. Waste package fabrication is the second largest cost to the repository (Figure 3). Improvements in understanding materials performance, simplifying the manufacturing process, improving fabrication and better non-destructive testing could significantly reduce this portion of the overall repository cost. These activities are included in the three S&T Initiatives focused on enhancing the performance and reducing the waste package costs.

Science and Technology Initiatives Focused on Waste Packages

- Advanced Welding for Waste Package Closure
- Waste Package Fabrication and Materials
- Materials Performance

Subsurface

Subsurface construction and operations (Figure 4), excluding closure activities, is estimated to be approximately $6 billion. Subsurface operations consist of tunneling more than 100 km of underground openings, keeping these openings open, ventilation, waste package emplacement and monitoring. Several opportunities exist to reduce this cost. Tunneling will be relatively slow and challenging due to the properties of the tuff and the need to maintain the underground tunnels. Similarly, emplacement and maintenance, which would normally be a standard operation, is made difficult by the fact that once waste packages are placed inside, tunnel workers will no longer be permitted in the area. Robotic or remote material handling and monitoring tools, remote sensors and long-term power sources for efficient operation can be improved. All of these activities are included in one Initiative, which is focused on improving the efficiency of the mining operation.

Science and Technology Initiatives Focused on Subsurface

- Advanced Tunneling Technology

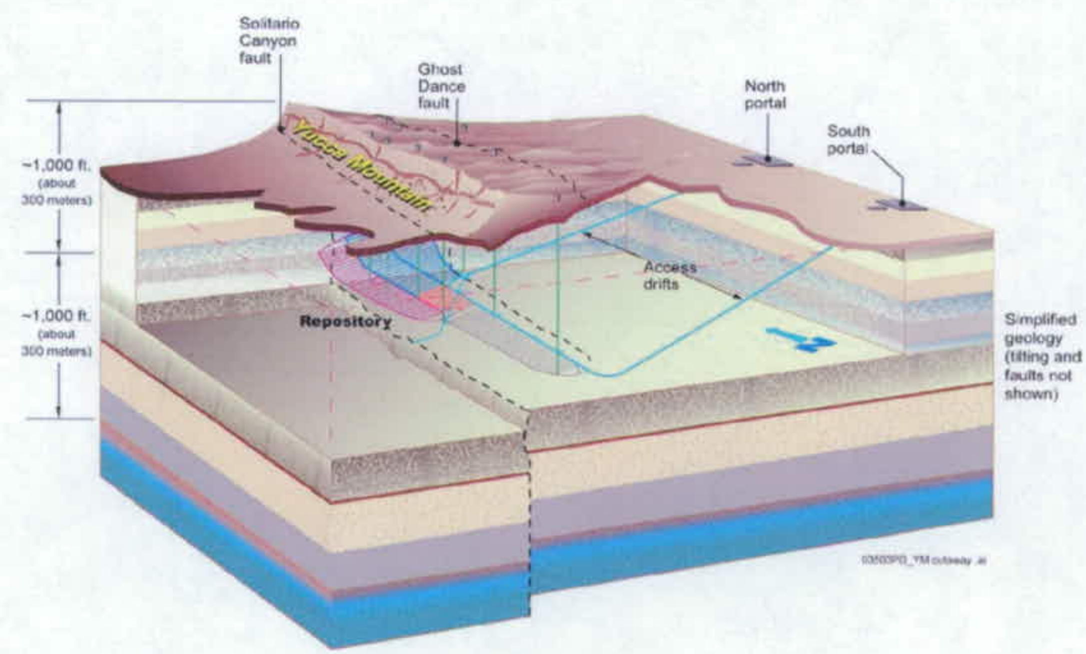


Figure 4 Generalized Location of the Repository

Science and Technology Initiatives Focused on the Surface

- Improved Understanding of Seismic Conditions at Yucca Mountain
- Improved Remote Material Handling Systems

Surface

Surface operations refers primarily to the surface buildings (Figure 5) located near the repository entrance portal that house the systems used to receive, prepare and package the waste before subsurface emplacement. Radioactive operations will be performed in the surface facilities. Each facility is designed to receive, process and package a specific waste type. The life-cycle cost to construct and operate the surface facilities is almost $7 billion. The cost of these facilities is driven by their robust nature, required by potential seismic conditions, and by the need for the remote handling and monitoring of the radioactive material. Specifically, the reinforced concrete walls surrounding the waste processing portions of these buildings are extraordinarily thick to provide shielding for workers during normal operations and to insure integrity in the event of a large earthquake. The S&T Program has identified research opportunities associated with the better understanding of seismic conditions at the site that would allow reduced conservatism on the design of earthquake resistant building, as well as more efficient use of robotic or advanced autonomous material handling (Figure 6) processes that could reduce the amount of shielding necessary for environmental safety and health protection. Advanced technical work in these areas may reduce the overall cost of surface operations. These two technology Initiatives are investigating ways to reduce the cost and improve the efficiency of surface operations.


Figure 6 Remotely Operated Manipulator

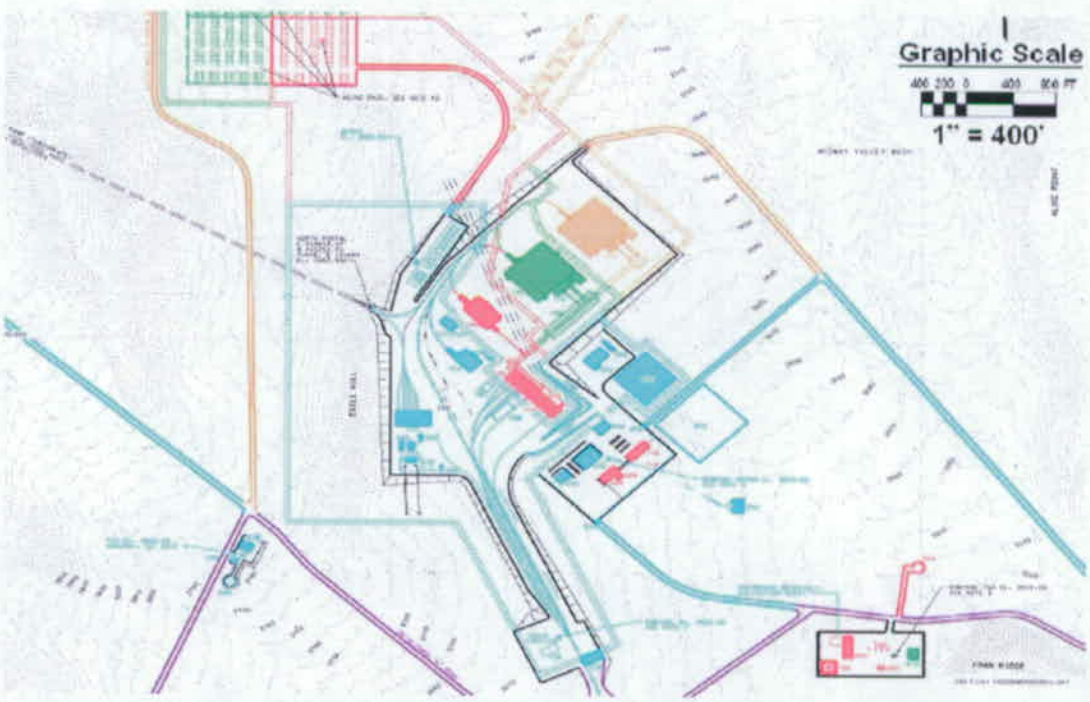


Figure 5 Surface Layout of the Proposed Yucca Mountain Repository

Natural Barriers

The natural barriers at Yucca Mountain are an important part of the overall system to prevent radioactive materials from reaching the accessible environment (Figure 7). The natural characteristics of the soil, saturated and unsaturated rock formations and volcanically-deposited rock layers work together to contain and isolate the waste. A major part of the characterization phase of the Repository System was devoted to understanding the characteristics of these natural barriers and to developing an analysis model that describes how they work together. The model currently in use utilizes many simplifications of the natural system. It represents a very conservative approach, but is adequate for the purpose of meeting the applicable regulatory standards. The S&T Program has identified several opportunities to better understand aspects of the natural barriers which may lead to enhancing the fidelity of the calculated long-term performance of the repository.

Science and Technology Initiatives Focused on Natural and Engineered Barriers

- Improved Understanding of Natural Processes in the Subsurface
- Radionuclide Getters

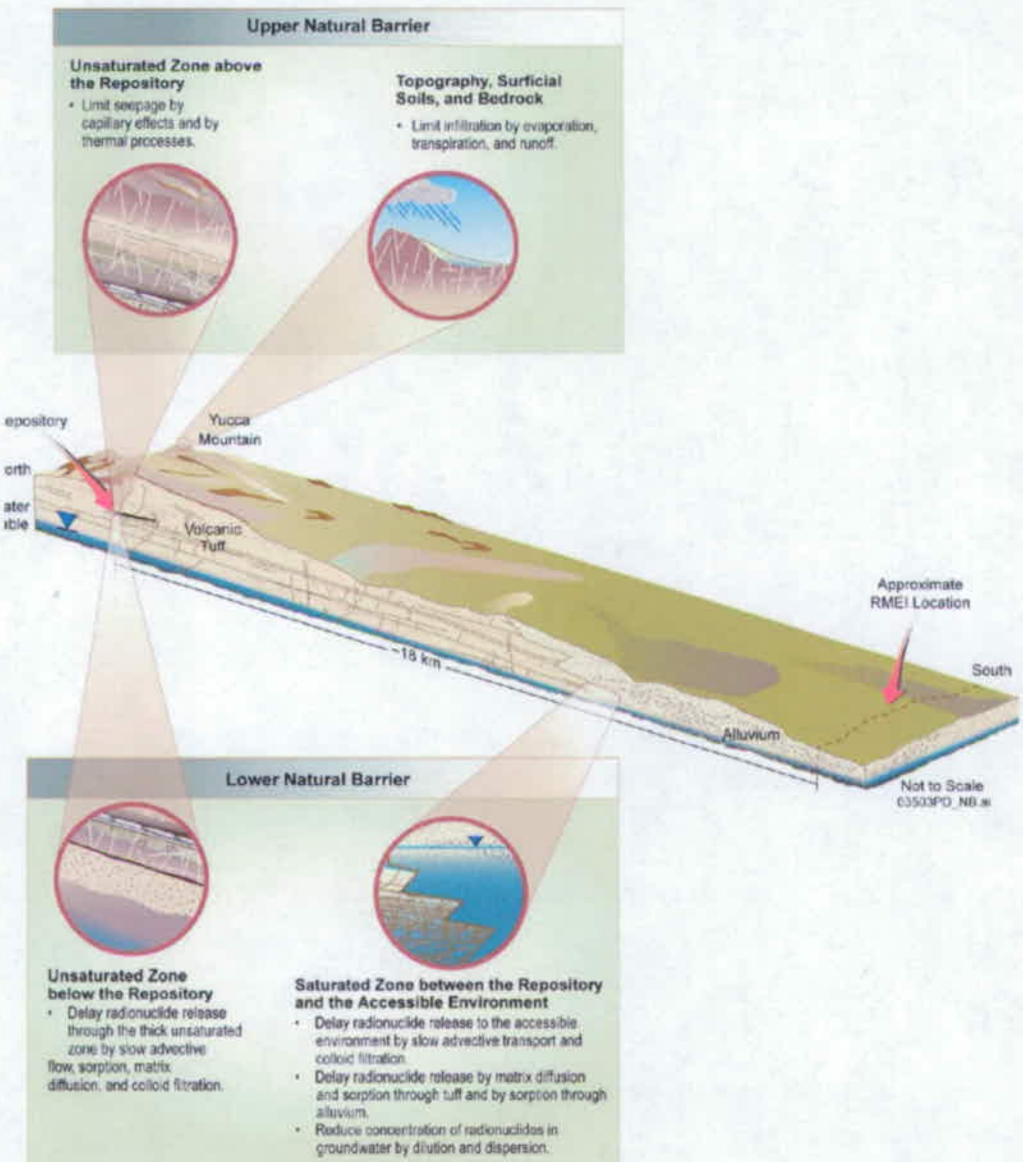


Figure 7 Components of the Natural Barrier System

Science and Technology Initiatives Focused on Waste Form Performance

- Improved Understanding of Natural Processes
- Source Term

Waste Form Performance

The waste form (Figure 8) is one of the "Engineered Barrier System (EBS) features" contributing to the repository's ability to limit dose in the accessible environment. However, the waste form's degradation and the mobilization of soluble radionuclides are modeled to occur more rapidly than experts believe is realistic for repository-relevant conditions. The conservatism of the present models were used to reduce the uncertainty in the understanding of the geochemical/hydrologic processes that control the corrosion of the waste under oxidizing conditions. Consequently, investigations to better understand aspects of the waste form behavior will enhance understanding of the long-term performance of the repository.

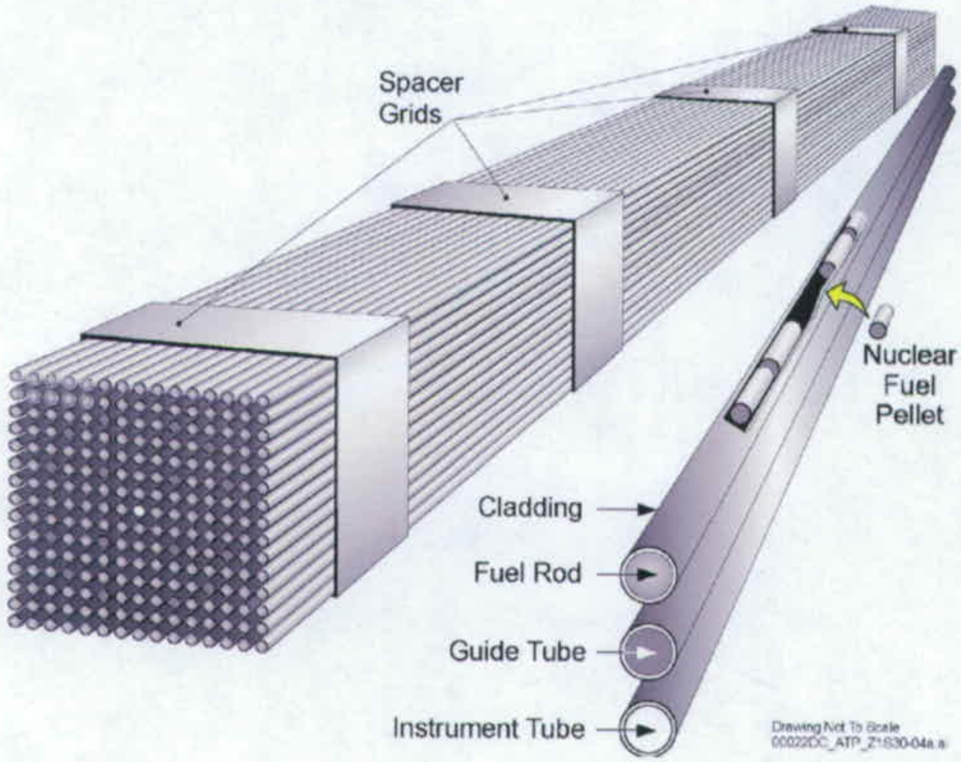


Figure 8 Spent Fuel Rod Assembly

Performance Confirmation, Monitoring and Closure

Ensuring public safety requires continued stewardship, including a program for evaluating new information obtained during the construction and operation of the repository. Performance confirmation is the set of testing, monitoring and analysis activities initiated during site characterization and continuing until repository closure. The focus of this work is to gather and analyze data on conditions and systems affecting the performance of the facility after closure and to evaluate their impacts on post-closure performance. Because this is such a long-term activity there are opportunities to enhance its effectiveness and reduce its cost using innovative sensor technology. Formal Initiatives (Figure 9) will be defined for this area once Performance Confirmation and Closure activities are defined by the Repository System.

Science and Technology Initiatives Focused on Performance Confirmation, Monitoring and Closure

- Initiative not Currently Defined

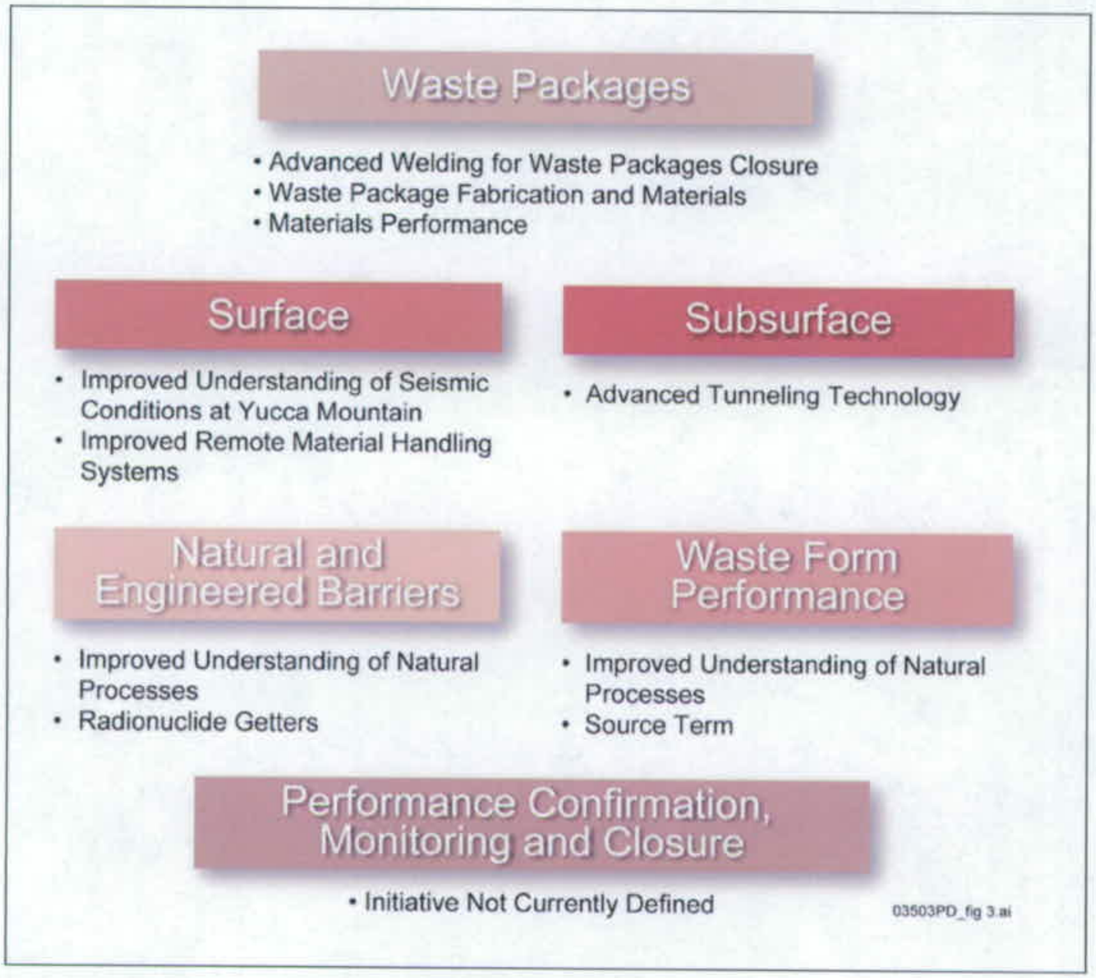


Figure 9 Relationship of Initiatives to Strategic Investment Areas

Goals and Objectives

The major objectives of the S&T Program flow down from the OCRWM Strategic Performance goal entitled, "Optimize the National Disposal System". The goals and performance indicators shown in the following table will be used to indicate the overall S&T contribution. Distinct milestones, go/no-go decision points and deliverables supporting each specific Initiative will be established and used to measure progress against the appropriate goals. Because the overall impact of the S&T Program's contribution to the Repository System will not be realized until some time after a specific project is completed, estimated cost savings, risk reduction or efficiency enhancements (also known as return on investment) will be calculated using information available at the time the project is completed and transferred to the Repository System.

GOAL	PERFORMANCE INDICATOR
Reduce total life-cycle costs through the insertion of new technology and knowledge into the proposed Yucca Mountain Repository	• Reduced cost of engineered barriers • Reduced cost of subsurface tunneling • Reduced cost of material handling
Advance scientific and technical understanding of the proposed Yucca Mountain Repository	• Improved understanding of post-closure performance • Improved capability for long-term testing, monitoring and analysis

Measuring Performance

The output of the S&T Program will be measured by the accomplishment of milestones as defined for each S&T Initiative. Progress against these milestones will be updated annually and reported. The estimated insertion points for the key products of the S&T Program are more fully described in Appendix A. In general, S&T products will be inserted into the Repository System in accordance with the established milestones shown in Figure 10.

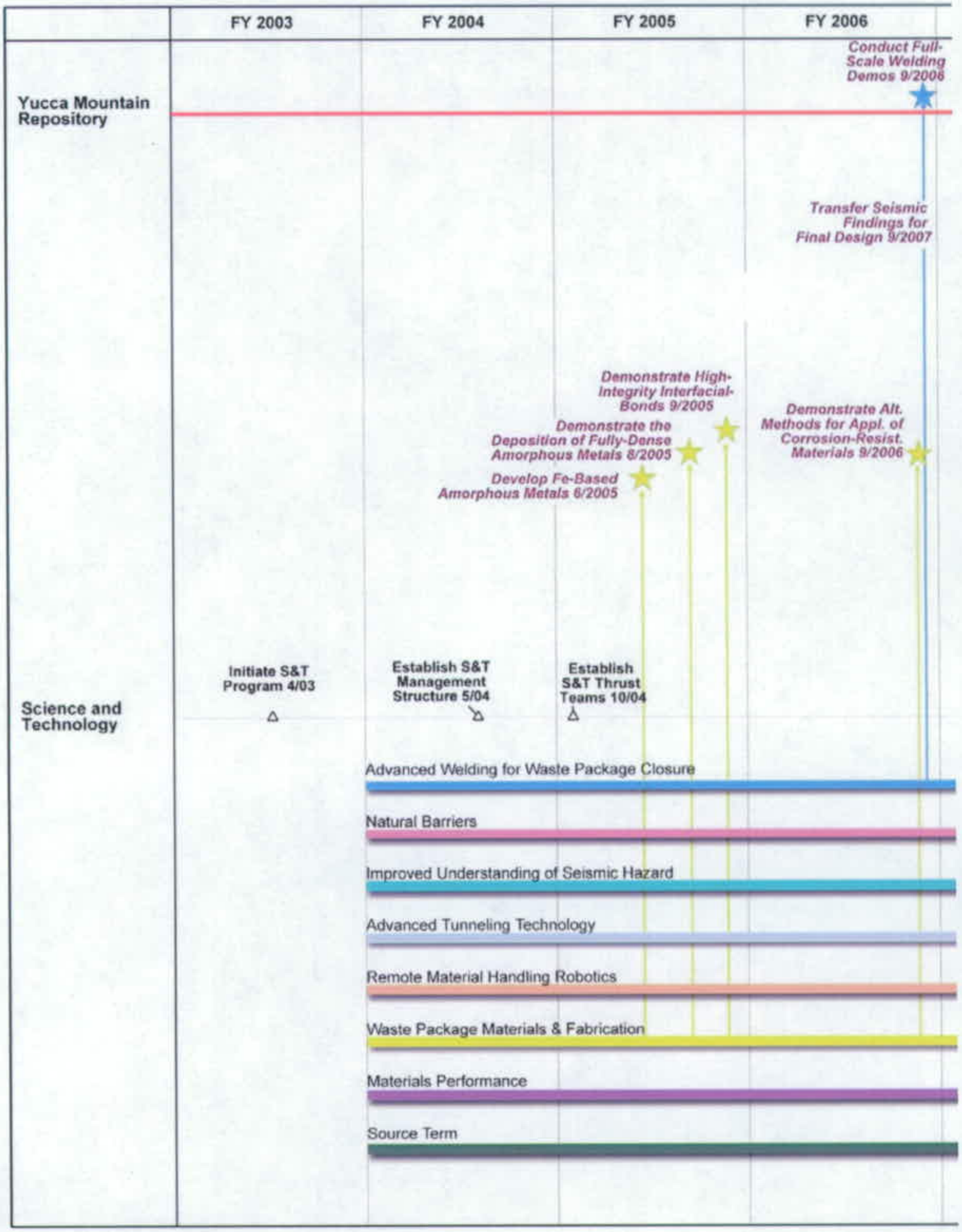
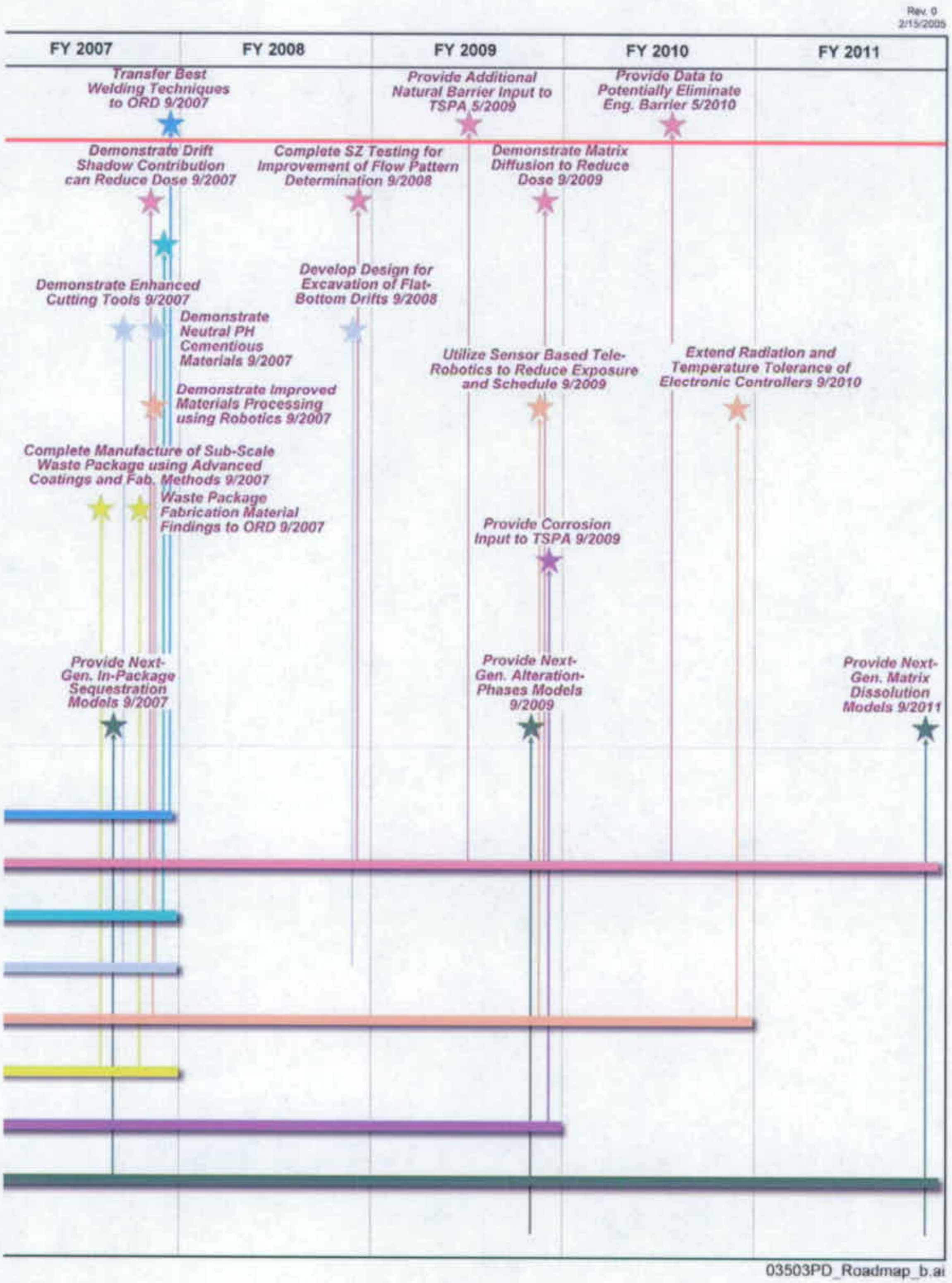


Figure 10 Established Repository System Milestones


Rev. 0
2/15/2005
FY 2007
FY 2008
FY 2009
FY 2010
FY 2011
Transfer Best Welding Techniques to ORD 9/2007
Provide Additional Natural Barrier Input to TSPA 5/2009
Provide Data to Potentially Eliminate Eng. Barrier 5/2010
Demonstrate Drift Shadow Contribution can Reduce Dose 9/2007
Complete SZ Testing for Improvement of Flow Pattern Determination 9/2008
Demonstrate Matrix Diffusion to Reduce Dose 9/2009
Demonstrate Enhanced Cutting Tools 9/2007
Develop Design for Excavation of Flat-Bottom Drifts 9/2008
Demonstrate Neutral PH Cementious Materials 9/2007
Utilize Sensor Based Tele-Robotics to Reduce Exposure and Schedule 9/2009
Extend Radiation and Temperature Tolerance of Electronic Controllers 9/2010
Demonstrate Improved Materials Processing using Robotics 9/2007
Complete Manufacture of Sub-Scale Waste Package using Advanced Coatings and Fab. Methods 9/2007
Waste Package Fabrication Material Findings to ORD 9/2007
Provide Corrosion Input to TSPA 9/2009
Provide Next-Gen. In-Package Sequestration Models 9/2007
Provide Next-Gen. Alteration-Phases Models 9/2009
Provide Next-Gen. Matrix Dissolution Models 9/2011
03503PD_Roadmap_b.ai


Appendix A
Science and Technology Initiatives

Science and Technology Initiatives

This Appendix provides the description, approach, goals and activities for each Initiative. It is organized by Initiative; first by the five Initiatives managed by the Advanced Technologies Thrust Teams, then by the four Initiatives managed by the Science Thrust Teams. The purpose of this section of the plan is to provide an overview of each Initiative at the programmatic level. For persons seeking additional information, data on each project is available on the OCRWM website: http://www.OCRWM.DOE.gov

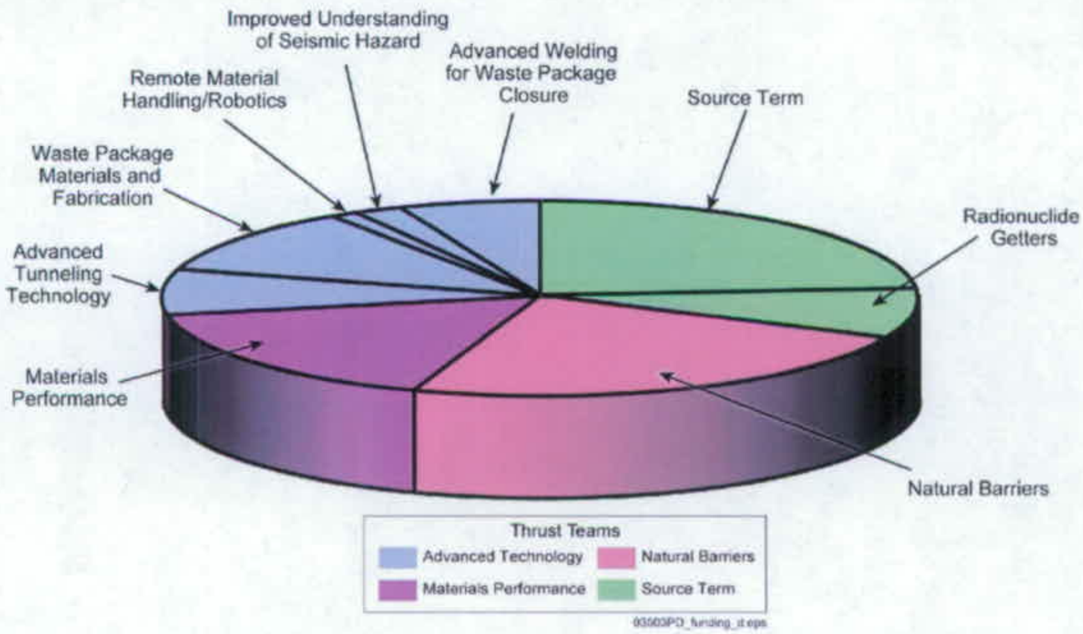


Figure A-1 FY05 Relative Funding and Relationships to Thrust Team. Total Program is Approximately $20 million per year

Advanced Technologies Thrust Team

The mission of the Advanced Technologies Thrust is to evaluate potentially adaptable technologies and/or systems requiring some additional development work leading to a demonstration. If successfully demonstrated to offer significant cost reductions or system acceleration, these technologies are then made available to OCRWM projects for possible insertion into the baseline. All technologies are targeted at reducing cost, increasing safety to humans and the environment, and accelerating schedule. The Advanced Technologies Thrust Team leader is located in the OST&I at DOE Headquarters. The Thrust Leader is responsible for the establishment of Thrust scope while the various Principal Investigators are responsible for execution.

Initiative 1 – Advanced Welding for Waste Package Closure

Description

Approximately 11,000 waste packages are to be fabricated in order to dispose of the 70,000 metric tons of SNF and other forms of HLW to be emplaced in the repository. The target of this Initiative is to produce a faster, superior quality weld between the closure lids (outer and middle) and the waste package. The current baseline for welding is the industry standard process, gas tungsten arc welding. It is a relatively slow process which, based on the current waste package design, requires as many as eight to ten separate passes across the weld joint to complete the weld. Furthermore, the heat generated during the welding process deforms the metal and requires additional machining before assembly of the waste package can be completed. Improvements in the welding process would reduce the time needed to perform the closure welds and eliminate post-weld and stress-reduction processes. Non-destructive evaluation methods and automated welding systems, which are required to operate in a hot cell environment, will also be investigated under this Initiative.

Approach

Research indicates advanced welding technologies are faster and may have sufficient power to complete the weld in one pass. These advanced welding technologies could also reduce or eliminate the need for post-weld machining or stress reduction processes on the waste packages. This investment may enable improved waste package processing and may contribute to reducing the cost of making and testing closure welds. In addition, these advanced welding technologies may also be applied during the fabrication and welding of the waste package cylinders, which could also lead to cost savings in overall waste package manufacturing. Preliminary data indicate that a cost saving of as much as $100,000 may be realized for each waste package.

Goals

- Reduce the cost of closure welding by greater than 20%
- Demonstrate by April 2006, at a reduced scale, an automated welding system that will be faster and will reduce or eliminate the need for post-weld machining and stress reduction processes. The automated welding system must also be hot-cell deployable
- Complete the full-scale prototype demonstration, in partnership with the Yucca Mountain Project (YMP), by September 2007.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Request for Proposal for Alternative Welding Approaches: Involves the issuance of a three-phase solicitation to industry seeking alternative welding technologies for the waste package closure welds. Phase III, a prototype demonstration, will be 90% co-funded by YMP.	• 20% reduction in welding cost. • Reduced material residual stresses induced by welding (e.g., a more favorable distribution of residual stress). • Reduced post-weld machining.
Analysis of Alternative Non-destructive Evaluation (NDE) Methods for Weld Integrity: Involves a trade study to evaluate the application of advanced NDE techniques, which will require operation in a hot cell, to alternative welding processes.	• Improved throughput and sensitivity.
Analysis of Automated Control Welding Processes: Involves the evaluation of advanced robotic or tele-operated control systems in support of closure lid welding in a hot cell.	• Implementation of an advanced welding control system.

Initiative 2 - Improved Understanding of Seismic Hazard at Yucca Mountain

Description

Extensive investigations over the past 15 years have provided a sound understanding of the seismic hazard (the likelihood of earthquakes of various sizes) at the Yucca Mountain site, but scientific advances are feasible to further refine understanding. The current understanding is embodied in a seismic-hazard probabilistic study. The results of that study still have important uncertainties, including the limited time over which actual earthquake records exist for the site, the inherent uncertainties in extrapolating knowledge gained worldwide to the site and to the inhomogeneities of the site. Especially for potential earthquakes that vastly exceed those actually experienced at the site, the understanding is limited and much uncertainty exists.

The seismological community believes the state of knowledge has advanced considerably in the last few years, and that other advances could be realized through a directed program of investigations involving laboratory work, field activities, advanced model development and other advanced theoretical studies. An integrated program is being planned that will likely encompass aspects of each of these types of work.

The benefit will be significantly less uncertainty in the understanding of the site's seismic hazard. This will translate into an increased confidence in knowledge of the seismicity, and will likely result in a decrease in the seismic-hazard values used by YMP for both site performance assessment and facility design. While the extent of such a decrease is difficult to predict until the work is accomplished, there is strong promise of major advances.

Approach

Research will be performed over a three- to five-year period, with some results becoming available earlier. The planned approach is to support a set of individual projects coordinated with similar work underway in California to better understand the seismicity of the major San Andreas Fault system. The result of this work will be the data that can be used to support an improved seismic hazard analysis that may be less conservative for the Yucca Mountain site.

Goals

- Substantially improve the understanding of the probability of occurrence for the extreme-ground-motion, which are predicted using current seismic hazard models
- Use the improved understanding to enable the reevaluation of the seismic response of the subsurface repository
- Use the improved understanding to enable the reevaluation of the seismic inputs used in the design of the surface facilities at the Yucca Mountain site
- Use the improved understanding to improve the effectiveness of the seismic monitoring as part of the long-term performance confirmation program.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Improved Ground-motion Propagation Analysis: Involves advancing the status of the current ground-motion modeling, which is the modeling of source-to-site propagation, by accounting for site-specific information, improved accounting for inelastic properties of the propagation medium and three-dimensional coupling.	• Ground-motion propagation analysis that reduces the uncertainty. • Achieve a reduction in the mean extreme ground-motion estimate.
Seismic Source Dynamics Modeling: Involves using both analogue information from earthquakes elsewhere, and improved understanding of rock failure properties, to provide a less conservative analysis of how the actual seismic source dynamics work during the fault slippage that comprises a major earthquake.	• Advanced model that includes most advanced current expert thinking about incorporating non-linear slip dynamics, non-linear rock-absorption.
Probabilistic Seismic Hazard Analysis (PSHA) Methodology: This task involves improving the way the expert-elicitation process develops input from seismic experts and then analyzes the experts' informed judgments, based on advanced understanding of how to process the judgments to arrive at a consolidated seismic-hazard analysis.	• Advanced PSHA method that incorporates uncertainty treatment using Bayesian updating.

Initiative 3 - Advanced Tunneling Technology

Description

The goal of this Initiative is to reduce the unit cost of subsurface tunneling through the demonstration of advanced mining approaches tailored specifically to the unique repository requirements and the introduction of new technologies. Although tunneling has been practiced for hundreds of years, the fact that more than 100 km of tunnels are to be constructed suggests that even small improvements could lead to large cost savings. The baseline excavation method is the application of conventional Tunnel Boring Machines (TBMs) (Figure A-2) for the access and emplacement drifts and road headers to cut "turn outs" and utility niches. Experience to date at Yucca Mountain suggests that excavation costs are high (~$30,000 per meter of advance) and progress is slow (approximately tens of meters per day), due to the abrasive nature of the volcanic tuff. The high silica content of this rock necessitates frequent change-out of the disc cutters and creates unique requirements for dust suppression.

The requirements of the proposed repository require the drifts to remain open for at least 50 years. Hence, supporting the drifts so that they retain their integrity during this time (i.e., with minimal rock fall and collapse) is of interest. While this is not an overwhelming engineering requirement, materials, which are normally used in tunneling - such as cast concrete tunnel liners - cannot be used in the repository due to the changes in the drift chemistry that may occur because of the alkalinity of common cements. The current baseline uses a stainless steel sheet drift liner (i.e., a mesh with a perforation size of ~ 2 cm) and stainless steel rock bolts without grout, which represents a significant cost.

Approach

Alternative earth excavation methods may offer potential improvements to the cost of this mining campaign. Areas of investigation include: 1) the development of improved rock cutting tools for TBMs and "roadheader" type mining machines; 2) improved dust suppression methods and/or reduced dust mining methods; 3) continuous monitors for silica dust and radon emissions; and 4) innovative TBMs to facilitate flat-bottom drifts.

A significant impact that can be made to the subsurface construction activities would be to develop a neutral pH cementitious material compatible with the chemistry of the surrounding tuff. Research has shown that silica-based cements are available that could meet the requirements for the repository, especially since the surrounding tuff is also a silica-based material. The use of such a material would improve the ground support in the repository, decrease capital costs, and would facilitate long-lived drifts without the need for removing concrete at a later time.

Figure A-2 Tunnel Boring Machine

Goals

- Demonstrate compatibility of neutral pH cementitious materials with Yucca Mountain host rock
- Demonstrate an approximate 20% increase in the wear life of rock cutting tools when operating on Yucca Mountain host rock
- Demonstrate silica dust monitoring, control methods and technologies that can be used in conjunction with tunnel excavation equipment during subsurface construction at Yucca Mountain
- Reduce the cost of subsurface construction by 20%.

Project Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Investigation of Cementitious Material Compatible with the In-drift Environment: Involves the investigation of various types of cementitious materials that would be compatible with the in-drift chemistry. The investigation would include the evaluation of the applicability of the material to YMP, its engineering properties and its durability for long-term performance.	• Complete Scoping Study. • Award multi-phase contract. • Identify alternative formulations. • Select alternative and begin qualification testing. • Complete qualification testing.
Dust Suppression and Continuous Emissions Monitor for Silica Dust: Investigate methods to reduce the dust generated by the YMP mining process and identify (or develop if necessary) an instrument for use with the tunnel boring machine.	• Sensors and monitoring network completed (Min. detectable part size ~0.010 mm). • Dust suppression system for the tunnel boring machine.
Innovative Tunnel Boring Machine Design: The ability to cut a flat bottom drift would be beneficial to YMP as it would allow a smaller opening to be cut and eliminate the need to transport additional material into the drift for construction of the invert.	• Complete scoping study & issue multi-phase Request for Proposal. • Select conceptual design. • Demonstrate sub-scale prototype.
Improved Rock Cutting Tools: Investigate the acceleration of mining by providing longer-life disc cutters and bits for mining machinery. This project will be initiated in the national laboratories and will be transferred to equipment manufacturers for implementation.	• Identify candidate materials. • Perform laboratory testing. • Perform field testing. • Transfer technology.

Initiative 4 - Improved Remote Material Handling Technologies at Yucca Mountain

Description

Operations at the proposed Yucca Mountain repository will make extensive use of remote handling (Figure A-3) and robotics technologies because the HLW and SNF are so intensely radioactive that they cannot be handled directly by workers. Both surface and subsurface operations will use these technologies. The design of the facilities currently attempts to incorporate the latest advances in these technologies, but this field is one where several fast-moving advances are occurring around the world, which can be taken advantage of in the future.

Figure A-3 Operator manipulating remote handling equipment

Approach

To assure the project is aware of advances and that it has the capability to incorporate them appropriately, the OCRWM S&T Program is planning this Initiative. The first phase of this work was a fact-finding evaluation, which investigated the current status of the Repository System's capabilities and made comparisons with advances now occurring elsewhere. In many cases, these advances cannot be directly adopted into the Repository System, but instead require some effort to be adapted to the special engineering circumstances of the proposed repository.

The principal development activities to be pursued would be to replace current "through the wall" mechanical manipulator systems with tele-robotic manipulator systems, which have greater flexibility and capability. Although operator friendly tele-operated manipulators are currently available, the amount of time required to perform a task remotely is between eight to ten times longer than if done "hands on". This is primarily due to the control systems and the design of the end effectors or tools. In tele-robotics, an emphasis is placed on sensor-based control, to improve efficiency by supplementing human control with task automation. A current tele-robotics technology includes preprogrammed constrained motions and a priori mode-based or "teach and repeat" capabilities. This Initiative would replace pure a priori mode-based techniques with dynamic sensor-based techniques. Dexterous manipulation, technologies to improve efficiency by improving the operator's sense of hands-on "presence" with the task, will also be pursued. These systems can also be used to support waste package inspection and decontamination tasks as well as material handling.

Radiation-hardened systems for long-term use in high-radiation environments are also targeted within this Initiative. First, a new family of non-silicon based integrated circuits or similar type electronics modules will be pursued to build equipment that is inherently radiation hardened. Second, an innovative radiation-based power cell that would take advantage of the intense radioactivity to produce electric power will be evaluated for application in the emplacement drifts, to power sensors or other electronics designed for long-term use.

Goals

- Demonstrate ability to substantially improve material processing capacity and minimize worker exposure through the use of robotics technologies to replace human work patterns
- Through the use of sensor-based tele-robotics and improved manipulator dexterity
  - Reduce remote task completion times in the production buildings by greater than 25%
  - Reduce worker exposure in material handling tasks by greater than 10%
- Deliver an improvement over best current state-of-the-art radiation hardened electronics.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Sensor-Based Tele-Robotics: Sensor-based robotics and the closely related topic of vision-based or visually-guided systems can provide improved efficiency and decreased fatigue by making use of automated robotic functions to assist the operator in task completion.	• Vision and spatial integrated sensor head system to target, characterize and register in 3-D space specific task objects under operator control. • Interactive semiautomatic task programmer to quickly program automated task "modules." • Integrated task management capability with feed back to target object positioning errors.
Dexterous Manipulation: Improve tele-operation such that the operator's sense of presence is strong enough that the operators feel they are working in a hands-on mode, although remotely positioned.	• Demonstrate advanced integrated operator stations that minimize fatigue and eye strain. • Demonstrate multi-fingered grippers. • Demonstrate integral master controllers with improved force-reflection and tactile sensing.
Radiation Resistant Electronics: Outlines the development of a new class of electronics that is inherently radiation and temperature resistant (does not need radiation hardening) and could be used in a wide variety of controls and sensing modules for YMP, to improve radiation tolerance and increase operational life, thereby decreasing maintenance costs and increasing operating time in high fields.	• Demonstrate module-based radiation hardened components capable of assembly into modular systems for control and communications tasks. • Demonstrate non-silicon based electronic systems specifically designed for radiation environments. • Demonstrate "radiation" based power cells for long-term use in the emplacement drifts.

Initiative 5 - Waste Package Fabrication

Description

More than 11,000 waste packages are required to dispose of the 70,000 metric tons of SNF and other forms of HLW destined for the proposed repository. The target of this Initiative is to identify and demonstrate less expensive waste package fabrication methods. Activities will include the identification, evaluation and demonstration of advanced fabrication techniques for large nuclear-qualified products. Activities may also include the development and testing of new corrosion-resistant metals and coatings. The current process for fabrication of the waste package involves the rolling and welding of thick plates of stainless steel and Alloy-22 and then machining them into concentric cylinders. This process can be done using current machining techniques, but is expensive and requires large machining equipment that can operate to tight tolerances. An innovative process for manufacturing the waste packages may result in significant cost savings.

The cost for fabricating the waste package is one of the highest associated with the repository. Each waste package is estimated to cost more than $600,000. Much of the cost can be attributed to its size and the requirements for precise machining of the surfaces to achieve the concentric cylinders. New manufacturing techniques and materials used for large military and industrial equipment show promise for reducing the fabrication costs. A 50 percent reduction in the cost of a waste package is targeted.

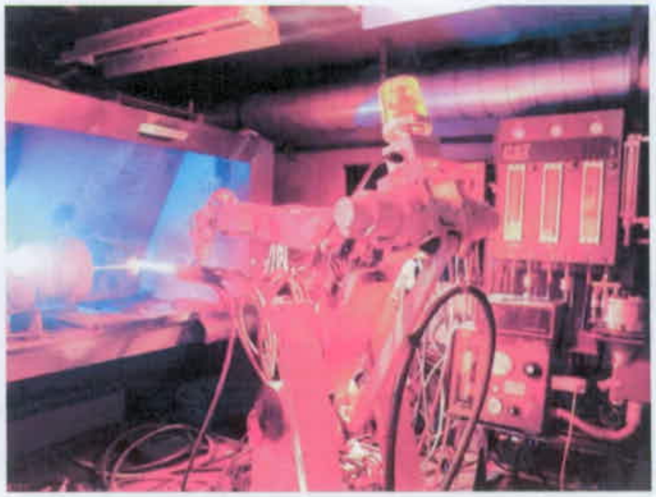


Figure A-4 Remote Spray Coating High Velocity Oxy-Fuel

Approach

A joint research program with the Defense Advanced Research Projects Agency to identify high-performance, cost-effective corrosion resistant metals has indicated the high velocity oxy-fuel spray casting method can produce an amorphous metal with corrosion resistance equal to or greater than Alloy 22. The purpose of this effort is to explore the possibility of developing an advanced, cost-effective waste package, capable of providing corrosion performance equivalent to or better than that of the container now under consideration by the baseline program. The current container design includes an inner structural support of Type 316NG stainless steel and an outer corrosion resistant layer of nickel-based Alloy 22. A promising alternative now being explored by the OCRWM S&T Program proposes the use of a newly developed iron-based amorphous metal, formulated to achieve high corrosion resistance without nickel to accomplish the desired performance and cost objectives. Amorphous metals derive substantial benefit from the absence of grain boundaries. These materials will be produced with advanced spray-casting technologies (Figure A-4), including high-velocity oxy-fuel and detonation-gun processes. Post processing, such as high-density infrared fusing, may be used to refine coating structures.

Goals

- By 2005, develop iron-based amorphous metals that can be applied with advanced spray casting (thermal spray) processes, and have corrosion resistances superior to:
  - Type 316L stainless steel
  - Nickel-based Alloy 22
  - Titanium Grade 7
- Demonstrate the deposition of fully-dense amorphous metals with virtually no interconnected porosity
- Demonstrate high-integrity interfacial-bonds between the thermally sprayed amorphous metal and the underlying substrate (Type 316NG stainless steel, nickel-based Alloy 22, or others)
- Identify and demonstrate alternative methodologies for application of inexpensive corrosion-resistant materials
- Conduct appropriate qualification tests of most promising materials
- Facilitate the transfer of this new technology to industrial partners.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Metal Design and Testing: Activities to develop, optimize and evaluate amorphous metal formulations and confirm the ability to produce consistent metal powder, control particle size to achieve a fully dense pore-free coating and reduce the critical cooling rate.	• Production of large quantities of graded metal powder. • Production of fully dense coatings. • Production of large quantities of metal. • Test coupons meet or exceed required micro-structure. • Test coupons meet or exceed Alloy 22 repassivation potential and corrosion resistance. • Test coupons meet or exceed surface bonding requirements.
Waste Package Fabrication Process: Amorphous metal coatings will be investigated and identification of the simplified fabrication process, specifications and cost comparison against baseline.	• Identification and demonstration of improved fabrication methods for use with structurally amorphous metal coatings. • Conceptual design and specifications for fabrication process. • Fabrication of a subscale prototype of current waste package design.
Testing and Validation: The applicability for the use of improved coatings and fabrication methods will be confirmed.	• Demonstrate corrosion resistance greater than or equal that of Alloy 22. • Demonstrate high integrity inter-facial bonds with no crevice corrosion.

Natural Barriers Thrust Team

The mission of the Natural Barriers Targeted Thrust is to enhance the understanding of the role of natural barriers in the performance of the proposed repository. Work is focused on the unsaturated zone (UZ) and the saturated zone (SZ) encompassing the proposed repository site. The objective of the work is to remove conservatism in the current understanding of the natural barriers that will lead to reduced costs by potentially replacing the need for redundant engineered components. The Thrust Team Leader for Natural Barriers is located at the Lawrence Berkeley National Laboratory (LBNL). In addition to principal investigators at LBNL, other Natural Barriers program participants include the University of Nevada, Pennsylvania State University, the Desert Research Institute, Los Alamos National Laboratory, Sandia National Laboratory, Lawrence Livermore National Laboratory, the Oak Ridge National Laboratory and the U. S. Geological Survey.

Initiative 6 - Improved Understanding of the Natural Processes at Yucca Mountain

Description

An arid site with a deep water table, Yucca Mountain has natural characteristics that can reduce and delay the transport of radionuclides from the repository to the accessible environment (Figure A-5). Natural barriers there include both the UZ (from the surface to the waste emplacement drifts to the water table), and the SZ (from the site at the water table to the compliance boundary).

The primary goal for the Natural Barriers Targeted Thrust is to seek enhanced understanding that may lead to the Repository System having additional options for reduced cost or improved representation in performance models. The Natural Barriers Targeted Thrust will focus its work where there is the greatest potential for demonstrating dramatic improvements in barrier performance. Important areas of investigation will target confinement of release, radionuclide transport delay and uncertainty quantification through understanding of processes.

Approach

The subsurface at Yucca Mountain can be divided into three zones according to depth: the UZ above the repository horizon, the UZ below the repository horizon, and the SZ. The elements of investigation within these three zones in which enhanced understanding would most significantly impact the repository performance are as follows:

UZ Above the Repository: One particularly important parameter relates to the nature and distribution of paths for water flow above the repository. Conceptually, less numerous flow paths or lower capacity for fluid flow reduces the potential for water to contact waste packages. Other in-rock and in-drift coupled processes—such as seepage under ambient and thermal conditions, in-drift ventilation, condensation, and the thermal-chemical environment—affect waste package corrosion rates and the amount of water available to mobilize radionuclides in the drifts.

UZ Below the Repository: Three mechanisms in the UZ regarded as being important to radionuclide mobility are likely to be modeled conservatively. They are: (1) matrix diffusion/sorption, (2) episodicity, and (3) the drift-shadow effect. Matrix diffusion studies will address issues such as scale effects that may convincingly demonstrate a less conservative conceptualization. The effect of episodicity in UZ transport is currently not considered, yet could result in significant retardation of radionuclide

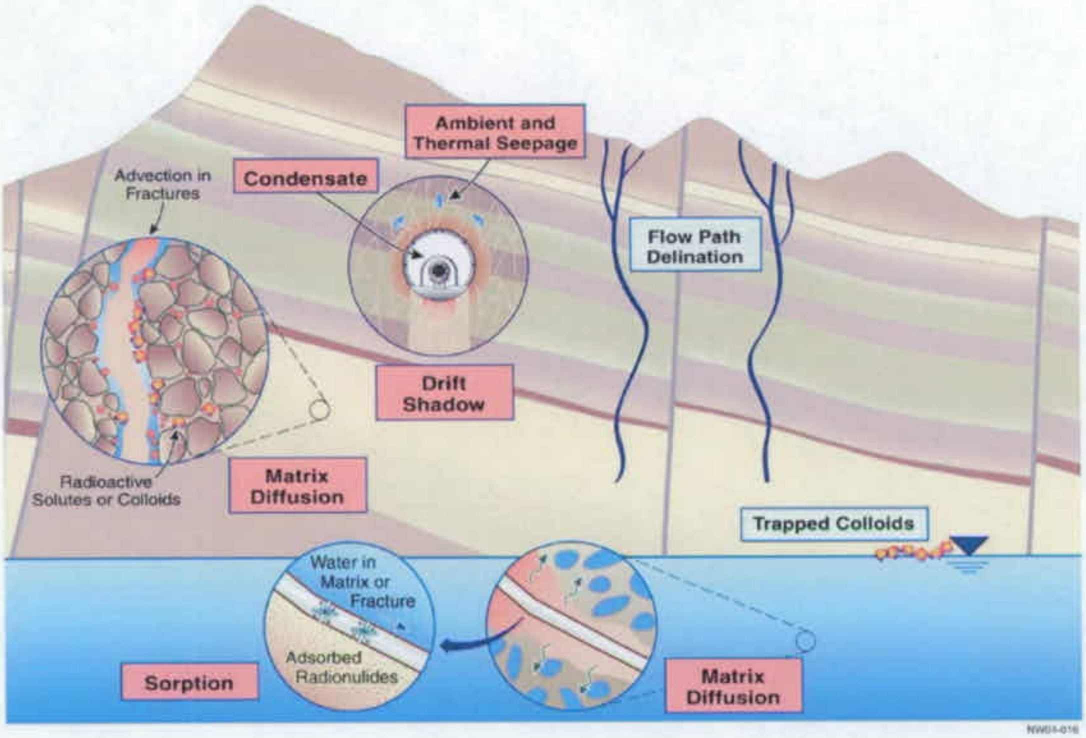


Figure A-5 Natural Characteristics Reduce and Delay the Transport of Radionuclides from the Repository

transport. A potential benefit from a drift shadow would be the reduction of radionuclide concentration by one order of magnitude and delay of transport by two to three orders of magnitude. Analog studies of cavities that may currently exhibit the drift shadow effect, laboratory investigations and examination of undisturbed natural openings in Yucca Mountain should all lead to improved understanding and less conservative representation of the drift shadow in performance assessment models.

SZ Below and Downgradient of the Repository: Comparable to the UZ, matrix diffusion also plays a role in the SZ. Further work in this area should lead to better understanding and less conservative assumptions in performance assessment models. In addition, studies of sorption mechanisms, plume characteristics of analogue sites and the possibility of nonoxidizing environments in the SZ may demonstrate that current models are overly conservative. Age dating of water in the SZ downgradient from Yucca Mountain, using new interpretive methods, may also demonstrate that the actual age is significantly older than that currently modeled.

Goals

- Produce a next-generation conceptual model with significantly reduced uncertainty
  - SZ modeling of dilution and sorption
  - In-drift coupled process models
- Provide new input to the TSPA model in the form of less conservative model assumptions, demonstrating significantly increased efficacy of the natural barriers in waste isolation
  - Show that drift shadow contribution can reduce the dose and can delay transport

- Complete SZ testing to support the improvement of SZ flow pattern determination and performance with dispersion and dilution contribution to reduction of peak dose
- Demonstrate effectiveness of matrix diffusion and sorption to dose reduction and transport delay
- Provide integrated scientific understanding adequate to support a decision on the possibility of eliminating one or more engineered barriers.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Flow Path Delineation, Seepage: Innovative ways of predicting and evaluating flow intervals. Improve accuracy of the determination of how much and how frequently water is capable of seeping into the drifts.	• Reduced projections of total potential released waste amounts. • Quantify uncertainty and improve realism in models.
Seepage into Drifts During Ambient and High Heat Conditions: Improve understanding of how water is prevented from entering the drift during ambient and thermal conditions.	• Reduced radionuclide releases associated with wet drifts. • Improved realism in models.
Coupled Processes in the Rock and Thermo-chemical Environment within Drifts: Improve understanding of thermal-hydrologic-chemical coupled process in the rock and within the drifts.	• Demonstrated maintenance of the integrity of dry drift leading to radionuclide concentration reduction. • Demonstrated delay of transport.
Reduction of Radionuclide Transport by Drift Shadow Effect: Demonstrate the nature and effect of the drift shadow in preventing moisture and solute transport through the drift shadow.	• Reduction of radionuclide concentration. • Delay of projected transport.
Transport Retardation in the UZ and SZ by Matrix Diffusion, Sorption and Trapped Colloids at the Water Table: Enhance understanding of these processes that are included in TSPA as bounding calculations or not included. Translate this understanding into less conservative models of the migration of radionuclides.	• Reduced uncertainty in the analysis of the total concentration of radionuclides. • Delay of peak arrival. • Improvement in projected transport retardation.
SZ Dispersion, Dilution, Sorption and Travel Time along the Flow Paths from Emplaced Wastes to Pumping Wells: Characterize a less conservative conceptualization of the processes affecting the size, 3-dimensional shape and movement of future contaminant plumes. Replace the current, conservative, direct flow paths with more realistic, dispersed and fingering plumes supported by hydrogeologic self-analogues at Yucca Mountain.	• Reduction of projected dose.

Materials Performance Thrust Team

The Materials Performance Targeted Thrust is focused on enhancing the understanding of material corrosion performance and to explore technical enhancements. Areas of investigation include corrosion processes in thin films, particulates and deposits; the evolution of corrosion damage by localized corrosion and the evolution of the environment on metal surfaces. The results from this Targeted Thrust seek to optimize the performance of waste packages and enhance cost effectiveness of metals used in the Repository System. The Thrust Team Leader for Materials Performance is located at Case Western Reserve University where the Corrosion Cooperative Agreement is managed. Participants in the Corrosion Cooperative include Arizona State, Ohio State, Pennsylvania State, University of California-Berkeley, University of Minnesota, University of Toronto, University of Western Ontario and University of Virginia. National laboratories include Lawrence Livermore, Lawrence Berkeley and Atomic Energy of Canada Limited.

Initiative 7 - Materials Performance

Description

Intact waste packages in the proposed Yucca Mountain Repository would fully contain and isolate radionuclides from the environment. Therefore, corrosion resistance is important to the long-term performance of waste packages and drip shields. While the principal construction materials have excellent corrosion resistance over a wide range of aqueous solution compositions and temperatures, a challenging aspect is for the determination of the long-term corrosion performance of materials over the thousands of years.

The Materials Performance Targeted Thrust will enhance the technical basis for understanding materials performance for the repository. The waste packages and drip shields are to be made of nickel-based Alloy 22 and titanium. These metals attain their corrosion resistance by the formation and tenacity of a passive film, i.e. a self-forming, protective oxide on the metal surface. The foundation for prediction of materials performance, therefore, is a determination of the boundaries of passive behavior and the comparison of these boundaries to the realistic environments that pertain within the repository.

Extremely long times with no penetrations are certainly feasible when the protective, passive films remain intact on metal surfaces. Measured corrosion rates for passive metals are on the order of 0.1 to 0.01 microns per year. At the latter rate, it would take 160,000 years to penetrate a metal with the thickness of one U.S. quarter (Figure A-6), and the Alloy 22 outer layer on waste packages is the equivalent of over ten quarters thick. So for passive metals that remain passive, extremely long times for full containment of radionuclides are realistic.

Figure A-6 Modeled Corrosion vs Waste Package Thickness

Approach

Enhancements to the long-term performance assessment are the primary focus of the Materials Performance Targeted Thrust. Three technical thrusts have been identified to achieve the overall objective of advanced analytical and computational procedures for determining the time evolution of corrosion damage:

- Corrosion in thin films, particulates and deposits
- Evolution of corrosion damage by localized corrosion
- Evolution of the environment on metal surfaces.

The first thrust addresses the least conservative condition within the proposed repository. The waste packages are supported in air, and they will never be fully immersed in water. Further understanding of the effects of moisture from the surrounding rock and humidity within the repository tunnels on the corrosion performance of waste packages offers more insight into how the materials will react over long periods of time.

The second thrust addresses the most relevant mode of corrosion for the conditions at Yucca Mountain, i.e., localized corrosion processes and particularly crevice corrosion (Figure A-7).

The third thrust enhances the analysis of corrosion performance, i.e., the amount, distribution and chemical composition of the moisture on waste packages at relevant time periods in the repository.

Goals

The materials used for isolating waste in the proposed repository are an important component of the overall approach to the design of the Repository System. Opportunities exist to enhance the understanding of material corrosion performance and to probe technical enhancements. The goal of the Materials

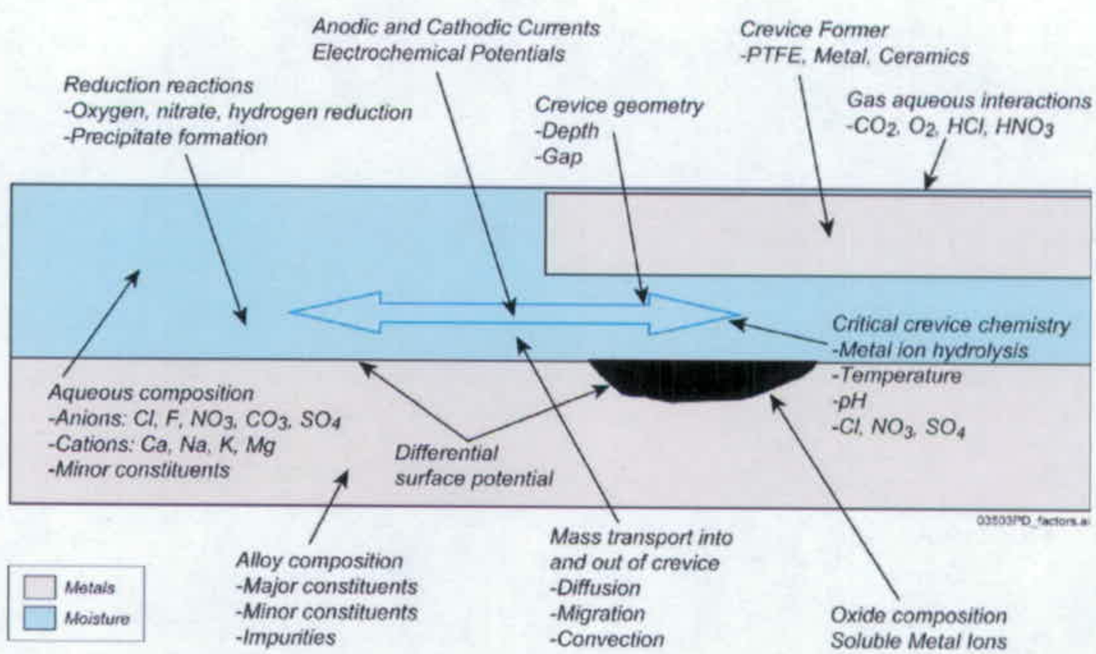


Figure A-7 Localized Corrosion Processes

Performance Targeted Thrust is to better understand the performance of the waste package. Determination of the status and future performance of waste packages based upon materials, design and less conservative repository conditions are important to guide rational, reliable and cost-effective decisions by policy-makers, managers and engineers.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATOR
Enable More Certain Life Prediction: Use advanced methods for prediction of corrosion damage.	• Provide new input to TSPA calculations for long-term evolution of corrosion damage to reduce uncertainty in waste package containment and retardation of radionuclide transport.
Develop Advanced Analytical and Computational Methods for the Evolution of Environment: Reduce uncertainty in environment on the waste packages.	• Produce a next-generation conceptual model with significantly reduced uncertainty. • Integrated new scientific understanding into models.
Develop Advanced Analytical and Computational Methods for the Time Evolution of Crevice Corrosion: Reduce uncertainty in localized corrosion initiation and address propagation and arrest phenomena leading to less conservative waste package lifetimes and dose decrease.	• Produce inputs for a conceptual model with significantly reduced uncertainty. • Integrated new scientific understanding into models.
Develop Advanced Analytical and Computational Methods for Corrosion Processes in Thin Films, Particulates and Deposits: Reduce uncertainty in corrosion in thin layers and deposits leading to potentially less conservative waste package lifetimes and dose decrease.	• Produce inputs for a conceptual model with significantly reduced uncertainty. • Integrated new scientific understanding into models.

Source Term Thrust Team

The mission of the Source Term Targeted Thrust is to enhance the scientific and technical understanding of radionuclide release and the changing conditions of the waste package over time. Work is focused on the kinetics of the waste form, formation of secondary phases, sorption-reduction on the surfaces of near-field materials and the formation and mobility of colloids. The objective of this research is to remove some of the conservative bounding assumptions about the environment and materials performance currently utilized in the TSPA. The Source Term Thrust Team Leader is located at the University of Michigan with a co-lead at the Argonne National Laboratory. Other Source Term program participants include the University of Notre Dame, Auburn University, Manchester University (UK), University of California-Davis, University of Nevada-Reno, University of Nevada-Las Vegas, University of Texas-Arlington, Northern Illinois University, University of Tennessee, Pennsylvania State University, Rice University, Washington State University, Idaho National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, the Illinois State Water Survey and the Nye County (NV) Nuclear Waste Repository Project Office.

Initiative 8 - Source Term

Description

The OST&I S&T Program sponsors work by the Source Term Targeted Thrust to advance the scientific and technical understanding of radionuclide releases. The waste form (Figure A-8) is the "source" of all radionuclides contributing to dose, so advances in this area will provide the Repository System with opportunities to improve estimates of repository performance. The waste form, together with the chemical and physical processes occurring within the waste package, describes the source term and EBS to radionuclide release. Increased understanding of this first step in radionuclide release will provide an enhanced level of confidence in understanding overall releases.

The primary goal of the Source Term Targeted Thrust is to study the processes controlling radionuclide release from the waste form and mobility in the near-field. Advances in this area may result in approaches the Repository System may consider to modify models supporting the performance assessment. These approaches may encompass enhanced understanding of processes applicable to very long time frames or allow cost-saving design changes.

Approach

Technical work for this program seeks to enhance the knowledge associated with the identification of the degradation and release mechanisms, and to define approaches that further the understanding and modeling of them for key radionuclides. The radionuclides of interest (238U, 234U, 233U, 239Pu, 237Np, 241Am, 129I, 99Tc, 79Se, and 36Cl) are generally considered to be the most important contributors to dose at different times after repository closure. Studies will elucidate the pathways of radionuclide release based on the evolution of the waste forms over time and the critical processes occurring within each time interval.

The program supports multi-laboratory teams conducting interdisciplinary, collaborative research that holds promise to improve the understanding of source term processes in the following focus areas:

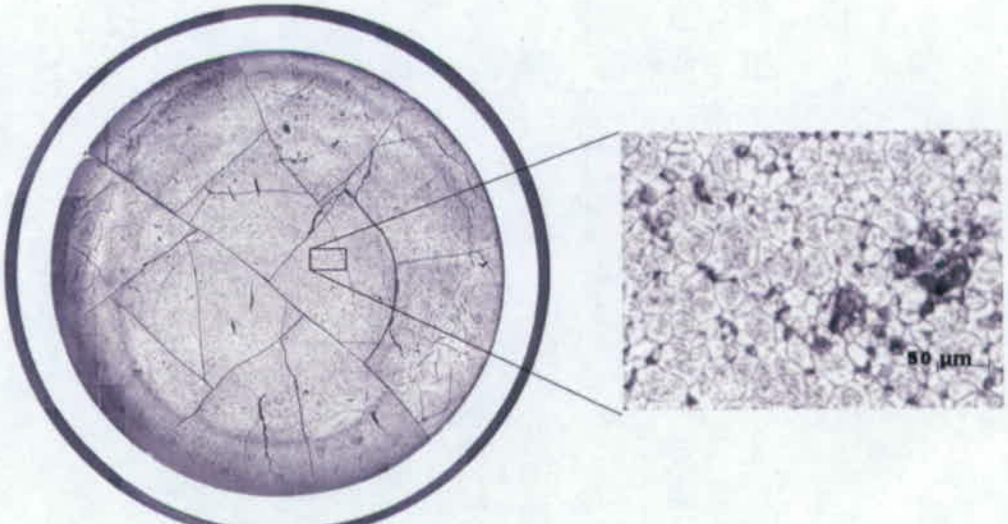


Figure A-8 Fuel Assembly with an Enlargement of a Fuel Rod and the Ceramic Material

- In-package sequestration: The waste-package internals will be constructed of steel that is expected to corrode before the waste forms. This corrosion will impact the in-package chemistry by generating steel alteration phases that may sequester radionuclides and/or by changing redox conditions inside the waste package such that SNF corrosion is inhibited. Studies will determine the effects of corrosion of waste-package internals on the in-package chemistry and on processes controlling the release of radionuclides.
- Alteration phases: As SNF degrades (Figure A-9), uranyl alteration phases form and evolve at the surfaces. These phases are expected to incorporate some radionuclides, reducing radionuclide mobility and release; however, they are not represented in current source term models. Studies will determine the effects of environmental conditions on the formation, evolution of, and radionuclide incorporation into these phases.
- Matrix dissolution: The current SNF degradation model, derived from fitting empirically-based data, assumes dissolution at the maximum, or "forward" dissolution rate of the solid matrix in contact with water, at the oxygen fugacity of ambient air and scaled to specific surface area. However, SNF is likely to exhibit lower dissolution rates under conditions of low water flux, reduced effective surface area and at lower-than-ambient redox potentials at the fuel surface. Studies will investigate the oxidation and dissolution of the SNF UO2 matrix and the local evolution of fuel surface and redox conditions under low-water conditions expected in the repository.

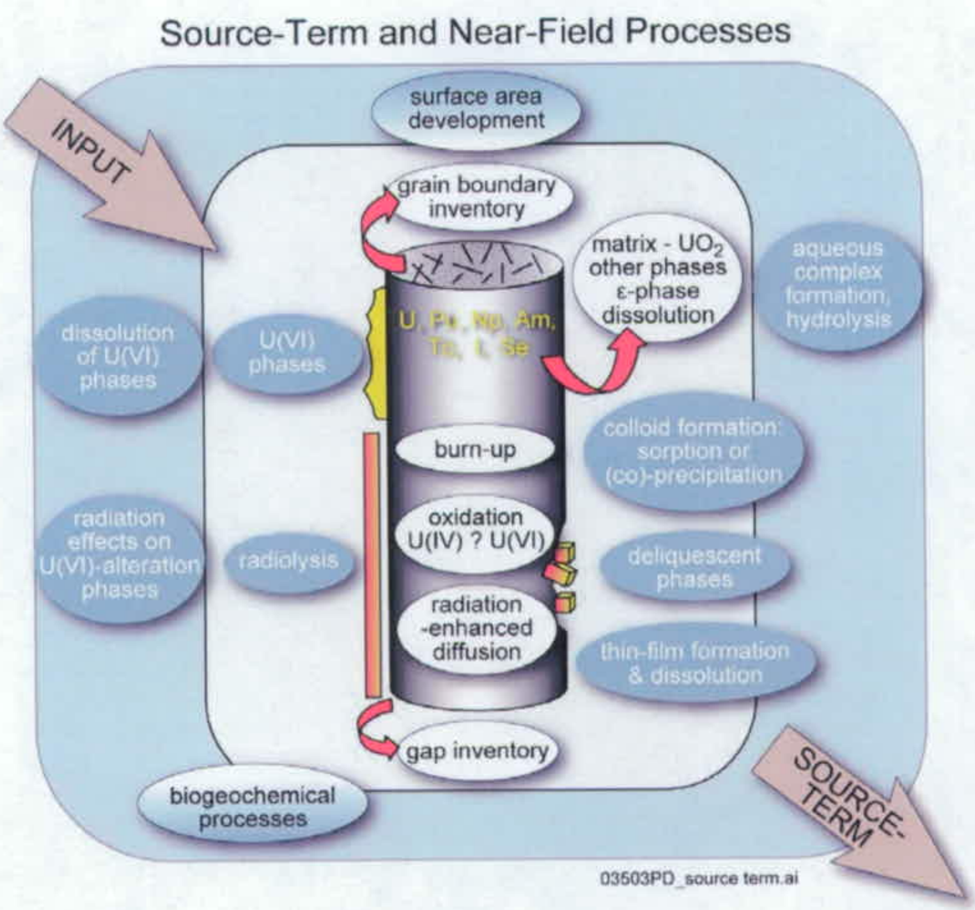


Figure A-9 Idealized Release and Transport of Radionuclides after Waste Package Failure

The program also supports projects of smaller scope exploring other controlling processes in order to: (1) investigate hypotheses or novel approaches that advance our understanding of key radionuclide releases and which may lead to additional focus areas for the future; (2) develop advanced analytical techniques for characterizing trace-element behaviors in radionuclide-bearing solids; (3) generate thermodynamic and/or speciation data necessary for implementing next-generation source term models; and (4) foster collaborations with international investigators for cooperative intellectual exchanges, including data, modeling concepts and technical expertise.

Goals

The goal of the Source Term Program is to develop a further understanding of processes likely to control radionuclide releases from the waste package and to represent these processes mechanistically in next-generation models. This research is expected to reduce uncertainties and conservatisms in current source-term models, potentially leading to reduced dose estimates compared to those using current models.

Near-term project goals include:

- In-package sequestration work will deliver new representations of processes relevant to corroding waste-package internals and their influence on in-package chemistry and sequestration of radionuclides
- Alteration phases work will deliver new representations of releases of Np and Pu that include their incorporation and/or sorption in or on uranyl alteration phases
- Matrix dissolution activities will deliver new mechanistic models of spent-fuel corrosion in thin aqueous films, coupled with realistic models of water flux and aqueous transport (e.g., diffusion) in thin films.

Program Activities

TASK DESCRIPTION	SUCCESS INDICATOR
In-package Sequestration: Studies will determine the effects of corrosion of waste-package internals on the in-package chemistry and on processes controlling the release of radionuclides.	• Establish more complete understanding of local redox conditions and in-package chemistry evolving from corrosion of internals. • Model mechanisms by which Tc sorbs onto, or is incorporated into, iron corrosion products and examine reversibility. • Develop models to represent uptake of Np and Pu by iron corrosion products.
Alteration Phases: Studies will determine the effects of environmental conditions on the formation, evolution of, and radionuclide incorporation into these phases.	• Identify alteration phases likely to sequester actinides, including relevant uranyl compounds. • Define environmental conditions effects on alteration-phase formation and stability. • Determine sorption of key radionuclides onto uranyl alteration phases; also examine reversibility of sorption reactions. • Collect thermodynamic and kinetic data for models that can represent paragenesis of radionuclide-bearing alteration phases.
Matrix Dissolution: Studies will investigate the oxidation and dissolution of the SNF UO2 matrix and the local evolution of fuel surface and redox conditions under low-water conditions expected in the repository.	• Establish a more complete understanding of aqueous-film chemistry. • Identify surface reactions likely to control rates of SNF oxidation and dissolution. • Develop a mechanistic model of spent-fuel oxidation and dissolution in humid air and in brines formed from deliquescent salts. • Identify and develop data necessary for modeling radionuclide speciation in high ionic-strength solutions. • Model the evolution of the surface of fuel as it interacts with small amounts of water and humid air. • Collaborate with the Materials Performance and Natural Barriers Targeted Thrusts to integrate knowledge about water flux and chemistry.
Cross-cutting Studies, Data Generation, Methods Development and International Collaborations	• Establish the speciation and distribution of actinides and fission products within SNF and its corrosion products. • Measure thermodynamic data for relevant aqueous actinide species at elevated temperatures. • Define the dissolution behavior of the 5-metal, or epsilon, particles. • Establish effective international collaborations.

Initiative 9 - Radionuclide Getters

Description

Performance assessment calculations for the proposed Yucca Mountain repository have indicated that 237Np, 129I, and 99Tc are among the most environmentally significant radionuclides ultimately to be released from the repository. To increase confidence in repository performance for long-term radionuclide containment, radionuclide "getter" materials that irreversibly bind the radionuclides could be beneficial. The Radionuclide Getters Targeted Thrust will provide recommendations of candidate getter materials, test results of their potential long-term performance and provide to Repository System for consideration the means of engineering deployment. Benefits may include enhanced engineered barrier performance through the addition of getters to the existing design.

The Radionuclide Getters Targeted Thrust is a collaborative effort between Sandia National Laboratories (SNL), Pacific Northwest National Laboratory (PNNL), Virginia Polytechnic and State University (Virginia Tech), and YMP. Other participants may join the program in the future. Development of new materials with nanoporous and mesoporous structures for radionuclide getters is the main focus of the program. A modeling effort to describe the interactions between radionuclides and the getters will be used to guide the applied experimental work and predict long-term behavior of the getters in the proposed Yucca Mountain repository.

Approach

The overall goals of the Radionuclide Getters Targeted Thrust are to: (1) select potential getter materials based on likely efficacy, cost and stability in projected repository environments (both physical and chemical); (2) use nano-engineering approaches to enhance sorption capabilities of the selected materials; (3) rigorously test the performance of the engineered materials in repository-relevant environments; (4) develop mechanistic model(s) to provide insights into long-term viability and robustness of performance with regard to changing environmental conditions; and (5) engineer the ion getter materials into an appropriate form for potential site deployment.

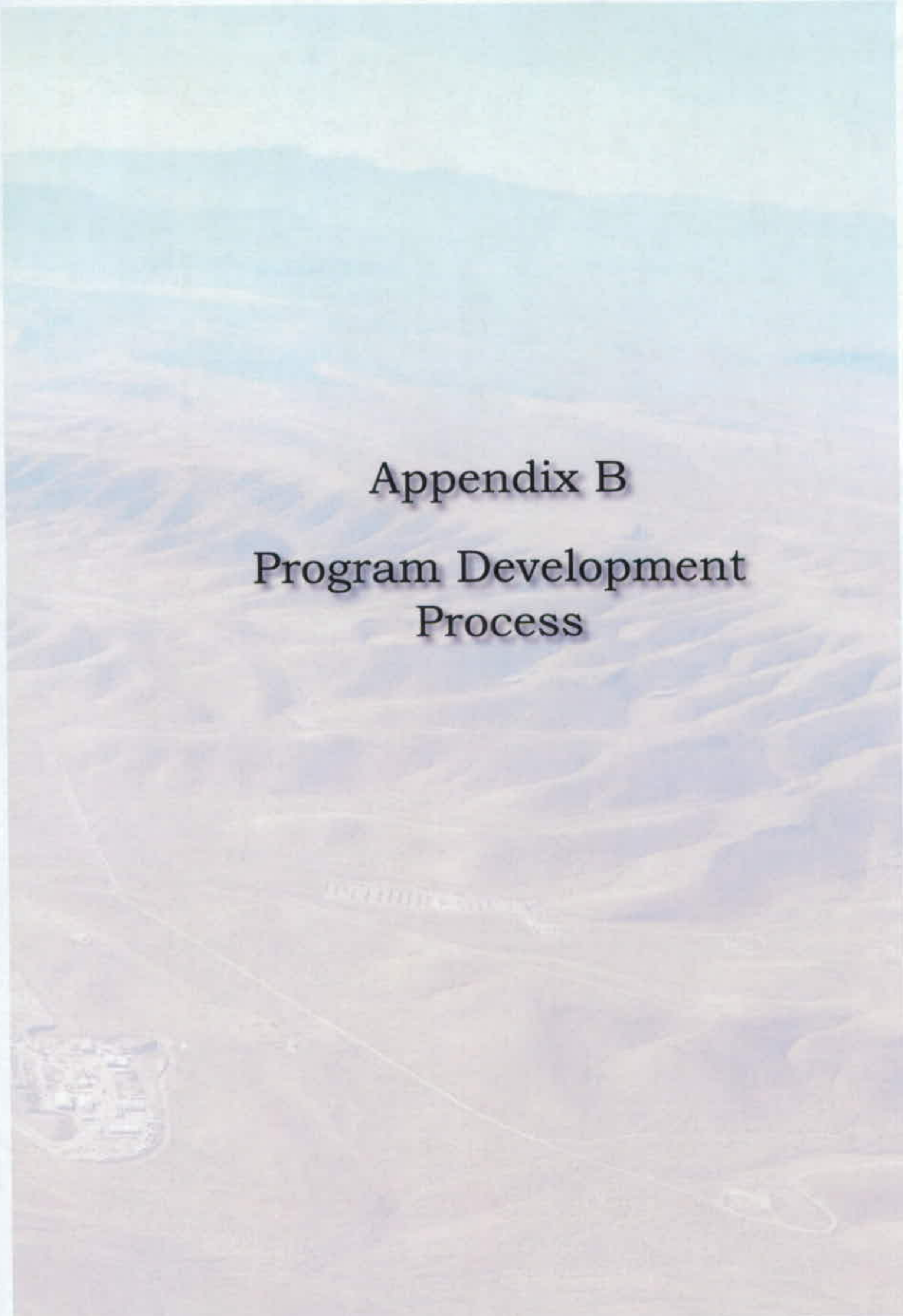
Getter development will center on the use of nanoporous and mesoporous compounds. SNL will focus on the synthesis of nanoporous oxides coated with inorganic functional groups selective for radionuclide binding. PNNL efforts will focus on the use of nanoporous phosphate materials as inherently functional radionuclide absorber materials. Virginia Tech will investigate the use of manganese oxides as getters.

Goals

- Identify promising families of synthetic radionuclide getters for both in-drift and waste package application and begin testing under simulated Yucca Mountain conditions
- Suggest preferred getter deployment method (in-drift or waste package) for possible incorporation
- Select final synthetic radionuclide absorber and application process, and begin engineering development and scale-up
- Complete scale-up and begin commercial production (following incorporation of an absorber into the repository design and approval by the NRC).

Program Activities

TASK DESCRIPTION	SUCCESS INDICATORS
Waste Package Getters: Develop nanoporous and mesoporous material getters that are selective for radionuclides of interest and capable of performance inside the waste package.	• Feasibility of applying getters in the waste package to permanently bind radionuclides. • Identify family of synthetic getter materials. • Select one or more synthetic material getters capable of functioning inside the waste package (with no adverse impact upon currently modeled performance). • Perform NQA-1 testing on selected materials.
In-Drift Getters: Develop tailored minerals (e.g., hydrotalcite and hydroxyapatite), metal (e.g., manganese) oxides, double-layer hydroxides and other promising sorbents that are selective for radionuclides of interest and capable of performing inside the drift (e.g., in the invert).	• Feasibility of applying getters in the drift to permanently bind radionuclides. • Identify family of synthetic getter materials. • Select one or more synthetic material getters capable of functioning outside the waste package (with no adverse impact upon currently modeled performance). • Perform NQA-1 testing on selected materials.
Getters Manufacturing and Systems Analysis: Resolve issues relating to scale-up, material fabrication, packaging and other considerations that enable getters to be deployable in Yucca Mountain, compatible with existing barriers and commercially produced.	• Select preferred getter deployment method In-drift or Waste Package. • Identify multiple commercial partners for the production of getter material. • Transition one or more getters from the lab-scale to a deployable prototype. • Complete scale-up and make material commercially available.



Appendix B

Program Development Process

Program Development Process
– *Defining Specific Projects*

The OCRWM S&T Program is structured in a manner similar to other federal applied S&T programs. Opportunities for research are typically identified by systems engineering and planning activities performed by other offices within OCRWM, by the knowledge developed by experts in the normal course of their work, or by others external to the program but who are familiar with the OCRWM mission. The S&T Program staff then build S&T Initiatives to address those opportunities.

The development and execution of the OCRWM S&T Program can be described in five distinct steps: 1) information gathering and analysis; 2) technical response and definition of Initiatives; 3) program formulation and project prioritization; 4) program execution and implementation; and 5) review and evaluation. These five steps are shown in Figure B-1 and are described in the following sections.

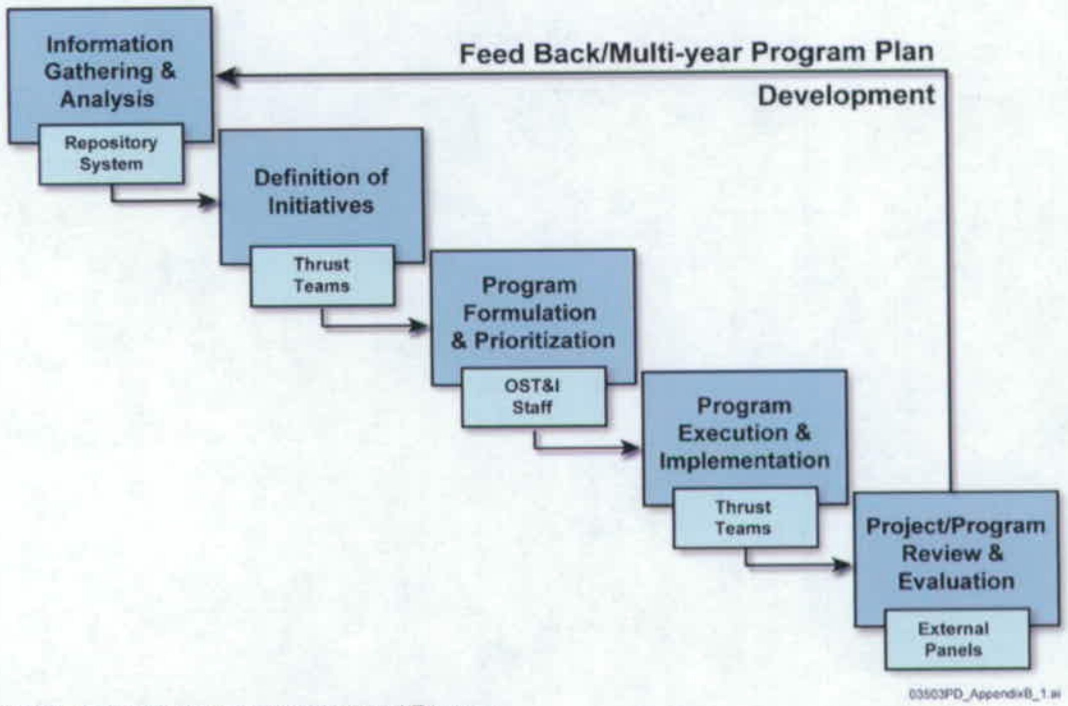


Figure B-1 S&T Program Development Process

The Thrust Teams, in discussion with key OCRWM personnel, are the principal individuals responsible for developing the program's technical scope and for selecting performers. In general, Thrust Teams will use national laboratories, other federal agencies, industry and universities in performing work. Where appropriate, international collaboration and participation through approved international agreements is desired and encouraged. Activities involving the investigation of advanced technologies will primarily take place through competitively awarded contracts with industry. In those instances where unique facilities are required, DOE laboratories, universities, or other federal agencies may also be involved.

Information Gathering and Analysis

Identification of the program Initiatives is the first step in the development of the S&T Program. This step is usually done in a collaborative manner between key individuals in OCRWM and the Thrust Teams. Input from project managers within the Repository System is essential to accurately define the Initiatives and link them to the overall OCRWM schedule. It is assumed the input from the Repository System includes consideration of issues resulting from stakeholder interactions with OCRWM.

Program Initiatives are currently derived from the following information sets:

- Project technical staff analyses – provide information on the priority, timing (including potential deployment/implementation schedule) and technical detail associated with a potential enhancement
- Information external to OCRWM – gathered from workshops and other venues used to supplement information within OCRWM
- System engineering studies – critical pathway analyses and disposal decision plan insertion mapping. The TSLCC, Total System Model (TSM) and the TSPA provide program-level input and technical insights about the potential benefits Thrust Teams may offer the Yucca Mountain Repository System
- OCRWM Cost Reduction Process – Initiatives may be identified by an integrated team annually evaluating improvements in cost and schedule, reductions in radiological dose to workers and projected long-term releases to the environment.

These information sets provide insight as to the size (costs and pervasiveness) and complexity of potential Initiatives to be considered. They also identify when the enhancement could be implemented and its impact.

Definition of Initiatives

S&T Initiatives are developed by the OCRWM Thrust Teams through dialogue among the OCRWM staff and their various performers. Once a proposed Initiative is approved, Thrust Teams prepare an overall plan or technical response for each proposed project within that Initiative. Each of these is in the format of a proposed statement of work including a description of specific tasks along with an associated budget and schedule. Annual and longer-term milestones and performance measures, including decision points ("off ramps") are identified for each of the projects. Information from the technical responses is then summarized in a multi-year plan for each Thrust.

The planning process includes the integration of the specific S&T investment with the corresponding Repository System project. It is through this process that joint planning is done to assure adequate budgets to support the development efforts, schedules line up with potential insertion points and the Repository System has plans for the financial resources and technical support to enable ultimate implementation and/or deployment.

Program Formulation and Prioritization

The complexity and duration of the OCRWM mission, combined with budget constraints and regulatory requirements, require the S&T Program to carefully prioritize and sequence its projects. These same factors drive a continuous effort to rank and prioritize S&T investments. The prioritization process is iterative and integrative, beginning at the specific project level within Thrust Teams and progressing to higher levels and greater breadth with each step. Prioritization factors include:

- Technical merit
- Cost reduction potential
- Enhanced repository understanding
- Enhancement of repository operations
- Technology maturity

- Relationship to repository goals
- Project schedule insertion
- Project cost.

Program Execution and Implementation

Once an Initiative has been approved and funding has been authorized, the Thrust Teams will solicit performers for individual projects. The requests for proposals are conducted through either targeted or broad solicitations depending on work scope. Generally, science efforts will be broadly announced to the larger, technical community, while technology demonstration opportunities will be targeted toward a narrower audience.

Prior to selection, proposals will be reviewed for technical merit and ranked. In cases such as the demonstration of advanced technology, it may be to the government's benefit to select multiple contractors to develop competing approaches, while delaying selection of a single performer until concepts are more fully developed.

In order to be as responsive and flexible as possible, the management of the projects will be done by the Thrust Teams. Individual performers will receive direction from, and must coordinate the presentation of results, deliverables, or other required submissions with the Thrust Team leaders. As such, it is the responsibility of the Thrust Team leaders to coordinate interactions among all individuals involved in each Initiative including OCRWM Program Managers, other researchers and other federal programs which may be investing in related research and development. The Thrust Team leader is also responsible to assure all OCRWM programmatic requirements are met in the performance of the assigned work. This includes but is not limited to: quality assurance, document review, conflicts of interest and intellectual property.

All participants are encouraged to meet regularly with the designated project point-of-contact at the Repository System and to attend professional meetings, where appropriate, in order to present interim or final results, share lessons-learned and maintain strong relationships with other workers in their chosen field. Furthermore, the S&T Program encourages all project investigators to publish the results of their work in refereed journals, in institutional reports and in conference proceedings, as appropriate. Such publications and attendance at such professional meetings serve to legitimize the work in the eyes of other professionals, to disseminate results more widely and to enable project scientists and engineers to participate more fully as recognized active professionals within their chosen disciplines.

Project/Program Review and Evaluation

Internal and external review by peers is generally recognized in the S&T community as important to sound work and to effective decision-making. Reviews by independent peers are widely used to evaluate research proposals and to assess the productivity and progress of ongoing work (Figure B-2). In addition, reviews present an opportunity to enable the OCRWM management and staff to ensure the work being supported by OST&I continues to meet the programmatic objectives and for the performer to receive expert commentary on the progress of their work.

Project selection reviews are employed by Thrust Teams to determine which projects to support. An external review panel evaluates the technical merit of proposals for projects. Once this is completed, a programmatic relevance review is performed by the cognizant Thrust Team management. The outcomes of these two reviews are then provided to OST&I management with recommendations for awarding of contracts. Although project selection reviews are similar for proposed projects at all maturity stages, reviews for applied research differ slightly from reviews for technology development and demonstration. Funded projects with a period of performance in excess of three years will require a specific project review at the end of the third year of performance. This will entail an updated proposal for review prior to continuation of the work beyond a three-year period.

In addition to the technical review performed during the selection process, each Thrust Team performs an annual mid-year review to evaluate technical and administrative performance of each project against its stated goals. These reviews combine the attributes of an independent technical evaluation and a programmatic review. This review documents the performance of the project, provides peer review comments and provides recommendations for the next year's program. Each Thrust Team conducts reviews according to consistent general guidelines adapted to its individual goals and methods.

At the OST&I level, a standing S&T Programmatic Evaluation Panel performs a programmatic review annually. The panel members are external, senior-level individuals with recognized expertise in the execution of both industry and governmental S&T programs. This review addresses issues of broad program importance and help guide the S&T Program in addressing areas of greatest significance to OCRWM and DOE. The review also assesses OST&I's overall performance against its programmatic goals and evaluates the relevance of the overall program and its major initiatives.

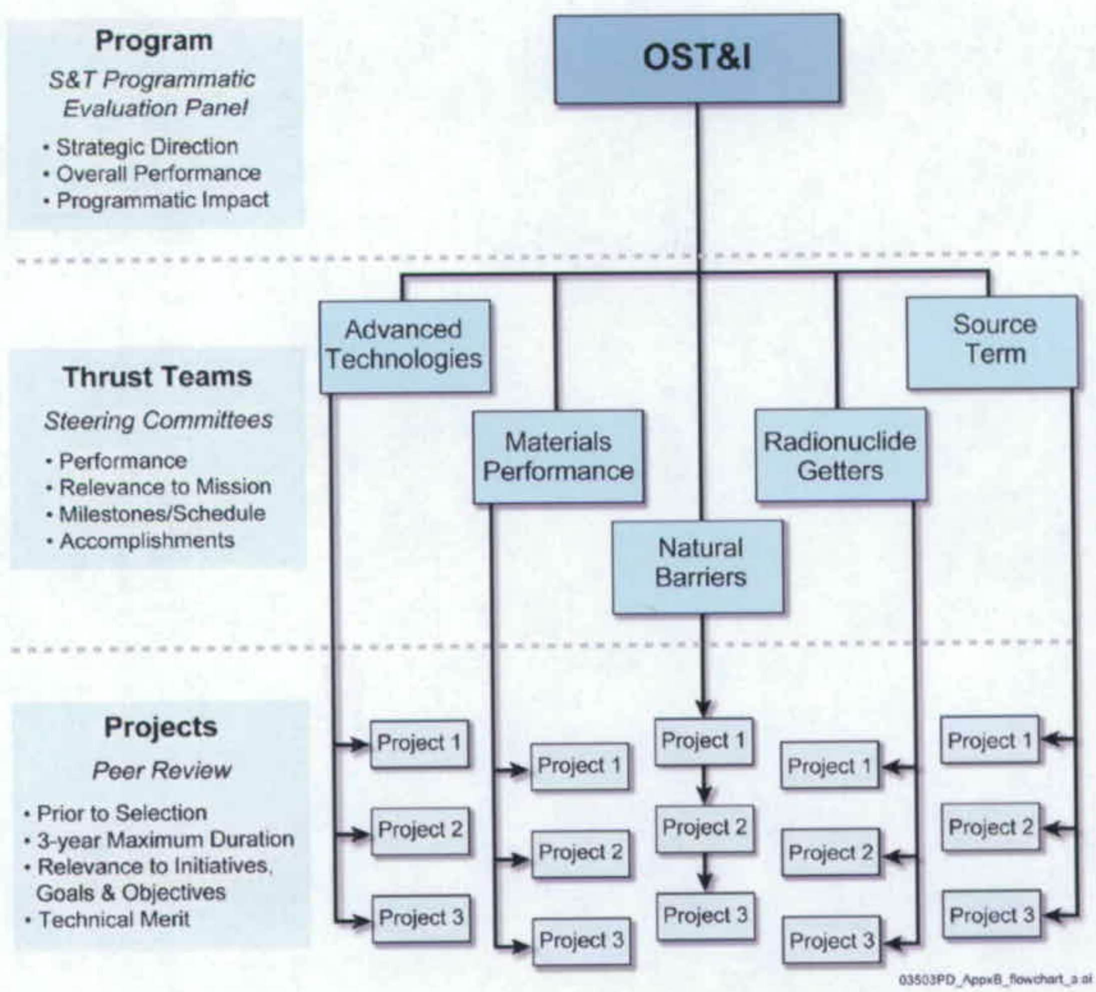


Figure B-2 OST&I Review Process

Benefits of Increased Understanding

A major objective of the S&T Program is to increase our understanding of the performance of the waste management system, with emphasis on the postclosure performance of the repository. This work is not pursued merely to satisfy a scientist's curiosity about how the repository will function, but to increase understanding sought for three highly practical reasons.

First, the Project's understanding of future repository performance can never be complete, so there will always be residual uncertainty about certain attributes and how they behave. To assure adequate safety in light of those uncertainties, the Project, like any large engineering endeavor, must embed certain conservatisms into the design, such as extra thickness or strength of materials, extra thermal margins against failure, and designing for corrosion as if the surrounding environment is more corrosive than it is actually believed to be. Reducing uncertainties, leading to a more realistic analysis, can enable the "extras" to be removed without in any way compromising the overall performance. This can lead not only to cost savings, but also to a better-understood and more-integrated design with improved performance.

Second, enhanced understanding can enable important design improvements, perhaps even radical changes - such as a different approach to the overall waste-emplacement strategy in the drifts, or a different configuration of the engineered-barrier system, or perhaps a different combination of engineered barriers. Historically, designers have been constrained not to adopt certain advanced design approaches because they did not have adequate ways to analyze the benefit of a proposed improvement. With enhanced understanding, these constraints can be relaxed, allowing substantially better performance along with substantial cost savings.

Third, increased understanding helps to assure the Project complies with the NRC regulations fully and with higher confidence. For example, the projects model for igneous consequences when magma would flow down the drifts is highly approximate because no full scale experiments have been done. Improved understanding of these processes based on small scale experiments or analogue studies could be sufficient to obviate the need for such large experiments.

Contacts

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