

GeoScience Limited

Deep Geotechnical Services : Capability Statement

(With specific reference to deep geological investigations associated with the subsurface disposal of radioactive waste)

The safe disposal of radioactive wastes, and specifically the need to protect humans and the environment in the far future, is given particular attention in all countries engaged in nuclear power generation. It is also a concern in many other countries making use of radioactive materials for medical, industrial, or research purposes.

As for many environmental protection situations linked to industrial development, including the management of hazardous chemical materials, the safe disposal of radioactive wastes requires consideration of a broad range of scientific and technical factors relating to potential impacts on the biosphere, as well as basic ethical principles that reflect the expectations of society.

(....extract from A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency)

GeoScience Limited

GeoScience Limited (GeoScience) is an earth science consultancy providing technical services to the Oil & Gas, Geothermal and Radioactive Waste Disposal industries around the world. The company was formed in 1985 by the Project Director and senior staff of the United Kingdom Hot Dry Rock (HDR) geothermal energy research programme to provide deep geoscientific expertise internationally. It is a wholly-owned British company.

Our services are organised to support the principle that our results are used to reduce risk and uncertainty for our clients in all aspects of working in the underground environment.

Since 1989 GeoScience has worked for the UK radioactive waste disposal agency, UK Nirex Limited (Nirex), on deep site investigations at Dounreay, Scotland and Sellafield in NW England. Initially appointed as Technical Specialists to the surface-based data acquisition programme, staff were responsible for the design, specification, realisation and site supervision of the deep boreholes, the hydrochemical and hydrogeological testing, the wireline geophysical logging, core logging, presentation and reporting of data.

Since 1993, in a parallel contract, staff have supported Nirex in the interpretation of a wide range of data and been appointed to a number of steering groups and advisory committees which have overseen the investigations. Other staff have been seconded to Nirex to manage elements of their overall programme.

In 1996 GeoScience formed and led a joint venture of three companies (GIGA JV Ltd) to bid for the Science Design contract in the proposed Rock Characterisation Facility (RCF) planned for Sellafield. The Joint Venture was successful in its bid, winning against strong international competition, and undertook the science design element of the contract before plans to construct the RCF were shelved.

In addition to its work for Nirex, GeoScience has undertaken work for radioactive waste disposal agencies in Switzerland, Sweden and Canada, and continued its interests in the characterisation of fractured rock masses for geothermal applications.

GeoScience staff have a long and accomplished track record in Deep Geological Investigations and the company has much to offer the radioactive waste disposal community in site investigations and projects at all stages of development. This capability statement summarises the work for which GeoScience staff were responsible, the experience we have and the expertise we are able to offer. If you would like any further information about the company, or would like to talk to someone about what you have read, please get in touch with Peter Ledingham at the following address:

*GeoScience Ltd, Falmouth Business Park, Bickland Water Road,
Falmouth, Cornwall TR11 4SZ, UK*

*Tel (44) 1326 211070
Fax (44) 1326 212754
e-mail ledingham@geoscience.co.uk*

Services

GeoScience can provide you with a range of services with the underlying theme of integrating drilling, testing and evaluation as part of a team, applying the best techniques to solve or manage real problems. The wide and unique experience of our staff means that we are able to offer services to your current or planned Deep Geological Investigations and radioactive waste disposal projects, with inputs tailored to the specific needs of the programme.

We would be pleased to discuss your individual needs with you and provide further information upon request but, by way of example, this section summarises important project activities and objectives that GeoScience can help you to achieve.

Project Management

- Top level programme review and strategic planning
- Preparation of designs and plans
- Data management
- Site supervision and quality control
- Reporting
- Liaison with government, funding agencies, review bodies and other programmes
- Presentations and evidence to Regulators and Inquiries
- Peer review and appraisal
- Public relations

Drilling

- Engineering design
- Equipment specification
- Drilling fluid tracers
- Supervision
- Progress review, optimisation and operational 'trouble-shooting'

Geology

- Core management
- Fault and fracture mapping
- Geophysical log analysis
- Remote sensing
- Automated geological mapping
- Conceptual modelling and interpretation

Geophysical Logging

- Specification of requirements and procurement of services
- Geophysical and production logging supervision and interpretation
- Image analysis
- Downhole fracture mapping
- Diagnosis of borehole conditions and interactions with drilling system

Hydrogeological Testing

- Complete test designs
- Integration of measurements with sampling and logging
- Equipment and services procurement
- Production logging
- Evaluation of test results in fractured and low permeability rock
- Coupled thermo-mechanical-hydraulic behaviour

Hydrochemistry

- Design of sampling and analytical programmes
- Preparation of specifications, procurement of services, training
- Data quality assessment and data management
- Development of sample contamination correction methods
- Tracers for drilling fluid
- Water-rock interaction studies and geochemical modelling
- Hydrochemical interpretation
- Noble gas recharge temperatures

Geomechanics

- In-situ stress determinations
- Borehole rock mechanics for drilling engineering support
- Underbalanced drilling and open hole completion assessments
- Excavation disturbance measurements
- Rock mass properties
- Coupled stress-structure interactions
- Stability of excavations

Interpretation

- Regional and structural geology
- Rock mass properties
- In-situ stress
- Geological controls on flow
- Characterisation of fractured formations
- In-situ hydraulic conditions
- Hydrochemistry - chemical, isotopic, gaseous
- Response to excavations
- Fracture network modelling
- Geochemical modelling for groundwater compositions
- Input to safety assessment models

Surface Based Investigations

Since 1989 GeoScience has provided specialist teams, individuals, interpretation services and technical support to radioactive waste disposal agencies in the UK, Switzerland, Sweden and Canada. The majority of this work has been carried out for Nirex on its two deep site investigations at Sellafield and Dounreay.

In its year-long review of the scientific work undertaken at Sellafield, The Royal Society said that it was "impressed by the quality of individual items of scientific work undertaken which command high respect from others engaged in parallel work overseas". GeoScience is proud of its association with this programme and the significant part it played in the investigation.

Some of the project accomplishments for which GeoScience was responsible are:

- Design and supervision of more than 20 km of wireline cored boreholes in fractured rock with better than 99.8% average core recovery
- Use of drilling fluid tracers to evaluate and monitor sampled fluid contamination
- Design and supervision of hydrogeological testing in both high and very low permeability formations
- Fluid sampling and assessment of groundwater compositions from both high and very low permeability formations
- Specification, procurement and supervision of geophysical wireline logs
- In-situ stress assessment
- Characterisation of geological controls on groundwater flow
- Mapping and evaluation of natural fracture systems
- Interpretation of structural geology by integration of core, geophysical logs and surface seismic data
- Determination of recharge temperatures of groundwater
- Features, events and processes analysis for the geological environment
- Evaluation of glacial history and flow patterns using high accuracy equilibrium temperature logs
- Geological hazard assessment for critical installations
- Management, interpretation and presentation of large data sets
- Production of numerous project reports
- Computer modelling of flow in both fractured and porous rocks
- Strategic planning, programme assessment and membership of steering groups
- Expert testimony at public inquiries

The Proposed Underground Laboratory at Sellafield

In 1994 Nirex applied for planning permission to construct an underground rock laboratory at the Sellafield Site, known as the Rock Characterisation Facility, or RCF. The first phase comprised the construction of two parallel shafts to a depth of 650 m with concurrent scientific measurements being undertaken to acquire data for validation of predictive models of the rock mass.

GeoScience formed and led a Joint Venture of three companies (GIGA JV Ltd^{*}) to bid for the prestigious Science Contract in the RCF and was awarded the contract in 1997 against strong international competition. Although plans for the RCF were shelved due to Government refusal of the planning permission, the design element of the contract was completed successfully.

Some accomplishments of the Joint Venture during this period were:

- Preparation of a set of conceptual designs for all of the key measurements:
 - Rock mass properties
 - Hydraulic conditions
 - Geotechnical and stress
 - Response to construction
- Preparation of Quality Plans for each measurement
- Preparation of Risk Assessments for each measurement
- Integration of the measurement designs into testing plans for each shaft
- Development of plans for implementation of the designs
- Design of an integrated data management system
- Integration of the science designs with the shaft construction designs
- Completion of the designs within the target programme and below the target price

* GIGA JV Ltd participants were GeoScience Ltd, INTERA Inc and GIBB Ltd

Staff

GeoScience staff have made significant contributions to Radioactive Waste Disposal programmes in the UK and Europe and, together, have more than 180 man-years of direct experience in Deep Geological Investigations. The following is a summary of their relevant experience that can be augmented with additional information upon request.

Dr Tony Batchelor is the owner and Managing Director of GeoScience Ltd and has worked for 25 years in the field of deep fractured rock investigations. He was the founder and Project Director of the UK Hot Dry Rock geothermal research programme until forming GeoScience and continues to specialise in applied rock mechanics relating to underground excavations. During the Sellafield Investigations, Tony was responsible for the management and design of the integrated drilling and testing programmes and was Managing Director of the Joint Venture Company (GIGA), which was awarded the Science Design Contract for the first Phase of the RCF.

Tony has written numerous technical papers and articles, been a member of many advisory boards and committees and appeared as an expert witness at the Planning Inquiry related to drilling in the Lake District National Park.

Jon Gutmanis is Senior Geologist specialising in structural and engineering geology. He was responsible for the design, technical control, and management of both data acquisition activities (eg fault and fracture characterisation in core) and interpretation work on both the Sellafield and Dounreay programmes. This work included the interpretation of geological, geophysical and hydrogeological test data from boreholes to characterise geological structures, integration with surface-derived datasets (seismic, remote sensing, outcrop mapping, etc), development of structural and flow models at a range of scales and conceptualisation of seismic-scale fault systems.

Jon was a member of the Nirex Geological Interpretation Team and led a number of multi-contractor and multi-disciplinary teams in interpretation work. He was also responsible for preparation of several public-domain reports presenting the results of these investigations, and contributions to many others.

Bill Lanyon is a Senior Scientist and Project Manager and has specialised for the last 17 years in fractured rock mass geology and the conceptual and numerical modelling of flow and transport in fractured rocks. He has applied this expertise to both HDR and radioactive waste disposal applications and has worked on programmes in the UK, Sweden and Switzerland. As part of this work, Bill has been responsible for the development of effective porosity upscaling, transient flow, contaminant transport and visualisation facilities for the NAPSAC discrete fracture network computer code.

Bill has been Project Manager for GeoScience's contract with NAGRA since 1992 and managed the company's Nirex Interpretation contract since 1997.

Peter Ledingham is Manager of Reservoir Interpretation/Geothermal Manager with GeoScience specialising in the development and management of integrated borehole testing programmes for HDR, radioactive waste disposal and geothermal applications. He was Hydrogeological Testing Specialist attached to the Site Investigations at Sellafield and Dounreay from 1989 and, later, a member of the Nirex Hydrogeology Overview Group, a steering group with responsibility for oversight and development of the hydrogeology programme.

From 1994 to 1997 Peter was Project Manager for GeoScience's Interpretation contract with Nirex and in 1997 was appointed Science Design Manager for GIGA, a Joint Venture company awarded the contract to design and undertake scientific measurements in the shafts of the proposed Nirex RCF at Sellafield, Cumbria.

Dr Ross McCartney is Hydrochemistry Group Manager specialising in water rock interactions and the acquisition of high quality groundwater samples from deep investigation boreholes. He gained his PhD studying the water-rock interactions in the experimental fractured reservoirs created for the UK HDR programme and was responsible for the design and implementation of a geochemical data acquisition and interpretation programme for water, rocks and drill cuttings.

Ross was Hydrochemistry Testing Specialist attached to the Site Investigations at Sellafield and Dounreay from 1989, with responsibility for the planning, design, specification, supervision and analysis of a comprehensive fluid sampling programme during drilling and testing of the deep boreholes. He was also responsible for the implementation and control of a drilling fluid tracer system, analytical laboratory selection, and sample Quality Control. Later he was seconded to Nirex for three years as Geochemistry Coordinator, with responsibility for coordinating interpretation work from a number of contractors.

Richard Pearson is Logging Manager with 20 years experience in geophysical wireline logging techniques and 17 years specialising in the particular problems associated with fracture characterisation in low permeability rocks and placing particular emphasis on acquisition of requisite data and Quality Control.

Richard was Technical Specialist for geophysical wireline logging attached to the Site Investigations at Sellafield and Dounreay from 1989, responsible for the specification, procurement and supervision of proprietary logs, planning of the logging programmes, production log interpretation for flow characterisation, logging data analysis and liaison with other interpretation teams. He was also appointed Technical Specialist for the RCF Science Design Contract.

Dr Robin Curtis is Technical Manager and has been active within the site investigations at both Dounreay and Sellafield since 1989, coordinating site staff and contractors, providing technical support and liaising with the client. He was Alternate Project Manager for the Dounreay Site Investigation. Robin was also responsible for development and implementation of company quality system to BS5882 and BS5750 standards for all Nirex related contracts.

On the Sellafield Programme, Robin managed the development of geochemistry software for estimating groundwater compositions, designed the groundwater database, developed an in-house ORACLE based document management system and studied theoretical shaft convergence behaviour.

Dr Colin Watson is a geotechnical modeller specialising in coupled processes. He has worked on the Sellafield Site investigation to investigate coupled flow, heat transport and solute transport, as well as coupled hydromechanical processes in fracture network models. Colin also developed a database for managing geological and hydrogeological data from the investigations.

Dr Timothy Wynn is a structural geologist who worked with the Nirex Geological Integration Team, contributing to the interpretation of the structural geology of the Sellafield. This work involved the analysis of structural data derived from core, wireline logs and seismic lines, and the synthesis of data into 3D structural models and conceptualisations of the Sellafield area structures for input into numerical hydrogeological models.

Publications by GeoScience Staff

GeoScience staff have contributed to the published literature on radioactive waste disposal issues in a number of ways. In addition to the following written and presented papers, several hundred project reports have been produced or co-produced and significant contributions made to a number of client Public Domain Reports.

Written papers:

Batchelor, A.S., Kwakwa, K.A., Proughton, A.J., Davies, N. (1997). Determination of maximum principal stresses and assessment of magnitudes of three principal stresses - Sellafield, a case study. In: Proc Third European Engineering Geology Conf. and 33rd Engineering Group Conf, Newcastle upon Tyne, 10-13 Sep., pp.1-18.

Batchelor, A.S., Kwakwa, K.A., Proughton, A.J., Davies, N. (1997). Determination of the in-situ stresses at Sellafield, UK: A case study. In: Proc. Int. Symp. on Rock Stress, Kumamoto, Japan, 7-10 Oct., pp.265-276.

Gutmanis, J.C., Bowden, R.A. (1994). Scientific drilling and geological overview for the proposed United Kingdom Radioactive Waste Repository. In: Proc. VIIth Int. Symp. on the Observation of the Continental Crust Through Drilling, Santa Fe, New Mexico, 25-30 Apr.

Gutmanis, J.C., Ledingham, P., Pearson, R.A., Lanyon, G.W. (1995). Geological characterisation of groundwater flow entries identified during production logging of deep boreholes in fractured basement rocks at Sellafield, NW England. In: Proc. Structural Geology in Reservoir Characterisation and Field Development, Imperial College, London, 27-29 Mar.

Gutmanis, J.C., Lanyon, G.W. (1995). Geological and hydrogeological characterisation of fracture systems in hard rocks. In: Proc. Fractures - a Cracking Good Seminar, London Petrophysical Soc., 20 Nov.

Gutmanis, J.C. (1996). Flow zone characterisation - understanding the nature of flow in fractured rocks and the influence of major structure. In: Abstr. of Faulting, Fault Sealing and Fluid Flow in Hydrocarbon Reservoirs, TSG/PESGB Conf., Leeds Uni., 23-29 Sep.

Gutmanis, J.C., Lanyon, G.W. (1997). Characterising and modelling the hydrogeological behaviour of faults in clastic and volcanic sequences at Sellafield, NW England. In: Proc. Yorkshire Geological Soc., Nov. - in preparation 1998.

Herbert, A.W., Gale, J. **Lanyon, G.W.**, MacLeod, R. (1992). Discrete fracture network modelling for Phase 3 of the Stripa Project using NAPSAC - in-situ experiments at the Stripa Mine. Proc. 4th Int. NEA/SKB Symp.

Herbert, A.W., **Lanyon, G.W.** (1992). Modelling fracture rock at Stripa. ISRM Conf. on Jointed Rock Masses, Lake Tahoe, USA, Jun.

Herbert, A.W., **Lanyon, G.W.** (1992). The application of a fracture network modelling approach to field experiments. 4th North Sea Chalk Symp. Deauville, USA, Sep, pp.1-19.

Herbert, A.W., **Lanyon, G.W.** (1994). Prediction of advective transport using discrete fracture network models. AGU Chapman Conf., Vermont, USA, Oct.

- Marschall, P., Vomvoris, S., **Lanyon, G.W.**, Jaquet, O., Vinard, P. (1997). The Wellenberg K-Model a geostatistical description of hydraulic conductivity distribution in the host rock for site characterisation and performance assessment. MRS Conf., Switzerland, Sep.
- Mazurek, M., **Lanyon, G.W.**, Vomvoris, S., Gautschi, A. (1997). Derivation and application of a geologic dataset for flow modelling by discrete fracture networks in low permeability argillaceous rocks. Presented at: Migration '97 Conf., Sendai, 26-30 Oct. and accepted for publication in J. of Contaminant Hydrology.
- Voborny, O., Vomvoris, S., **Lanyon, G.W.** (1994). Flow characterisation in crystalline rocks from combined continuum and stochastic models. In: Proc. IAHR/AIRH Symp. on Transport and Reactive Processes in Aquifers, Dracos and Stauffer (Eds.), Apr., pp.311-316.
- Vomvoris, S., Muller, W.H., Thury, M., **Lanyon, G.W.** (1996). Stochastic models of existence and explorability of fault bounded blocks in crystalline rock beneath sedimentary cover. Proc. Int. Conf. on Deep Geological Disposal of Radioactive Waste, Winnipeg, Canada.
- Vomvoris, S., Blumling, P., **Lanyon, G.W., Watson, C.R.** (1997). Excavation Disturbed Zone: Assessment of its hydraulic properties based on surface investigations. MRS Conf., Switzerland, Sep.
- Lanyon, G.W.**, Marschall, P., Vomvoris, S., Jaquet, O., Mazurek, M. (1998). Effective property determination for input to a geostatistical model of regional groundwater flow: Wellenberg T-K. Pres. at 3rd Äspö Int. Sem. on Characterisation and Evaluation of Sites for Deep Geological Disposal of Radioactive Waste in Fractured Rocks, Oskarshamn, Sweden, 10-12 Jun.
- Ledingham, P.**, Proughton, A.J., Saulnier, G. (1998). Science design for two shafts in Phase 1a of the proposed Rock Characterisation Facility at Sellafield, UK. Pres. at 3rd Äspö Int. Sem. on Characterisation and Evaluation of Sites for Deep Geological Disposal of Radioactive Waste in Fractured Rocks, Oskarshamn, Sweden, 10-12 Jun.
- McCartney, R.A.**, Bath, A.H., Richards, H.G., Metcalfe, R., Crawford, M.B. (1996). The geology and hydrogeology of the Sellafield area: Hydrochemical data acquisition and interpretation. Quarterly J. Engineering Geology, Vol. 29, pp.S39-S57.
- McCartney, R.A., Ledingham, P.** (1998). Design considerations for the acquisition of hydrochemical data from deep boreholes. Pres. at 3rd Äspö Int. Sem. on Characterisation and Evaluation of Sites for Deep Geological Disposal of Radioactive Waste in Fractured Rocks, Oskarshamn, Sweden, 10-12 Jun.
- McCartney, R.A.**, Solbe, M.J. de L-G. (1999). Use of tracers in drilling muds to allow the estimation of in-situ formation water compositions from drilling-mud-contaminated formation water samples. In: SPE Int. Symp. Oilfield Chemistry, Houston, SPE 50721, p. 219-226.

Presented papers:

Batchelor, A.S. (1992). The application of wireline drilling techniques to deep cored boreholes. Geological Society - Borehole Research Group - Nirex: Geological Investigations in the Sellafield Area, London, 13 Oct.

Lanyon, G.W., Herbert, A.W. (1993). Fracture networks and the REV concept. Int. Soc. Rock Mechanics Symp., Portugal, Jun.

Ledingham, P. (1992). The development of a cost-effective integrated, hydrogeological testing programme. Geological Society - Borehole Research Group - Nirex: Geological Investigations in the Sellafield Area, London, 13 Oct.

McCartney, R.A. (1992). Sampling and analysis of fluids during the drilling and testing of deep boreholes. Geological Society - Borehole Research Group - Nirex: Geological Investigations in the Sellafield Area, London, 13 Oct.

McCartney, R.A. (1994). Systematic scientific approach to obtaining and analysing samples. Quality assurance of data to ensure high reliability of information. Presentation to The Royal Society, Harwell, 15 March.

Pearson, R.A. (1992). The application of wireline geophysical logging of the Sellafield boreholes. Geological Society - Borehole Research Group - Nirex: Geological Investigations in the Sellafield Area, London, 13 Oct.

Richards, S., Lanyon, G.W., Wynn, T.J. (1998). Transmissivity description and scaling in the hydrogeological characterisation of the Borrowdale Volcanics Group in the potential repository zone at Sellafield. Geological Society, London, 3 Feb.