STATUS OF GEOLOGIC ASPECTS OF SITE SELECTION AND INVESTIGATION

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ABSTRACT

In the search for a nuclear-waste repository, the Department of Energy (DOE) is concentrating on specific sites in basalt lava, tuff, and salt. An exploratory shaft will be sunk in each of these three rock types for in situ testing, final characterization of geology and hydrology, and verification of site suitability to support application for license to construct a repository at the one site to be selected.

A site has been selected in the basalt lava flows at the Hanford Site in Washington; a Site Characterization Report (SCR) has been issued, and drilling of an exploratory shaft has begun. A site has been selected in tuff at the Nevada Test Site; an SCR will be issued by the middle of this year and excavation of an exploratory shaft will begin this fall. By mid-year, one salt site will be selected from among those being studied in salt domes and bedded salt; an SCR will be issued later in the year and drilling an exploratory shaft is planned for early 1984.

The recently enacted Nuclear Waste Policy Act of 1982[1] authorizes the development of a small-scale Test and Evaluation Facility (TEF), which may be located at one of the three sites that will have exploratory shafts. Retrievable emplacement of not more than 100 canisters of high-level waste or spent fuel --not to exceed 100 metric tons-- in the TEF will be part of a step-by-step program to gain experience with emplacement operations and to gain information and experience for final decision to construct full-scale facilities in the early 1990s.

OBJECTIVES AND ISSUES

The objective of the DOE program for managing high-level radioactive waste is to construct regionally located underground repositories which will isolate the waste from the biosphere and ensure health and safety while protecting the environment.[2] The only plausible way the waste could get into the biosphere is via groundwater, which must reach the canisters, breach them by corrosion and then dissolve the radionuclides and transport them upward to the biosphere. Therefore, hydrology is the prime criterion; all siting studies relate to it and address the following issues regarding waste isolation:[3]

1. Is the groundwater flow-path slow enough and does it contain sufficient sorptive material to isolate the waste?
2. Can it be determined that future climatic, seismic, tectonic, geochemical, and geothermal processes and conditions will not adversely change the hydrologic regime?
3. Will heat from the waste affect the ability of the rock mass to isolate the waste, and will it result in adverse rates of reaction of the water, rocks, and waste packages?
4. Can shafts and boreholes which penetrate the repository horizon be adequately sealed so as not to adversely affect hydrologic isolation?
5. Can the performance of the total natural and man-made system be satisfactorily modeled to demonstrate the long-term hydrologic isolation?

BASALT LAVA FLOWS

A thick succession of Tertiary strata beneath the Hanford Site grades upward from entirely basalt lava flows in the lower part to lavas and increasing amounts of interbedded sediment. Especially favorable attributes are the reducing character of the groundwater, apparent lack of vertical mixing of layered groundwater, and great strength and lateral extent of individual thick lava flows.[4,5]

Two horizons are under consideration; about 1,000 meters and 1,200 meters below surface. Lava breccias in the upper parts of flows, as well as sedimentary interbeds, present potential pathways of groundwater flow. This aspect of the hydrology is a key issue under detailed study.

Deformation of the lava flows, apparently by north-south compression, has resulted in a series of anticlines. Between these folds the lavas are quite flat, though they possess high residual horizontal stresses--one of the reasons for detailed study of rock mechanics underway.

VOLCANIC TUFF

Yucca Mountain is underlain by thousands of meters of tuff, mostly sheets of welded ash-flow tuff. Much of it has been altered to zeolites and clays, whose sorptive properties are renowned. Yucca Mountain is unique in that two potential repository horizons lie above the water table. Only a small amount of rainfall percolates through the unsaturated zone and into the groundwater. Thus, leaching of waste would be reduced by orders of magnitude over other sites. Additional isolation is afforded by downward flow from the repository horizon to the water table and then laterally to distant recharge areas --all this flow being through highly sorptive rocks. Key issues under investigation include the nature and rate of flow in the unsaturated zone, the apparently low strength of the rocks, ages of movement of faults, and the ambiguous conditions of high extensional stress and low seismicity in an area surrounded by conditions of high seismicity.[6]

SALT

At the time of this writing, a salt site had not been selected. During 1983, one site for an exploratory shaft is scheduled to be selected from among the three regions now under consideration:

1. salt domes of the Gulf Interior Region -- Vacherie Dome (LA) Cypress Creek Dome (MS), and Richton Dome (MS);
2. bedded salt at depths of 750 to 975 meters in Deaf Smith and Swisher Counties in the Palo Duro Basin (TX); and
3. bedded salt 800 to 1000 meters beneath Davis Canyon and Lavender Canyon in the Paradox Basin (UT).

Advantages of salt include: high thermal conductivity, plastic flow tends to seal dislocations, easily excavated, and the presence of salt demonstrates a dry environment. Issues unique to salt are: dissolution, pockets of pressurized brine and gas, room closure by creep, and highly corrosive chemical environment which could affect life of the waste package and instruments used for monitoring. In addition potential occurrences of oil and gas are higher around salt domes and in bedded-salt structural basins than in regions of igneous rocks. These issues are actively being studied.

CRYSTALLINE ROCKS

In addition to the above studies, DOE is investigating granite and other crystalline rocks. These are the most abundant rock types in the upper part of the earth's crust, and afford far-greater volumes of rock potentially suitable for repositories than do any of the other rock types. Large volumes of crystalline rocks occur in many places which have low seismic and very low tectonic activity. Many bodies of crystalline rocks are very large and homogeneous. They generally have great strength, inherent mechanical stability, and predictable engineering characteristics; many have been stable for millions of years. The rocks are composed of high-temperature silicate minerals which are likely to remain stable during the period of heat generation by the waste. These minerals have good sorptive properties, intermediate between those of salt and shale. The quantity and ionic strength of any water present usually is low, thereby minimizing corrosion of the waste container. Crystalline rocks have very low primary permeability and generally do not constitute deep aquifers. The principal potentially adverse condition is that water is essentially restricted to fractures, and the flow of groundwater through the fractures is difficult to model. However, fractures tend to diminish in frequency, length, and aperture and (or) become hydraulically closed with depth.[3]

Nationwide surveys formed the basis for selecting three regions for further study:

1. Lake Superior Region
2. Northern Appalachians and Adirondacks
3. Southern Appalachians.

Screening methodologies are being developed and applied as a basis for selecting small areas for further study as possible regional repositories to be sited at some later time.

FIELD TESTS

Field tests of radionuclide migration and of hydrologic effects of heat provide further bases for focusing on specific sites. Tests conducted in granite, shale, bedded salt, salt domes, gneiss, basalt, and tuff have resulted in removal from the "critical list" of such issues as the effects of earthquakes on structures underground, inflow of brine, effects of coupled thermal and mechanical behavior of rock and radiation damage to rocks. These field tests form the basis for in situ tests to be conducted from exploratory shafts. In addition, tests are being conducted on sealing of shafts and boreholes.

A near-surface test facility was constructed in the basalt lava flows in Gable Mountain at Hanford, Washington.[7] Data were obtained on the thermomechanical behavior of basalt as it was subjected to heat simulating that which would be generated by high-level waste. The measurements of the magnitude and distribution of temperature and stress were within a few percent of pre-test estimates. The installation of apparatus for a jointed-block test is in progress, which will assess the effects of joints on the thermal, mechanical, and hydrologic behavior of a 2-m by 2-m jointed block of basalt.

In another test facility 1,400 feet below the surface in the Climax granite stock at the Nevada Test Site, spent nuclear fuel had been successfully encapsulated, transported, emplaced, monitored, and retrieved.[8] The hydrologic and mechanical behavior of the host rock in the presence of heat and radioactivity from this waste was studied. The value for thermal conductivity measured during the first heater test was within 15 percent of the mean of laboratory data. This value was used to model calculations for the spent-fuel test and resulted in agreement within a few percent. It was concluded that ventilation was effective in removing part of the heat.

Welded tuff at the Nevada Test Site was tested to determine the nature of water migration through heated porous media.[9] Migration occurred by vapor diffusion, driven by partial-pressure gradients. The data have been used to develop a model which is in good agreement with experimental data. The next text involves determining radionuclide migration along a single fracture which has been delineated by drilling and by examination in a drift. Tests were completed recently in the Avery Island Salt Dome in Louisiana to study heat conduction, the mechanical effects of heat, and brine migration.[10] Heat conduction and temperature correspond to model calculations which were based on laboratory measurements of conductivity. Moisture content was too low ($<0.01\%$) to provide successful tests of brine migration.

A study of gneisses has been completed in the Colorado School of Mines experimental mine at Idaho Springs.[11] Measurements of the thermal expansion of a heated block (about 2 m by 2 m) were inconsistent but were lower than predicted, apparently due to a present inability to predict the behavior of joints The nature and extent of the excavation blast damage to the rock is predictable and can be used in the design of repositories in crystalline rocks.

These U.S. studies supplement the results of highly successful cooperative studies of granite in a mine at Stripa, Sweden, in which the Department of Energy is actively participating.[12] In those ongoing experiments, it was determined that the variations of temperature in time and space within the granite mass compare closely to calculations based on laboratory data and can be predicted reasonably well with present models--rock expansion was less than predicted, owing to the role of joints, and the effect of fractures on thermal conduction was insignificant. A large-scale permeability experiment was conducted to determine the bulk permeability of a large volume of rock. The end 33 m of a drift were sealed off and equipped with a ventilation system the temerature of which could be controlled by evaporate all the water seeping into the sealed-off drift. The seepage was determined by measuring the mass flow rate and the difference in humidity between the input and exhaust air streams. From these data, a bulk hydraulic conductivity of 10^{-11} m/s was calculated.[13]

These tests add to a comprehensive base of data from laboratory studies and provide critical information for computer modeling codes the development of which parallels the development of field and laboratory studies.

PUBLIC AND PEER REVIEW

Achievement of goals requires consensus of all levels of government and the public. Increased technical knowledge of the sites and issues is being used as primary focus to achieve that consensus. Technical peer review and field examinations by nationally acclaimed experts provide additional program guidance. Frequent field visits by NRC staff and their consultants, and exchange of DOE and contractor documents with them, are effective means of keeping the NRC staff current on the developments so that they will be familiar with all technical aspects of sites when DOE makes application to the NRC for a license to construct a repository.

CONCLUSION

Emphasis of the program has changed from generic to site-specific. Significant progress has been made on studies of specific candidate sites, and a schedule which can be attained has been set.

Early access to repository horizons via exploratory shafts, and early testing in actual drifts and boreholes will give tangible evidence of capability to safely handle and dispose of waste. Such extensive exploration at depth will significantly increase the level of confidence in ultimate success of the mined geologic repository concept. Socioeconomic conditions make the schedule desirable; technological advances in the program make it feasible.

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