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ANN RILEY & ASSOCIATES, LTD.
1025 Connecticut Avenue, NW, Suite 1014
Washington, D.C. 20036
(202) 842-0034

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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BRIEFING ON THE HIGH LEVEL

WASTE PROGRAM VIABILITY ASSESSMENT

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PUBLIC MEETING

Nuclear Regulatory Commission
One White Flint North,
Room 1F-16
11555 Rockville Pike
Rockville, Maryland
Monday, February 8, 1999

The Commission met in open session, pursuant to notice, at 2:05 p.m., Shirley A. Jackson, Chairman, presiding.

COMMISSIONERS PRESENT:

SHIRLEY A. JACKSON, Chairman of the Commission
NILS J. DIAZ, Member of the Commission
EDWARD McGAFFIGAN, JR., Member of the Commission
GRETA J. DICUS, Member of the Commission
JEFFREY S. MERRIFIELD, Member of the Commission

STAFF PRESENT:

JOHN C. HOYLE, Secretary

KAREN D. CYR, General Counsel

ANNETTE L. VIETTI-COOK, Assistant Secretary

PRESENTERS:

LAKE H. BARRETT, Acting Director, Office of Civilian Radioactive Waste Management

STEPHAN BROCOUM, Yucca Mountain Site Characterization, Office, Department of Energy

P R O C E E D I N G S

[2:15 p.m.]

CHAIRMAN JACKSON: Good afternoon. ladies and gentlemen. Today the Department of Energy will provide the Commission with a briefing on its viability assessment of a repository at the Yucca Mountain, Nevada site.

DOE last briefed the Commission on the High Level Waste Program on May 15th, 1997. Over the past 15 years, the Department of Energy has been studying the site at Yucca Mountain to determine if it is a suitable place to build a geologic repository for the nation's spent nuclear fuel and high level radioactive waste. In response to Congressional direction in the FY 1997 Energy and Water Development Appropriations Act, on December 18th, 1998, DOE issued a viability assessment. The purpose of it is to provide the President, the Congress and the public with information on the progress -- see, I am taking some of your words, Lake, probably -- at the Yucca Mountain site and to identify the critical issues that need additional study before a decision can be made on whether to recommend the site for development as a repository.

Although there is no specific requirement for the NRC review of the viability assessment, the NRC Staff presently is doing so as part of its responsibility for prelicensing consultation required by the Nuclear Waste

Policy Act of 1992. This is consultation with the DOE.

The objectives of the NRC staff review are, first, to identify DOE progress in developing information necessary for complete license application; second, to determine the potential for licensing vulnerabilities that could preclude or pose a major risk to licensing; and third, to determine if there are any major concerns that if not resolved by DOE would result in an unacceptable license application.

On March 16th and 17th the NRC Staff, the State of Nevada, the affected local governments, the Advisory Committee on Nuclear Waste, and the Nuclear Waste Technical Review Board are all scheduled to brief the Commission on the viability assessment, but we welcome today Mr. Lake Barrett, DOE's Acting Director of the Office of Civilian Radioactive Waste Management, to the briefing. If DOE does not object, Mr. Barrett in particular, we may interrupt your presentation from time to time to ask pertinent questions, and then at the close of the presentation I will open the discussion to any additional general questions from the Commission. We will try to let you get through, however, your presentation.

Now I understand that copies of the viewgraphs and the viability assessment overview are available at the entrances to the room, so unless my colleagues have anything to add, Mr. Barrett, Please proceed.

MR. BARRETT: Thank you very much, Chairman Jackson, members of the Commission.

Since I last appeared before you, the Civilian Radioactive Waste Management Program has continued to make substantial progress in carrying out its responsibilities under the Nuclear Waste Policy Act. Despite reduced FY 1998 and 1999 appropriations, we have maintained and often exceeded our schedules by achieving efficiencies and re-prioritizing work activities while maintaining the safety and integrity of the scientific work.

When I spoke to you last, the program was focused on preparation of the Yucca Mountain viability assessment. On December 18th the Secretary submitted the viability assessment and its companion documents to the President, the Congress, and released it to the public.

The viability assessment serves as an important management tool for the program to guide the completion of the site characterization by identifying the critical issues that need to be addressed before the Secretary of Energy decides whether to recommend the Yucca Mountain site to the President for development as a repository.

While the viability assessment is not one of the decision points defined in the Nuclear Waste Policy Act, its completion is significant because it gives policymakers like the Commission key information regarding the prospects for geologic disposal at Yucca Mountain.

Based on the viability assessment, we believe the work should proceed to support a decision by the Secretary in 2001 on whether to recommend the site. While the viability assessment reveals no show-stoppers, it does identify areas where additional work is required before suitability can be determined and the Secretary can decide whether to recommend the site.

We hope the VA will provide our respective staffs with a frame of reference to conduct the prelicensing interactions necessary to facilitate the timely submittal and review of a high quality license application if the site is found suitable. We expect that the information contained in the viability assessment and the performance assessment components will provide an adequate technical basis for a license application when combined with the additional information that will be obtained as a result of the work described in the License Application Plan.

The Commission's views regarding the acceptability of our approach will be important to forming a mutual understanding of what will be expected of this program during the licensing process.

We are now refining our licensing approach and obtaining the necessary scientific and technical information to support our safety analyses. Central to this work is refinement of our safety case, which supports the evaluation of the site and the key design decisions that are forthcoming.

In addition, we will continue to focus on improving the implementation of our quality assurance requirements. Today I will provide you with an overview of the program and focus on the program elements that in combination with an updated regulatory framework will be essential to licensing a repository at Yucca Mountain should the site be recommended and approved.

For our budget in FY 1999 Congress appropriated $358 million -- $22 million less than President Clinton's budget request. Congress further directed that $4 million of that $358,000,000 be used for the study related to accelerated transportation of waste, thus leaving $354 million available to the program at Yucca Mountain.

The President's request was intended to maintain our schedule for completing necessary site activities for a site suitability determination, issuing environmental impact statements, and submitting a repository license application if the site is recommended. Congress endorsed this work but reduced the appropriation. The FY 1999 funding is adequate to continue implementing the revised program approach as refined in the viability assessment.

We plan to publish a draft Environmental Impact

Statement this coming summer. We have made the necessary programmatic adjustments to maintain our schedule and conduct additional studies of issues identified in the viability assessment.

The cumulative effect of the budget reductions over the last three years, however, coupled with the additional studies needed to address key scientific issues, is stretching the program's resources. Our FY 2000 budget request, which has a significant increase for Yucca Mountain, supports the funding requirements identified in the viability assessment. As the program continues to build on the momentum achieved over the last five years, our budget request supports the activities necessary to determine the suitability of the site and to develop the documentation needed for a Secretarial decision on the site recommendation in 2001.

Specifically in 2000 we will issue a final Environmental Impact Statement. The Nuclear Waste Policy Act requires a final Environmental Impact Statement accompany the site recommendation and to the extent practicable be adopted by the Commission in connection with the issuance of a construction authorization and a license if we are successful in our licensing endeavor.

CHAIRMAN JACKSON: Mr. Barrett, let me -- can I ask you a question?

MR. BARRETT: Sure.

CHAIRMAN JACKSON: You mentioned about having the program's resources stretched. Have you had to postpone other aspects of the program like canister design to maintain the schedule to complete these additional studies of issues identified in the viability assessment?

MR. BARRETT: Unfortunately, we have had to do that. We have in the national transportation program, we have pretty much had to defer most of our activities in any transportation hardware development, the multipurpose canister initiatives. We are basically not doing any Federal work in that area, working on the institutional issues of national transportation -- which are very important -- we have had to unfortunately defer those until a national decision is made on siting, so we have had to basically focus almost exclusively on the scientific aspects of Yucca Mountain that lead toward its suitability and license application.

CHAIRMAN JACKSON: Okay. Thank you.

MR. BARRETT: In addition, we will begin evaluating the site for compliance with the repository siting guidelines, that's DOE 10 CFR 960, and we will complete the internal review of a working draft LA and will initiate development of an acceptance draft LA which we will make available to your Staff starting next year.

CHAIRMAN JACKSON: LA being license application.

MR. BARRETT: Thank you very much, Madam Chairman.

The viability assessment, as the Chairman mentioned in the beginning, does contain four primary components.

First, it describes the preliminary design concept for the critical elements of a repository and the waste package. Second, it contains the total system performance assessment based on the design concept and the scientific data analyses available at this time and describes the probably behavior of the repository in the Yucca Mountain geologic setting. Third, it presents a plan and cost estimate for the remaining work to complete -- to submit the license application. Fourth, it lays out an estimate of the cost to construct and operate the repository consistent with the reference repository design concept.

The VA as published also contains an introduction and a detailed description of the characteristics of the site. In front of each of the Commissioners is a copy of the overview. One thing I will mention we did in the viability assessment is an attempt to make this widely disseminated to interested members of the public. We have put this entire document on our Internet site, which we have had tens of thousands of hits or visits to by members of the public and also in this is a CD ROM that has the entire viability assessment document in it as well.

The viability assessment identifies the inherent advantages of the Yucca Mountain as a potential repository site, including its remote location, semi-arid climate and deep groundwater table. Less than half an inch of water reaches the level of the repository per year. Based on the viability assessment, we believe Yucca Mountain remains a promising site for a geologic repository and the work should proceed to support a decision in 2001 whether to recommend the site as the nation's first repository.

We understand that the uncertainties remain about the key natural processes, the preliminary design, and how the site and the design would interact and we recognize that our assumptions and analyses have yet to be challenged in a rigorous licensing proceeding. To address these uncertainties, we will focus on improving our understanding of the key natural processes as well as improving the repository and waste package design.

The primary objective of our licensing approach is to integrate the rationale and plans for the remaining technical work with the statutory and regulatory framework within which the work must be done and the decisions must be made.

We support your efforts to create a site-specific Part 63 that would apply exclusively to Yucca Mountain. To revise 10 CFR Part 63 will address our need to understand the key licensing requirements for a repository site at Yucca Mountain.

Our current License Application Plan describes our overall approach to completing the site characterization and is contained in Volume 4 of the viability assessment. The License Application Plan presents the activities we believe should be completed prior to determining the suitability of the site and preparing a license application. Your review is essential to forming a mutual understanding of what is expected from the program in the licensing process.

We fully expect our approach to licensing will continue to evolve as we work toward understanding and resolving potential licensing issues.

Several years ago your Staff refocused your program around 10 key technical issues deemed most important to repository performance. We are continuing to focus on resolving these key technical issues. The LA Plan contains a crosswalk that indicates where each of your key technical issues is addressed in our viability assessment.

Of the remaining additional technical work identified in the License Application Plan, the postclosure safety case is clearly the highest priority. Our postclosure safety case must provide reasonable assurance that a repository at Yucca Mountain will protect the public health and safety and the environment after a repository is closed and sealed. The safety case is a set of arguments that will be made to show that the repository system will contain and isolate waste sufficiently.

Underpinning the set of arguments is an understanding of the performance of the repository system. The repository safety strategy is the framework for integrating the performance assessment, site information and exploration, and the repository design to develop the postclosure safety case. Our safety strategy is based upon demonstrating that a Yucca Mountain repository with four key attributes would protect the public health and safety and the environment for thousands of years.

The four attributes are limited water contact with the waste packages, long waste package lifetime, slow release of the radionuclides from the breached waste packages, and reduction in the concentration of radionuclides as they are transported from the breached waste packages to the environment.

Evaluations of these attributes are guided by summarizing current knowledge and developing testifiable hypotheses to address the issues. Each attribute is influenced by natural processes and the placement of the engineered components -- in other words, multiple natural and engineered barrier, iteration among the site exploration, design, and performance assessment teams produces an evolving picture of what site information and design features are important to the performance of the repository system.

The major thrust of the remaining technical work is to select the design which will be carried through licensing. Selecting the design will include comparisons of the options and alternatives. It will require a sequence of decisions regarding criticality issues, approaches to repository sealing and closure and evaluation of design alternatives.

The viability assessment reference design was developed to define a workable repository concept for Yucca Mountain and to provide a consistent basis for evaluating the significance of natural processes and engineered features. The design is not fixed and enhancements will continue to be included throughout the repository design process evolution.

Our design approach balances the need to develop and maintain a coherent working concept with the recognition that the design concept will invariably evolve throughout the process of suitability, licensing, and construction. Our design process has and will continue to consider the potential advantages of alternative design features, concepts, and options.

For example, on the same day that I last briefed the Commission Nye County presented its views on ventilation and extended monitoring of the repository. We listened to this exchange and agreed that future generations should make the ultimate decision on whether it is appropriate to continue to maintain a repository in an open, monitored condition or to seal and close the repository if they are comfortable with the risks involved.

To ensure the flexibility for these future decision-makers, the viability assessment reference design allows the repository to be closed as early as 50 years or as late as 300 years from the initiation of waste emplacement. An extended monitoring period also provides the flexibility needed to allow the project to move forward and obtain an improved understanding of the remaining uncertainties.

As I stated earlier, the viability assessment and License Application Plan guide the completion of a site characterization and the design by identifying the critical issues that need to be addressed and by laying out our technical work plans that will support the resolution of these issues.

I am pleased to report that since I last briefed you we have made significant progress in the site exploration, site characterization, science, design, and performance assessment areas. The progress has permitted us to evaluate the degree to which the viability assessment reference design exhibits the four key attributes outlined in the repository safety strategy.

At this time I would like to point the Commission to the monitors and I would like to go through a few of the experiments that have been going on since we last addressed the Commission.

This is the sketch of the underground area of exploratory facilities.

The dark is the main five-mile loop that we completed some time ago. The new red is the cross-drift that is a little over three kilometers long, which goes to the west side of the block, about 20 meters above the actual repository emplacement horizon.

There are two experiments that I will show in the next slides, but the upper section is the Alcove Number 1 where we have done an experiment, and the large heater test down at the lower corner here. Next slide, please.

This is the start of the cross-drift. This is the small, 16 foot diameter tunnel bar machine being placed into the starter tunnel for the cross-drift.

This is the cross-drift after it has been completed at the intersection with the main 25 foot tunnel. This is where you see the conveyers from the two systems converging.

This is the infiltration experiment that is over Alcove 1. This is where we sprinkled tens of thousands of gallons of water on the surface and below this, directly below this is the Alcove Number 1, where we put in catchers to try to determine our models and calibrate our models on the infiltration rates and seepage into tunnels.

This is the sketch of the large heater test. Here the heater test is in the section on your right. It is a 160 foot long tunnel. Part of it is concrete-lined, part is not, for emplacement. We put heaters in there. We drilled over three kilometers of instrumented bore holes around this with over 3,000 channels of information for temperature, water, chemistry, rock strain, and we applied heat to the mountain -- and the next slide, please.

This is looking in through some of the insulated windows into the tunnel. We are up to over 300 degrees Fahrenheit inside the tunnel. The way -- we can actually track the water fronts as the water steams and recondenses as we go through. Again, this is where we are comparing this against our models for the thermal zone and the interaction between the engineered aspects of the repository with the natural. Here you see the predicted on the top and the measured on the bottom, and you can see over the last year how this has grown and basically our measured results -- we are very encouraged -- track very nicely with our predicted results in this area, so this is an eight-year test that the Staff, the NRC Staff, follows very carefully.

The next area I would like to turn to is our Busted Butte facility which is located nine kilometers south of the tunnel -- the Yucca Mountain tunnel area. Here there is a section of the Calico Hills formation, which is the rock strata below the repository has been thrust up.

We have dug into the Busted Butte area and we have exposed areas of the Calico Hills formation and we are doing chemical tests here to determine what the behavior of the liquids would be in the strata below. This is an experiment where we have put in the Fluorescein Disodium salt tracer material to determine what kind of flow conditions we have here in the Calico Hills, which would be below the repository. We have been encouraged at some of the initial results. It looks like the flow in this area is dominated by matrix flow as opposed to fracture flow, which will be important in the overall performance, but again, a lot of work continues in this next period there. Next slide.

Also we have a very active drilling program on the surface. Nye County is doing some of the drilling in the saturated zone, south of Yucca Mountain toward Lathrup Wells. They are drilling 22 different wells and they have been drilling around the clock in several locations. I am very pleased with the results that we are doing in the drilling in the saturated zone by Nye County. Next slide, please.

There has also been work on the engineering aspects. This is a quarter-scale model of the tunnel actually where we are looking at different backfill -- set up a Richards barrier where we could sort of look for potential design alternatives where we could diffuse the water away from the heated waste package if we were to backfill in the tunnels. Backfill is not the reference design, but we have evaluated that as an option to try to improve the performance of a repository in the geologic setting of Yucca Mountain.

I think that should be the last of the slides.

Now our work is being performed and we believe we have been completing world class science. We also know that world class science is necessary but insufficient for a license application. As I know each of you is aware, your Staff has expressed serious concerns about the implementation of our quality assurance program. These concerns have been expressed in the reports by your on-site representatives, letters from your Staff, and face-to-face interactions. Although your Staff acknowledges that most of the QA issues have been self-identified by the Department, I want to make it perfectly clear that as we move towards licensing a quality assurance program that is capable of identifying issues but is ineffective at preventing and resolving them in a timely manner is unacceptable to the Department of. Energy.

Let me begin by stating unequivocally that we do not disagree with the conclusions of your Staff regarding the implementation of what is structurally a sound quality assurance program. This program's management team is absolutely committed to making the improvements that are required to become that of a licensee.

To date, in the viability assessment we did focus on the world class science and we recognized that that is not going to be sufficient. It must also be performed under an NRC-approved quality assurance program with the necessary processes and documentation that are required. We are working hard to bring that dimension into every scientist, engineer, and administrator's daily routine.

During the last fiscal year we completed the consolidation of our multiple quality assurance programs into one overall DOE QA program and have made significant progress in integrating the quality assurance functions of the Office of Quality Assurance with those of the Management and Operating Contractor, TRW.

Our QA audit function has been retained solely by DOE and remains independent of TRW. Having one quality assurance organization reporting to the Director of the Office of Quality Assurance, who reports directly to me, provides the support to all the program participants and allows a more consistent approach to the implementation and interpretation of the QA program requirements.

At our December 9th, 1998 and January 26th, 1999 meetings with your Staff to discuss quality assurance issues, we identified actions necessary to address the quality assurance deficiencies, many of which are related to technical data, procurement, software, and model development and use. We recognize the need to adopt an integrated approach to resolution as well as prevention of similar deficiencies in the future. To that end, the program has developed and is implementing our corrective action request management plan and response to corrective action requests, which identifies the actions already taken as well as those actions planned to effect the needed improvements in our QA implementation.

As you recall, we faced a similar quality assurance program implementation issue in 1994 when we began to design and then construct the Exploratory Studies Facility. In that case we also needed to improve the performance in the mining and engineering workforce that was unfamiliar with the nuclear culture and unpracticed in quality assurance processes.

We were successful in that transition and we are now taking many of the same steps to effect change in the natural system and performance assessment activities. We recognize the need for comprehensive change in a limited time period, but we have the confidence that we can again do it successfully.

We believe that the implementation of the corrective action report management plan will permit us to employ effective corrective actions that will have a high probability of preventing reoccurrence of the deficiencies. The program is planning to devote adequate resources to this issue.

Accordingly, our Corrective Action Board will provide additional management oversight of the corrective action processes. Their objectives are to decrease the overall time for completed corrective actions, to decrease the number of rejected deficiency responses and verifications, and to decrease the overall number of open deficiencies and the ensure the integration of corrective actions for similar deficiencies in the future.

The Board charter was approved this January and the Board members have been selected. The formulation and implementation of the management plan and establishment of the Corrective Action Board illustrate our ongoing commitment to achieving full compliance with nuclear quality assurance requirements. We will apply the appropriate level of resources and the highest level of management attention to ensure that performance meets management's expectations as well as the NRC's requirements.

In addition to the actions mandated by our management plan and as overseen by the Corrective Action Board, it is often appropriate to implement some corrective actions in advance of the identification of root causes. For example, the Yucca Mountain Project began providing regulatory and licensing training that portrays quality assurance as an integral part of the nuclear culture and a necessary underpinning of the licensing process.

Our four national laboratories are supporting our program and are being trained in the control and use of scientific notebooks by our program. The training is being conducted to promote a better understanding of the purpose and objectives of scientific notebooks in our program and the rigor of scientific notebook documentation to ensure traceability of our work in any future licensing proceeding.

With regard to data qualification, we are verifying the documentation supporting the status of qualified data and identifying existing nonqualified data that will be directly relied on in the license application, and must therefore be qualified.

Our ongoing process validation and re-engineering initiative will permit us to develop and implement an interdependent project infrastructure that conforms to project requirements, provides defensibility, traceability, reproduceability, and retrievability for products and information used in the Environmental Impact Statement, the site suitability, the site recommendation and the license application.

Once the process validation and re-engineering initiative is complete, the program will have reviewed and verified work processes, developed a set of integrated work procedures, established an integrated training curriculum supporting the procedures, and create an implementation plan specifying our approach as well as individual roles and responsibilities.

DOE considers the improvements and implementation of the quality assurance program to be of paramount importance. As our program moves beyond just world class science, and our quality assurance performance improves, the project expects to enhance its ability to respond to deficiencies and promptly identify root causes and implement the appropriate corrective actions to prevent reoccurrences.

We intend to routinely communicate our progress to the NRC Staff and are looking forward to briefing the Staff on the status of our management plan and results achieved to date when we meet this coming April.

The program is reaching a conclusion of our site characterization efforts. The viability assessment clarified the remaining work required and identified those technical issues that should be addressed prior to determining the suitability of the site.

We are addressing those issues and have commenced work on assembling the information required to support national decisions on geologic disposal at Yucca Mountain.

In closing I would also like to note that since I last addressed the Commissions, our respective organizations have interacted frequently and have made progress in a number of areas. The valuable efforts of your Staff have resulted in tough but fair critique an have stimulated positive change within our team. I hope that we can continue to build on this progress as we move forward.

We intend to keep you and your Staff apprised of our progress and look forward to a constructive dialogue as we carry out our mutual responsibilities.

Thank you for the opportunity to brief the Commission and I would be pleased to try to answer any questions that the Commission may have.

CHAIRMAN JACKSON: Thank you. I have a couple of questions. Let me ask one question about your QA program.

Will you revalidate the aspects of your program, meaning data models and samples, that already comprise your basis for the viability assessment against or, you know, the standards of your improved QA program?

MR. BARRETT: Some of the data has already -- is satisfactory and has met the requirements. Some of the data has not. What we will do as we proceed now toward a license application, we will go back and qualify the data that needs to be, and as the budget permits, go back and get that data.

We will have to wait and see how the 2000 budget turns out but we have had basically a 20 percent increase for the Yucca Mountain science activity in 2000 and want to pick that up for one integrated science program that serves all the needs, of which the most restrictive and demanding program is the one the NRC would require for a license application.

CHAIRMAN JACKSON: Will your Environmental Impact Statement address the transportation aspects of high level waste disposal?

MR. BARRETT: Yes, it will. It will also -- it will look at the inter-Nevada transportation among multiple routes and multiple methods of transport as well as it will look at the national transportation from reactors or the high level waste sites to a possible Yucca Mountain repository.

CHAIRMAN JACKSON: Okay. These are a couple of questions about remaining technical work and then evaluating the design against the four key attributes you mentioned.

You know, the review of the design for the waste packages as well as the repository itself are going to be a critical factor in terms of time and resources needed by the NRC to review. Does your schedule take into account the effect of delaying the finalization of the design by you, the effect that that would have on NRC's completion of the review of the License Application?

MR. BARRETT: Yes. In the License Application Plan in the viability assessment and in supporting management schedules that we have, and as we have explained, your Staff is aware of those, we have plans on that. Our desire in the concentrated activity currently underway on the design alternatives is our goal is this June to basically select the reference design that we would use for site suitability and for licensing that would allow your staffs as well as my staffs to be able to focus on a specific reference design we would wish to carry through the process so it would be an integrated system.

CHAIRMAN JACKSON: When do you actually plant to have the waste packages designed for all the waste forms projected for Yucca Mountain?

MR. BARRETT: Well, the key is the majority of the material, which would be the commercial fuel as well as the generic high level waste packages for the Savannah River and the West Valley borosilicate glass. Also, the Navy is pursuing fairly rapidly their package for the Navy spent fuel.

Regarding the many different -- tens of types of DOE's own spent fuel, those are coming along on various schedules as our environmental management colleagues work on that, so that has a various schedule but the main central focus is for the classical commercial spent fuel and the DOE borosilicate glass in the Navy.

CHAIRMAN JACKSON: Glass in the Navy, and those are -- so what kind of schedule are they on?

MR. BARRETT: The commercial fuel, the waste package design basically would be -- we'd hope to have that pretty well -- the reference design advanced enough for the design, the reference design --

CHAIRMAN JACKSON: To cover those three things --

MR. BARRETT: For those, this summer.

CHAIRMAN JACKSON: And are you planning on disposing of greater than Class C waste at Yucca Mountain?

MR. BARRETT: That is not in our reference design. the greater than Class C waste is one of the modules that will be discussed in the Environmental Impact Statement for Yucca Mountain, but that is not presently part of our License Application design.

CHAIRMAN JACKSON: And how will you address failed spent fuel in terms of credit for cladding and so forth? Have you worked that out?

MR. BARRETT: As in the models in the viability assessment, it depends upon the fuel. The algorithm is, for example, stainless fuel, which is about 1 percent of the inventory of the commercial fuel that we have, we do not -- that is not of the higher integrity of the zircalloy fuel, so there it is a higher fraction, assumed to be failed basically we have assumed at 10,000 years. It does not provide a barrier at all so it depends upon the fuel.

CHAIRMAN JACKSON: So you are taking a graded approach based on what fraction of the fuel you think has what degree of failed cladding, is that basically --

MR. BARRETT: That is correct.

CHAIRMAN JACKSON: -- basically correct.

MR. BARRETT: And as we refine the models more, we may take into account burnups and different aspects as we basically develop the sophistication in the models for modelling the different source material as it relates to the system.

CHAIRMAN JACKSON: Commissioner Dicus?

COMMISSIONER DICUS: Yes. One of the conclusions of the U.S. Geological Survey report from this past November states that in view of the enormous technical complexity of the total system performance assessment that as they called it a semi-quantitative assessment -- in other words, a plain English with simple calculations assessments -- of Yucca Mountain would be valuable.

It went on to state that such an analysis is likely to be more readily comprehended by the public, by legislators and by intervenors.

Do you have any plans to do such an assessment?

MR. BARRETT: We have worked on that and it becomes a very difficult balance between oversimplification and looking at the true risk-informed -- I think this body has dealt with risk-informed regulation -- so we have done some deterministic. We intend to do more deterministic as together with your Staff we work on a defense-in-depth aspect of your regulation that we suspect will be there in your regulation -- it is in your existing -- in your future. That will involve some deterministic as we look at different barriers, but we want to keep the main thrust on the probabilistic risk informed, but we will also be doing some deterministic, but we are very careful with the deterministic that people don't make sound bites out of deterministic calculations that can mischaracterize the situation.

COMMISSIONER DICUS: Okay, thank you.

CHAIRMAN JACKSON: Okay, Commissioner Diaz.

COMMISSIONER DIAZ: Yes. This is mostly -- it might be a qualitative question, but what is the sensitivity of the design of the engineered barriers as a function of protection standards? Is it -- will changes in protection standards of a factor of two will change your engineered barriers by an order of magnitude in cost or complexity? Have you done sensitivity analyses of the potential impact of protection standards?

MR. BARRETT: We have done that. We have done some of those. In the viability assessment, we looked at two options past the reference design, which basically were some advanced technology that we could try to put in.

We cannot change -- Yucca Mountain is what God made and we really cannot change the natural mountain. The only thing we can control are man-made things and engineered system, so we looked at three.

We looked at backfill, which is one of the experiments we showed where you could put like a Richards barrier to diffuse water droplets away from the waste package. We looked at advanced material, ceramic material, which has come from commercial advances over the last several decades as well as classified defense work on ceramic barriers.

We have looked at ceramics and also drip shields that you could put to try to shed any drips away from the waste package out of various types of material.

So we have looked at some of these that in theory could basically give you 100 percent containment in theory for 10,000 years -- at least that is what our models would say. I am not sure those would be sustainable in a rigorous licensing environment based on what science and technology could tell you.

Part of the reason we did some of these options studies was we do not know what the final requirements will be for Yucca Mountain repository until the standards by EPA are issued and the NRC regulations that we will follow are issued, so we are trying to be flexible. We are trying to explore other engineering ways and some of the design alternatives work looks at 26 different options in different cases of different thermal loads, different tunnel diameters, and different things to try to be exploring best available technologies, where we are basically at the state-of-the-art and pushing the state-of-the-art in technologies to try go toward a goal of basically zero release, if one can get there, but I don't believe we could ever sustain it for 10,000 years or more, as the case may be.

COMMISSIONER DIAZ: Who will pay for it?

MR. BARRETT: Pardon?

COMMISSIONER DIAZ: Who will pay for it?

MR. BARRETT: Cost is one of the lesser issues we looked at. We did evaluate the cost of the advanced, say the ceramic coatings. I mean we are looking at different costs of around a billion dollars added on. The cost was not a major driver. We were really looking at the performance and the sustainability of those performance claims in a licensing process.

Then there is also the national debate, I would predict, in the EPA standards as to at what cost for what benefit. If one were, say, to change by a fraction of a millirem or something 10,000 years in the future, what is that cost worth relative to today's dollars in a billion dollars, so we wanted to have that information available for organizations and policymakers like the Commission, like the Congress to look at that in the future.

CHAIRMAN JACKSON: Thank you. Commissioner McGaffigan?

COMMISSIONER McGAFFIGAN: Commissioner Dicus has already referred to this USGS report that was sent to the Director of USGS back in November and if there is a thrust to it, and I am sure you saw it at the time, it's that there's a lot of overly conservative, from their perspective, design features and assumptions in your viability assessment.

Perhaps from a regulator's perspective that is a good thing but they claim at times in here that it can lead to perverse results in terms of you are optimized for one thing and you actually end up having an adverse result somewhere else.

I could go through bit by bit but have you all analyzed the USGS critique and is there a document that has been prepared to sort of deal with the comments, or do you agree with some of them? What is the situation -- because they are ahead of us. We are still at least a month away probably from giving you a response to the viability assessment.

MR. BARRETT: Well, the USGS Director's Review Team is valuable input to us as the Commission's views, I am going from the Staff, and in the future from the Commission is valuable. The Nuclear Waste Technical Review Board input has been valuable, so we are factoring all of these in, basically to our ongoing dynamic work plans which, you know, are spelled out in general in the viability assessment and more and more detail as they go on.

We will look at some of those issue, but for every -- as you mentioned, these are all inter-related. For every place that may look like it's an advantage there is also an uncertainty on the other side, so on water flow and a lot of these issues on future climate, we are looking to have expert elicitations on future climate but then again, you know, who knows what future climate is going to be and is that really where we can put our resources on some of these when we have near-term engineering issues. We have got quality assurance issues which are a major time and cost thing for us to do is to get our earth scientists to basically do what they need to do as far as the documentation and process and maybe not go on to the absolute best piece to it, so we are evaluating our work plans in light of that and in light of all the input to try to get the right balance to get the best progress that we can as far as the scientific aspects of Yucca Mountain, how it does perform in the future, balancing the resources.

We try to avoid excess pieces of paper. We are not planning a specific response to the USGS but we will fold that into our work plans of which the USGS is part of the team.

COMMISSIONER McGAFFIGAN: You said that you plan to select your reference design for the site suitability determination by June. Somewhere in your testimony -- I couldn't find it exactly -- you also suggested that this is a design that will change again perhaps all through this what will undoubtedly be a very long process.

How do you build flexibility in and to allow for those changes? I assume that the site suitability reference design will be different from the viability assessment reference design, depending on the sort of comments you get and your reaction to them, and then there could be other design changes just as more science comes in or more analysis comes in.

Is there enough flexibility in the process to allow that?

MR. BARRETT: This is a constant balance we make as we go forward. Design never, never stops. It is never stagnant. It is always trying to do as good as or better than your reference, and when you start looking at things, is this design concept better? -- you have to look "better" from what perspective.

One of the things, for example, we have had a lot of internal debates about is the placement tunnel diameters. Here you are trading off one design aspect from another. From a tunnel stability point of view, if you make the tunnel smaller, they are more stable than a larger emplacement tunnel, but then if you line up 100 waste packages down the tunnel if for some reason you want to take one out from the center you would have to take, you know, 49 to get to that. Now you have an operational concern versus a 100,000 year performance concern, and you try to balance these two.

So we are looking at these and we are very careful about decisions that will sort of preclude another decision. For example, some of the basic concepts of tunnel diameter, heat load, and some of those kinds of things we are very careful about, so we put most of our focus on the issues that given us less flexibility in the future.

We have deferred much of our preclosure surface design work and left that very conceptual, focusing on the postclosure aspect, so we constantly go at this. There is no right single answer, and then as the natural system information becomes more refined and more specific, we want to make sure that we can accommodate that, those situations, in the design.

You find out that maybe a higher water infiltration design is not so good for a drier and vice versa, so we are trying to balance these things and it is not a simple answer to how to do it.

COMMISSIONER McGAFFIGAN: And this may be a question more fair to address to our own Staff than to you, but in our licensing process, how will this be handled? Will there be license conditions, do you envision that will allow flexibility or how does it get built into the license application and then our license which if granted, you know, how do they deal with the uncertainty as to what the final design will look like?

MR. BARRETT: In the existing 10 CFR 60 -- I don't recall, I think it is still 10 CFR 63, is the Staff requires that we evaluate alternatives and provide information of these types of things for the Staff to look at.

Now I think when it comes to specific license conditions I think we are far away from that level of detail, you know, until we come up with a design that would go into the license application phase, and then it becomes a reference design, and as we go through the licensing process, through construction, it is always as good as or better than, and we do hope to be able to advance the designs as technology advances hopefully over the next many decades, that we can do it better, better quality assurance, better fabricability, better QC issues as well as maybe lower costs we could hope too that we could achieve.

CHAIRMAN JACKSON: Commissioner Merrifield.

COMMISSIONER MERRIFIELD: I just have one brief question.

There has been a lot of notoriety in the news lately about some of the seismic activity that has been present near the site, within 10 miles of the site. I was wondering if you could comment on that -- any of the information that you received from out at the site, information related to how that has affected the site itself.

MR. BARRETT: We know we are in a seismically active area in Nevada. The whole state of Nevada is seismically activity -- not a seismically active as

California but seismically active.

We have had earth tremors and earthquakes there and these are constantly ongoing. The underground postclosure, which is our main focus, is not heavily influenced by earthquakes because the earthquake energy goes through the ground and dissipates at the surface much like a wave at the beach will dissipate its energy when the wave hits the shore, so in the cases of the recent events, we had people in the tunnels -- didn't feel a thing -- whereas you could actually feel the ground shake at the surface over near the test site, so we are looking at this.

We are not surprised by these tremors. They are expected. We believe that we can design surface facilities that can withstand it. That's a matter of concrete and steel.

The Commission, as you said, we have submitted two topical reports to the Staff over the last several years concerning seismic design criteria and we have another topical report that is scheduled I think it is later this year or next for the Staff, so we believe that through design we can deal with the seismic risks and it is not going to be a major determinant regarding the site.

COMMISSIONER MERRIFIELD: Okay.

CHAIRMAN JACKSON: You had some concerns that you had expressed relative to the prescriptive performance confirmation requirements that were in the draft, 10 CFR Part 63. Could you elaborate upon those a bit?

MR. BARRETT: I will ask Dr. Stephan Brocoum, who is our Assistant Manager of Licensing and Regulatory, to come and assist me on that one.

CHAIRMAN JACKSON: Okay. Welcome, Mr. Brocoum.

MR. BROCOUM: I am not sure what -- we haven't formally to my knowledge --

CHAIRMAN JACKSON: -- responded --

MR. BROCOUM: -- responded on 63, okay --

CHAIRMAN JACKSON: Okay.

MR. BROCOUM: -- so we have had informal discussions with your Staff --

CHAIRMAN JACKSON: Right.

MR. BROCOUM: -- and offhand I don't know what the concerns were --

CHAIRMAN JACKSON: Okay.

MR. BROCOUM: -- on the performance confirmation.

CHAIRMAN JACKSON: All right. This may be something that is too sensitive for you to answer because of litigation, but --

MR. BROCOUM: No -- let me ask Mr. Jack Bailey here.

CHAIRMAN JACKSON: Okay, while he is coming forward, let's do this one.

Are you looking at alternative funding, like funding dry storage facilities at licensee sites, that kind of thing?

MR. BARRETT: That answer is no. We are not.

We are executing the law as it is presently written.

CHAIRMAN JACKSON: Okay.

MR. BARRETT: There are discussions about changing the statute. You know, those would be a matter of administration record. Regarding the Act said specifically that we are to prepare a repository for the waste, the eventual disposition of the waste, regarding paying for onsite storage through our inability, Secretary Pena had a proposal to utilities, a deferred payment option, to try to resolve some of the lawsuits. That was not accepted by the contract-holders. We are in 100 different lawsuits in different courts at this time, but that will run its own course, but as far as the program, he's not planning --

CHAIRMAN JACKSON: -- following the existing nuclear waste policy?

MR. BARRETT: Yes, ma'am.

CHAIRMAN JACKSON: Did you have --

MR. BROCOUM: No. We don't have any issues with the current 63 as you have published it on the Internet.

CHAIRMAN JACKSON: Right. If you anticipate the need for the use of advanced materials or engineered barriers, have you folded that in? Are you going to be able to complete the testing and demonstration of these materials on a schedule to support the license application?

MR. BARRETT: It depends on what that is.

The reference design is with C-22, or commercially known years ago as hastalloy, for those of us who used to do valve work. That -- there is material, 50 years' worth of data on that material and the A516 outer is well-known material to the engineering field for 100 years.

Here -- for that case we feel that we could make a case on the schedule we have. If we were to drastically change designs, we would not submit a license application until we felt it was one that was sustainable and would be accepted by the Commission, so it depends upon what it is.

CHAIRMAN JACKSON: Okay, and one last question. You have the Busted Butte tracer tests -- you know, the large migration study. Will those results be available in time to support a licensing application or are you planning to use that information as part of a performance confirmation?

MR. BARRETT: No, that will be, much of that information will be available for the license application part of our license application case.

We will also probably continue to do some performance confirmation work indefinitely at that facility.

CHAIRMAN JACKSON: Okay.

MR. BARRETT: Funding permitting.

CHAIRMAN JACKSON: Funding permitting. Any other comments, Commissioners?

[No response.]

CHAIRMAN JACKSON: Well, let me thank you, Mr. Barrett and Dr. Brocoum and the Department for today's briefing. Obviously you have made substantial progress in the repository program since our last meeting.

I think we will be meeting a little more frequently than every two years. The Commission and the NRC Staff will benefit from the clarity of your presentation that you have given of the DOE viability assessment process considerations and conclusions.

It helps us. It helps to facilitate the NRC's ongoing review of the viability assessment and it will be useful, I believe, to the Staff's general review of the issues with regard to your continuing efforts -- and so, if there is nothing more, then I thank you and the meeting is adjourned.

MR. BARRETT: Thank you.

[Whereupon, at 3:10 p.m., the briefing was concluded.]

CERTIFICATE

This is to certify that the attached description of a meeting of the U.S. Nuclear Regulatory Commission entitled:

TITLE OF MEETING: BRIEFING ON THE HIGH LEVEL WASTE PROGRAM VIABILITY ASSESSMENT PUBLIC MEETING

PLACE OF MEETING: Rockville, Maryland

DATE OF MEETING: Monday, February 8, 1999

was held as herein appears, is a true and accurate record of the meeting, and that this is the original transcript thereof taken stenographically by me, thereafter reduced to typewriting by me or under the direction of the court reporting company

Transcriber: Rose Gershon

Reporter: Mark Mahoney

STATEMENT FOR THE RECORD

PRESENTATION TO THE U.S. NUCLEAR REGULATORY COMMISSION

STATUS OF THE CIVILIAN RADIOACTIVE WASTE

MANAGEMENT PROGRAM

BY

LAKE H. BARRETT, ACTING DIRECTOR

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

U.S. DEPARTMENT OF ENERGY

February 8, 1999

Introduction

Chairman Jackson and Members of the Commission:

Since I last appeared before you, The Civilian Radioactive Waste Management Program has continued to make substantial progress in carrying out its responsibilities under the Nuclear Waste Policy Act. Despite reduced FY 1998 and FY 1999 appropriations, we have maintained and often exceeded our schedules by achieving efficiencies and reprioritizing work activities, while maintaining the safety and integrity of the scientific work.

The size, complexity, and sheer number of scientific tests being conducted at Yucca Mountain are unprecedented. We have developed and are applying some of the world's most advanced scientific techniques to answer questions about Yucca Mountain with emphasis on hydrologic flow in the unsaturated zone. We are conducting the world's largest heater tests to determine the effects of heat from the waste packages on the geology and hydrology at Yucca Mountain. Our Sample Management Facility has documentation for over 60,000 specimens. We will conduct field and laboratory tests and make hundreds of thousands of measurements. Yucca Mountain is, without question the most studied geologic setting in the world. We have also developed unique waste package material corrosion test facilities to give us insights into corrosion processes that otherwise would not be obtainable.

When I spoke to you last, the Program was focused on preparation of the Yucca Mountain Viability Assessment. On December 18, 1998, DOE submitted the Viability Assessment and its companion documents to the President and the Congress, and released it to the public. The Viability Assessment serves as an important management tool for the Program to guide the completion of site characterization by identifying the critical issues that need to be addressed before the Secretary of Energy decides whether to recommend the Yucca Mountain site to the President for development as a repository. While the Viability Assessment is not one of the decision points defined in the Nuclear Waste Policy Act, its completion is significant because it gives policy makers key information regarding the prospects for geologic disposal at Yucca Mountain.

Based on the Viability Assessment, we believe that work should proceed to support a decision by the Secretary in 2001 on whether to recommend the site. While the Viability Assessment reveals no "show stoppers", it does identify areas where additional work is required before site suitability can be determined and the Secretary can decide whether to recommend the site.

We hope that the Viability Assessment will provide our respective staffs with a frame of reference to conduct the prelicensing interactions necessary to facilitate the timely submittal and review of a high-quality License Application, if the site is found suitable. We expect that the information contained in the Viability Assessment design and performance assessment components will provide an adequate technical basis for a License Application, when combined with the additional information that will be obtained as a result of the work described in the

License Application Plan. The Commission's views regarding the acceptability of our approach to licensing as set forth in the License Application Plan will be important to forming a mutual understanding of what will be expected from this program during the licensing process.

We are now refining our licensing approach and obtaining and analyzing necessary scientific and technical information to support our safety analyses. Central to this work is refinement of our safety case, which supports the evaluation of the site and the key design decisions. In addition, we will continue to focus on improving the implementation of Quality Assurance requirements. Today, I will provide you with an overview of our program and focus on those program elements, that in combination with an updated regulatory framework, will be essential to licensing a repository at Yucca Mountain, should the site be recommended.

Program Overview

Budget

For our budget in FY 1999, Congress appropriated $358 million, $22 million less than the President's budget request. The President's request was intended to maintain our schedule for completing necessary site activities for the site suitability determination, issuing an Environmental Impact Statement, and submitting a repository License Application, if the site is recommended. Congress endorsed this work, but reduced the appropriation and further stipulated that the program reduce management and administrative support service contractors by 10 percent. Within this amount, Congress appropriated $5.5 million for the local counties and $250 thousand for oversight by the State of Nevada. Congress further directed that $4 million be used for a study related to accelerator transmutation of waste. Specifically, we are developing, with international collaboration, a road map to identify the benefits and issues regarding treatment of civilian spent nuclear fuel with accelerator transmutation technology. Issues that must be addressed are technical feasibility, time schedules, capital and operating costs, and the institutional challenges involved in such an endeavor.

The FY 1999 funding is adequate to continue implementing the revised program approach as refined by the Viability Assessment. We plan to publish a draft environmental impact statement this coming summer. We have made the necessary programmatic adjustments to maintain our schedule and conduct the additional studies of issues identified in the Viability Assessment. The cumulative effect of the budget reductions over the last three years, however, coupled with the additional studies needed to address key scientific issues, is stretching the Program's resources.

Our FY 2000 budget request supports the funding requirements identified in the Viability Assessment. As the Program continues to build on the momentum achieved in the last four years, our budget request supports the activities necessary to determine the suitability of Yucca Mountain and to develop the documentation needed for a Secretarial decision on Site Recommendation in FY 2001. Specifically, in FY 2000 we will issue the Final Environmental Impact Statement. In addition, we will complete an internal review of a Working Draft License Application, and we will initiate development of the Acceptance Draft License Application.

<u>Waste Acceptance Litigation</u>

Monetary damages that may be awarded in litigation between the Department and the utilities are being considered in our out-year budget forecasts. The Department is in litigation with utilities in several courts. As you already know, in 1996 the U.S. Court of Appeals for the D.C. Circuit held that the Department has an obligation to start disposing of utility spent nuclear fuel no later than January 31, 1998. In 1997, the same court held that the Department could not excuse its delay because it was "unavoidable." The court also held that the contracts between the

Department and utilities provide a potentially adequate remedy for the Department's delay and therefore, refused to order the Department to remove the fuel from reactor sites. The State agencies and the Federal government each sought to have the Supreme Court review portions of the court's decision. The State agencies asserted that the court should have ordered the Department to begin removing spent fuel from utility sites and sought a Supreme Court review of that portion of the ruling. The Federal government requested that the Supreme Court review the portion of the ruling which prohibited the Department from making a determination that the delay in removing utility spent fuel was "unavoidable." On November 30, 1998, the Supreme Court declined to accept either request for review and the appeals court ruling stands. The Department will comply with the court's ruling and process any claims presented to it under the standard disposal contract.

Viability Assessment

Purpose of the Viability Assessment

We released the Viability Assessment in December 1998. The assessment contains four primary components. First, it describes the preliminary design concept for the critical elements of a repository and waste package. Second, it contains a total system performance assessment, based on the design concept and the scientific data and analyses available, that describes the probable behavior of a repository in the Yucca Mountain geologic setting. Third, it presents a plan and cost estimate for the remaining work required to complete and submit the License Application. Fourth, it lays out an estimate of the costs to construct and operate a repository consistent with the reference design concept. The Viability Assessment, as published, also contains an introduction and a detailed description of the characteristics of the site.

Viability Assessment Results in Brief

Based on the Viability Assessment, we believe that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site. We understand that uncertainties remain about key natural processes, the preliminary design, and how the site and design would interact and we recognize that our assumptions and analyses have yet to be challenged in a rigorous licensing proceeding. To address these uncertainties we will focus on improving our understanding of the key natural processes, as well as improving the repository and waste package design.

The Viability Assessment identifies the inherent advantages of Yucca Mountain as a potential repository site, including its remote location, semiarid climate, and deep groundwater table. Less than half an inch of water per year reaches the level of the repository. About seven inches of water a year fall on Yucca Mountain, nearly all of which runs off or evaporates. The nearest groundwater, which is about 1,000 feet below the repository, is isolated in a closed basin and does not flow into any rivers that reach the ocean. This closed basin feature is unique to the southwestern region of the country. Studies of past climates indicate that the precipitation may increase to a long-term average of about 12 inches per year. However, most of the water would run off or evaporate. Even if future climates are much wetter than today the water table is not expected to rise high enough to reach the waste.

The Viability Assessment also addresses the potentially adverse characteristics at the Yucca Mountain site. Our analysis considers both the likelihood and the effect of possible disruptive processes and events, such as volcanism, earthquakes, human intrusion, and "nuclear criticality." We have concluded that there is little likelihood that such processes or events at Yucca Mountain would significantly affect the long-term performance of the repository.

The results of 15 years of testing and analysis have validated many, but not all of the expectations of scientists. One important test result was finding traces of chlorine-36 associated with above-ground nuclear weapons tests at the repository horizon. This finding suggests that, while most groundwater travel times are considerably greater than 1,000 years, some water traveled from the ground surface to the level of the repository in less than 50 years. More data and improved models are needed to fully evaluate groundwater travel times along potential pathways of radionuclide travel in both the unsaturated and saturated zones. Additional data collection and analyses are currently underway, including the Nye County drilling program. This program consists of new wells in approximately 22 locations, 500-2,500 feet deep, down gradient from Yucca Mountain to investigate the shallow and deep saturated zone hydrology. These efforts are expected to reduce some uncertainties associated with the current models and to enhance confidence in our understanding of the processes that affect water movement, radionuclide transport, and dilution.

Licensing Approach

To obtain an NRC license, we must demonstrate with reasonable assurance that a repository can be constructed, operated, monitored, and eventually closed that would protect the health and safety of workers and the public. The challenge in licensing a geologic repository is demonstrating a reasonable assurance of compliance with long-term safety standards for many thousands of years. The primary objective of our licensing approach is to integrate the rationale and plans for remaining technical work with the statutory and regulatory framework within which the work must be done and decisions must be made. We support your efforts to create a site-specific Part 63 that would apply exclusively to Yucca Mountain. The revised 10 CFR Part 63 will address our need to understand the key licensing requirements.

Our current License Application Plan describes our overall approach to completing site characterization and is contained in Volume 4 of the Viability Assessment. The License

Application Plan presents the activities we believe should be completed prior to determining the site suitability and preparing a License Application. Your review is essential to forming a mutual understanding of what is expected from this program in the licensing process. We fully expect that our approach to licensing will continue to evolve as we work toward understanding and resolving potential licensing issues. Several years ago, your staff refocused your program around ten key technical issues deemed most important to repository performance. We are continuing to focus on resolving these key technical issues. The License Application Plan contains a crosswalk that indicates where each of your key technical issues is addressed in the Viability Assessment.

Remaining Technical Work

The additional technical work identified in the License Application Plan falls into three major areas: refining the postclosure safety case, refining the preclosure safety case, and supporting remaining design decisions. Preparing our postclosure safety case is clearly the highest priority.

Our postclosure safety case must provide reasonable assurance that a repository at Yucca Mountain will protect public health and safety and the environment after the repository is closed. The safety case is the set of arguments that will be made to show that the repository system will contain and isolate waste sufficiently. Underpinning this set of arguments is an understanding of the performance of the repository system.

Performance assessments are used to evaluate how a repository system is likely to work over long time periods. From the results of scientific studies, analysts build detailed mathematical models or "representations" of the features, events, and processes that could affect the performance of the design. They then abstract these detailed process models into an overall model of the repository system. The models are used to assess how the natural and engineered elements of a waste disposal system are likely to work together over the long period required to isolate wastes. They help identify which uncertainties about the behavior of a disposal system are significant and which are not. They also help identify which elements of the repository system are most important to how well it is likely to work and where scientists and engineers should focus their efforts to improve performance. These assessments are repeated and refined during the course of developing, evaluating, and improving a repository design.

The Repository Safety Strategy is the framework for integrating performance assessment, site information, and repository design to develop the postclosure safety case. Our safety strategy is based upon demonstrating that a Yucca Mountain repository with four key attributes would protect public health and the environment for thousands of years. These four attributes are: limited water contact with waste packages; long waste package lifetime; low rate of release of radionuclides from breached waste packages; and reduction in the concentration of radionuclides as they are transported from breached waste packages. Evaluations of these attributes are guided by summarizing current knowledge and developing testable hypotheses to address the issues. Each attribute is influenced by natural processes and the placement of engineered components, in other words, multiple natural and engineered barriers. Iteration among the site, design, and performance assessment teams produces an evolving picture of what site information and design features are important to the performance of the repository system.

The preclosure safety case must demonstrate that worker and public health and safety will be protected in accordance with your regulations while waste is being emplaced and monitored. There are four key elements that comprise our preclosure safety case: a systematic evaluation of design basis events; classification and design of the structures, systems, and components that are important to safety; verification that our design complies with all applicable requirements; and reliance on the use of demonstrated technology and accepted design criteria.

The major thrust of the remaining technical work is to select the design that will be carried through licensing. Selecting the design will include comparisons of options and alternatives. It will require a sequence of decisions regarding criticality issues, approaches to repository sealing and closure, and evaluation of design alternatives.

The Viability Assessment reference design was developed to define a workable repository concept for Yucca Mountain and to provide a consistent basis for evaluating the significance of natural processes and engineered features. The design is not fixed and enhancements will continue to be included throughout the repository design process. Our design approach balances the need to develop and maintain a coherent working concept with the recognition that such a design concept will invariably evolve throughout the process of determining the suitability of the site, licensing, and construction. Our design process has, and will continue to consider the potential advantages of alternative design features, concepts, and options. For example, on the same day that I last briefed the Commission, Nye County presented its views on ventilation and extended monitoring of a repository. We listened to this exchange and agree that future generations should make the ultimate decision on whether it is appropriate to continue to maintain the repository in an open monitored condition or to seal and close the repository. To ensure flexibility for these future decision makers, the Viability Assessment reference design allows the repository to be closed as early as 50 years or as late as 300 years from initiation of waste emplacement. An extended monitoring period could also provide the flexibility needed to allow the project to move forward and obtain improved understanding of remaining uncertainties.

We are factoring several considerations into the design selection process. First, we want to determine whether there are fundamentally different repository design concepts that could meet performance standards more effectively than the reference design. Second, we will evaluate whether there are design features that could be added or incorporated into either the reference design or any alternative design with significant benefit. Lastly, we will consider whether there are alternative concepts or features that, in addition to meeting performance standards, could provide advantages with regard to operational and regulatory issues.

Obtaining and Analyzing Scientific and Technical Information

As I stated earlier, the Viability Assessment and the License Application Plan guide the completion of site characterization and design by identifying the critical issues that need to be addressed and by laying out the technical work plans that will support resolution of the issues. I am pleased to report that, since I last briefed you, we have made significant progress in construction, site characterization, science, design, and performance assessment. This progress has permitted us to evaluate the degree to which the Viability Assessment reference design exhibits the four key attributes outlined in the Repository Safety Strategy.

Construction, Site Characterization, and Science

Construction in the Exploratory Studies Facility (ESF) progressed significantly since I last briefed you. The Project completed construction of two more experiment location niches in the ESF main drift. Excavation of the repository block cross drift was completed on October 13, 1998. Exploration of the cross drift also progressed. Geotechnical mapping revealed ground conditions and stratigraphy generally consistent with predictions, with the exception of a few unpredicted minor faults in the western half of the potential repository block. The faults are not apparent at the ground surface and are thought to be older than the Tiva Canyon Tuff, which is one of the rock units overlying the proposed repository. This would indicate that there has been no movement on these faults during the last 12 million years, supporting our analysis of disruptive events.

We have continued to collect data that address key issues and advance our modeling capability to better understand natural processes significant to repository performance. We extended Borehole USW WT-24 below an upper zone of perched water to further characterize the large hydraulic gradient north of the proposed repository site. Since encountering a water-filled fracture on May 12, 1998, no other water-bearing fractures have been encountered. Further characterization of the aquifer is planned. Another borehole, USW SD-6, is being drilled on the western edge of the repository footprint to acquire stratigraphic data and provide more accurate information on the various rock layers near the repository. No perched water has been encountered in this borehole.

We completed updates to both the Geologic Framework Model and the Integrated Site Model. The updated Geologic Framework Model represents the Project's significantly improved understanding of geologic variability at Yucca Mountain, as well as having improved our capabilities to predict geologic conditions in the site area. The Integrated Site Model integrates the geologic framework with rock properties and mineralogical models. These data supported a 3-dimensional representation of the site, and provide a consistent documented set of initial conditions on which to run process models, such as flow and transport models. There are also direct applications of the Integrated Site Model to repository design, which must accommodate the geometry of favorable waste emplacement horizons.

The Project completed construction of the Drift Scale Test in the Thermal Testing Facility and the heating phase of the test was started in December, 1997. Comparative analyses of measured and predicted temperatures in the rock mass surrounding the heated drift indicate generally good agreement between measured and predicted values, although measured temperatures are slightly lower than the predicted values. One of the reasons for the overprediction of rock temperatures is that the actual heater power is slightly lower than the heater power used in making the predictions. Measured values of rock displacements indicate that the heated rock mass is expanding and moving toward the open heated drift. Concentrations of carbon dioxide in the gas samples collected from the test block after the start of heating are substantially higher than that in the atmosphere. The source of the increased carbon dioxide is the porewater of the rock and the calcite in the fractures, both of which give out carbon dioxide on heating.

Within the mountain, at the approximate level of the proposed repository a drip detection system has not detected any water movement at the repository horizon as a result of the El Niño storms of last winter and spring. Liquid release seepage testing in niches has helped determine seepage threshold values, and comparison of field data to modeling results shows good correlation. Investigations in ESF Alcove 1 were used to evaluate the infiltration rate and travel time through the Tiva Canyon Tuff.

Scientists working at the Busted Butte analog site are studying tracer movement and using those results to evaluate fluid flow and transport behavior in rock of the Calico Hills Formation. The Calico Hills Formation lies between the repository horizon and the water table. These tests are yielding information that can be used to evaluate how far and how fast key radionuclides may move in the non-welded rock below the repository in the unsaturated zone. Preliminary results from the Busted Butte tracer tests indicate that a majority of the flow in the Calico Hills non-welded rocks is through the matrix. In addition, only when the matrix becomes nearly saturated is there substantial fracture flow. These results, if generally applicable to the nonwelded tuffs in the unsaturated zone below the repository, suggest that significant retardation of radionuclides by sorption processes will occur in these rocks. In the natural system, there are mineral phases that act as chemical sponges to certain radionuclides, and this is called sorption. Sorption can occur by either "ion exchange", a process similar to that used to purify drinking water, or "surface complexation", a process to remove radionuclides from the waste waters at the National Labs. At Busted Butte, we are investigating, in both field and laboratory tests, how efficient this process may be at Yucca Mountain in slowing the migration of radionuclides away from the proposed repository.

Testing in the Prow Pass welded hydrogeologic unit is important to assessing repository performance because this unit is the uppermost hydrogeologic unit in the saturated zone immediately downgradient from the potential repository. Hydraulic and tracer testing in the Prow Pass Tuff in the upper part of the saturated zone is nearing completion. C-Well tracer testing of the Prow Pass interval in the saturated zone below the level of the proposed repository was initiated to better characterize the flow and dilution potential in the saturated zone. Results to date indicate that, as expected, the hydraulic conductivity and the rates of groundwater flow within this interval are less than in the more transmissive deeper interval that was tested previously. The tracer testing indicates that diffusion of solutes into the rock matrix from water moving through fractures is a mechanism for reducing solute concentration in the moving water, as was also indicated in previous testing. More sorption of a reactive tracer was observed in the field testing than predicted by laboratory experiments, indicating that the laboratory results are conservative. Tracer testing with two sizes of microspheres, which were used to investigate potential transport of colloids, suggest appreciable physical filtration by the formation. Evaluations of oxidation/reduction potential for two boreholes that penetrated the saturated zone indicate that reducing groundwater exists in the vicinity of Yucca Mountain. Reducing water could greatly decrease the transport of technetium and neptunium in the saturated zone.

Waste Package Design

Waste package design took a step forward with successful demonstrations of remote welding and non-destructive examination. Shrink fit of two cylindrical shells, similar to those under consideration for the waste package, was accomplished with a much lower preheat than had previously been demonstrated. This lower heat resulted in little oxidation on the contacting surfaces, thereby facilitating a complete contact. In another activity, the Project performed a criticality evaluation of a degraded model of the 44-BWR waste package. This evaluation applied the disposal criticality analysis methodology outlined in a topical report recently submitted to your staff. The evaluation is used as an example and described in an appendix to the report.

To allow waste package barrier materials selection in time for reference License Application design selection, a short term materials test program was formulated and initiated at Lawrence Livermore National Laboratories on October 1, 1998. This program supplements on-going experimental and modeling efforts and is focused on resolving key potential materials issues.

Performance Assessment

Performance assessment activities focused on final development and refinement of the approach, methodology, and technical basis for assumptions and results of the Total System Performance Assessment for the Viability Assessment. Our Repository Safety Strategy calls for the integration of performance assessment with the development of site information and repository design. Revision 01 of the TSPA-Viability Assessment Technical Basis Document, which provides the technical basis for assumptions and results of the TSPA-Viability Assessment, was issued in November 1998. TSPA-Viability Assessment presents analyses representing the "base-case" parameters and models for the Viability Assessment reference design, as well as sensitivity analyses that examine alternative models and parameter sets.

Other analyses described in the performance assessment include consequence analyses for disruptive events and analyses of alternative engineered barrier system designs. These analyses show which factors, such as waste package corrosion rates and net infiltration rates, have the most influence on dose rate during different time intervals. These results are helping us design a repository that will protect the environment and public health and safety, using the best of today's technology.

Evaluating the Design Against the Four Key Attributes

In the reference design, waste packages would be placed about 1,000 feet below the mountain's surface and about 1,000 feet above the water table. Our studies indicate that, even if future climates are much wetter than today, the mountain is not expected to erode and leave the waste exposed, and the water table is not expected to rise high enough to reach the waste. Nearly all precipitation would run off or evaporate. Once waste packages are placed in the repository, the heat generated from radioactive decay would raise the temperature in the tunnels above the boiling point of water. Using the reference design, our models show that the heat is expected to dry out the surrounding rock and drive any water away for hundreds to thousands of years. However, as the waste decays and the repository cools, some water is expected to seep into the drifts through fractures in the rock and pass through the repository. We estimate that, after the repository cools, about five percent of the packages could experience dripping water, under the current climate. If the climate changes to a wetter long-term average, about 30 percent of the packages could experience dripping water.

The waste package in the Viability Assessment reference design has two layers: a thick outer layer made of carbon steel that provides structural strength and delays any contact of water with the inner layer, and a thinner inner layer of a high-nickel alloy that resists corrosion after the outer layer is penetrated. Preliminary results, utilizing conservative assumptions, indicate that most of the waste packages would last more than 10,000 years, even if water is dripping on them. However, we estimate that dripping water could cause the first penetrations—tiny pinholes—to appear in some waste packages after about 4,000 years. More substantial penetrations could begin to occur about 10,000 years later.

Once water enters a waste package, it would have to penetrate the metal cladding of the spent nuclear fuel to reach the waste. The majority of the commercial spent nuclear fuel is clad in a highly corrosion-resistant metal that is designed to withstand the extreme temperature and radiation environment in the core of an operating nuclear reactor. While current models indicate that it would take thousands of years to corrode cladding sufficiently to allow water to reach the waste and begin to dissolve the radionuclides, estimates of cladding integrity are uncertain. Although the Viability Assessment assumes cladding credit in our performance analyses, we recognize these assumptions will be challenged in the licensing process.

It is expected that most of the waste would not migrate from the package even if it were breached. However, certain long-lived, water-soluble and colloidal radionuclides could move down through about 1,000 feet of rock to the water table. As these radionuclides begin to move down through the rock, we believe some will stick (or adsorb) to the minerals in the rock and be delayed in reaching the water table. After reaching the water table, radionuclides will disperse to some extent in groundwater beneath Yucca Mountain, and the concentrations will be diluted. Eventually, groundwater with varying concentrations of different radionuclides will reach locations down gradient from Yucca Mountain where the water could be withdrawn and consumed.

Improving Implementation of Our Quality Assurance Program

Your staff has expressed serious concerns about the implementation of our Quality Assurance (QA) program. These concerns have been expressed in the reports of the on-site representatives, in letters from your staff, and in face-to-face interactions. Although your staff acknowledges that most QA issues have been self-identified by the DOE, I want to make it perfectly clear that, as we move towards licensing, a Quality Assurance program that is capable of identifying issues but is ineffective at preventing and resolving them in a timely manner is unacceptable. Let me begin by stating unequivocally that we do not disagree with the conclusions of your staff regarding the implementation of what is structurally a sound program. This program's management team is absolutely committed to making the improvements that are required to become a licensee.

To date, in the Viability Assessment, we focused on world-class state-of-the-art science. We recognize, though, that world-class state-of-the-art science alone is not sufficient for a License Application. It must be performed under an NRC approved QA program with necessary processes and documentation. We are working hard to bring that dimension into every scientist's, engineer's, and administrator's daily routine.

During the last fiscal year, we completed the consolidation of our multiple QA programs into one overall DOE QA Program and have made significant progress in integrating the QA functions of the DOE Office of Quality Assurance with those of the Management and Operating contractor. Our QA audit function has been retained solely by DOE and-remains independent of the M&O. Having one QA organization, reporting to the Director of our Office of Quality Assurance who reports directly to me, providing the support to all program participants allows a more consistent approach to implementation and interpretation of the QA program requirements.

At our December 9, 1998 and January 26, 1999 meetings with your staff to discuss Quality Assurance (QA) issues, we identified actions necessary to address the QA deficiencies, many of which are related to technical data, procurement, software, and model development and use. We recognize the need to adopt an integrated approach to resolution as well as prevention of similar deficiencies. To that end, the Program has developed and is implementing our CAR Management Plan and Response to Corrective Action Requests, which identifies the actions already taken as well as those actions planned by the Yucca Mountain Project to effect the needed improvements in our QA implementation.

As you may recall, we were faced with a similar QA Program implementation issue in 1994 as we began to design and then construct the Exploratory Studies Facility. In that case we also needed to improve performance in the engineering work force that was unfamiliar with the nuclear culture and unpracticed in quality assurance processes. We were successful in that transition and we are now taking many of the same steps to effect change in the natural system and performance assessment activities. We recognize the need for comprehensive change in a limited time period, but have the confidence we can again be successful.

We believe that the implementation of the CAR Management Plan will permit us to employ effective corrective actions that will have a high probability of preventing recurrence of the deficiencies. The Program is planning to devote adequate resources to this issue. Accordingly, our Corrective Action Board will provide additional management oversight of the corrective action process. Their objectives are to decrease the overall time for completing corrective actions, to decrease the number of rejected deficiency responses and verifications, to decrease the overall number of open deficiencies, and to ensure integration of corrective actions for similar deficiencies. The Board charter was approved on January 12, 1999, and Board members have been selected.

The formulation and implementation of the Management Plan and the establishment of the Corrective Action Board illustrate our ongoing commitment to achieving full compliance with nuclear quality assurance requirements. We will apply the appropriate level of resources and the highest level of management attention to ensure that performance meets management's expectations as well as the NRC's requirements.

In addition to the actions mandated by our Management Plan and overseen by our Corrective Action Board, it is often appropriate to implement some corrective actions in advance of identification of root causes. For example, the Yucca Mountain Project began providing Regulatory and Licensing training that portrays QA as an integral part of the nuclear culture and a necessary underpinning of the licensing process. The four national laboratories (LANL, LBNL, SNL and LANL) that are supporting our program are being trained on the control and use of scientific notebooks for OCRWM activities. The training is being conducted to promote a better understanding of the purpose and objectives of scientific notebooks in our program and the rigor of scientific notebook documentation to ensure traceability of our work.

With regard to data qualification, we are verifying the documentation supporting the status of qualified data and identifying existing, non-qualified data that will be directly relied on in the License Application and must be qualified. Our ongoing Process Validation and Re-engineering (PVAR) initiative will permit us to develop and implement an interdependent project infrastructure that conforms to project requirements and provides defensibility, traceability, reproducibility, and retrievability for products and information used in the Environmental Impact Statement, Site Recommendation and License Application. Once the PVAR initiative is complete, the program will have: reviewed and verified work processes; developed a set of integrated work procedures; established an integrated training curriculum supporting the procedures; and created an implementation plan specifying our approach as well as individual roles and responsibilities.

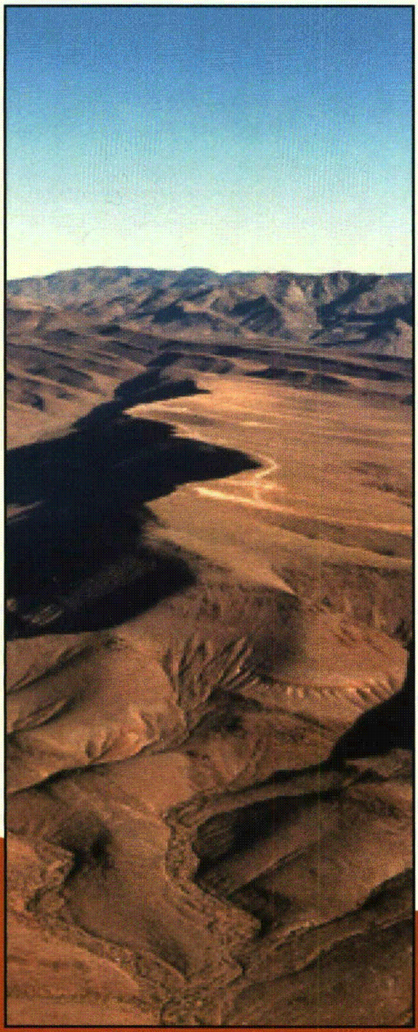
DOE considers improvements in the implementation of the QA Program to be of paramount importance. As our program moves beyond just world-class science and our QA performance improves, the Project expects to enhance its ability to respond to deficiencies and to promptly identify the root causes and implement the appropriate corrective action to prevent recurrence. We intend to routinely communicate our progress to NRC staff, and we are looking forward to briefing the staff on the status of implementation of the Management Plan and results achieved to date when we meet in April.

Conclusion

The Program is reaching the conclusion of our site characterization efforts. The Viability Assessment clarified the remaining work required and identified those technical issues that should be addressed prior to determining the suitability of the site. We are addressing those issues and have commenced work on assembling the information required to support national decisions on geologic disposal at Yucca Mountain.

In closing, I would like to note that since I last addressed the Commission, our organizations have interacted frequently and have made progress in a number of areas. The valuable efforts of your staff have resulted in tough, but fair critique and have stimulated positive change. I hope that we can continue to build on this progress as we move forward. We intend to keep you and your staff apprised of our progress and look forward to a constructive dialogue as we carry out our mutual responsibilities.

Thank you for the opportunity to brief the Commission. I would be happy to answer any questions you may have.



Viability Assessment of a Repository at Yucca Mountain

Overview

U.S. Department of Energy

Office of Civilian Radioactive Waste Management

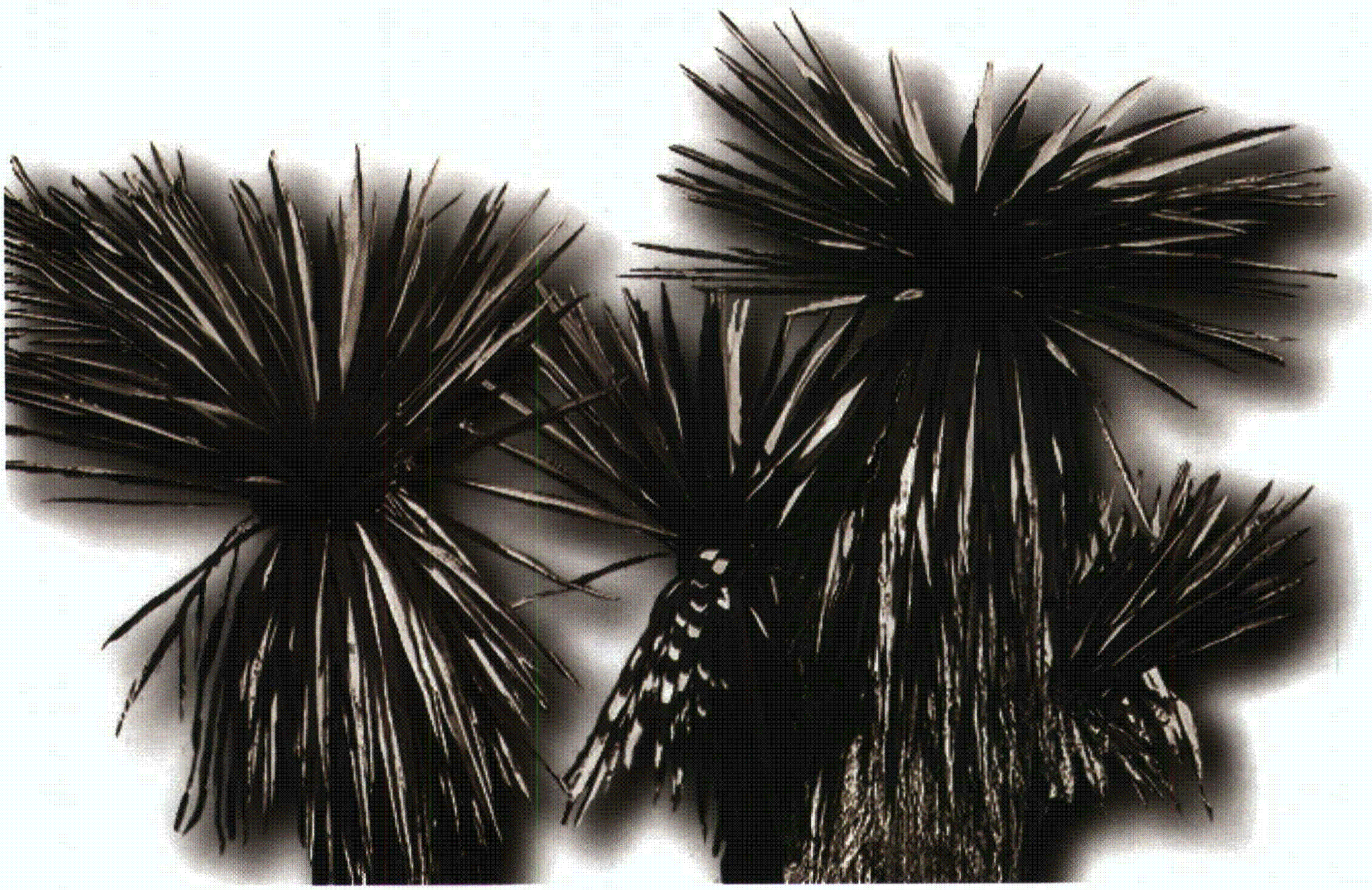
DOE/RW-0508

DOE/RW-0508

Viability Assessment of a Repository at Yucca Mountain

Overview

December 1998



U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office

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For further information contact:
U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

or call:
Yucca Mountain Information Center
1-800-225-6972

or visit:
Yucca Mountain Site Characterization Project website
http://www.ymp.gov

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Contents

The Viability Assessment

The U.S. Department of Energy (DOE) has been studying a site at Yucca Mountain, Nevada, for more than 15 years to determine whether it is a suitable place to build a geologic repository for the nation's commercial and defense spent nuclear fuel and high-level radioactive waste. This overview presents the results of DOE's study to date.

In 1996, DOE announced that it would complete in 1998 a viability assessment of the Yucca Mountain site that would describe the following:

- The preliminary design concept for the critical elements of a repository and waste package
- A total system performance assessment, based on the design concept and the scientific data and analyses available by 1998, that describes the probable behavior of a repository in the Yucca Mountain geologic setting
- A plan and cost estimate for the remaining work required to complete and submit a license application to the Nuclear Regulatory Commission
- An estimate of the costs to construct and operate a repository in accordance with the design concept

In the 1997 Appropriations Act,[1] Congress required DOE to prepare the viability assessment.

The purpose of the viability assessment is to provide Congress, the President, and the public with information on the progress of the Yucca Mountain Site Characterization Project. The assessment also identifies the critical issues that need to be addressed before a decision can be made by the Secretary of Energy on whether to recommend the Yucca Mountain site for a repository.

This overview of the *Viability Assessment of a Repository at Yucca Mountain* describes the nuclear waste problem and explains why the United States and other nations are considering deep geologic disposal as the solution. The overview describes why the United States is considering Yucca Mountain and how a monitored geologic repository would work in the mountain. It presents a repository design, an assessment of its expected performance, and an evaluation of the possible effects on people living near Yucca Mountain. Also presented is the work remaining to be completed prior to a license application, along with the estimated cost of building and operating a geologic repository at Yucca Mountain. Finally, based on the information in the viability assessment, the overview concludes with DOE's assessment of whether work at Yucca Mountain should proceed.

Results in brief

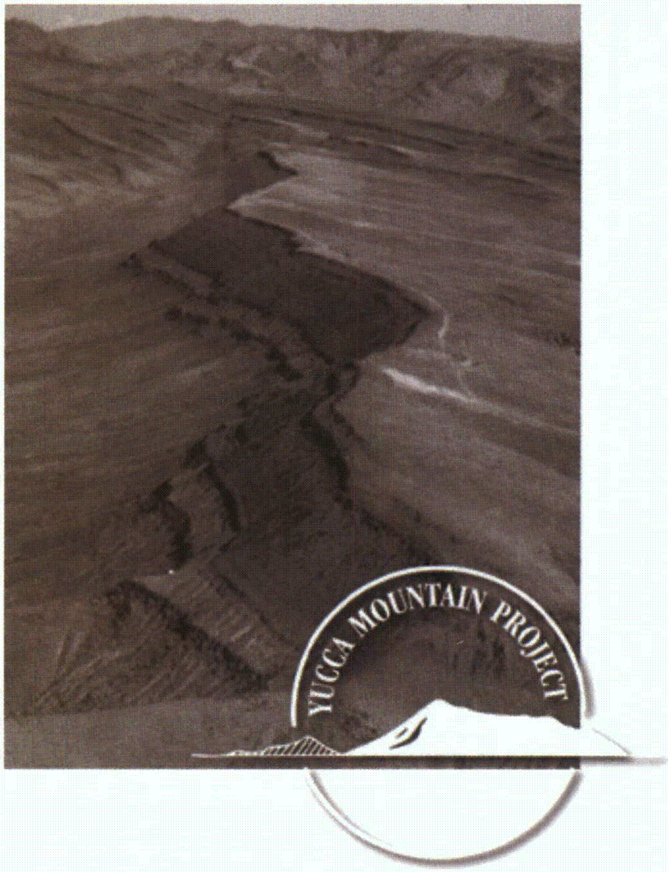
Based on the viability assessment, DOE believes that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository. For the site to be recommended, DOE needs to demonstrate that a repository can be designed and built at Yucca Mountain that would protect public health and safety and the environment for thousands of years. Uncertainties remain about key natural processes, the preliminary design, and how the site and design would interact. To address these uncertainties, DOE plans to advance the design, complete critical tests and analyses, and prepare draft and final environmental impact statements. When this work is completed in 2001, a decision will be made by the Secretary of Energy on whether to recommend the site to the President.

The advantages of Yucca Mountain as a potential repository site include its location, semiarid climate, and deep groundwater table.

- Yucca Mountain is about 100 miles northwest of Las Vegas, Nevada, on unpopulated land owned by the Federal Government and adjacent to the Nevada Test Site. More than 900 nuclear weapons tests have been conducted at the Nevada Test Site.

- Water is the primary means by which radioactive elements (radionuclides) could be transported from a repository. Yucca Mountain is located in a desert environment, with an average rainfall of about 7 inches per year.

- The nearest groundwater, which is about 1,000 feet below the planned location of the repository, is isolated in a closed regional basin and does not flow into any rivers that reach the ocean. This closed basin feature is unique to the western region of the country.



The preliminary repository design includes a long-lived waste package and takes advantage of the desert environment and geologic features of Yucca Mountain. Together, the natural and engineered barriers can keep water away from the waste for thousands of years. Analyses of the preliminary design using mathematical models, though subject to uncertainties, indicate that public health and the environment can be protected.

- For 10,000 years after the repository is closed, people living near Yucca Mountain are expected to receive little or no increase in radiation exposure.

- The maximum radiation exposure from the repository is expected to occur after about 300,000 years. People living approximately 20 kilometers (12 miles) from Yucca Mountain at that time might receive additional radiation exposures equivalent to present-day background radiation.

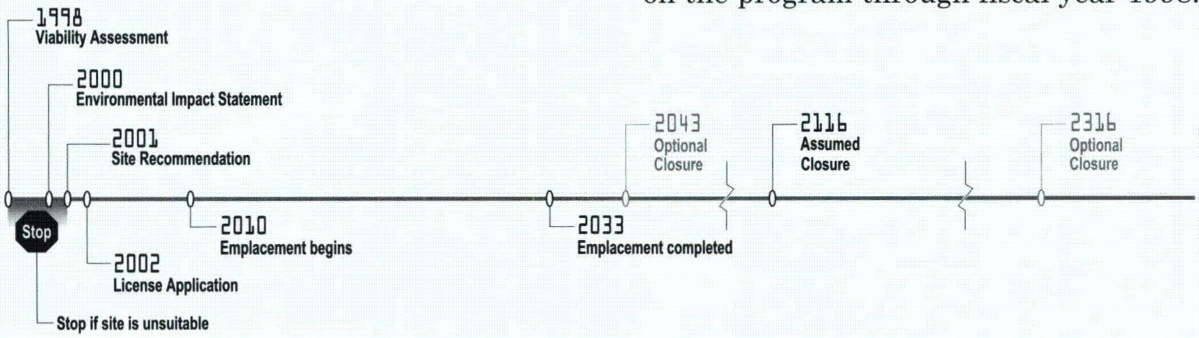
Although current assessments of repository performance are encouraging, more work is needed before the site can be recommended and a license application for construction of a repository can be submitted to the Nuclear Regulatory Commission (NRC).

Current schedules anticipate that the Secretary of Energy will decide whether to recommend the site to the President in 2001, after considering the views of States, affected Indian tribes, and NRC, as required by the Nuclear Waste Policy Act. In turn, the President will decide whether to recommend the site to Congress. If Congress agrees with the President's recommendation and the site is designated, DOE would submit to NRC in 2002 a license application for construction authorization. To support these plans, DOE will:

- Obtain more information on key natural processes, including how radionuclides could be transported by groundwater beneath the repository
- Test the performance of candidate waste package materials and evaluate alternative repository designs
- Continue analyzing the interaction between the repository and the natural processes
- Prepare an environmental impact statement, publish it for public comment in 1999, and finalize it in 2000

These tasks will cost approximately $1.1 billion to complete. If the site is suitable and DOE submits a license application in 2002, the estimated cost to successfully complete the licensing process, build a licensed repository, emplace the waste, and monitor and close the repository is approximately $18.7 billion, in constant 1998 dollars. Given adequate funding and successful completion of the licensing process, the first waste could be emplaced in a repository in 2010, and the last waste, in 2033. With NRC approval, a repository could be closed and sealed as early as 10 years after the last waste is emplaced; or it could be kept open and actively monitored for hundreds of years, if it appears desirable to do so. The $18.7 billion cost estimate assumes a monitoring period of 100 years, beginning with initial waste emplacement. The repository is being designed to allow future generations to decide how long the repository should be monitored, and whether and when to close and seal it.

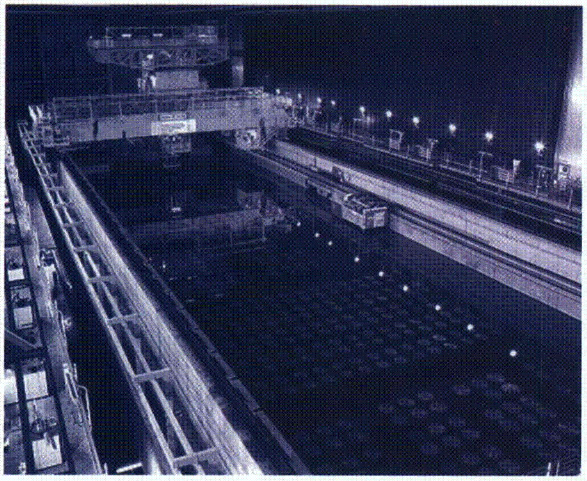
A monitored geologic repository is one component of a total waste management system. The total estimated future cost to complete the program, including transportation of waste and storage at the repository, is $36.6 billion, in constant 1998 dollars. This includes costs from 1999 through closure and decommissioning, assumed to begin in 2110 and to be completed in 2116. It does not include $5.9 billion that has been spent on the program through fiscal year 1998.



Schedule for major repository milestones

The nuclear waste problem

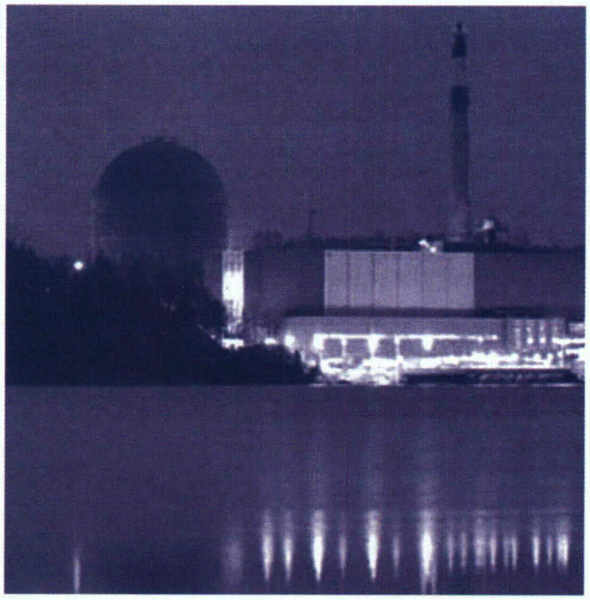
Countries worldwide have accumulated high-level radioactive waste by using nuclear materials to produce electricity, to power naval vessels, and to make nuclear weapons. Some elements of this waste are hazardous for a few years to several hundred years; some elements are hazardous for many thousands of years. This waste must be safely contained until it no longer poses a significant risk to human health and the environment.[2]



Storage pool for commercial spent nuclear fuel

Commercial spent nuclear fuel

As of December 1998, the United States had accumulated 38,500 metric tons of used or "spent" nuclear fuel from commercial nuclear power plants; this amount could more than double by the year 2035 if all currently operating plants complete their initial 40-year license period. The spent fuel is now stored in 33 states at 72 power plant sites and one commercial storage site and is likely to remain where it is until a disposal or central storage facility is constructed. When a power plant ceases operations, the spent nuclear fuel and other radioactive materials must be removed before the plant can be fully decommissioned and the site used for other purposes.



Indian Point Nuclear Power Plant, Buchanan, NY

DOE spent nuclear fuel

By 2035, the United States will have accumulated approximately 2,500 metric tons of spent nuclear fuel from reactors that produce materials for nuclear weapons, from research reactors, and from reactors on the Navy's nuclear-powered ships and submarines. The majority of DOE spent nuclear fuel is currently stored at three major sites in Idaho, South Carolina, and Washington. Under a negotiated settlement agreement between the State of Idaho, the Navy, and DOE, all spent fuel must be removed from Idaho by the year 2035.[3]

F Area Tank Farm at Savannah River Site, near Aiken, SC

High-level radioactive waste

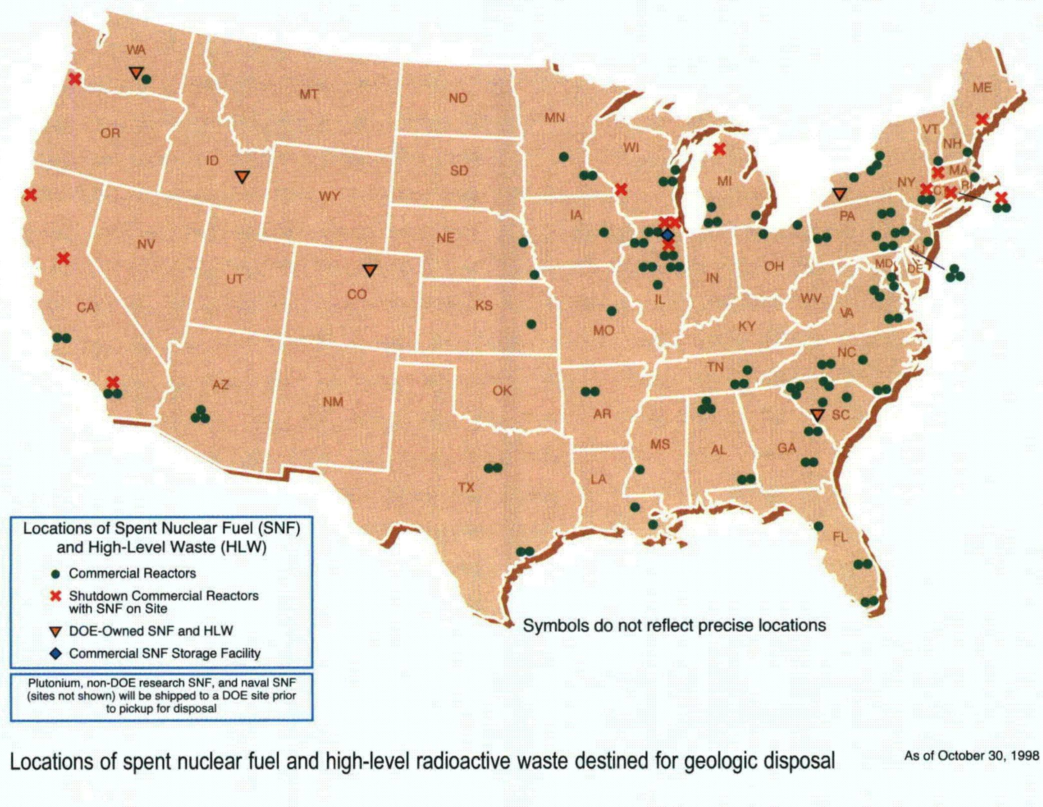
The production of nuclear weapons has left a legacy of high-level radioactive waste that was created when spent nuclear fuel was treated chemically to separate uranium and plutonium. The remaining high-level waste is in liquid and solid forms; 100 million gallons are stored in underground tanks in Washington, South Carolina, Idaho, and New York.[4] Under agreements between DOE and the states where the waste is stored, this high-level waste will continue to be solidified and placed in about 20,000 canisters for future disposal in a permanent geologic repository.

Surplus plutonium and other nuclear weapons materials

The end of the Cold War has brought the problem of cleaning up and closing weapons plants that are no longer needed and disposing of surplus plutonium and other nuclear materials associated with weapons production. These radioactive materials must be disposed of in a secure facility that will not only keep the waste away from people but will also keep people away from the weapons-usable material for thousands of years. Ensuring national security and preventing the proliferation of nuclear weapons depends on developing a permanent, safe, and secure disposal facility for surplus plutonium and other weapons materials.

Total inventory

At present, spent nuclear fuel and high-level radioactive waste are temporarily stored at 78 locations in 35 states, as shown below. Some of these storage sites are close to population centers and are located near rivers, lakes, and seacoasts. The stored materials, if left where they are indefinitely, could become a hazard to nearby populations and the environment. These nuclear materials require safe and permanent disposal.



Locations of spent nuclear fuel and high-level radioactive waste destined for geologic disposal

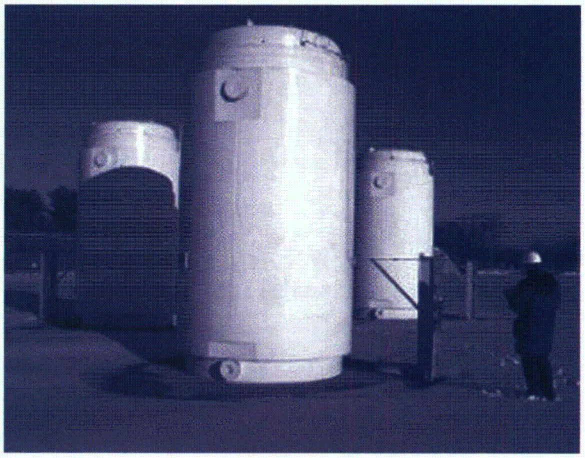
As of October 30, 1998

Geologic disposal

Geologic disposal of radioactive waste has been the focus of scientific research for more than 40 years. As early as 1957, a National Academy of Sciences' report to the Atomic Energy Commission recommended burying radioactive waste in geologic formations.[5] In 1962, the Atomic Energy Commission began investigating salt formations, including bedded salt and salt domes, as potential host rock for repositories. In 1975, the Energy Research and Development Administration, predecessor to DOE, selected a site near Carlsbad, New Mexico, for the Waste Isolation Pilot Project, which is to dispose of transuranic waste. In 1976, the Energy Research and Development Administration also began to investigate other geologic formations and to consider different disposal concepts, including deep-seabed disposal, disposal in the polar ice sheets, and rocketing waste into the sun. After extensive evaluation of the options, DOE concluded in 1981 that disposal in an underground mined geologic repository remained the preferred option.[6]

Unlike the hazards of toxic materials such as lead, mercury, and arsenic, which do not break down, the hazard of radioactive materials declines over time. Early efforts to study disposal options, therefore, sought to find the most effective ways for available technology to isolate waste long enough for the hazard to decline to low levels. That search led to geologic environments that have remained stable for millions of years and are likely to remain so. Scientists widely agreed that waste packaged in robust, long-lived waste packages and placed deep in such stable geologic environments could be isolated from the biosphere for the long time periods necessary.

Since the first scientific study in 1957, virtually every expert group that has looked at the nuclear waste problem has agreed that a geologic repository is the best approach for nuclear waste disposal. A panel of the National Academy of Sciences noted in 1990 that there is "a worldwide scientific consensus that deep geological disposal, the approach being followed by the United States, is the best option for disposing of high-level radioactive waste."[7]



Dry cask storage of commercial spent nuclear fuel

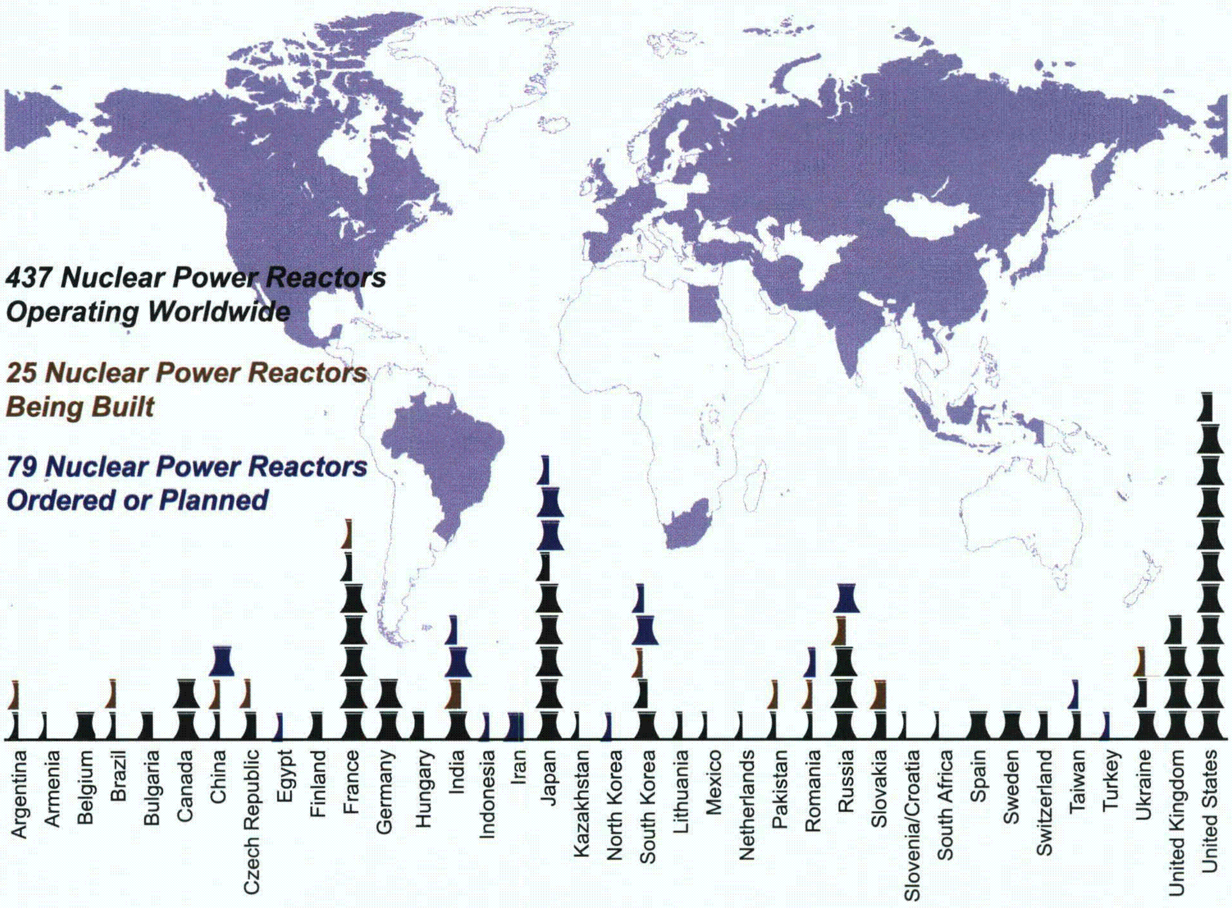
However, there are differing views on how rapidly waste should be disposed of and whether it should be disposed of irreversibly. Some argue that waste should be stored for several generations to allow scientists to learn more about geologic disposal and to take advantage of new and better technologies that may come along. That would keep all options open for future generations. But it would also require them to bear all the costs of exercising those options.

One way to preserve these options and still provide a permanent solution is to dispose of waste in a manner that permits, but does not require, the retrieval of waste; the waste would be disposed of, but not irreversibly. The Nuclear Waste Policy Act of 1982 [8] requires that spent nuclear fuel emplaced in a repository be retrievable for any reason pertaining to public health and the environment, or to permit recovery of the potentially valuable contents of the spent fuel prior to permanent closure of a repository.

Nuclear Regulatory Commission (NRC) regulations require that a geologic repository be designed for waste retrieval at any time up to 50 years after waste emplacement begins.[9]

The DOE is designing a monitored geologic repository at Yucca Mountain that could give future generations the choice of closing and sealing the repository as early as allowable under NRC regulations, or of keeping it open and monitoring it for hundreds of years.

A geologic repository will not require perpetual human care and will not rely on the stability of society for thousands of years into the future. It will rely instead on geologic formations that have remained relatively stable for millions of years and on long-lived engineered barriers.



Worldwide status of nuclear power reactors. In the United States, 104 operating reactors produce 20 percent of the nation's electricity. Worldwide data is from the files of the Australian Nuclear Science and Technology Organisation, based on information as of June 5, 1998.

The law and the regulations

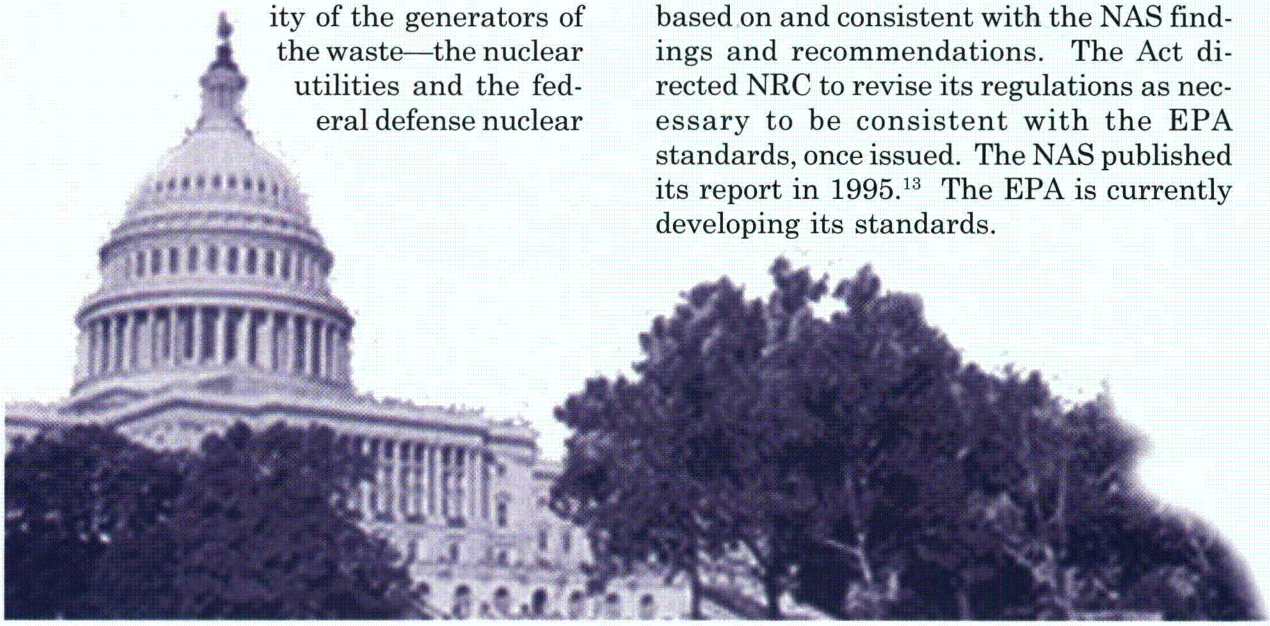
The Nuclear Waste Policy Act of 1982 (NWPA) directed DOE to develop a system for the safe and final disposal of spent nuclear fuel and high-level radioactive waste.

The NWPA set an ambitious schedule for DOE to site two geologic repositories and required DOE to contract with utilities to begin disposal in the first one by January 31, 1998. The DOE formally identified nine potentially acceptable sites across the nation and later narrowed the list to three sites: Deaf Smith County, Texas; Hanford, Washington; and Yucca Mountain, Nevada. In 1987, Congress directed DOE to study only one of the sites—the one at Yucca Mountain—to decide whether it is suitable for a repository. This legislation, known as the Nuclear Waste Policy Amendments Act of 1987,[10] also established the Nuclear Waste Technical Review Board, composed of experts appointed by the President to review the DOE program.

The NWPA reaffirms the Federal Government's responsibility for developing repositories for the permanent disposal of spent nuclear fuel and high-level radioactive waste. It also affirms the responsibility of the generators of the waste—the nuclear utilities and the federal defense nuclear program—to pay for that effort. The NWPA requires utilities with nuclear power plants to pay a fee to fund the disposal program. The Federal Government bears the costs of disposing of defense waste.

The NWPA also assigns distinct roles to the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC). The EPA is required to establish standards for protection of the general environment from releases of radioactive material from a repository. The NRC is responsible for establishing technical requirements and criteria, consistent with EPA standards, for approving or disapproving applications to construct, operate, and eventually close a repository. In 1981 and 1983, NRC issued regulations for a geologic repository in anticipation of EPA standards.[11]

Subsequently, the Energy Policy Act of 1992[12] modified the process for setting environmental standards for a repository at Yucca Mountain. The Act directed the National Academy of Sciences (NAS) to provide findings and recommendations on these standards and directed EPA to issue standards for the Yucca Mountain site based on and consistent with the NAS findings and recommendations. The Act directed NRC to revise its regulations as necessary to be consistent with the EPA standards, once issued. The NAS published its report in 1995.[13] The EPA is currently developing its standards.



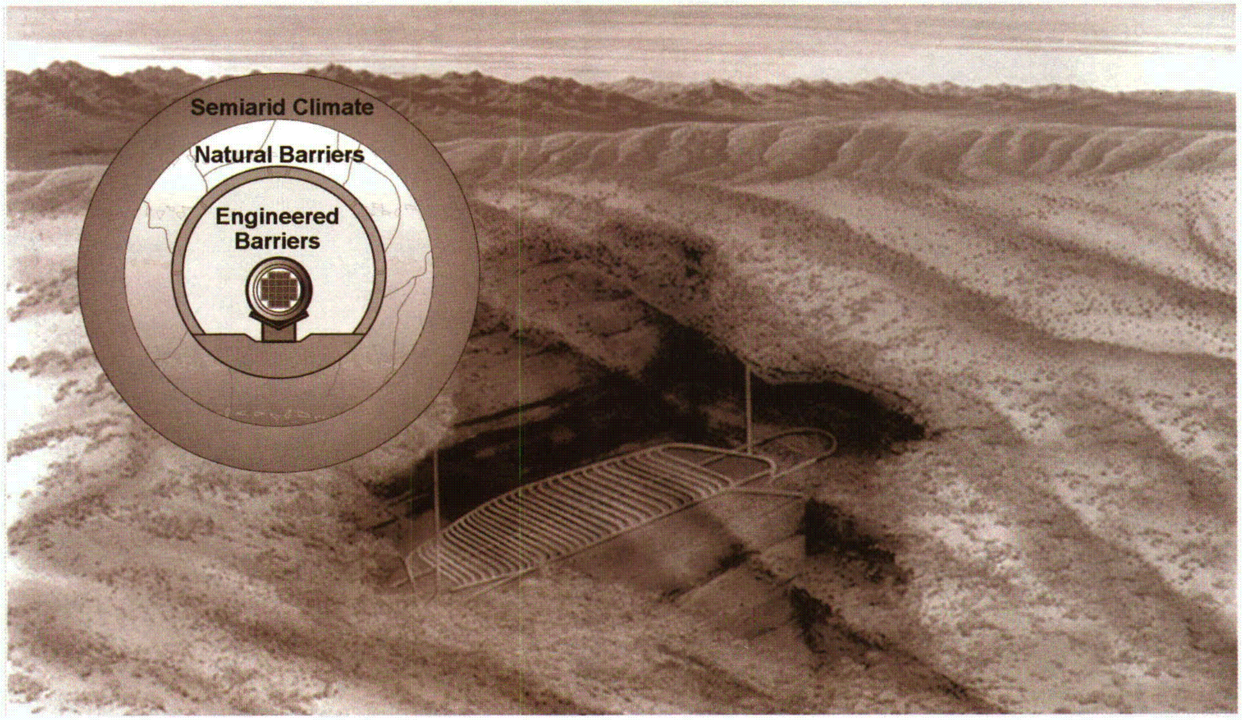
How geologic disposal would work

The basic concept of geologic disposal is to place carefully prepared and packaged waste in excavated tunnels in geologic formations such as salt, hard rock, or clay. The concept relies on a series of barriers, natural and engineered, to contain the waste for thousands of years and to minimize the amount of radioactive material that may eventually be transported from a repository and reach the human environment.

Water is the primary means by which radionuclides could reach the human environment. Therefore, the primary functions of the barriers are to keep water away from the waste as long as possible, to limit the amount of water that finally does contact the waste, to slow the release of radionuclides from the waste, and to reduce the concentrations of radionuclides in groundwater.

All countries pursuing geologic disposal are taking the multibarrier approach, though they differ in the barriers they emphasize. The German disposal concept, for example, relies heavily on the geologic barrier, the rock salt formation at the prospective disposal site. The Swedish method, on the other hand, relies heavily on thick copper waste packages to contain waste.

The U.S. approach, as recommended in the 1979 Report to the President by the Interagency Review Group on Nuclear Waste Management,[14] is to design a repository in which the natural and engineered barriers work as a system, so that some barriers will continue to work even if others fail, and so that none of the barriers is likely to fail for the same reason or at the same time. This design strategy is called defense in depth. The barriers include the chemical and physical forms of the waste, the waste packages and other engineered barriers, and the natural characteristics of Yucca Mountain.



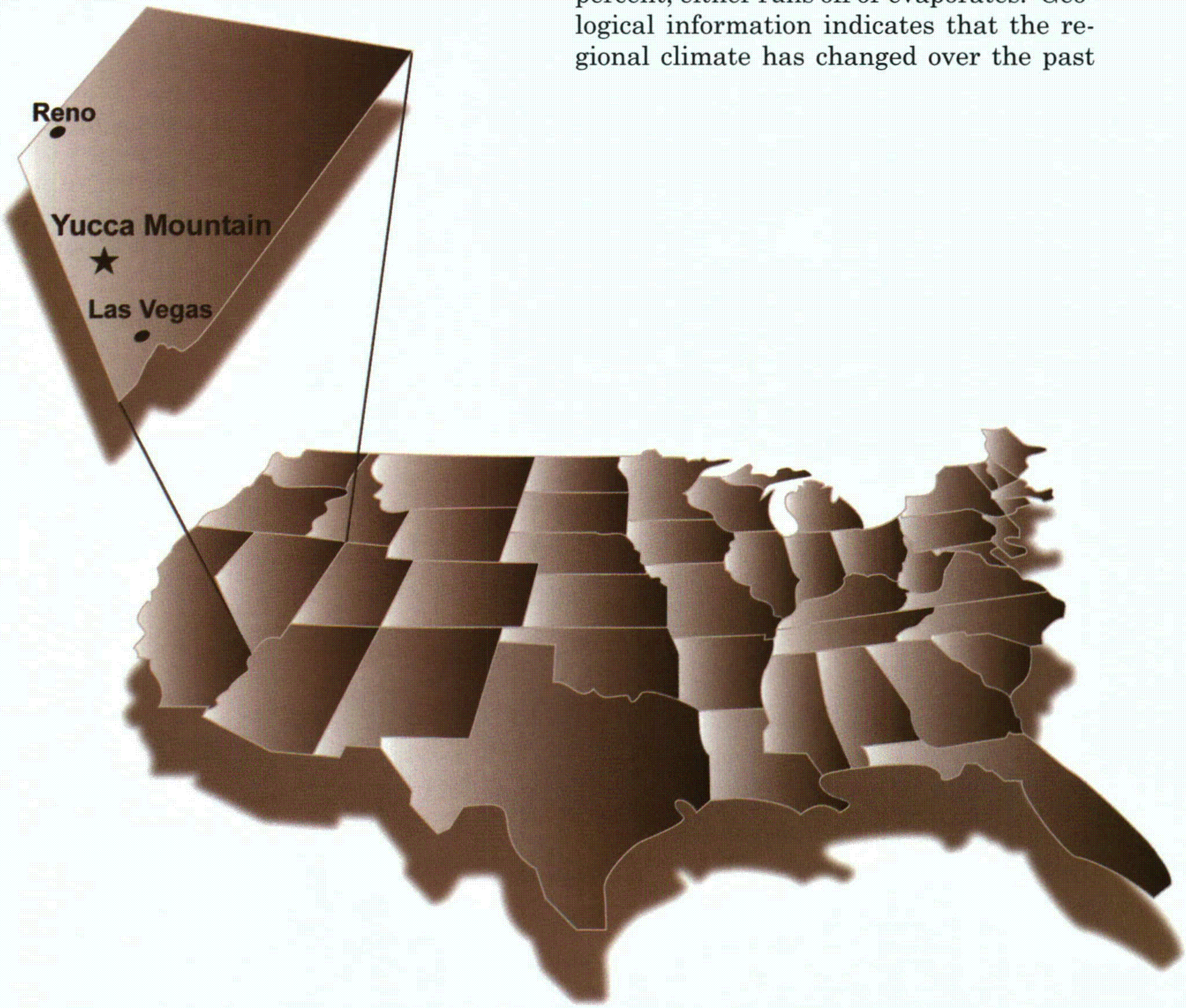
Cutaway showing artist's concept of the complex of underground tunnels into which waste would be emplaced. A repository at Yucca Mountain would rely on the semiarid climate, natural barriers, and engineered barriers to contain and isolate waste for thousands of years.

Why Yucca Mountain?

Yucca Mountain is remote from population centers. Located about 100 miles northwest of Las Vegas, Nevada, Yucca Mountain is on the edge of the nation's nuclear weapons test site, where more than 900 nuclear tests have been conducted. This unpopulated land is owned by the Federal Government.

Yucca Mountain provides a stable geologic environment. A flat-topped ridge running six miles from north to south, Yucca Mountain has changed little over the last million years. Based upon what is known about the site, disruption of a repository at Yucca Mountain by volcanoes, earthquakes, erosion, or other geologic processes and events appears to be highly unlikely.

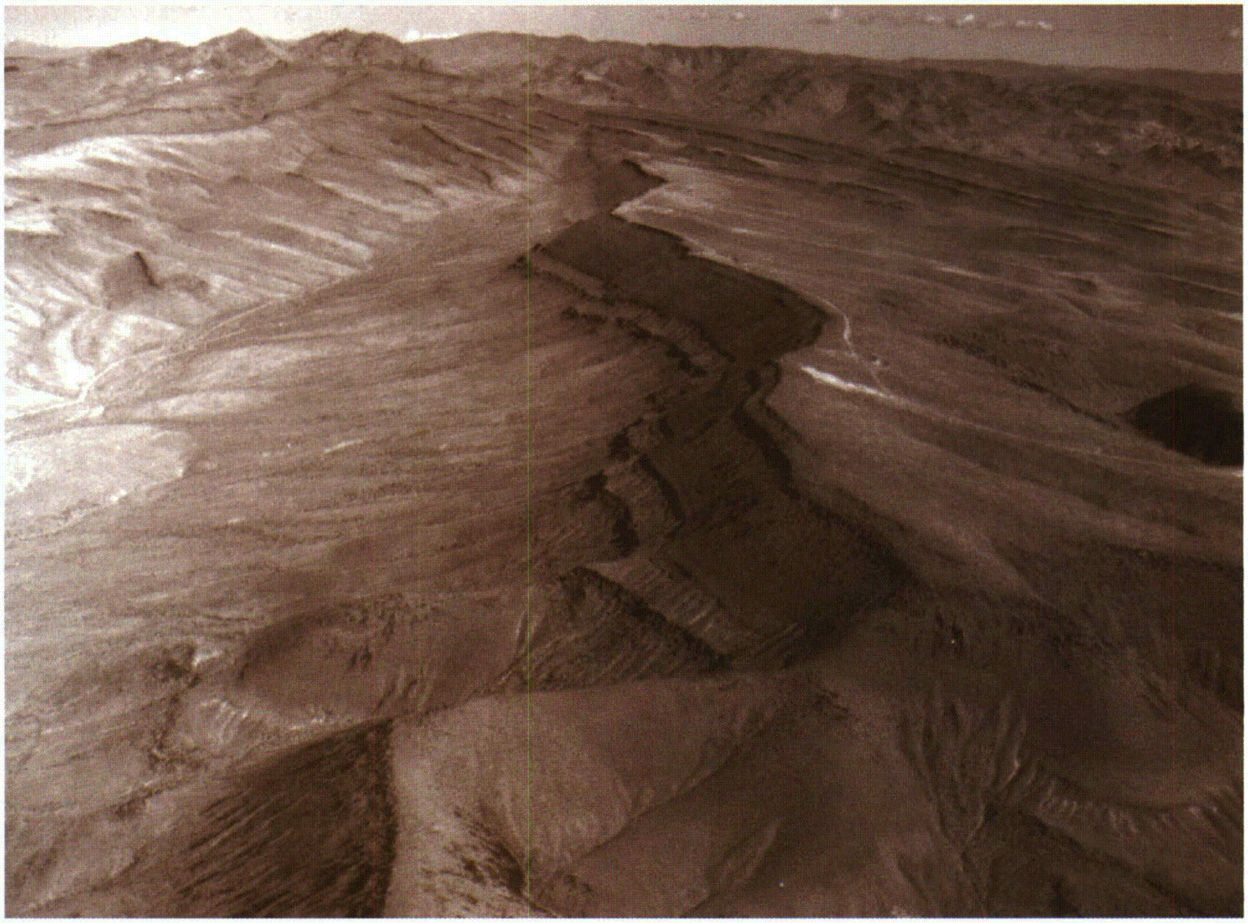
Yucca Mountain has a desert climate. This is important because water movement is the primary means by which radioactive waste could be transported from a repository. On average, Yucca Mountain currently receives about seven inches of rain and snow per year. Nearly all the precipitation, about 95 percent, either runs off or evaporates. Geological information indicates that the regional climate has changed over the past



Location of the proposed monitored geologic repository at Yucca Mountain, Nevada million years and the long-term average precipitation has been about 12 inches per year—comparable to that of present-day Santa Fe, New Mexico. Even if this were to be the case in the future, most of the water would run off or evaporate rather than soak into the ground and possibly reach the repository.

A repository would be built about 1,000 feet below the surface and 1,000 feet above the water table in what is called the unsaturated zone. The water table is about 2,000 feet beneath the crest of Yucca Mountain. Any precipitation that does not run off or evaporate at the surface would have to seep down nearly 1,000 feet before reaching the repository. Between the repository and the water table, it would have to move through another 1,000 feet of the unsaturated zone before reaching the water table. The groundwater in the region is trapped within a closed desert basin and does not flow into any rivers that reach the ocean.

The concept of disposing of waste in the unsaturated zone in the desert regions of the Southwest was first advanced by the U.S. Geological Survey in the 1970s. In 1976, the director of the Geological Survey suggested that the region in and around the Nevada nuclear weapons test site offered a variety of geologic formations and other attractive features, including remoteness and an arid climate.[15] In 1981, a Geological Survey scientist noted that the desert Southwest has water tables that are among the deepest in the world and that the region contains multiple natural barriers that could isolate wastes for "tens of thousands to perhaps hundreds of thousands of years."[16]



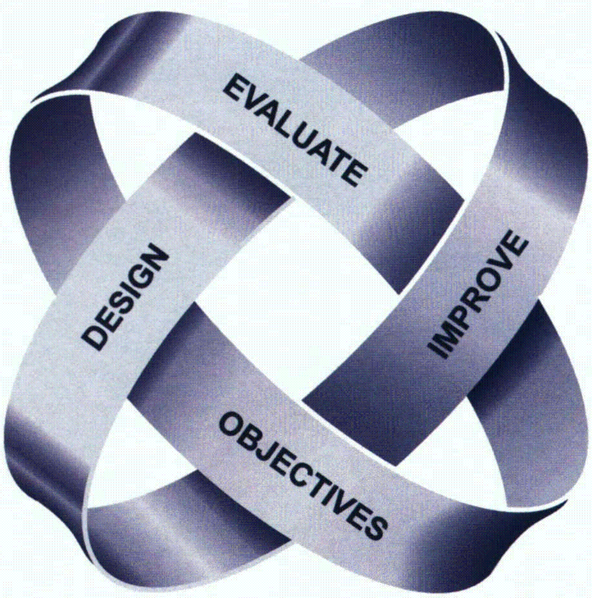
View of Yucca Mountain from the south

The design process

Designing a repository is an iterative process. The process begins with defining the primary design objectives: protecting the health and safety of both the workers and the public during the period of repository operations; minimizing the amount of radioactive material that may eventually reach the accessible environment; and keeping costs down to an acceptable level.

To achieve the design objectives, engineers work with scientists to design the man-made components of a repository to work effectively with the natural system. The engineered barriers are intended to work with the natural barriers—the geology and climate of Yucca Mountain—to contain and isolate waste for thousands of years. The waste package design, for example, includes materials that are chosen to be compatible with the underground thermal and geochemical environment, and the layout of tunnels takes into consideration the geology of the mountain.

Through successive evaluations and improvements, the repository design has evolved to the current reference design. The reference design represents a snapshot of the ongoing design process, thus providing a frame of reference to describe how a repository at Yucca Mountain could work. The repository design also offers insights about how to reduce uncertainty and modify the design to improve its performance. Improvements are expected to continue as more work is completed and more information about the site is obtained.



A conceptual model of the design process. Design objectives for repository components are identified, and then the designs are developed, evaluated, and improved.

The reference design

In the current reference design, spent nuclear fuel and high-level radioactive waste would be transported to Yucca Mountain by truck or rail in specially designed, shielded shipping containers licensed by the Nuclear Regulatory Commission; removed from the shipping containers and placed in long-lived waste packages for disposal; carried into the underground repository by rail cars; placed on supports in the tunnels; and monitored until the repository is finally closed and sealed.

Surface facilities and operations

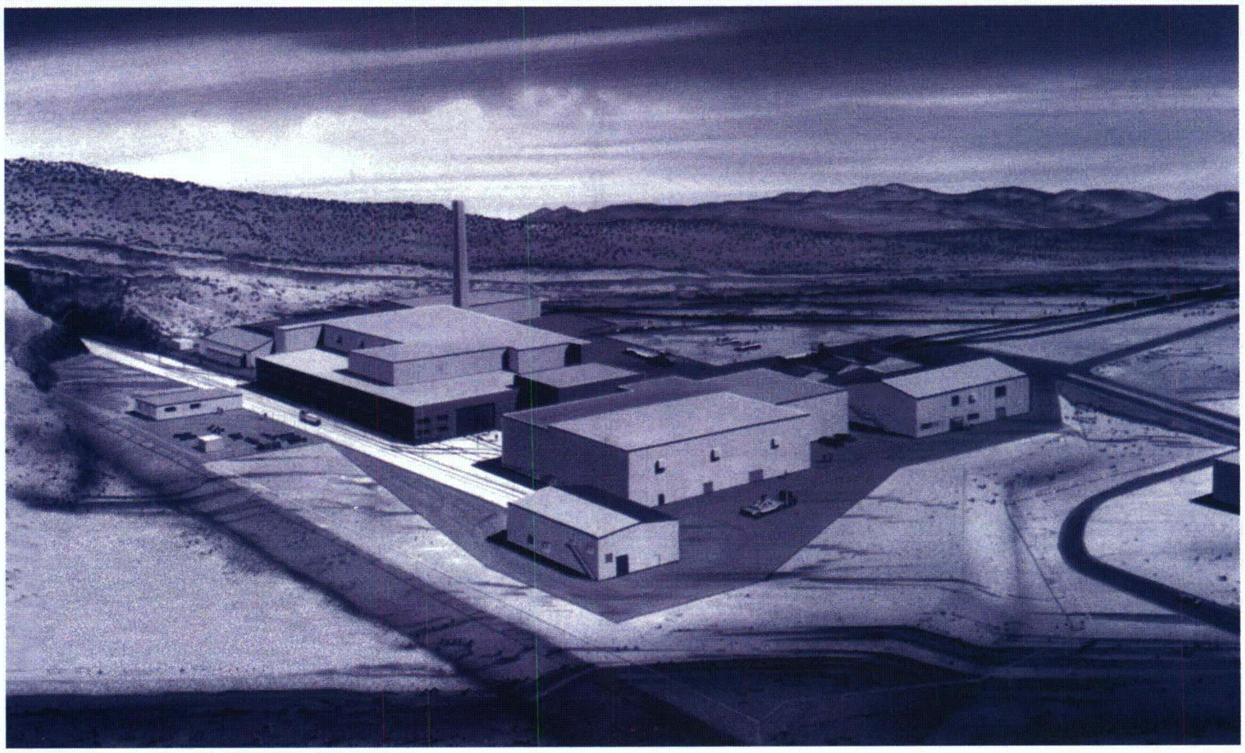
Surface facilities would be designed to receive the waste and prepare it for final disposal, and to support the excavation, construction, loading, and ventilation of the repository tunnels. The entire surface layout would cover about 100 acres and have three main areas:

- At the north entrance to the underground repository would be the facilities and equipment to transfer waste from shipping containers to waste packages. Each waste package would be welded closed and thoroughly checked before being loaded onto a shielded transporter to be taken underground.

- At the south entrance would be the facilities to support the excavation and construction of the tunnels.

- Near the top of the mountain would be the facilities that house the air intake and exhaust fans for ventilating the repository.

Workers would be shielded from direct exposure to radiation and contamination because waste would be handled remotely.



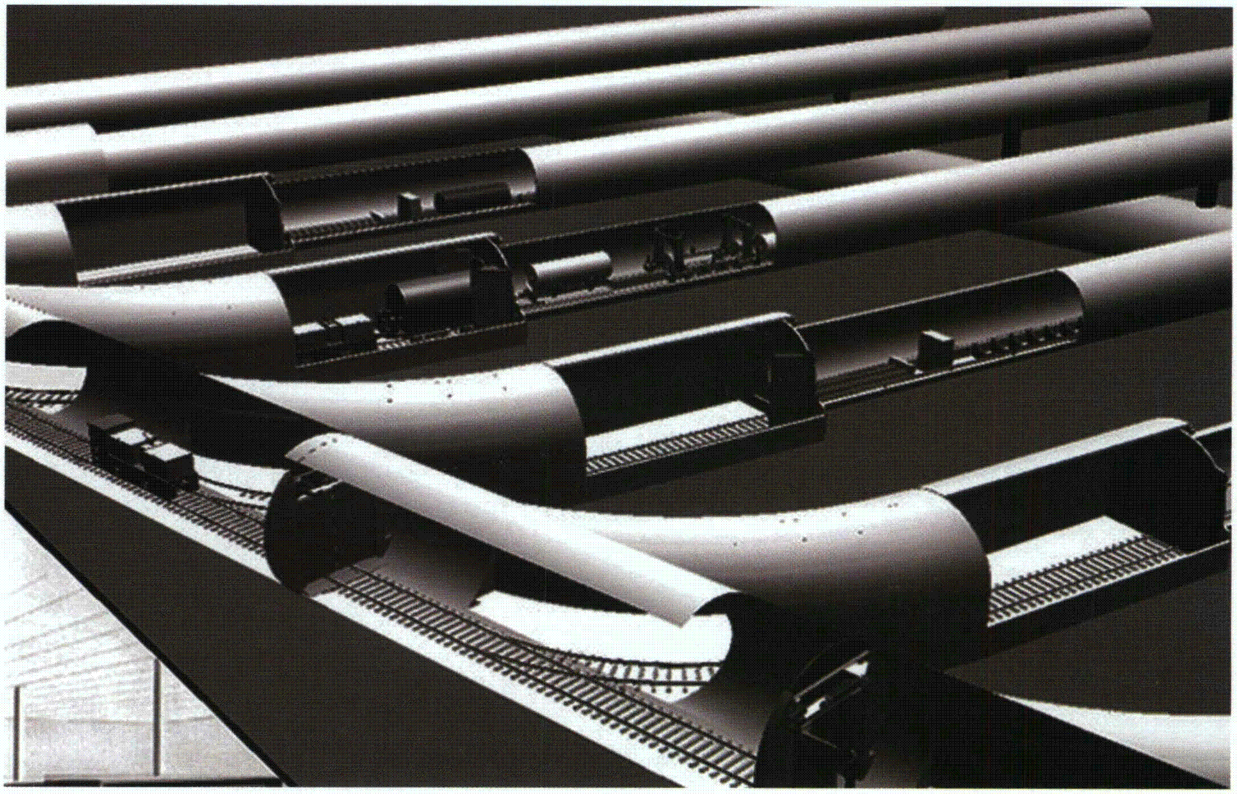
Artist's concept of repository surface facilities

Underground facilities and operations

The underground repository would consist of about 100 miles of tunnels. The main tunnels would be designed for moving workers, equipment, and waste packages. Ventilation tunnels would provide air for workers. The emplacement tunnels (or drifts) would accommodate the waste packages. Two gently sloping access ramps and two vertical ventilation shafts would connect the underground and surface areas.

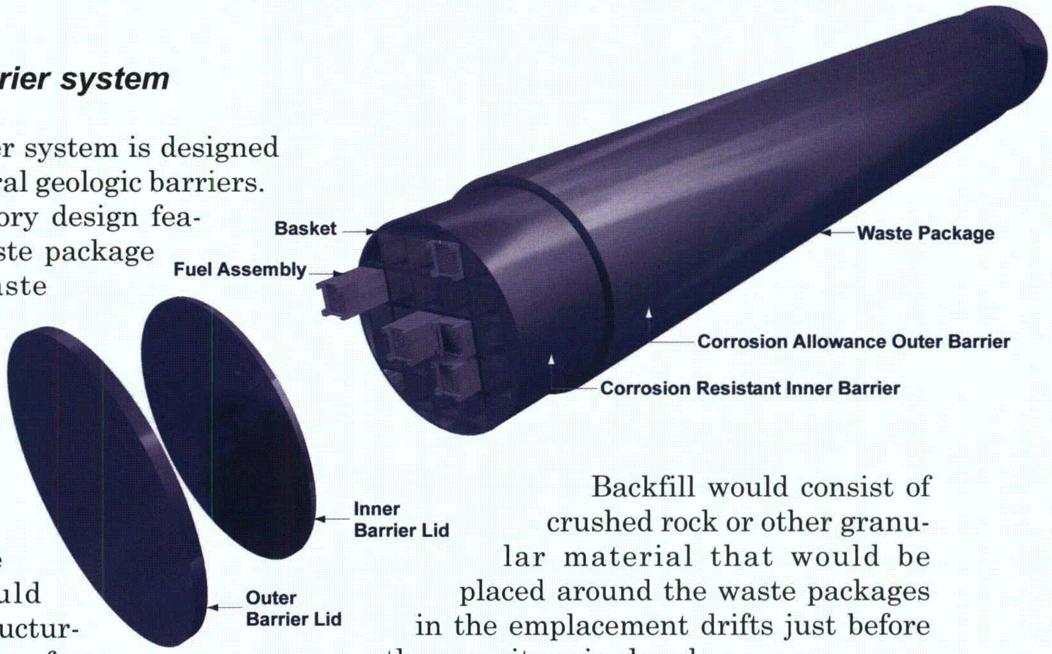
Transportation underground would be by rail. A locomotive would haul the shielded transporter with its waste package underground from the waste-handling building to the entrance of an emplacement drift. Then a remotely operated crane (or gantry) would lift the waste package, carry it along the drift, and lower it onto its supports.

Current schedules anticipate that waste emplacement would begin in 2010 if a license is received from the Nuclear Regulatory Commission, after construction of surface facilities, the main tunnels, ventilation system, and initial emplacement drifts. Additional drifts would be constructed over a period of about 20 years while waste is being emplaced. The current design would accommodate 70,000 metric tons of waste, a limit imposed by the Nuclear Waste Policy Act of 1982. However, the site is large enough to accommodate additional waste, if that were authorized.



Artist's concept of repository underground facilities and operations

The engineered barrier system



The engineered barrier system is designed to work with the natural geologic barriers. The reference repository design features a long-lived waste package and includes the waste form, the concrete tunnel floor (or invert), and the steel and concrete support for the waste package.

The current waste package design would have two layers: a structurally strong outer layer of carbon steel nearly four inches thick, and a corrosion-resistant inner layer of a high-nickel alloy about three-fourths of an inch thick. These two layers would work together to preserve the integrity of the waste package.

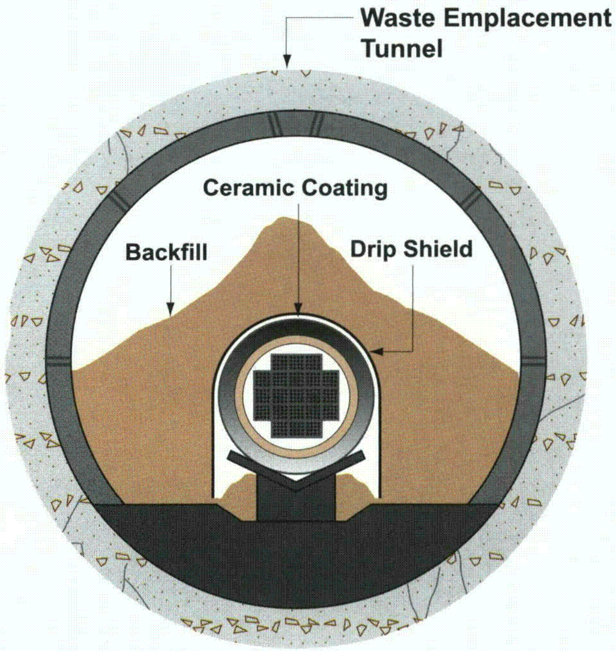
The waste forms inside the waste package would provide additional barriers against transport of radionuclides away from the repository. Most spent nuclear fuel is encased in Zircaloy, a metal cladding that is highly resistant to corrosion. Defense high-level radioactive waste would be solidified as glass inside stainless steel canisters.

As the design process continues, DOE is evaluating several design options that might increase the ability of the engineered barrier system to contain waste. These include the following:

- Drip shields that could keep water from dripping on the waste packages
- Ceramic coating on the waste packages that could further prevent corrosion
- Backfill that could protect the waste packages from falling rock or tunnel collapse, raise the waste packages' temperature and lower the relative humidity

Backfill would consist of crushed rock or other granular material that would be placed around the waste packages in the emplacement drifts just before the repository is closed.

The DOE also is evaluating alternative designs, some of which might reduce uncertainties regarding repository performance. (Design alternatives are discussed further under Long-Term Safety, page 30.)

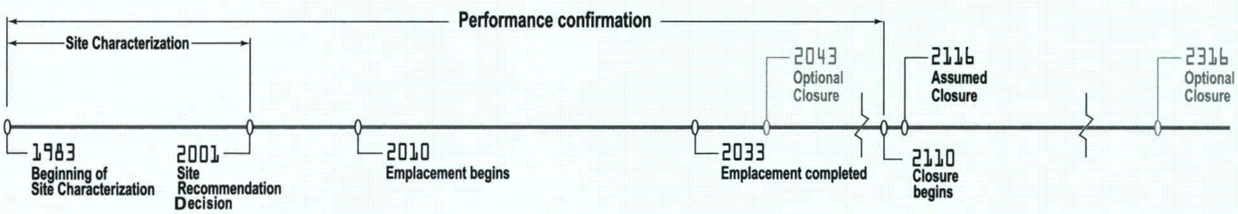


Confirmation and retrieval

Activities to confirm that a repository would work as expected begin long before the first waste is emplaced. In the current site characterization phase, information about Yucca Mountain and the surrounding environment is being collected and compiled to provide a baseline against which to compare what would happen if a repository were built and waste were emplaced.

Using mathematical models based on the collected data and analyses of the engineered components, scientists forecast the probable behavior of the engineered system and the effects of a repository on the Yucca Mountain environment. If repository operations begin, remote sensors would monitor the waste packages, tunnels, and surrounding rock. The effects of a repository would be monitored, and the observed effects would be compared to the model predictions. These confirmation activities would help determine whether a repository is operating as expected.

If a problem is detected prior to closing the repository, remedial action or retrieval of the waste would be possible using remotely operated equipment. The Nuclear Regulatory Commission currently requires that a repository be designed to allow the retrieval of waste at any time up to 50 years after waste operations begin. Retrieval of waste, if needed, would follow, in reverse order, the same steps taken in emplacing the waste.



The performance confirmation program begins with site characterization to establish a baseline and continues until repository closure begins.

Repository closing

Even under the most ambitious schedules for disposal, future generations would make the final decision to close a repository. To give future generations the option of closing the repository or monitoring it for long periods of time, DOE is designing the repository so that it could (with Nuclear Regulatory Commission approval) be either closed as early as 10 years after emplacement of the last waste package, or kept open for hundreds of years from the start of waste emplacement.

Permanently closing the repository would require the sealing of all shafts, ramps, exploratory boreholes, and other underground openings. These actions would discourage any human intrusion into the repository and prevent water from entering through these openings.

At the surface, all radiological areas would be decontaminated, all structures removed, and all wastes and debris disposed of at approved sites. The surface area would be restored as closely as possible to its original condition. Permanent monuments would be erected around the site to warn any future generations of the presence and nature of the buried wastes.

The DOE also would continue to oversee the Yucca Mountain site to prevent any activity that could breach a repository's engineered or geologic barriers, or otherwise increase the exposure of the public to radiation beyond allowable limits.

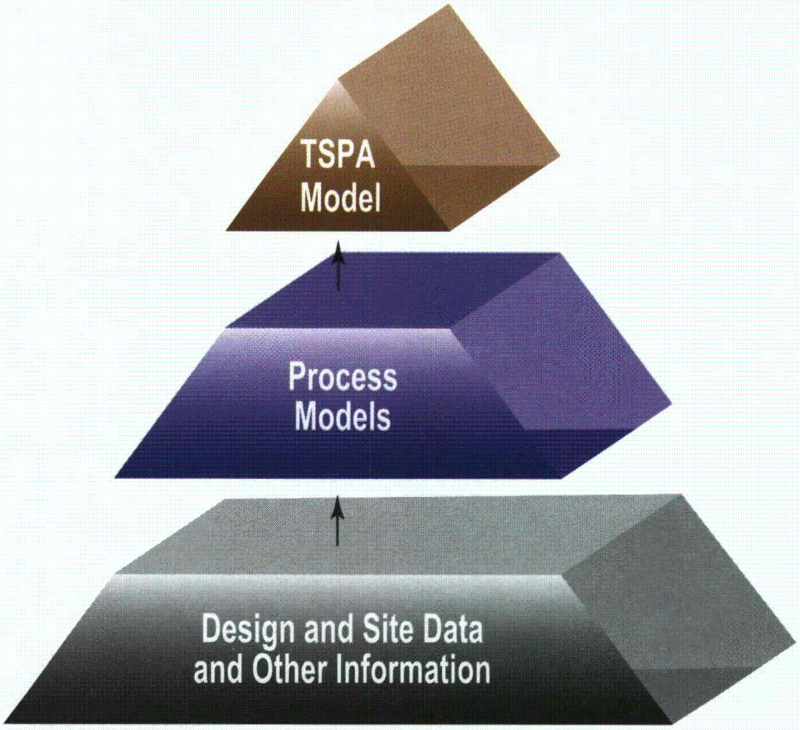
View of Yucca Mountain from the northwest

Performance assessment models

Performance assessment evaluates how a repository system is likely to work over long time periods. From the results of scientific studies, analysts build detailed mathematical models or "representations" of the features, events, and processes that could affect the performance of the design. They then incorporate the results of these detailed process models into an overall model of the repository system, which is called the total system performance assessment model. The models are used to assess how the natural and engineered elements of a waste disposal system are likely to work together over the long period required to isolate wastes.

Performance assessments help identify which uncertainties about the behavior of a disposal system are significant and which are not, which elements of the repository system are most important to how well it is likely to work, and where scientists and engineers might most usefully focus their efforts to improve performance. These assessments are repeated and refined during the course of developing, evaluating, and improving a repository design.

A total system performance assessment represents a reasonable approach to the challenging task of projecting how a repository would work over thousands of years. However, as a National Academy of Sciences panel observed, "Confidence in the disposal techniques must come from a combination of remoteness, engineering design, mathematical modeling, performance assessment, natural analogues and the possibility of remedial action in the event of unforeseen events."[17] The DOE is taking this combined approach.



Approach to constructing a total system performance assessment (TSPA) model. Analysts develop detailed mathematical models of the natural processes that are important to repository performance and then combine these models into a model of the entire repository system.

The attributes of safe disposal

The results of fifteen years of testing and analysis, including four years of underground exploration, have validated many, but not all, of the expectations of scientists who first suggested that remote desert regions are well-suited for a geologic repository. One important and unexpected test result was finding underground, at the level of the proposed repository, traces of a radioactive isotope (chlorine-36) that is associated with above-ground nuclear weapons tests. As atmospheric nuclear testing began in the mid-1940s, this finding suggests that some water travels from the ground surface to the level of the repository in about 50 years or less. Another important finding was evidence that the average amount of water that filters down through the mountain is about a third of an inch per year, which, while only about five percent of the average annual precipitation, is more than DOE initially expected. Taken together, the findings, both expected and unexpected, underscore the importance of building engineered barriers that work with the natural barriers to keep water away from the waste.

The results indicate that a repository at Yucca Mountain would need to exhibit four key attributes to protect public health and the environment for thousands of years. The four key attributes are:

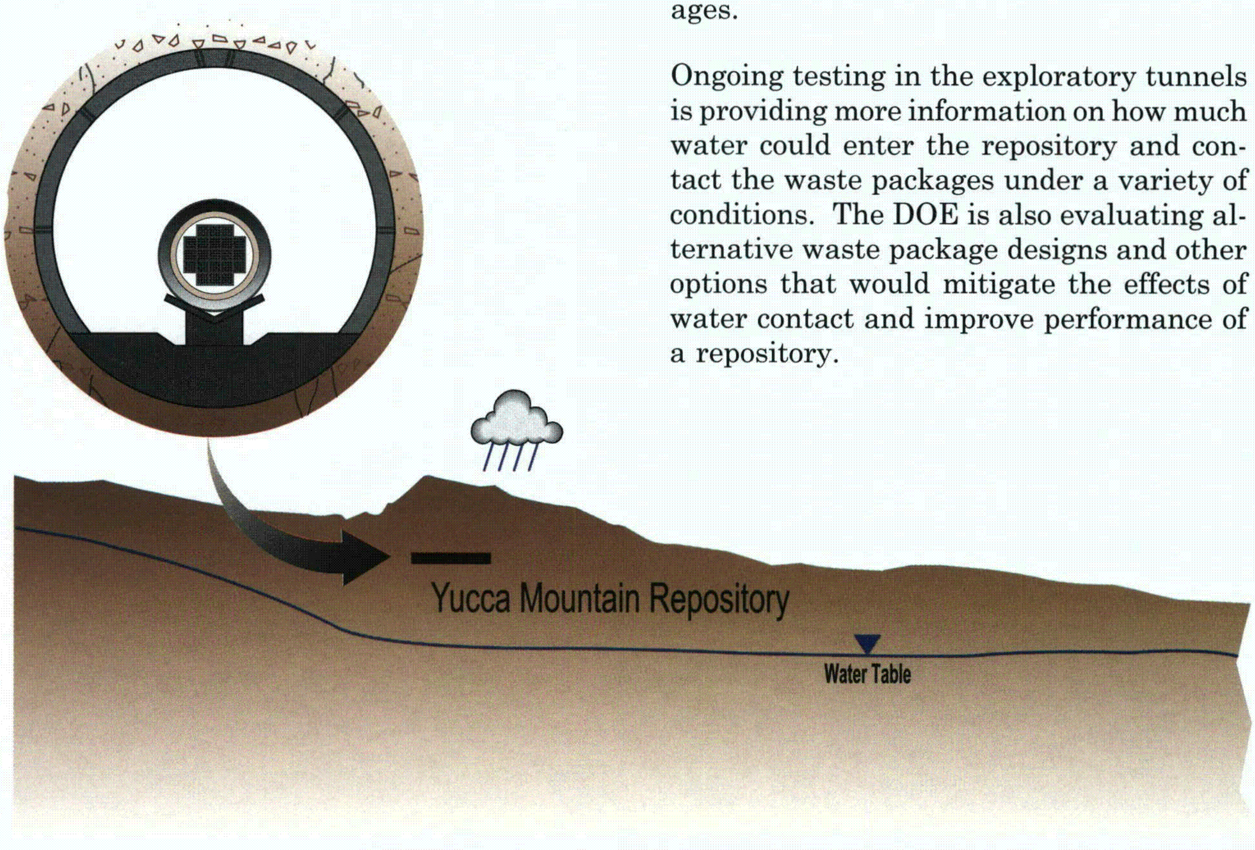
- Limited water contact with waste packages
- Long waste package lifetime
- Low rate of release of radionuclides from breached waste packages
- Reduction in the concentration of radionuclides as they are transported from breached waste packages

Based on performance assessment models, DOE has evaluated the degree to which the reference design exhibits these four key attributes, and has identified additional scientific studies and design improvements that could reduce uncertainties and enhance long-term repository performance.

Limited water contact with waste packages

In the reference design, waste packages would be placed about 1,000 feet below the mountain's surface and about 1,000 feet above the water table. Even if future climates are much wetter than today, the mountain is not expected to erode and leave the waste exposed, and the water table is not expected to rise high enough to reach the waste.

In the current semiarid climate, about seven inches of water a year from rain and snow fall on Yucca Mountain. Nearly all of that precipitation, about 95 percent, runs off or evaporates. Only about one-third of an inch of water per year moves down (or percolates) through the nearly 1,000 feet of rock to reach the level of the repository. Studies of past climates indicate that the precipitation may increase to a long-term average of about 12 inches per year. However, most of the water still would run off or evaporate rather than soak into the ground.



Once waste packages have been placed in the repository, the heat generated from radioactive decay would raise the temperature in the tunnels above the boiling point of water. The heat is expected to dry out the surrounding rock and drive any water away for hundreds to thousands of years. However, as the waste decays and the repository cools, enough water to cause drips would begin to seep into the drifts through fractures in the rock.

Using mathematical models, analysts estimate that, after the repository cools enough, about five percent of the packages could experience dripping water, under the current climate. If the climate changes to a wetter long-term average, about 30 percent of the packages could experience dripping water. These estimates are based on a number of assumptions that remain to be validated. Nonetheless, the results suggest that limited water would contact the waste packages.

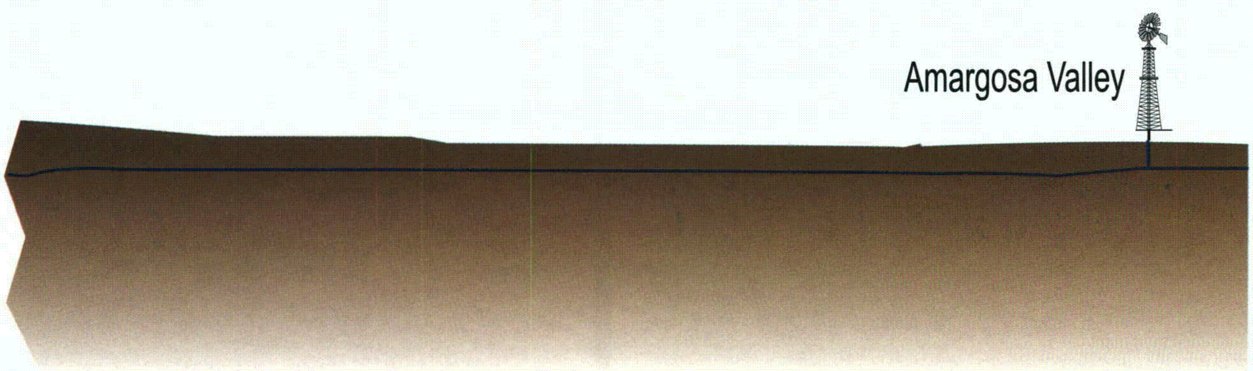
Ongoing testing in the exploratory tunnels is providing more information on how much water could enter the repository and contact the waste packages under a variety of conditions. The DOE is also evaluating alternative waste package designs and other options that would mitigate the effects of water contact and improve performance of a repository.

Long waste package lifetime

The waste package in the reference design has two layers: a thick outer layer made of carbon steel that provides structural strength and delays any contact of water with the inner layer, and a thinner inner layer of a high-nickel alloy that resists corrosion after the outer layer is penetrated.

Based on preliminary results of corrosion experiments and the opinions of experts, computer simulations indicate that most of the waste packages would last more than 10,000 years, even if water is dripping on them. The longevity of man-made materials in the repository environment over such long periods of time is subject to significant uncertainty, however, and some waste packages could fail earlier. Scientists estimate that dripping water could cause the first penetrations—tiny pinholes—to appear in some waste packages after about 4,000 years. More substantial penetrations could begin to occur about 10,000 years later. Projections of waste package performance also assume that at least one waste package will fail in 1,000 years due to a manufacturing defect.

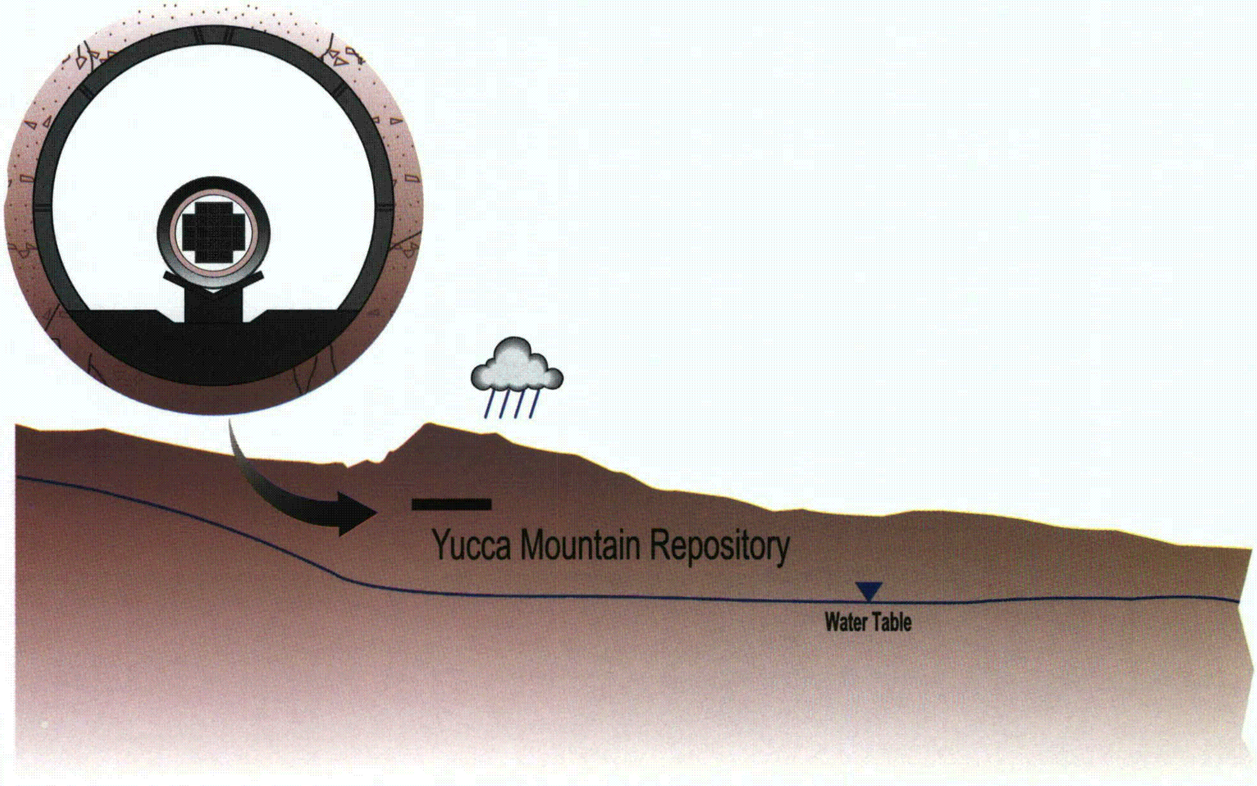
To reduce the uncertainty in waste package performance, further research on the conditions that waste packages will be exposed to and testing of waste package materials is underway. In addition, DOE is evaluating alternative waste package designs and materials that could compensate for the uncertainty and enhance longevity.



Low rate of release of radionuclides from breached waste packages

Once water enters a waste package, it would have to penetrate the metal cladding of the spent nuclear fuel to reach the waste. For about 99 percent of the commercial spent nuclear fuel, the cladding is highly corrosion-resistant metal that is designed to withstand the extreme temperature and radiation environment in the core of an operating nuclear reactor. Current models indicate that it would take thousands of years to corrode cladding sufficiently to allow water to reach the waste and begin to dissolve the radionuclides. However, estimates of cladding performance are uncertain, and more work in this area is planned.

During the thousands of years required for water to reach the waste, the radioactivity of most of the radionuclides would decay to virtually zero. For the remaining radionuclides to get out of the waste package, they must be dissolved in water, but few of the remaining radionuclides could be dissolved in water at a significant rate. Thus, only the long-lived, water-soluble radionuclides, such as isotopes of technetium, iodine, neptunium, and uranium, could get out of the waste package. Although most of the waste would not migrate from the package even if it were breached, the release of any radionuclides is reason for concern and motivation for seeking improvements in the repository design. Ongoing tests are providing more information on how radionuclides dissolve in water.



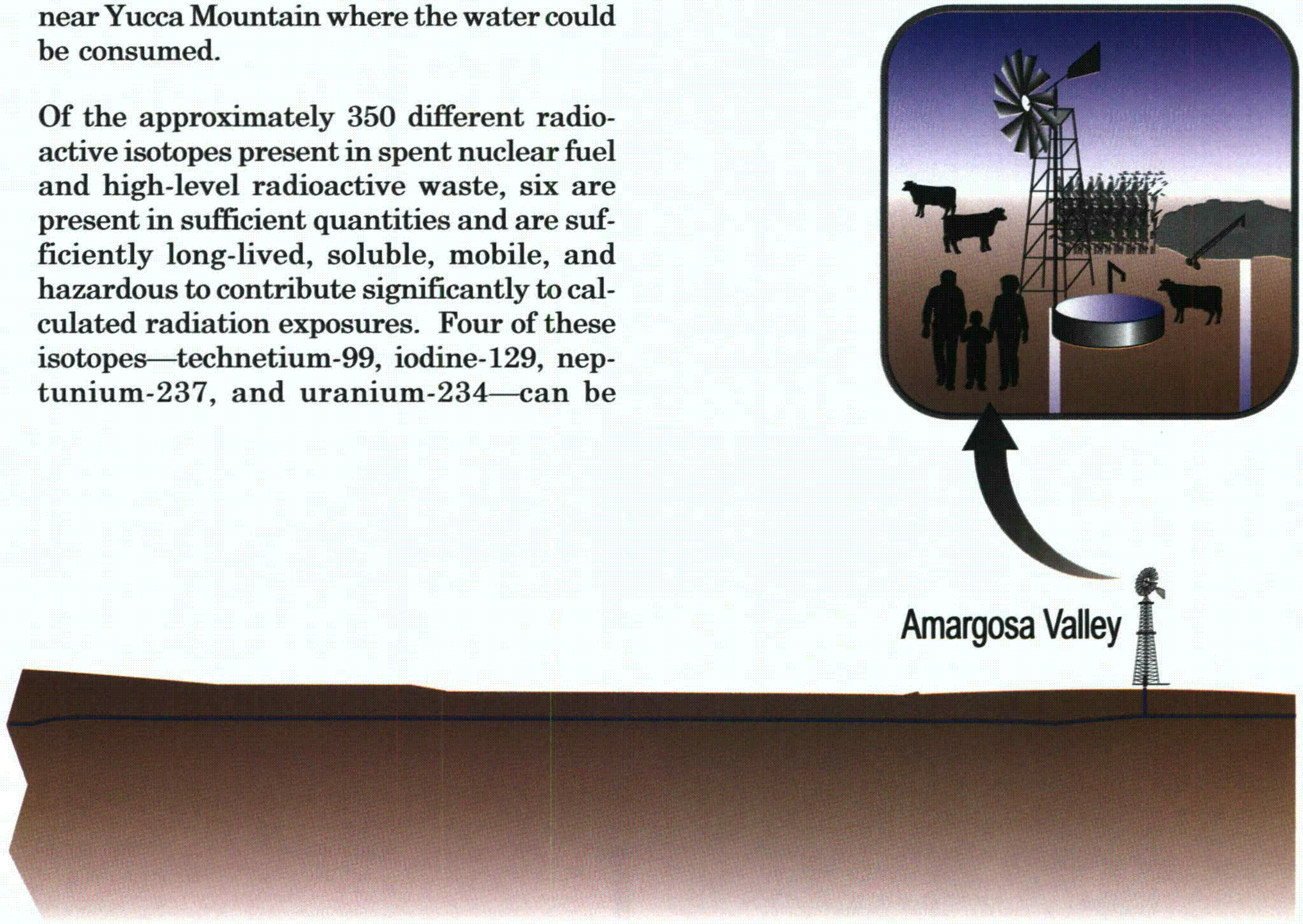
Reduction in the concentration of radionuclides as they are transported from the waste packages

Long-lived, water-soluble radionuclides that migrate from the waste packages will have to move down through about 1,000 feet of rock to the water table and then travel about 20 kilometers (about 12 miles) to reach a point where they could be taken up in a well and consumed or used to irrigate crops.

As the long-lived, water-soluble radionuclides begin to move down through the rock, some will stick (or adsorb) to the minerals in the rock and be delayed in reaching the water table. After reaching the water table, radionuclides will disperse to some extent in the larger volume of groundwater beneath Yucca Mountain, and the concentrations will be diluted. Eventually, groundwater with varying concentrations of different radionuclides will reach locations near Yucca Mountain where the water could be consumed.

Of the approximately 350 different radioactive isotopes present in spent nuclear fuel and high-level radioactive waste, six are present in sufficient quantities and are sufficiently long-lived, soluble, mobile, and hazardous to contribute significantly to calculated radiation exposures. Four of these isotopes—technetium-99, iodine-129, neptunium-237, and uranium-234—can be transported by moving groundwater because they do not adsorb well to minerals. Two isotopes—plutonium-239 and plutonium-242—tend to adsorb but could be mobile because they can attach themselves to small particles (or colloids) and then be transported along with those particles.

Given the uncertainty about the rate at which groundwater moves and the possible existence of fast pathways or channels through the saturated zone, the DOE is continuing to investigate groundwater flow characteristics and is analyzing the possible effects on radionuclide transport and dilution.



Possible dose

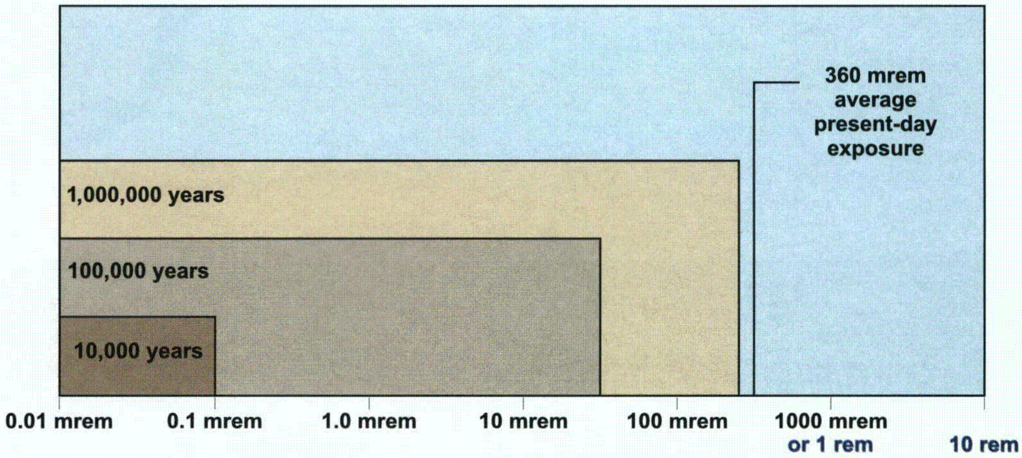
Analysts have calculated the possible radiation dose rate to people who may be living near the repository thousands of years in the future. Because where and how people will be living in the distant future cannot be predicted, analysts base their calculations on the current situation. They assume that the nearest population lives 20 kilometers (about 12 miles) from the repository boundary and has a lifestyle similar to the average person living today in Amargosa Valley, about 30 kilometers (about 19 miles) from Yucca Mountain.

During the first 10,000 years after the repository is closed, current models indicate that the mean peak annual dose rate to an average individual in this future population would be about 0.1 millirem. However, given the uncertainties associated with the assumptions and the performance assessment models, the peak dose could be higher or lower than the estimated average. There is a 5 percent (1 in 20) chance of exceeding 0.8 millirem and a greater than 25 percent chance of no exposure at all.

During the first 100,000 years, the mean peak annual dose rate to an average individual is estimated to be 30 millirem with a 5 percent chance of exceeding 200 millirem and a greater than 20 percent chance of zero dose.

Radiation is a form of energy that is everywhere in the natural and man-made world. The basic unit for measuring the damage that a given dose of radiation can cause to human tissue is called a rem. Each year in the United States, the average person receives a dose of about 360 millirem (a millirem is one one-thousandth of a rem) from natural and man-made sources. Natural sources—cosmic rays, radon gas, soil and rock, and the human body itself—account for about 300 millirem of the total annual average dose, with man-made, mostly medical, sources accounting for the remaining 60 millirem.[18] Man-made sources of radiation include diagnostic X-rays and other medical procedures, television sets, and computer monitors. Radiation exposures vary widely depending on geographic location and life choices. For example, a person living at an altitude of 5,000 feet in Denver, Colorado, receives nearly two times as much cosmic radiation as a person living near sea level in Washington, D.C.[19]

During the first 1 million years, the mean peak annual dose rate to an average individual is estimated to reach 200 millirem, with a 5 percent chance of exceeding 1,000 millirem (or 1 rem) and a 5 percent chance of being lower than 0.07 millirem.



Mean peak annual dose rate from the repository

Other safety issues

The analysis of the safety of a repository at Yucca Mountain must also consider both the likelihood and the effect of possible disruptive processes and events, such as volcanism, earthquakes, human intrusion, and "nuclear criticality." The DOE has concluded that there is little likelihood that such processes or events at Yucca Mountain would significantly affect the long-term performance of a repository.

Volcanism

The area around Yucca Mountain was very active volcanically millions of years ago. The rock of Yucca Mountain—called tuff—is composed of volcanic ash from eruptions that occurred about 13 million years ago. However, large-scale volcanism in the area ceased about 7.5 million years ago, and the last, small eruption occurred about 75,000 years ago. Experts have concluded that the chance of future volcanic activity disrupting the site is negligible. As a result, volcanism would be unlikely to affect the long-term performance of the repository.

Earthquakes

Yucca Mountain is located in the southern Great Basin, a large region that has some earthquakes. Yucca Mountain itself is a tilted block of rock that is bounded by geologic faults. A magnitude 5.6 earthquake occurred about 12 miles away in 1992. A repository and surface facilities would be designed to withstand earthquakes, as are modern tunnels, buildings, and power plants in seismically active areas.

Accidental human intrusion

It is possible that future human activities might intrude on the repository. One possible activity would be exploration for valuable natural resources. However, Yucca Mountain exhibits few characteristics that would make it an attractive location for future generations to drill or otherwise explore for gold, hydrocarbons, or other materials.

The National Academy of Sciences (NAS) concluded that there is no scientific basis for predicting such human activities over the very long periods of time for which the repository must function. The NAS, therefore, recommended that future human intrusion not be considered in the quantitative performance assessments. However, to evaluate how the repository would perform if humans were to intrude, the NAS recommended,[20] and DOE has conducted, a separate analysis of a theoretical case in which a waste package is penetrated by someone drilling into the repository in the future. Performance assessments indicate that peak dose rates would increase if a waste package were penetrated by exploratory drilling and if waste were then carried down the drillhole to the water table. However, as noted, natural resource assessments indicate that the Yucca Mountain site does not exhibit characteristics that would make it an attractive location for exploratory drilling.

Nuclear criticality

A nuclear criticality occurs when sufficient quantities of fissionable materials come together in a precise manner and the required conditions exist to start and sustain a nuclear chain reaction. The waste packages would be designed to prevent a criticality from occurring inside a waste package. In addition, it is very unlikely that a sufficient quantity of fissionable materials could accumulate outside of the waste packages in the precise configuration and with the required conditions to create a criticality. If, somehow, an external criticality were to occur, analyses indicate that it would have only minor effects on repository performance. An explosive external criticality is not credible.

What we are learning

The performance assessment shows that the most significant single factor affecting the ability of the repository to protect public health and safety would be the amount of water that directly contacts the waste. Yucca Mountain itself would provide the first major barrier to such contact, ensuring that the repository would not be flooded by either a rise in the deep water table or by infiltration of water from the surface during periods much wetter than the present. However, some waste packages will experience dripping water, and the amount is uncertain.

To address this concern, the reference design includes multiple barriers to limit water contact with the waste. The inner and outer waste package layers and the metal cladding on the spent fuel are barriers between water and the waste.

The vast majority of the radionuclides in the waste are not mobile in water and thus pose no threat to public health and safety, even when the waste package and cladding are breached and the waste is exposed to water. However, a very small fraction of the radionuclides (representing less than 0.2 percent of the initial radioactivity of all the radionuclides) are able to dissolve and move. While the quantities of the radionuclides that could reach the environment appear to be small, they nevertheless pose a potential health hazard that must be addressed.

Total system performance assessments of the reference design indicate that, for 10,000 years after the repository is closed, people living near Yucca Mountain would receive little or no increase in radiation exposure. After about 300,000 years, people living about 20 kilometers (12 miles) south of Yucca Mountain might receive additional radiation doses that are comparable to present-day doses from natural background radiation.

Although the performance assessments are encouraging, there are remaining uncertainties that should be addressed before a site recommendation decision is made and a license application is submitted to the Nuclear Regulatory Commission. Therefore, DOE plans to conduct further tests of the site and of candidate waste package materials in support of the license application. The DOE also plans to evaluate alternative repository designs that could reduce the possible doses to people living near Yucca Mountain thousands of years in the future.

Plan to complete a license application

In the next four years, DOE will focus on improving the repository and waste package design, strengthening the understanding of the key natural processes, preparing the environmental impact statement, and developing the information needed to support the site recommendation decision. Because a license application takes years to prepare, DOE has begun to assemble the information needed to support one.

Before DOE can submit a license application to the Nuclear Regulatory Commission (NRC), the Nuclear Waste Policy Act requires the following decisions, any one of which can stop the process:

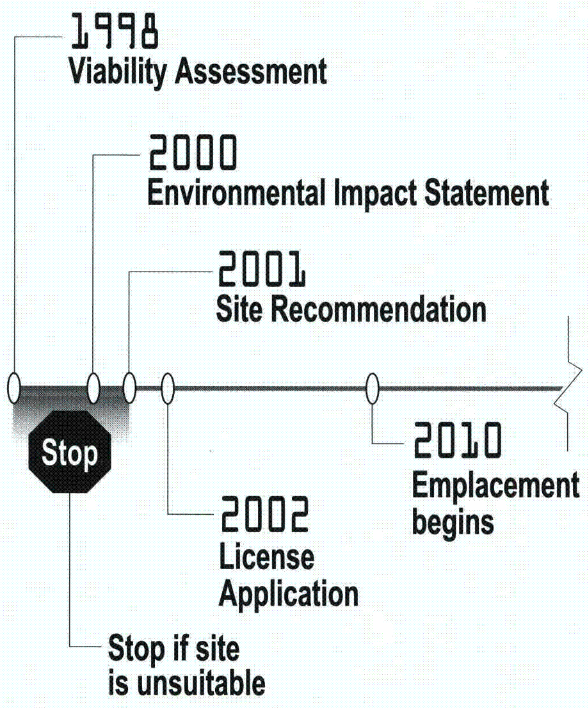
- The Secretary must decide, based on a formal evaluation of the site and after considering the views of States, affected Indian tribes, and the NRC, whether to recommend the site to the President. A site recommendation must be accompanied by an environmental impact statement, which is scheduled for completion in 2000. Current schedules plan for a site recommendation to be made in 2001.

- The President will then decide, possibly in 2001, whether to recommend the Yucca Mountain site to Congress.

- If the Governor and legislature of Nevada submit a notice of disapproval to Congress, Congress must then decide whether to override Nevada's objections and approve the Yucca Mountain site.

If the preceding decisions are made in a timely manner and ultimately support development of a repository at the Yucca Mountain site, DOE would submit a license application to NRC in 2002.

To obtain an NRC license, DOE must demonstrate that a repository can be constructed, operated, monitored, and eventually closed without unreasonable risk to the health and safety of workers and the public. The challenge in licensing a geologic repository is demonstrating a reasonable assurance of compliance with long-term safety standards for many thousands of years. However, the recent issuance of a permit by the Environmental Protection Agency for the disposal of long-lived transuranic waste in the Waste Isolation Pilot Plant shows that compliance with long-term safety standards is achievable. In preparing to submit a license application, DOE is drawing on the Waste Isolation Pilot Plant experience and focusing on both operational and long-term safety issues.



Operational safety

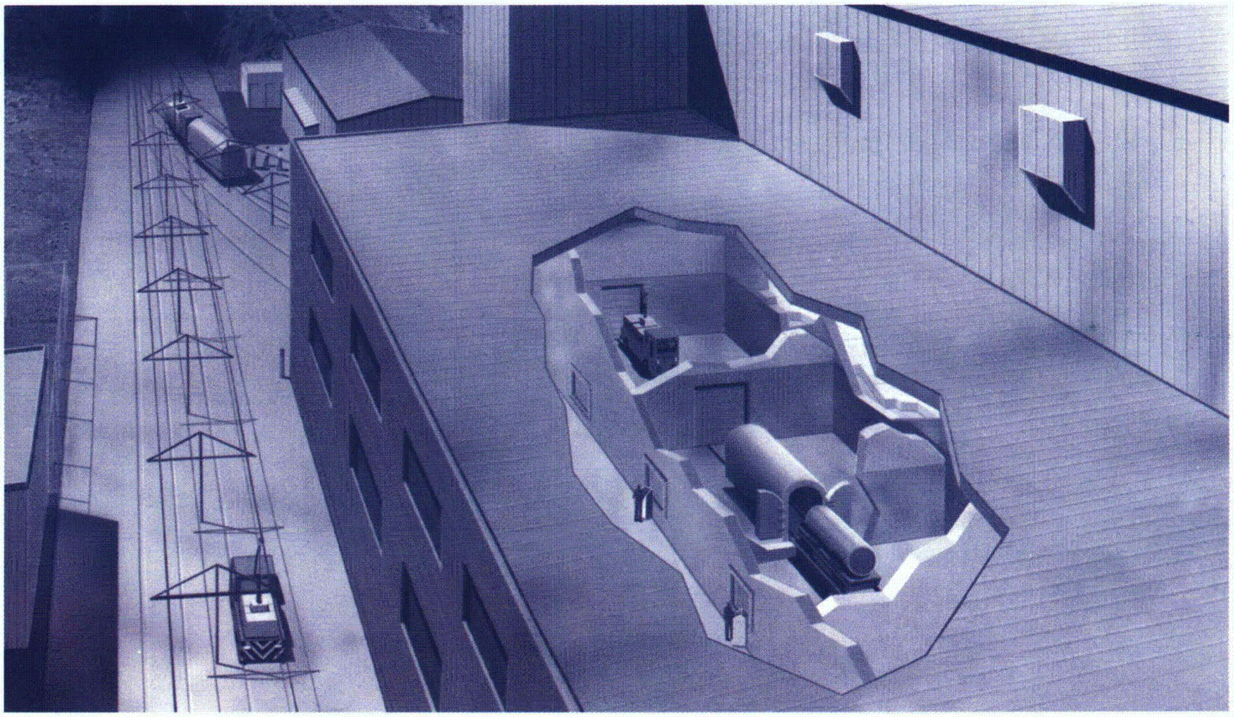
To ensure that a repository can be operated safely, DOE is using demonstrated technology and accepted design criteria, systematically identifying design-basis events, and classifying all repository structures, systems, and components on the basis of their importance to safety.

Demonstrated technology and accepted design criteria

Designing waste-handling facilities and operations is not a unique endeavor. Many codes, standards, and Nuclear Regulatory Commission regulatory guidance documents, along with many years of industry experience in the operation of nuclear facilities, can be applied to preclosure repository design and operations. (Preclosure refers to the time when waste is being emplaced and monitored.) Many elements of the reference design are based on demonstrated technology and accepted design criteria to ensure protection of both workers and the public during the preclosure period of repository operations.

Identification of design-basis events and safety classifications

Nuclear Regulatory Commission regulations require DOE to identify internal design-basis events (such as dropping a waste package) and external design-basis events (such as an earthquake) that could cause accidents resulting in unacceptable radiation exposures to workers or to the public. The regulations require that DOE protect both workers and the public when designing any engineered structures, systems, or components that are important to safety: all such elements must be able to withstand design-basis events. The DOE is now identifying design-basis events, performing safety classifications, and incorporating the resulting design requirements into its design requirements documentation.



Artist's concept of operations to move waste underground. Remote-controlled equipment would be used to place waste packages on rail cars and move the rail cars into shielded transporters. Human-operated electric locomotives would take loaded transporters underground.

Long-term safety

To reduce current uncertainties and increase confidence that a repository can contain and isolate waste for thousands of years, DOE is focusing its ongoing efforts on three major areas:

- Increasing understanding of the key natural processes that are important to long-term performance of a repository
- Improving the design of key engineered components of a repository
- Increasing confidence in performance assessment models

These three sets of activities will be the focus of DOE work between this viability assessment and the site recommendation decision, which could lead to submission of a license application.

Increasing understanding of the key natural processes that are important to long-term performance of a repository

The key natural processes are water movement through the unsaturated zone above and below the repository, the effect of heat from the waste packages on moisture in the rock around the tunnels, and the movement of groundwater beneath the repository. Increased understanding of these processes will reduce the uncertainties about the performance of a repository.

The DOE is conducting experiments to determine how water could move through the unsaturated zone above and below the repository tunnels. In one experiment, water containing chemical tracers is being injected into the rock, and scientists are measuring how much and how quickly water moves through the rock. In another experiment, microspheres are being injected into the rock to simulate possible colloidal transport of radionuclides. These experiments will provide more data on how much water might infiltrate the repository and how water could transport radionuclides to the water table.

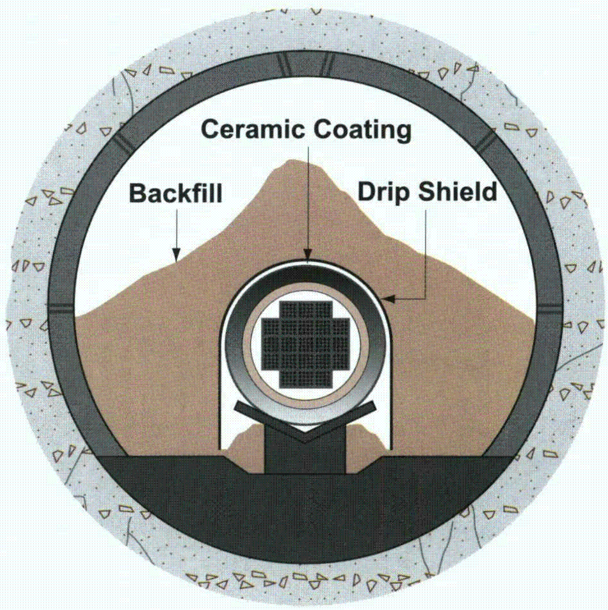
The DOE is also conducting experiments on the effect of heat generated by the waste packages on moisture in the surrounding rock. Large heaters have been placed in areas of the existing tunnel, and scientists are observing the effect of the heat on the unsaturated rock. These experiments will increase understanding of how water would be driven away from the waste packages during the period of high temperature and how, later, declining temperatures could affect water movement through the unsaturated zone.

Additional information on the movement of water in the saturated zone below the water table will be gained from a series of wells installed by DOE and from wells being installed by Nye County, Nevada.

Completed single-element heater test

Evaluating ways to improve the design of key engineered components of a repository

As the design process progresses, DOE is evaluating several design options and alternatives that could reduce existing uncertainty and improve the performance of the repository system. Some of these options and alternative concepts were suggested by the Nuclear Waste Technical Review Board and by stakeholders such as the Nuclear Waste Repository Project Office of Nye County, Nevada.



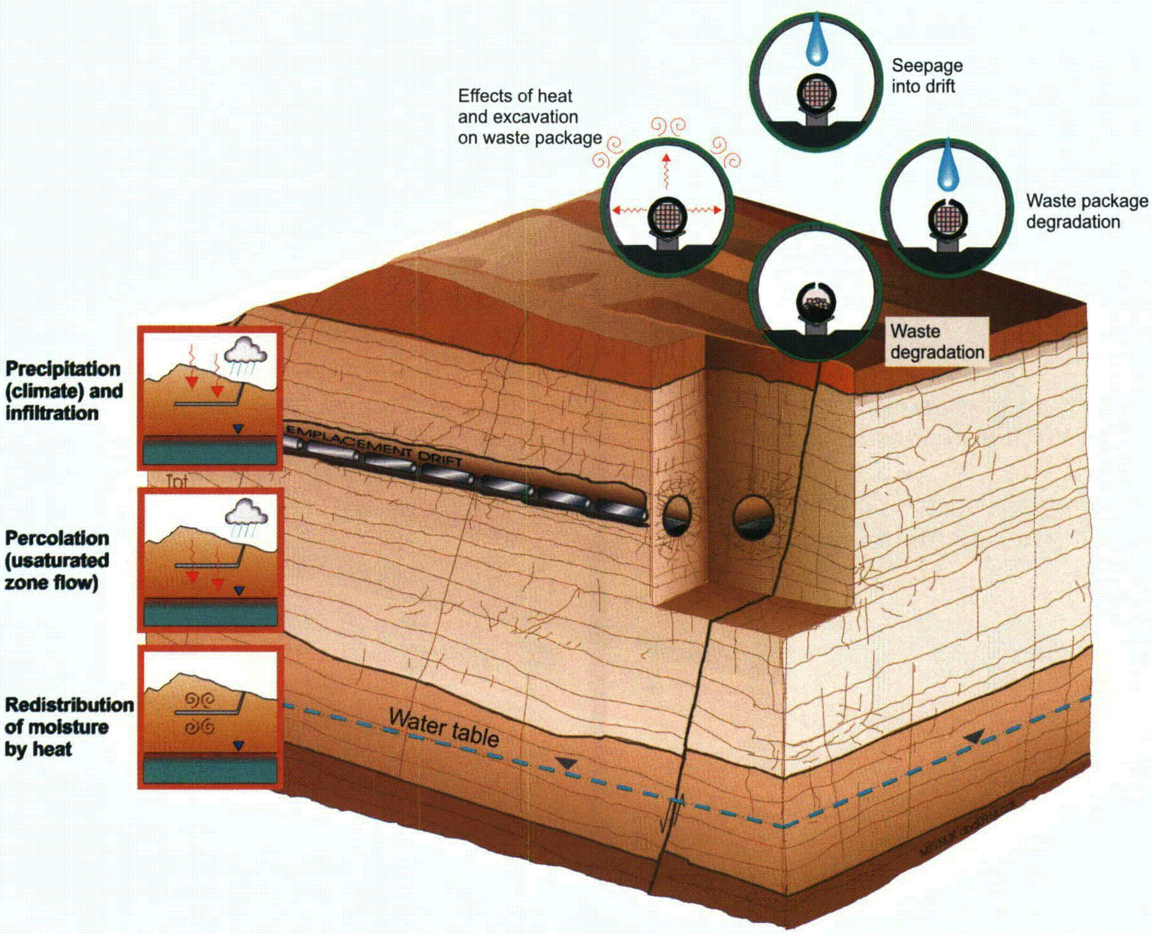
The repository design will incorporate design margin and defense in depth to increase confidence in repository performance. Design margin provides an extra margin of safety. For example, the waste package thickness could be increased to provide extra design margin. Defense in depth is intended to ensure that failure in any one barrier would not lead to unacceptable performance of the entire repository system.

The DOE will continue evaluating drip shields, ceramic coatings, and backfill options that could increase both design margin and defense in depth.

The DOE is also considering alternative repository design concepts, some of which are significantly different from the current reference design. One alternative involves a much cooler, ventilated repository design, so that moisture in the surrounding rock would never reach the boiling point. This alternative would reduce the complexity of the interaction between the natural and engineered barriers. Another alternative is to use a shielded waste package that would allow human entry into the emplacement drifts for inspection and, if necessary, remedial action.

Increasing the reliability of performance assessment models

While forecasts of repository performance over thousands of years can never be proven, laboratory and field studies and experiments provide opportunities to validate the performance assessment models. By comparing the empirical results of the experiments with the predicted results of the models, analysts can assess how well their models represent the natural processes and engineered features of a repository. Validating the performance assessment models will reduce uncertainties and increase confidence that a repository will work as expected.



Schematic cross-section of Yucca Mountain and depiction of processes that are important to repository performance

Cost of licensing, building, operating, monitoring, and closing a repository

The estimated cost to complete the repository design and other necessary work and to prepare and submit a license application in 2002 is approximately $1.1 billion, in constant 1998 dollars. This includes the costs of completing an environmental impact statement in 2000, and providing the information needed by the States, the Secretary, the President, the Congress, and the public.

The estimated cost to complete the licensing process and construct, operate, monitor, and close a repository is approximately $18.7 billion, in constant 1998 dollars. This cost estimate is based on the following assumptions:

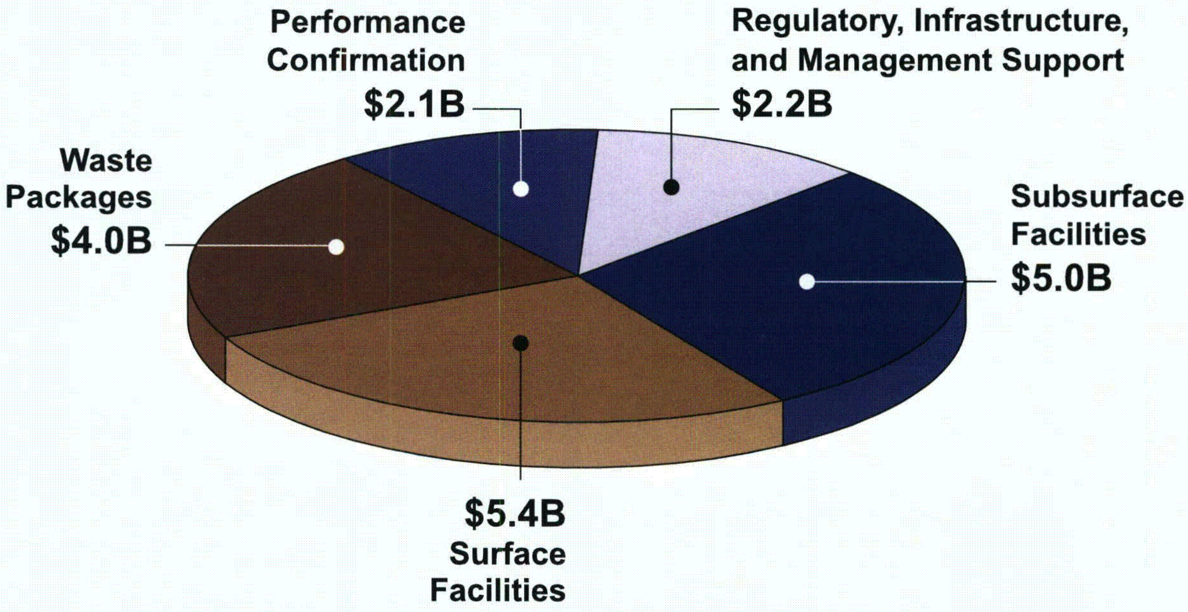
- A license application is submitted in 2002, and the Nuclear Regulatory Commission approves construction of the repository in 2005.
- Emplacement of waste in the repository begins in 2010 and ends in 2033.
- After a five-year start-up phase, commercial spent nuclear fuel is emplaced at a full-scale rate of approximately 3,000 metric tons per year.
- A total of 70,000 metric tons of waste is emplaced, including 63,000 metric tons of commercial spent nuclear fuel, 2,333 metric tons of defense spent nuclear fuel, and 4,667 equivalent metric tons of high-level radioactive waste.
- The repository remains open for 100 years after the start of operations. Closing and sealing the repository begin in 2110 and are completed in 2116.

The DOE is evaluating options for constructing and operating the repository that would reduce construction costs before emplacement begins in 2010. The surface facilities and tunnels could be constructed in phases, or modules. This modular approach could reduce annual costs but also could increase the total cost of constructing and operating the repository. These options will be evaluated in conjunction with the study of alternative designs described in the preceding section.

Repository costs

The $18.7 billion estimated repository cost reflects several factors. The repository subsurface facilities would consist of approximately 100 miles of steel- or concrete-lined tunnels, and underground operations would involve remotely operated equipment. The waste packages would be made of high grade materials and manufactured under strict quality controls and standards. The surface facilities would be designed to handle a high volume of commercial spent fuel—3,000 metric tons per year. Performance confirmation and monitoring would continue for 100 years before closing and sealing the repository.

Because research is ongoing and the repository design has not yet been selected, there is uncertainty in the cost estimate. To compensate for the uncertainty, contingencies have been incorporated into the cost estimates.



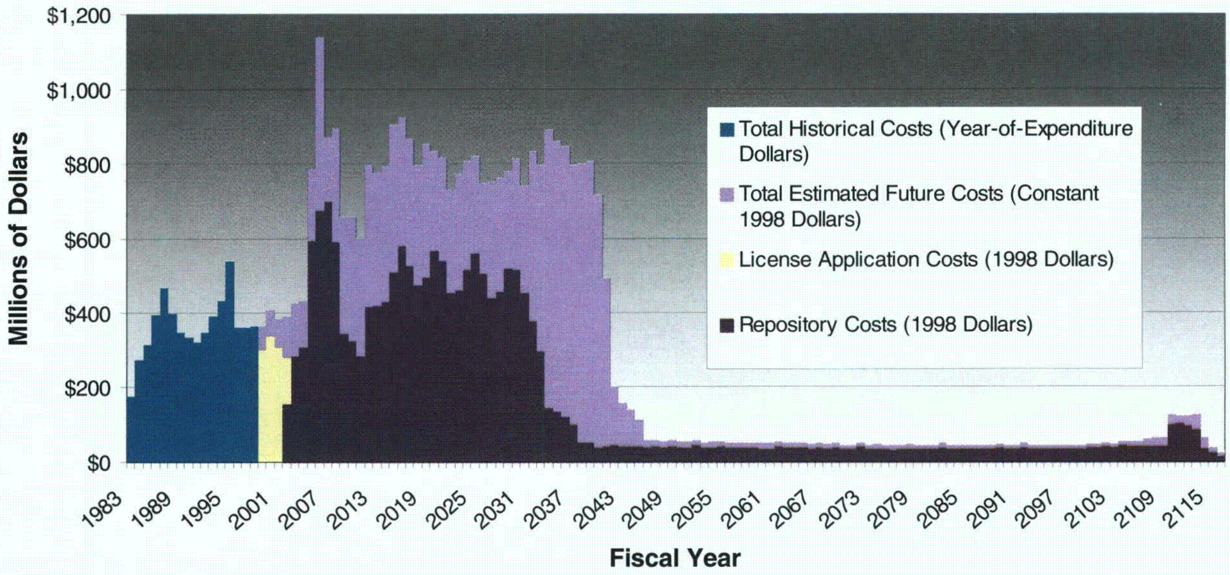
Allocation of costs to construct, operate, monitor, and close a geologic repository at Yucca Mountain

Total system life cycle costs

A monitored geologic repository is only one component of a total waste management system, which would also include overall system management, transportation, and benefits to the State of Nevada. The total life cycle costs for a complete waste management system include the following elements:

- Total program costs from 1983 through 1998 were approximately $5.9 billion in year-of-expenditure dollars. Site characterization activities at all nine of the initial candidate sites and the five-mile exploratory tunnel at Yucca Mountain account for the largest portion of the costs to date.
- The estimated costs to complete a license application and supporting documents is $1.1 billion, in constant 1998 dollars.
- The estimated costs to complete the repository design and licensing process, and then build, operate, monitor, close, and seal the repository are $18.7 billion.
- The estimated costs of expanding the repository to accommodate additional waste beyond the current 70,000 metric-ton statutory limit, if authorized, would be approximately $4.5 billion.
- The estimated costs of transporting wastes to Yucca Mountain are approximately $6.7 billion.
- Estimated payments equivalent to taxes and other benefits to the State of Nevada and affected units of local government are approximately $3.2 billion.
- The estimated costs of managing the entire system are $2.5 billion.

The total of estimated future costs is $36.6 billion, in constant 1998 dollars. (The additive total of the elements above differs due to rounding.)



Profile of total system life cycle costs. These cost estimates reflect DOE's best projections, given the scope of the work identified and planned schedule of required activities. Future events and information could result in changes to both costs and schedules. Future budget requests for the program have yet to be established and will be determined through the annual executive and congressional budget process.

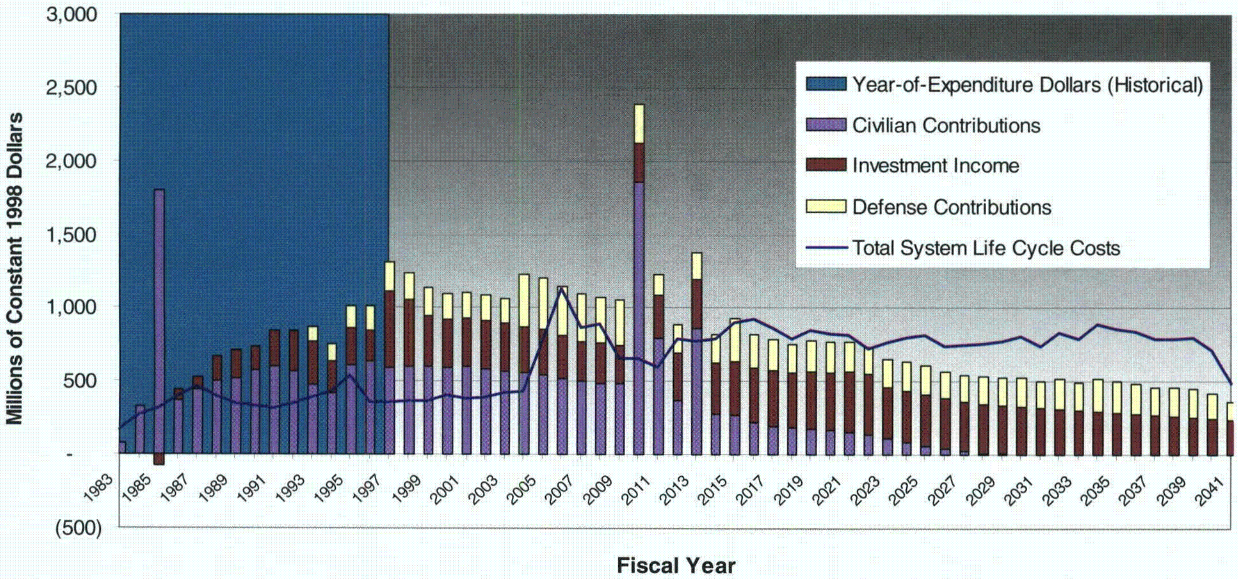
Who pays?

The Nuclear Waste Policy Act of 1982 requires entities that generate spent nuclear fuel and high-level radioactive waste to pay for the costs of disposal. The utilities with nuclear power plants pay a fee to fund the disposal of wastes from their plants, while the Federal Government uses tax revenues to pay for the disposal of radioactive waste from the nation's defense programs.

The Act directs the Secretary of Energy to enter into fee-for-service contracts with utilities for disposing of the waste. In return for this service, utilities pay annual fees that are deposited into a Nuclear Waste Fund where the money earns interest until spent. In setting up the Fund, Congress recognized that the disposal program is an extremely complex, first-of-a-kind scientific and engineering project and one that can succeed only through a sustained effort over many decades. Thus, the Fund is designed to provide the adequate, assured, and stable funding—free from normal budgetary pressures—required for such a long-term effort.

The Nuclear Waste Fund is intended to cover the entire cost of disposing of commercial spent nuclear fuel. The Secretary of Energy regularly reviews the Fund and projected costs of the program to determine whether the fees will be enough to recover the full costs. If the fees are too high or too low, the Secretary is authorized to propose any required changes.

The DOE has determined that the amount generated by the current fees, including the unspent balance and accumulating interest, is sufficient to cover the total system life cycle costs of disposing of commercial spent nuclear fuel. This assumes that the unspent balance and interest income from the Nuclear Waste Fund will remain available for their originally intended purpose.



Historical and projected program income and costs through the waste emplacement phase. These cost estimates reflect DOE's best projections, given the scope of the work identified and planned schedule of required activities. Future events and information could result in changes to both costs and schedules. Future budget requests for the program have yet to be established and will be determined through the annual executive and congressional budget process.

Concluding observations

Based on the viability assessment, DOE believes that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository. Over 15 years, extensive research has validated many of the expectations of the scientists who first suggested that remote, desert regions of the Southwest are well-suited for a geologic repository. Engineered barriers can be designed to contain waste for thousands of years, and the natural barriers can delay and dilute any radioactive material that migrates from the waste packages. Current models indicate that the possible radiation exposure to future populations living nearby could be comparable to present-day exposure levels from natural background radiation. Design alternatives that may improve performance and reduce remaining uncertainties are now being evaluated.

The performance of a geologic repository over such long time periods—longer than recorded human history—cannot be proven beyond all doubt. Forecasts about future geologic and climatic conditions and engineering estimates of how long the waste packages will remain intact cannot be directly validated. The mathematical models used in the performance assessment are subject to uncertainties that can be reduced but never completely eliminated.

The Nuclear Regulatory Commission's general standard for meeting geologic repository regulatory criteria and objectives is reasonable assurance. While considerable uncertainties remain today, DOE believes that reasonable assurance should be achievable in the licensing process after the planned work is completed. The DOE believes, therefore, that ongoing work at Yucca Mountain should proceed as planned.

Endnotes

The numbers at the end of each reference are Office of Civilian Radioactive Waste Management accession numbers. See the inside front cover of this document for whom to contact regarding more information.

[1] Energy and Water Development Appropriations Act, 1997. Public Law 104-206. 238115.

[2] For a description and discussion of radioactive waste and its management, see The League of Women Voters 1993. *The Nuclear Waste Primer: A Handbook for Citizens.* New York: League of Women Voters Education Fund. 210697.

[3] U.S. District Court, Utah 1995. Joint Motion for Entry of Consent Order Based on Settlement Agreement and Consent Order in the Case of Public Service Co. of Colorado v. Batt, October 17, 1995. Civil Case No. 91-0054-S-EJL (Legal Pleadings). U.S. District Court for the District of Idaho. 240346.

[4] U.S. Department of Energy 1997. *Linking Legacies: Connecting the Cold War Nuclear Production Processes to Their Environmental Consequences.* DOE/EM-0319, pp. 34-38. Washington, D.C.: DOE. 241255.

[5] National Academy of Sciences/National Research Council 1957. *The Disposal of Radioactive Waste on Land.* Publication 519, p. 4. Washington, D.C.: National Academy Press. 241256.

[6] U.S. Department of Energy 1980. *Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste.* DOE/EIS-0046F. Washington, D.C.: DOE. 205022.

[7] National Research Council 1990. *Rethinking High-Level Radioactive Waste Disposal, A Position Statement of the Board on Radioactive Waste Management,* p. vii. Washington, D.C.: National Academy Press. 241259.

[8] Nuclear Waste Policy Act of 1982. Public Law 97-425. 222165.

[9] 10 CFR [Code of Federal Regulations] 60. Energy: Disposal of High-Level Radioactive Waste in Geologic Repositories. 239474.

[10] Nuclear Waste Policy Amendments Act of 1987. Public Law 100-203. 223717.

[11] 10 CFR 60. Energy: Disposal of High-Level Radioactive Wastes in Geologic Repositories. 239474.

[12] Energy Policy Act of 1992. Public Law 102-486. 233191.

[13] National Research Council 1995. *Technical Bases for Yucca Mountain Standards.* Washington, D.C.: National Academy Press. 104723.

[14] Interagency Review Group on Nuclear Waste Management 1979. *Report to the President by the Interagency Review Group on Nuclear Waste Management.* TID-29442, p. 37. Washington, D.C.: DOE. MOL.19980625.0169.

[15] Letter from Dr. Vincent McKelvey to Richard W. Roberts, Assistant Administrator for Nuclear Energy, U. S. Energy Research and Development Administration, Washington, D.C. July 9, 1976. 238792.

[16] Winograd, I.J. 1981. "Radioactive Waste Disposal in Thick Unsaturated Zones." *Science, 212*, pp. 1457-1464. Washington, D.C.: American Association for the Advancement of Science. 217258.

[17] National Research Council 1990. *Rethinking High-Level Radioactive Disposal, A Position Statement of the Board on Radioactive Waste Management,* pp. 5–6. Washington, D.C.: National Academy Press. 241260.

[18] DOE 1992. *Science, Society, and America's Nuclear Waste, Unit 1, Teacher Guide.* DOE/RW-0361 TG. Washington, D.C.: DOE. 214909.

[19] League of Women Voters 1993. *The Nuclear Waste Primer: A Handbook for Citizens,* p. 12. New York: League of Women Voters Education Fund. 210697.

[20] National Research Council 1995. *Technical Bases for Yucca Mountain Standards*, p.12. Washington, D.C.: National Academy Press. 104273.

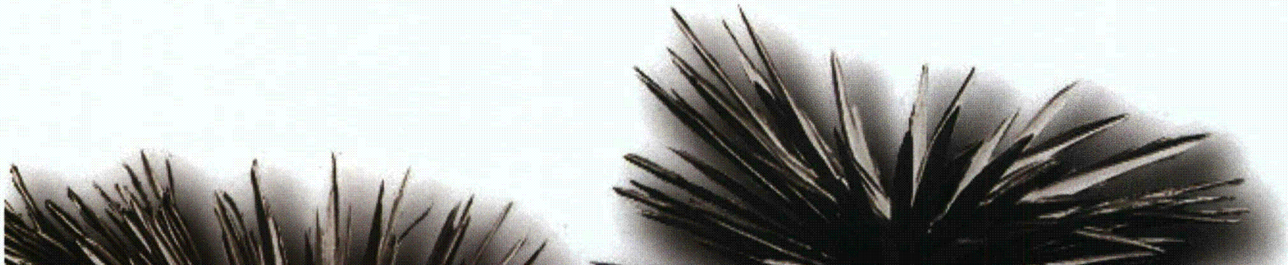
Glossary

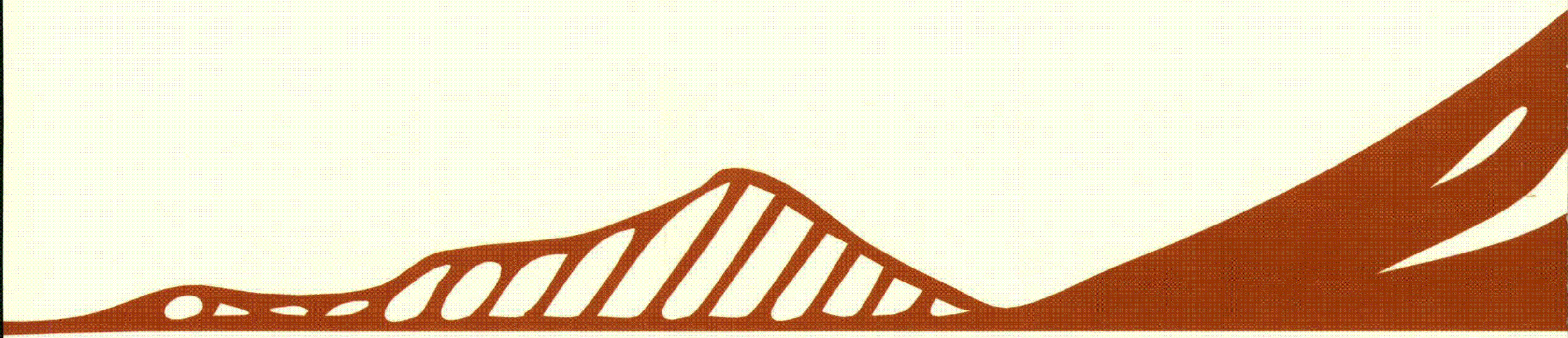
Adsorb	To transfer dissolved materials, including radionuclides, in groundwater to the solid geologic surfaces with which they come in contact.
Background radiation	Radiation arising from natural radioactive material always present in the environment, including solar and cosmic radiation, and radiation from radon gas, soil and rocks, and the human body.
Cladding	The metallic outer sheath of a nuclear reactor fuel element, generally made of a zirconium alloy. It is intended to isolate the fuel element from the external environment.
Colloid	Small particles in the size range of 10^{-9} to 10^{-6} meters that are suspended in a solvent. Naturally occurring colloids in groundwater arise from clay minerals.
Defense in depth	A strategy based on a system of multiple, independent, and redundant barriers, designed to ensure that failure in any one barrier does not result in failure of the entire system.
Design margin	Margin of safety in specifications for engineered components to account for uncertainty in the conditions to which the components will be subjected and for variability in the properties of component materials.
Dose	A quantity of radiation or energy absorbed by any material; measured in rads. Equivalent dose measures the amount of damage to human tissues from a radiation dose; equivalent dose is measured in rems.
Drift	From mining terminology, a horizontal underground passage.
Gantry	A movable crane carried on a four-legged portal frame that runs along rails.
High-level radioactive waste	Highly radioactive material resulting from the reprocessing of spent nuclear fuel. Originally produced in liquid form, high-level radioactive waste must be solidified before disposal.
Invert	(1) The low point of something such as a tunnel, drift, or drainage channel. (2) An engineered structure or material placed on excavated drift floors (the low points) to serve as structural support for drift transportation or emplacement systems.
Isotope	One of two or more atomic nuclei with the same number of protons (i.e., the same atomic number) but with a different number of neutrons (i.e., a different atomic weight). For example, uranium-235 and uranium-238 are both isotopes of uranium.
Metric ton	In this document, metric ton means a *metric ton of heavy metal.* A metric ton is a unit of mass equal to 1,000 kg (about 2,205 lb). Heavy metals are those with atomic masses greater than 230. Examples include thorium, uranium, plutonium, and neptunium.

Millirem	A millirem is one one-thousandth of a rem, which is the unit of equivalent dose. Equivalent dose is a measure of the effect that radiation has on humans. The equivalent dose takes into account the type of radiation and the absorbed dose. Rem is an initialism for Roentgen equivalent man.
Natural analog	Natural geologic systems that parallel situations that can develop in man-made systems. An example of a natural analog is the natural nuclear reactor at the Oklo uranium deposit in Gabon, Africa, which can be used as a source of analog data for conceptual models of nuclear criticality.
Non-welded tuff	See *Tuff.*
Percolate	Referring to the movement of water downward through soil and rock.
Performance assessment	An analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Repository performance assessments will include estimates of the effects of uncertainties in both data and modeling.
Radioactive waste	For the purpose of this document, spent nuclear fuel or high-level radioactive waste.
Radionuclide	A radioactive isotope.
Saturated zone	The region below the water table where rock pores and fractures are completely saturated with groundwater.
Spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
Transuranic waste	Waste contaminated with uranium-233 or with radionuclides having atomic numbers greater than that of uranium.
Tuff	Rock derived from volcanic ash. *Welded tuff* results when the volcanic ash is hot enough to melt together and is further compressed by the weight of overlying materials. *Non-welded tuff* results when volcanic ash cools in the air sufficiently that it doesn't melt together, yet later becomes rock through compression.
Unsaturated zone	The zone of soil and rock between the land surface and the water table.
Water table	The upper limit of the portion of the ground wholly saturated with water.
Welded tuff	See *Tuff.*

Acronyms

DOE	Department of Energy
EPA	Environmental Protection Agency
NAS	National Academy of Sciences
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982





Viability Assessment of a Repository at Yucca Mountain