Safe disposal of high-level long-lived radioactive waste is one of the primary concerns of all the countries engaged in nuclear power programmes. It is a central issue for the future of nuclear power and poses considerable challenge, be it technical, political or social. Such wastes due to their higher half lives and heat emitting nature require their isolation from biosphere for very long periods of time, preferably in a geological repository located at depths of 500-600 m in suitable host rocks. The challenge for the disposal of such radioactive wastes is to establish scientific and technological requirements so as to ensure long-term safety, now and in the future. The research in various aspects of geological disposal has matured considerably in last two decades especially due to some epoch making efforts in Sweden and USA. The geologists of today find themselves better equipped to offer convincing evidences demonstrating the ability of a good host rock coupled with suitable geological set up in providing long term isolation and confinement to nuclear wastes from the biosphere.

The concept of geological disposal met with serious doubts about its feasibility in early fifties among waste management fraternity, perhaps with the same intensity, as did the concept of "drifting continents" in early twenty century among academia. Over the years, the situation has improved dramatically mainly due to large scale demonstration projects being pursued worldwide. The frequency of questions like "Can geologists guarantee isolation of nuclear wastes for thousands of years?" which made repeated appearances in leading journals two decades ago, have reduced substantially.

An official notification by French Commissariat a l' Energy Atomique (CEA) in 1972, announcing the discovery of the remains of a natural fission reactor at Oklo, now known as the Gabon Republic in West Africa, took the world nuclear brains by surprise at one end, while strengthening the belief in possibility of realization of safety of geological disposal of nuclear wastes in practice many folds. The six natural reactors at Oklo that operated in Frenciville sandstone at a depth of about 4 kilometers consumed about 6 tonnes of $^{235}U$ about two billion years back, did produce 15000 megawatts energy and 6000 tonnes of nuclear wastes during its 2 to 6 lakh years of operation. The waste products though residing in highly permeable sandstones remained in their place over geological periods that followed, without any significant movement (Pearce, 1980). This is probably the best argument in support of the feasibility of geological disposal of such wastes.

The environmental hazards associated with heat and radiations of the high level long lived wastes that arise mainly from spent fuels and reprocessing activities have been shown to reduce substantially over a period of the order of a few tens of thousands years. Hence geological environment is expected to provide protection against these wastes over a minimum of this duration. In the initial years geological options like seabed, inland basin, seaward dipping strata, subduction zone etc were also given a thought. The options were found more imaginary in nature than real. Gradually consensus among nations evolved about the possibility of disposing such wastes in suitable rocks at depth.

Efforts to put the concept into practice to confine the heat emitting high-level waste, after immobilizing them in suitable glass matrix, deep into a stable geological environment at suitable site have been continued worldwide for last five decades. The focus of these investigations always centered around finding a site devoid of groundwater and seismicity and also trying to build up models demonstrating the evolution of these sites over next few thousands of years. The initial years from 1955 to 80 were mainly devoted for identification of suitable rock types and regions world wide without much success. The US programme that focused on salt beds for this purpose was met with serious social and political opposition leading to closure of their research activities in salt mines. In early eighties most of the nations like France, Japan, Hungary, etc with substantial nuclear
power generation programmes started assessing various processes and parameters of importance in underground mines while a few other went ahead with the construction of dedicated Underground Research Laboratories (URL) in suitable rocks in the depth range of 400-500 m. These included Sweden, Belgium, Canada, Switzerland and USA.

Geological research on nuclear waste disposal in these mines and URLs mainly included assessment of rock response to heat generation, accelerated ground water movements, 

msitu stresses, excavation, geochemical changes, radionuclide migration through fractures and also processes like seismicity, volcanism, uplift, fault movements etc. For such purpose highly sophisticated instrumentation and methodology to measure and monitor these variations 

insitu over extended period of time have been developed. A variety of rocks like basalt, granites, shale, clay, volcanic tuff and salt beds have been extensively characterized (Witherspon, 2001). The message from this research is clear. The existing rock mass characterization methodology, construction technology, instrumentation and techniques require large-scale refinement to meet the requirement of a geological repository. Expenditure and time required for such a kind of research have been enormous and runs into billions of US dollars.

The extensive research in these laboratories has brought to light the magnitude of technical uncertainties in predicting natural processes over longer time duration successfully. While the role of public in the overall process of site selection and characterization has become more visible most of the nations are yet to find a solution to address this issue. The Selffield site, identified as possible waste disposal site in UK met with serious public rejection finally forcing NIREX, the agency entrusted with the characterization work, to abandon the site. NIREX has spent about 800 million pounds on exploration of this site over last 20 years (Hooper, 2001). Similarly Sweden, Switzerland, Belgium and Canadian Progi amme have suffered a set back due to public reactions. The lesson learnt is very clear. There is clear need to acknowledge the socio-political dimension of the whole problem and evolve a long-term strategy for the same. However, the situation has not been totally dismal. Commencement of Waste Isolation Pilot Plant (WIPP) at New Maxico, IN k a major development in this field. Here an underground geological repository at about 2300 ft depth in bedded salt started receiving Transuranic nuclear wastes in 1999 mainly from USA nuclear weapon programme (Patterson, 2001). The year 2002 has also witnessed a landmark development in the history of geological disposal of wastes. The US president approved a site in welded tuff in Yucca Mountain, lying in Nevada test site, about 120 km NW of Las Vegas, as their national site for further characterization leading to construction of a geological repository. This is unique in the world as it offers disposal of wastes in unsaturated zone about 300 m above the water table as compared to other nations who intend to dispose off the waste well below the groundwater table. The application for obtaining license for construction of the geological repository at this site is expected to be made shortly by US department of energy. In this way the Yucca Mountain site is likely to become the first geological repository for such wastes by the year 2011 (Dyer et al 2001). Also South Korea, Finland and Japan have witnessed progress in their programme. Most of the site evaluation studies at Yucca Mountain have been carried out by US Geological Survey.

India has an ambitious nuclear power programme having many operating power reactors and has opted for a closed nuclear fuel cycle involving reprocessing to recycling. Over the last three decades, India has systematically created capabilities for management of waste that include design, construction, operation and disposal. High level and long-lived radioactive wastes from reprocessing facilities are immobilized in vitreous matrices. The vitrified wastes are over packed and kept under constant surveillance in an interim facility till their decay heat comes to a level where these can be ultimately disposed off in a geological repository. One such interim storage facility is operational and is co-located with a vitrification plant. Final disposal of these overpacks is envisioned in suitable geological formations and set-ups at a depth of 500-600 m. Indian programme on geological repository commenced in early eighties with underground experiments at a depth of about 1000 m in an abandoned section of a gold mine at Kolar Gold Fields (KGF). This was a pure research and development endeavour using simulated waste overpacks and marks the first Indian effort to evaluate deep geological environment in underground mines. The investigations were mainly directed towards development of methodology for 

msitu assessment of the mechanical behavior of the host rock (amphibolite) and to develop and validate the mathematical models. It also addressed the development of associated instrumentation for the measurements and monitoring (Mathur et al 1998).

Regional screening of a few geological domains with the objective of assessing a suitable site for a geological repository has also been initiated. The site selection programme is being carried out based on the principle of narrowing down the target regions ad measuring tens of
thousands of square kilometres to a few kilometres in a phased manner. More emphasis currently is to locate a few suitable sites for development of site-specific Underground Research Laboratory (URL). The investigations involve extensive geoscientific investigations and development of state of the art methods and technologies. While Bhabha Atomic Research Center, Mumbai serves as the nodal agency for formulating site selection and characterization programme, expertise available with leading national agencies in the field of earth sciences and rock mechanics like Geological Survey of India, National Geophysical Research Institute, Central Mining Research Institute, National Institute of Rock mechanics, Atomic Minerals Division, Mineral Exploration Corporation Limited and IIT’s are utilized for quality work.

Site selection commenced with the evaluation of Indian granites. These are known to occur in a variety of geological and geographic domains ranging in age from 30 million years to 2500 million years and spread over millions of square kilometers of area. These have also favorable physico-chemical and thermo-mechanical properties so as to be suitable as a good natural barrier in a geological repository (Mathuretal. 2001). As a result of continuous investigations in the last two decades, a comprehensive database has been generated on desirable features of the host rock as a natural barrier in the geological disposal viz. massiveness with depth continuity, structural and mineralogical isotropy, mechanical strength, geochemistry, hydrogeology, thermal conductivity, permeability, alteration potential etc.

Research is also underway to design a URL/geological repository based on the rock characteristics established during these investigations. The conceptual design forms an integral part of the geological repository programme. It begins with conceptualization of a highly generalized underground structure based on the initial description of disposal features like size and number of waste overpacks, temperature, rock properties and thickness of various barriers. This conceptual design undergoes modification as more and more site specific data becomes available and also adapt to changing waste form descriptions. The design of URL considered in initial stage in our programme has multiple chambers for insitu experiments to generate design data for geological repository in future. The layout initially considered, extends over an area of about 4 square kilometers and considers emplacement of around 10,000 high level wastes over packs on a pit mode. It is proposed to have four main tunnels branching from the central shaft. Each main tunnel will have disposal tunnels on either side with boreholes to emplace the radioactive waste overpacks (Goel et al. 2002). This conceptual design based on preliminary data sets will be analyzed under combinations of geological situations in the light of more site-specific data sets to optimize final design.

Bhabha Atomic Research Center looks forward for close association with leading Earth Science departments of Indian Universities for high quality research projects on various aspects of the geological disposal of nuclear wastes. A few funding schemes are presently available to support such research. It also looks forward towards these departments to include sufficient coverage of this field in their post-graduate programmes as well to commence degree and diploma courses related to nuclear waste disposal.

References


