C. WASTE MANAGEMENT

17. DISPOSAL OF RADIOACTIVE WASTES

INTRODUCTION

A multi barrier approach is followed in the disposal of radioactive solid wastes. The overall safety against migration of radionuclide is achieved by proper selection of waste form, suitable engineered barriers, backfill materials and the characteristics of the geo-environment of the repository site. Based on the nature and type of the radionuclide present in the solid waste and its concentration the repository could be near-surface or in deep geological formations. Operation of various Near Surface Disposal Facilities (NSDF) has led to considerable expertise in this field. Our programme on site selection & host rock characterization is under evaluation for deep geological disposal.

17. DISPOSAL OF RADIOACTIVE WASTES

Disposal as a final step in the management of radioactive waste involves confinement or isolation of these wastes from biosphere in the repositories. Based on the longevity and concentration of the radionuclide present in the waste, the repository could be either near-surface or in deep geological formation.

India has extensive & varied experience in the operation of near surface disposal facilities (NSDFs) in widely different geohydrological and climatological conditions. Over the years, considerable expertise has gone in refining and improving the design and construction of these NSDFs. A system of multiple barriers employed in these NSDFs ensures isolation and release of radionuclides below permissible limits to the environment. This is ensured by regular monitoring and periodic performance assessment of these NSDFs.

Disposal of long-lived and high level waste in deep underground geological formation is one option which has received world-wide attention. In India, the most promising formation is granitic rocks. In this context, our programme of site selection and host rock characterization for an Underground Research Laboratory is under evaluation.

17. 1 NEAR SURFACE DISPOSAL

As a national policy, each nuclear facility in India has its own Near Surface Disposal Facility (NSDF). There are seven NSDFs currently operational within the country. These NSDFs in India have to address widely varied geological and climatological conditions.

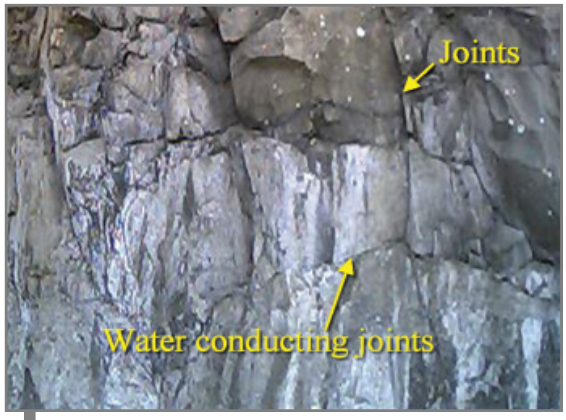
The performance of these NSDFs is continuously evaluated to enhance the understanding of migration, if any and to adopt measures for upgrading the predictability over a long period of time.

■ Performance assessment and service life prediction of Reinforced Concrete Trenches:

Performance assessment of Reinforced Concrete Trench (RCT) is systematically undertaken through field investigations and predictive modeling. NDT investigations on operating RCTs and laboratory studies on NSDF materials have demonstrated that RCTs are in sound condition even after an operational period of three to four decades. Mathematical models have been developed to predict the probability of failure as a function of target lives for various safety indices such as concrete cover thicknesses, climatic factors, maintenance period for the structure, water to cement ratio, water proofing etc. Modeling studies for a typical RC trench under limiting conditions have predicted a minimum service life of nearly 240 years. This study was completed in collaboration with CBRI, Roorkee.

■ Geohydrological studies – A tool to identify the groundwater pathways for migration

Sub-surface evaluation of these NSDFs is carried out systematically by geological and geohydrological investigations to identify potential groundwater pathways defined by top soil, weathered rock, fracture networks, interflow porous layers, contact planes etc. in different lithological units as depicted in fig. below.

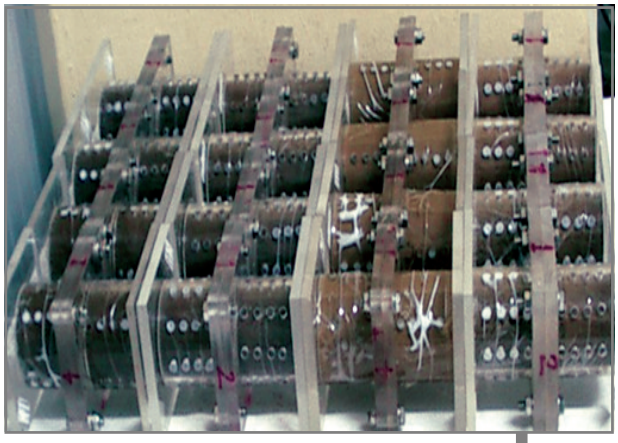


Typical Groundwater Pathways due to Intersecting Joints in Basaltic Formations – Trombay

Fig. typically depicts groundwater pathways due to intersecting joints in basaltic formation at RSMS Trombay. This sub-surface information has been obtained by means of drilling and lithological studies, i.e. heterogeneity and multi-well tracer experiments. For precise determination of subsurface pathways, state-of-art geophysical surveys using Ground Penetration Radar (GPR) are planned up to a depth of 30m.

■ Radionuclide migration through unsaturated soil – Laboratory and Field studies

The top soil in NSDFs is generally unsaturated and provides a retarding barrier against contamination of groundwater. Understanding of migrational behaviour of contaminant through this zone, is carried out both at laboratory and field.

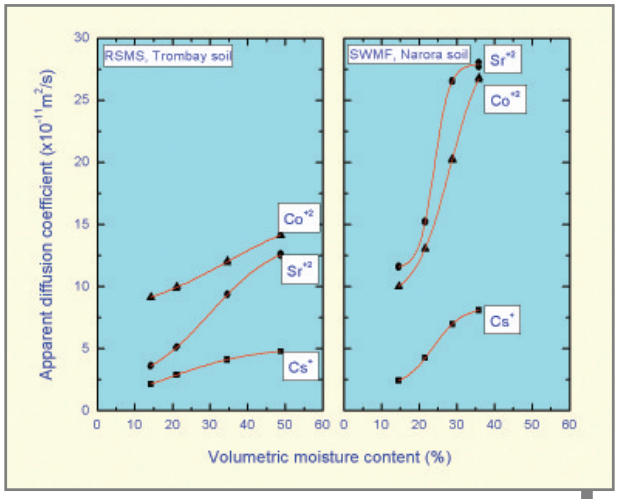


Diffusion cells with spiked and virgin soils

In laboratory experiment apparent diffusion coefficients have been determined using soil samples from Trombay and Narora for radioisotopes ^{137}Cs, ^{90}Sr and ^{60}Co in the dedicated lab scale diffusion cells.

The study reveals that apparent diffusion coefficient is a function of moisture content and it can't be linearly extrapolated over the range of moisture content.

The apparent diffusion coefficient for Trombay soil, ranges from (2.12-14.20) E-11 m^2/s and for Narora soil from (2.41-28.06) E-11 m^2/s depending upon compaction states of the soil samples and radionuclides.



The variation of apparent diffusion coefficient with volumetric moisture content for different soil samples

Lysimeter experiments include Time Domain Reflectometer (TDR) along with pore solution samplers

Field tracer experiments (Lysimeter experiment) have been initiated to evaluate *in-situ* hydraulic conductivity and radionuclide migration through unsaturated soil.

These experiments provide valuable information on the travel time of different radionuclides.

■ Monitoring and validation of mathematical models of migration

Mathematical models are developed to predict the migration of radionuclides in near and far field as a part of safety assessment of NSDFs. Continuous monitoring is undertaken to validate the assessments and to enhance confidence.

Based upon these studies the average migration rate of radionuclide is calculated, which corroborates well with the prediction of mathematical modeling.

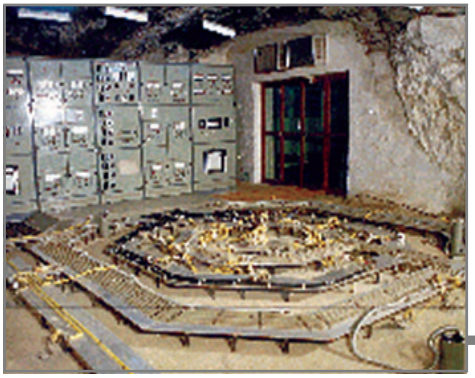
17. 2 DEEP GEOLOGICAL REPOSITORY

A programme for development of a geological repository for vitrified high level long lived wastes is being pursued actively, involving *Insitu* experiments, site selection, characterization and laboratory investigations.

A. *Insitu* underground experiments

For assessment of the rock mass response to thermal load from disposed waste overpack, an experiment of 8-years duration was carried out at a depth of 1000 m in an abandoned section of Kolar Gold mine. The thermal processes were also modeled by developing suitable codes. Good agreement between predicted and measured parameters was obtained.

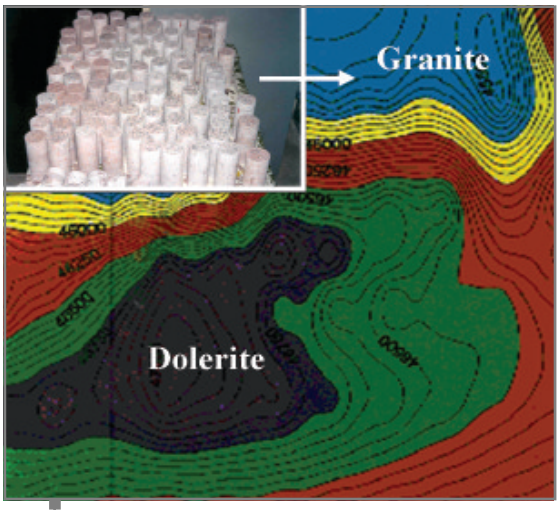
Some more *in situ* experiments pertaining to testing of full-scale engineered barriers i.e. simulated waste overpack, bentonite clay buffers and clays sand admixture, are planned to study the behavior of thermal, chemical, mechanical and hydraulic processes around overpack. Also for development of methodology and technology for charecterization of field scale fractures as pathways for radionuclide and gas migration, experiments are planned in abandoned underground mines in future.



Underground experiment in Kolar Gold Field, Mysore

B. Site selection and characterization

Geologically, India is endowed with a number of suitable rocks to serve as host rocks for geological repository viz. granites, basalts, shales etc. The current investigations focus on granites due to availability of vast regions occupied by these massive granitic rock with very good mechanical, geochemical and geohydrological properties.



Magnetic Intensity map of a site with granitic rocks retrieved from 450m (inset)

A few promising areas lying in NW and Central India, occupied by good quality granites were systematically investigated using satellite data, geological and structural mapping on different scales, geophysical surveys viz. electro-magnetic, resistivity and magnetic to generate three dimensional structural and lithological models. These models were validated and refined with shallow and deep drilling amounting to about 5000 m in 25 boreholes.

After characterizing the host rock for its geochemical, hydraulic and rock mechanical properties, about 22 zones, 100 sq km each have been demarcated as potential regions for further investigations. One on these zones has been investigated in detail to narrow down an area of about 4 sq km as suitable candidate site.

Such investigations are being pursued with the involvement of national agencies like Geological Survey of India, Mineral Exploration Corporation Ltd. and National Geophysical Research Institute, Central Mining Research Institute, National Institute of Rock Mechanics, IISc, IIT etc.

C. Laboratory Investigations

Geochemical Characterization

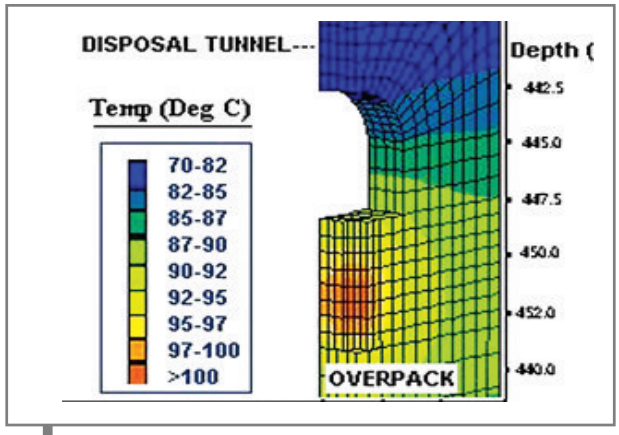
The host rock from potential sites has been subjected to detail petro-mineralogical and geochemical investigation to evaluate the their impact on rock mechanical and hydraulic properties. Diffusion coefficient for a number of radionuclides like Cs, Sr etc have been determined.

Rock mechanical Characterization

As a part of host rock characterization, study on the pre and post failure behavior of granitic rocks under varying loading and permeability test at different temperatures (30°-160°C) including three-dimensional micro-crack development at aforesaid temperatures using SEM, acoustic emission and ultrasonic techniques. Rock mechanical properties like Joint roughness, basic friction angle, joint wall compressive strength, peak shear strength, normal stiffness, shear stiffness in heat treated rocks from deeper level have also been measured with the help of instruments specifically designed for such purpose.

Shear apparatus developed at NIRM for rock mechanical studies of jointed rock

Finite Element Modelling of thermo-mechanical response in granites



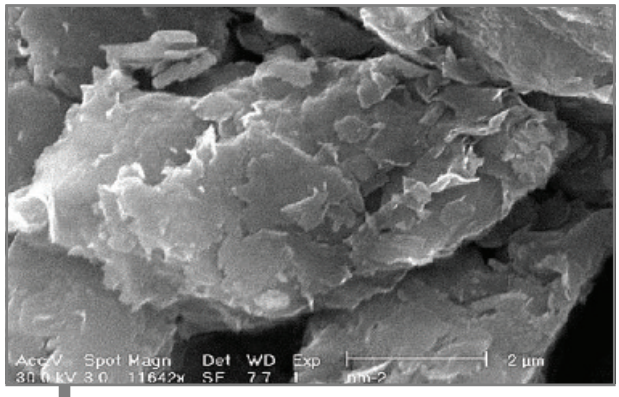
Numerically simulated temperature fields around a disposed over in a disposal tunnel of 5m diameter

Numerical analysis for the rock mass has been performed using three-dimensional finite difference code to model the inelastic behavior of the rock mass, simulate the excavation sequence and ground support installations and thermal–mechanical coupled behaviour. The thermal impact on host media has been modeled for 1000 overpacks.

A typical case of disposal of single overpack with a heat out put of 500 W in a 5 m diameter disposal tunnel in granitic rock is shown in figure.

17.3 BACKFILLS AND BUFFERS FOR GEOLOGICAL DISPOSAL

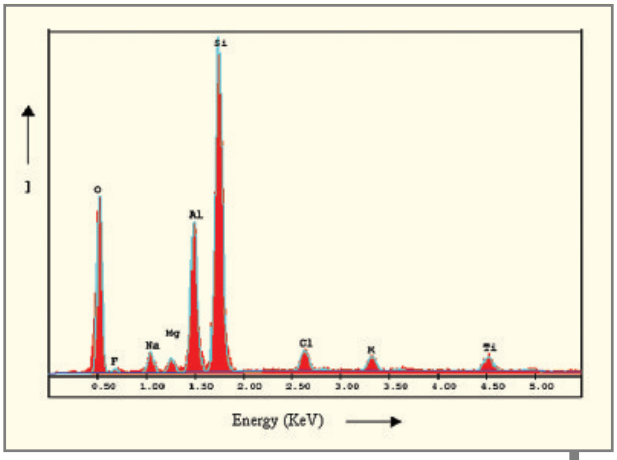
Backfills and buffers constitute the most important components of multibarrier scheme adopted in a geological disposal system in hard rocks. These layers are placed between



SEM Micrograph indicating Flake Morphology

the waste overpack and the host rock mainly to restrict the groundwater flow towards the waste form and to retard the migration of radionuclides in the event of their release from the overpack. Swelling bentonitic clays predominantly composed of smectite mineral have emerged as preferable choice for such use due to their very low hydraulic conductivity and high retardation for radionuclides. Besides, their swelling property adds in sealing the fractures in the host rock.

Indian swelling clay deposits are being evaluated for their suitability. Studies are underway to characterize their mineralogical compositions, geochemical characteristics viz. pore water compositions, hydration, cation effect, diffusion and adsorption for various radionuclides, engineering properties viz. Atterberg limit, plasticity index, swelling potential etc both under normal and elevated temperatures. Suitable admixtures of these clays with sand and crushed rocks are also being optimized for future testing *insitu* environment.



EDX spectra of swelling clay-2 from western India

Studies suggest that Bentonite deposits of Barmer Basin in Rajasthan with reserves of about 20 million tonnes are suitable. Mineralogicaly, they mainly contain mineral smectite (50-60 %) with quartz, felspar, kaolinite etc.

XRD pattern of heat treated (400 & 600°C) clay samples show a change in d-value corresponding to Montmorillonite phase indicating temperature dependent transformations of the mineral, This is also supported with thermogravimetry analysis. Smectite content, free swelling volume (20 – 30 mL/g) and also Cation Exchange Capacity (50 – 65 meq/100 g) of these clays have been found to decrease with temperature.

A mixture of 50% Barmer clays and 50% sand, with maximum dry density of 1.61 g/cc and optimum moisture content 21% with good compaction characteristics has been found suitable for fabrication of highly compacted bentonite clay bricks for use as buffer around disposed waste overpacks. Future investigations will involve laboratory and *insitu* testing of these compacted buffers under varying temperatures for evaluation of change in key functions like swelling, dehydration, illite conversion, thermal conductivity and evolution of near-field geochemistry.

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