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RADIOACTIVE WASTE DISPOSAL IN GRANITE

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Abstract The principal geotechnical problems in selecting a repository site for radioactive waste disposal in granite are to evaluate the suitability of the rock mass in terms of: (i) fracture characteristics, (ii) thermomechanical effects, and (iii) fracture hydrology. Underground experiments in a mine in Sweden have provided an opportunity to study these problems. The research has demonstrated the importance of hydrogeology and the need to improve predictions of the thermomechanical behavior of fractured rocks. To characterize a site, measurements made from the surface must be supplemented by extensive subsurface experiments. Much effort is needed to generate the technology required for the development of waste repositories.

Introduction Radioactive wastes have special properties that distinguish them from other hazardous wastes. They range from dilute and short-lived materials to high-level wastes (HLW), in the form of spent fuel rods or the products from the first cycle of reprocessing. High-level waste is intensely radioactive and generates large quantities of heat by radioactive decay.

Plans for underground disposal of HLW use a multibarrier approach consisting of (i) the form of the waste, (ii) the waste canister, (iii) backfilling material that surrounds the canister, and (iv) the geologic system (rock mass) surrounding the repository. Each component's contribution to the control of rates and amounts of radionuclides released to the biosphere must be predicted. To perform its role, the rock mass must have several attributes: low permeability, low interconnected porosity, low hydraulic gradient, and high sorptive capacity. It must also have adequate thermomechanical and chemical stability. In addition the candidate site as a whole must permit the practical design, construction, and operation of the repository. Geologic media are inherently heterogeneous. The ability to adequately characterize the properties of a rock mass may ultimately dictate the choice of the type of host rock and the specific repository site.

Four rock types are being actively considered as candidates for disposal of HLW in the United States. These are the granitic rocks, basalt, tuff, and salt. Prospective repository sites are currently being investigated in basalts at Hanford, Washington, in tuff at the Nevada Test Site, and in several locations underlain by bedded and domal salt formations. Repository sites in granitic rock have not yet been selected in the United States. However, an underground research facility in granitic rock has been operated in Sweden for several years under the sponsorship of a Swedish-American cooperative program. Sites in granitic rock are also being investigated in Canada, Finland, France, Britain, Japan, and Switzerland.

Basic Problems The principal geotechnical problems in selecting a repository site in granite are to evaluate the suitability of the rock mass in terms of: (i) fracture characteristics, (ii) thermomechanical effects, and (iii) fracture hydrology. Investigations in all rock types must address some or all of these problems. The properties of geologic media are site-specific. Thus, the safety of a nuclear waste repository cannot be fully evaluated unless appropriate design, testing, and analysis is performed for the rock conditions prevailing at the actual location.

The fracture system in the rock mass plays a dominant role in determining the suitability of a repository site. In granitic rock masses the fracture system is made up of different types of discontinuities: joints, faults, and shear zones. They may persist over distances ranging from meters to kilometers. Fracture systems may exhibit an abundance of discontinuities or they may be so scarce that hundreds of meters of core may not exhibit a single discontinuity. These characteristics are of the utmost importance because they control the movement of aqueous solutions of radionuclides and affect the stability of underground openings. The search for granite sites must look for geologically stable areas where tectonic conditions have produced a favorable system of fractures. Recent investigations at the site of an underground facility for waste storage research in the Canadian program at Pinawa, Manitoba, suggest such favorable conditions can be found.

Granitic rocks are generally very competent. Openings can be expected to be stable if properly designed and thermal effects are accounted for. However, a more significant problem is the effect of thermal loading on the hydrologic characteristics of the rock mass. Based on current conceptual designs for HLW repositories, maximum rock temperatures in the vicinity of the waste canisters in the range of 100° to 200°C can be expected. As the waste decays, the thermal field propagates out into the rock mass reaching peak temperatures that are less and less with distance from the source; the whole process extends over hundreds of years. The consequunt changes of stress and deformation of the fractured rock mass can affect its hydraulic properties. This problem is not well understood and requires much more investigation.

The question of fracture hydrology raises a critical issue. Migration of radionuclides will occur by solution in groundwater seeping through the site. The rate of migration depends on three basic rock properties: (i) permeability, (ii) effective porosity, and (iii) capacity for sorption. The permeability of a rock such as granite is essentially controlled by the hydraulic properties of the fracture system. A permeability tensor can be developed from measured fracture orientations and spacings and an assumed model of aperture distributions. The presumption is that the permeability of the intact rock should be negligibly small, and the hydraulic conductivity is due to the fractures. Effective porosity can only be obtained in practice by measuring the actual

velocity of fluid migration with a tracer introduced along a known flow path and observing its time of arrival downstream. The mechanisms
velocity of fluid migration with a tracer introduced along a known flow path and observing its time of arrival downstream. The mechanisms controlling sorption of radionuclides on mineral surfaces are not yet well understood. This is true for all rock types and much more investigation both in the laboratory and in the field is needed.

Field Experience at Stripa Over the past four years, a comprehensive series of investigations have been conducted at a depth of about 340 m below the surface in a depleted iron ore mine at Stripa, Sweden, as part of the Swedish-American cooperative program. Some of the mine workings intersected a granitic (quartz monzonite) pluton and provided easy access for the investigations. A series of over 30 reports have been produced describing the experiments, the data collected, and the analytic results (1). Technical summaries of the findings obtained so far have also been published (2,3).

The experiments at Stripa have produced important results that could only be obtained from underground studies at depths comparable with those envisaged for an actual repository. Experiments at such depths give rise to unexpected and sometimes difficult problems that cannot be anticipated solely from laboratory-scale research. Experience obtained at Stripa raises a number of key questions that must be resolved before reliable procedures can be developed for site characterization.

The thermomechanical, hydrologic, and geochemical behavior of a low-permeability crystalline rock mass is determined by the properties of the rock matrix and, more importantly, by the discontinuities within it. This raises the question of defining the geometry of the fracture system. Although some preliminary studies suggest that fracture orientations between surface and subsurface are similar, there are no data to demonstrate that the important characteristics of length and continuity of such features can be reliably predicted from surface measurements. However, when detailed mapping was carried out in the underground at Stripa, we obtained reliable results. Mapping of fractures must be carried out so that the orientation, spacing, continuity, and aperture distribution are determined in sufficient detail to enable the behavior of the rock mass as a whole to be predicted.

Thermomechanical results obtained thus far at Stripa show that much work will be needed to develop a reliable basis for predicting thermally induced effects in discontinuous rock masses. The behavior is complex, and the mechanical and hydrological effects of the discontinuities are not fully understood. Rock temperatures were not difficult to predict. However, difficulties arose in predicting rock mass displacements. Analyses based on assumptions of linear thermoelasticity predicted displacements about twice those observed. Better results were obtained when temperature-dependent rock properties were used, but there were still inconsistencies. This raises another question of how to reliably predict the global thermal response of a discontinuous rock mass. In our view, this can only be done in a properly designed and instrumented test facility constructed underground at the specific repository site.

With regard to fracture hydrology, an attempt is being made at Stripa to measure the permeability tensor by conventional methods in three inclined boreholes drilled from the surface. These methods seem to be working well, but the hydraulic conductivity at Stripa is about 10^{-11} m/sec. Less permeable rock masses may have values two to three orders lower than this, and whether conventional methods will still give reliable results remains to be seen.

A new large-scale method of measuring permeability (3), developed at Stripa, offers a potential solution to this problem. This involved sealing off a 33-meter length of drift and providing a ventilation system with which the air temperature can be controlled to evaporate and measure the rate of seepage into the room. This technique enables the average permeability of a large volume of rock (10^6 m^3) to be measured. The method should be easily adaptable to rock masses with permeabilities far less than those at Stripa.

Taken together, experience from the research performed at Stripa indicates that site characterization for nuclear waste disposal must include extensive subsurface experiments. The thought is often expressed that the technology of underground waste storage is essentially developed, but in our view, much remains to be done.

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