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The Los Alamos Contribution to the Nevada Nuclear Waste Storage Investigations

by N. N. Sheheen

"Designing a system for such long-term isolation presents a fascinating challenge faced only a few times in the past, as when engineers of ancient Egypt designed the tombs of the pharaohs."*

Yucca Mountain is located along the southwestern boundary of the Nevada Test Site about 100 miles northwest of Las Vegas. The mountain is a long, narrow ridge generally running north and south with a steep western slope and a gentler eastern slope. The ridge rises about 1,200 feet above the surrounding plains.

*Waste Isolation Systems Panel, Board on Radioactive Waste Management, *A Study of the Isolation System for Geologic Disposal of Radioactive Wastes* (National Academy Press, Washington, DC, 1983).

Introduction

The safe disposal of spent nuclear fuel and high-level nuclear waste is a matter of national importance. Electric utilities have accumulated over 11,000 metric tons of spent nuclear fuel. By the year 2000, this inventory could reach 50,000 metric tons. In addition, over 300,000 cubic meters of high-level waste from defense and research activities are being stored in temporary facilities throughout the country. The safest and most feasible way to isolate these wastes from the environment is to store them in mined geologic repositories that can be inspected and monitored. The Nuclear Waste Policy Act (P.L. 97-425), signed into law in 1983, requires the President to recommend the first such site to Congress by March 31, 1987.

The Nevada Nuclear Waste Storage Investigations (NNWSI) Project, managed by the US Department of Energy (DOE), Nevada Operations Office, is a multifaceted scientific and engineering assessment of the Yucca Mountain site. Our associates on the investigating team are scientists and engineers from Sandia National Laboratories (SNL), Lawrence Livermore National Laboratory (LLNL), US Geological Survey (USGS), Westinghouse Electric Corporation (WEC), and Science Applications International Corporation (SAIC). SNL is responsible for repository design and performance assessment; LLNL for waste package design; USGS for site-specific and regional assessment of geology and hydrology; WEC for tests on waste packaging and handling techniques; and SAIC for technical and management support.

The Role of the Los Alamos Researchers

Our main contributions are

- to study the geochemistry and mineralogy/petrology of Yucca Mountain and the surrounding area and
- to coordinate the design, construction, and testing for the exploratory test shaft.

The results of these studies, combined with the hydrogeological model of Yucca Mountain provided by the USGS and with the waste package studies from LLNL, will be the basis for the radionuclide transport portion of the Yucca Mountain assessment. In addition, we are evaluating the potential for future volcanism by studying the history of volcanic activity in the candidate area.

Drill holes and existing wells are yielding information on area geology, geophysics, geochemistry, and hydrology. However, more detailed subsurface data will be needed if the President selects Yucca Mountain as one of the three sites for detailed characterization. In particular, we would need underground access for exploration and for large-scale tests in the target area (Topopah Spring). We would characterize the subsurface by mining an exploratory shaft, from which further samples could be taken and experiments made. Horizontal drilling and at-depth testing would provide additional information that could not be obtained from surface-based testing.

Scanning electron micrograph of a sample taken from 1,666-ft depth in the altered Topopah Spring basal vitrophyre. The photo reveals spherical smectite aggregates and tubular heulandite crystals.

Yucca Mountain

Yucca Mountain consists of layers of tuff, a rock primarily composed of volcanic ash, pumice, and crystals with some rock fragments; the layers were formed millions of years ago by complex volcanic eruptions. The physical, mechanical, and chemical properties of tuff depend on its cooling and alteration history; several layers in Yucca Mountain have been altered to highly sorptive zeolites that should retard the migration of leached radionuclides from the burial site and help prevent their reaching the biosphere.

The Yucca Mountain site has a combination of very slight rainfall and deep static water level. Thus, relatively little water will be available for contact with the buried waste. The area being characterized is in a unit of tuff about 1,000 to 1,200 feet below the surface and about 550 to 750 feet above the static water table.

A further advantage is Yucca Mountain's location about 100 miles from the nearest large population center, Las Vegas, Nevada, on land owned jointly by the Department of Energy, the Air Force, and the Bureau of Land Management. Federal ownership will simplify land acquisition and protection should Yucca Mountain be selected as the site for a repository.

Geochemistry

The key issue in our investigation of Yucca Mountain is to what extent the natural geochemical barriers will prevent the release of radionuclides. We have calculated the activity of various radionuclides in light-water-reactor waste and combined that data with standards proposed by the Environmental Protection Agency for disposal of spent fuel and high-level waste to assess the radionuclides in the waste that might be stored at a Yucca Mountain repository. We developed a computer code to help predict the long-term capacity of the natural barriers to contain just such radionuclides. We are supplementing this work with measurements of permeability, sorption, and transport on samples of Topopah Spring and Calico Hills tuff. These measurements are necessary to model waste-element movement from fractures into and through the tuff matrix to determine migration patterns to the static water level. We have also been determining permeability, sorption, and transport data on tuff below the water table to understand the entire sequence of natural geochemical barriers to radionuclide transport.

Our objectives are to

- determine the groundwater chemistry along flow paths to the accessible environment.
- develop limiting models to explain the present mineral distributions and to predict possible changes in this distribution from future alteration.
- develop methods to estimate the solubility of radionuclides in Yucca Mountain water in anticipated repository conditions and along flow paths to the accessible environment.
- determine sorption coefficients of representative tuff samples as a function of mineralogy, micro-biological activity, and presence of drilling fluids. Sorption on particulates and colloids will also be measured. We will then develop limiting models for predicting sorption.
- examine how radionuclides interact with Yucca Mountain tuff during transport to simulate the possible situation along a flow path from the repository to the accessible environment. Then we will validate transport models experimentally for geochemical and flow processes in Yucca Mountain.
- analyze how variations in geochemical and hydrological retardation properties affect radionuclide travel times and release amounts.
- demonstrate experimentally at Yucca Mountain the statistical validity of the radionuclide migration predicted from laboratory experiments and from computations.

As in any experimental program, the direction or emphasis may change as data and results are collected and interpreted. We are now shifting our effort toward studying less well-known phenomena such as

- microbial processes that may affect retardation of waste elements;
- effects of alpha radiolysis on the geochemistry of waste elements under natural conditions;
- unsaturated rock flow phenomena;
- speciation of waste elements in groundwater of neutral pH;
- kinetics of sorption processes; and
- colloid formation, retardation, and transport.

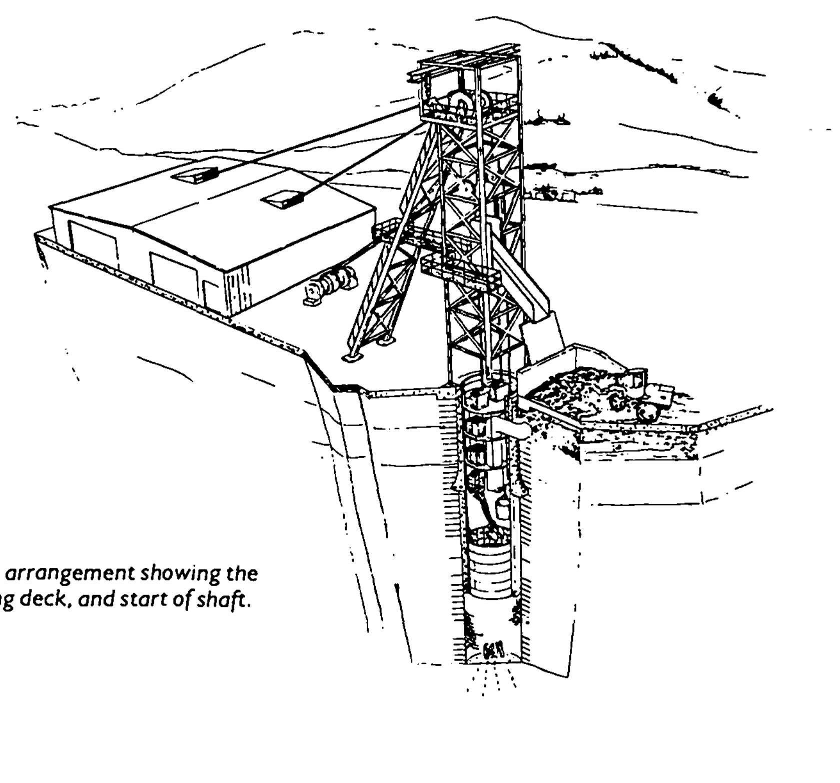
Mineralogy/Petrology

The mineralogy and petrology of Yucca Mountain must be portrayed before a decision can be made to construct a waste repository. Our studies define the nature and distribution of minerals and other solids that could come into contact with migrating waste. We also study fractures and voids that may contain different minerals than the surrounding rock matrix but that may also effectively isolate waste.

Altered phases of tuff, containing smectite clays and some zeolites, may augment long-term isolation because they are present in large amounts at Yucca Mountain. Although diffusion into the rock matrix will provide significant retardation, sorption is another process directly coupled to mineralogy. Zeolites, which are crystalline, hydrated aluminosilicates containing exchangeable alkali or alkaline-earth cations, are known as molecular sieves and are currently used for pollution control and other purification processes. Additional sorption might be provided by manganese-rich minerals along fractures. However, the faults and fractures must be mapped and the history of alteration within them known to assure that no natural rapid paths to the static water level occur in the host rock. Additionally, we are studying the low-temperature kinetics of zeolite alteration to assure that we can predict the stability of these minerals in zones near the repository.

Our objectives are to

- study the bulk rock alteration, including the upper-level alteration



Exploratory shaft arrangement showing the headframe, sinking deck, and start of shaft.

of primary glass to sorptive minerals, to determine the conditions and timing of alteration.

- study mineral stability to assess the impact of the repository's thermal aureole on minerals that naturally retard radionuclide migration.
- understand host rock mineralogy and petrology in relation to retardation determinations, particularly along transport pathways in the unsaturated zone. These studies will include the determination of mineral distributions all the way to the accessible environment. We will also establish a mineralogic and petrologic stratigraphy within the host rock that will guide the determination of working elevations should unanticipated faults be encountered during repository construction.
- study the exploratory shaft, the experimentation rooms within it, and the associated lateral drill holes for a level of site characterization at a depth that is presently not possible.

The Exploratory Shaft Facility

Geologic, geophysical, hydrologic, and other data obtained from the Yucca Mountain investigations were used to identify the best possible horizon for a repository. However, extensive subsurface characterization is needed. This will be accomplished in an exploratory shaft facility (ESF).

The ESF will have two vertical shafts plus horizontal drifting to form underground testing rooms. One shaft will be a concrete-lined, 12-foot-diam, 1,480-foot-deep opening for transporting people and equipment to breakout rooms at three levels, one of which will be the main underground test facility. A secondary 6-foot shaft is also planned to provide ventilation and an emergency escape route.

The 12-foot-diam shaft will be constructed by conventional drill, blast, and muck mining techniques. The shaft bottom will be about 100 feet below the target unit. Construction of the shaft by mining rather than by drilling will minimize the potential for introducing large quantities of water and drilling fluids into the fractured unsaturated zone before *in situ* tests are conducted. The decision was based on experience with drilling fluid loss in Yucca Mountain drill holes.

A breakout room will be mined from the larger shaft at about the 1,200-foot level so that engineers can assess the integrity of the tuff for drift construction in the target unit. If the findings are favorable, the drifts, alcoves, and rooms for *in situ* testing will then be mined. The mining operations will remove about 400,000 cubic feet of rock.

Researchers will perform *in situ* tests in the drifts, rooms, and alcoves as well as in the shaft during and after construction. They will examine fractures, as well as groundwater composition and age, from the surface to slightly below the target unit. This information is necessary for evaluating groundwater flux in the unsaturated zone. In addition, researchers will measure deformation of the rock mass around the shaft during shaft construction. These and other tests will also help determine the best physical, mechanical, and chemical properties for the waste package, for repository layout and development schedules, and for the engineered barrier design and backfill. The underground work will also reveal the extent and pattern of faults and fractures within, above, and below the candidate horizon.

Related Obligations

The scrutiny of Yucca Mountain will not stop with exploration at depth. Rather, the NNWSI Project must address the issues that are being raised by the State of Nevada and affected Indian tribes and must defend its findings to the Nuclear Regulatory Commission (NRC).

All NNWSI Project procedures must also meet rigid standards to assure that our findings are valid. Therefore, strict quality assurance procedures must be followed and evaluated during regular audits and inspections. In addition, unbiased technical peers must review all procedures and data; and interested organizations and individuals may review and comment on environmental assessment and impact statements and on site characterization documents.

Before the Yucca Mountain site can be developed into a repository and licensed to operate, our research must stand the test of public hearings and reviews at several stages. Then the President and Congress will decide from among the contenders. Finally, the DOE will petition the NRC for a license to operate a repository.

All these efforts are intended to ensure that the site selected for the nation's first high-level radioactive waste repository withstands time, temperature changes, and geologic conditions long enough to allow the waste to decay to safe byproducts. That span of time exceeds our guardianship; nevertheless, the repository must protect future generations for thousands of years. The purpose of the NNWSI Project is to determine if Yucca Mountain is a safe and lasting site for a repository. Only through meticulous and open research can an existing problem be solved and the challenges met for a legacy of assurance in the future.

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