1: 48 Lee, H.: Proceedings of GIG conference on Geological Visualisation - the Intelligent Picture?
British Geological Survey, October 1996

Data Management in the Proposed Rock Characterisation Facility*

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Abstract

United Kingdom Nirex Limited has applied for permission to construct a Rock Characterisation Facility (RCF) within the Potential Repository Zone at Sellafield in Cumbria (UK). The purpose of the RCF is to enable Nirex to decide whether or not to propose the development of a repository at Sellafield and, subsequently, to develop an evaluation of post-closure safety that will enable a decision to be made on authorisation of disposal of wastes when, and if, a repository is constructed.

The purpose of the Data Management function is to receive, catalogue, store, protect, organise, distribute, check, and report (as required) all data acquired from the RCF for Nirex's requirements. This paper describes the current concept of the arrangements for managing the RCF data for Phase 1a (Shaft Sinking) once acquired.

Because the RCF data will be generated in an environment of integrated and simultaneous activities, it is important that the data are integrated in time and space so that their validity, and their meaning, can be readily assessed. The strategy for developing an efficient data model, for links with other databases, for operation of the database, and for managing changes in database requirements as the RCF proceeds, are described.

Vulcan (a UNIX-based 3D geological package) will be used for visualisation, checking, and handling of most of the Scientific data. Data from monitoring the construction activities, such as grouting, probe drilling, blasting, and shaft lining will also be handled using Vulcan. Vulcan will be linked to a relational database using Oracle. Oracle and Vulcan are trade names of the Oracle Corporation, and of Maptek, respectively.

Introduction

United Kingdom Nirex Limited (Nirex) is responsible for developing and managing a national disposal facility for solid intermediate-level (ILW) and some low-level (LLW) radioactive waste (Nirex, 1992). In 1991 Nirex announced that it was to concentrate its investigations at Sellafield (Figure 1). A range of surface-based investigations are proceeding in and around the Potential Repository Zone (PRZ) within which the repository could be located at Sellafield. These are undertaken to provide data that will enable a Post-Closure Performance Assessment of the site to be undertaken to establish whether a repository at the site could meet regulatory requirements (Hickford and Billington, 1994).

To date the investigations have included drilling at 22 borehole sites to obtain core, in situ stress data, and to provide access for hydrogeological and geophysical investigations. Geological mapping, hydrogeological and geophysical surveys, and earthquake monitoring have been carried out from the surface. A very good appreciation and understanding of the geological and hydrogeological conditions that exist at the site has been gained, however there remain 3 key areas of uncertainty that cannot be resolved adequately solely on the basis of surface investigations. These three key areas of uncertainty are: (a) groundwater flow and radionuclide transport, (b) natural and induced changes to the geological barrier, and (c) design and construction of the repository (Mellor and Davies, 1996).

As a result, Nirex announced in October 1992 its decision to develop an underground Rock Characterisation Facility (RCF) at Sellafield (Nirex, 1992). The RCF will provide the means by which Nirex can acquire data to help understand the characteristics of the site in relation to the three key areas of uncertainty. The data acquisition activities in the RCF will enable Nirex to make a decision on whether to submit a planning application to construct a repository at Sellafield. Subsequently RCF data will be used to develop an evaluation of post-closure safety that will enable a decision to be made on authorisation of disposal of wastes when, and if, a repository is constructed (Mellor and Davies, 1996).

This paper will describe the current concept of the arrangements for managing the RCF data for phase 1a (Shaft Sinking) once acquired.

The RCF

The design of the RCF

The RCF is designed as a three phase facility (Figure 2). Phase 1 comprises the construction by drill and blast of two 5 metre internal diameter shafts (termed North and South shafts), 50 metres apart, to the facility depth. The final depth for the shafts will be decided during shaft sinking. The majority of the scientific measurements taken during Phase 1

*Note: The RCF project was cancelled after refusal of planning permission by the Secretary of State for the Environment on 17 March 1997.

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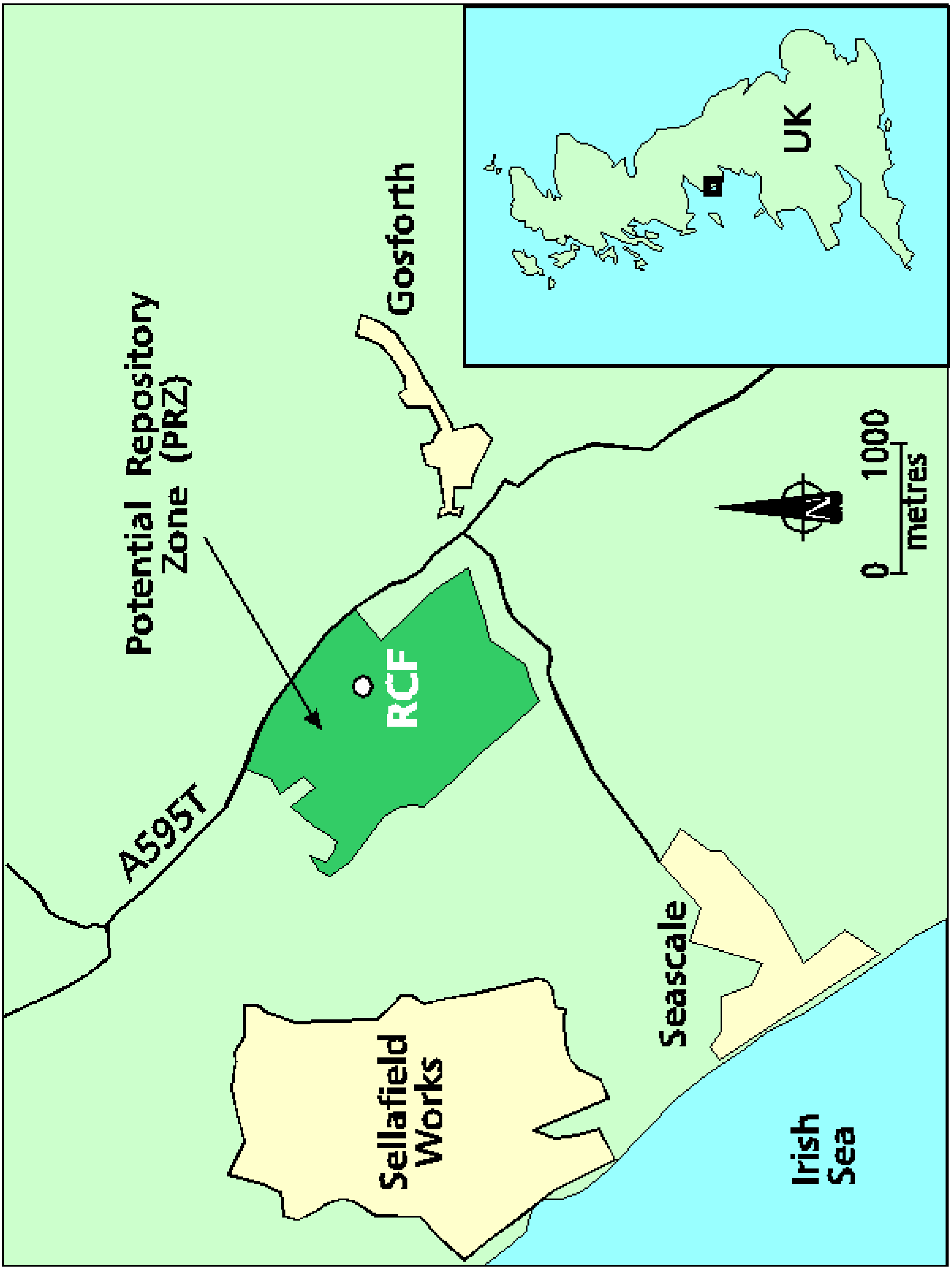

Fig. 1: Location of the RCF

will be conducted in the South shaft. Phase 2 will comprise the construction of 3 main galleries where the main experimentation and testing programme will commence. Phase 3 is an extension of Phase 2. The total duration of the project is around 10 years (Mellor and Davies, 1996).

Forward predictions

In radioactive waste safety assessment, validation is the term applied to the iterative process of building confidence in the fitness-for-purpose of models used in developing a performance assessment for a repository. Forward predictions before and during the excavation stage of the RCF will allow the validation process to be applied to a variety of concep-

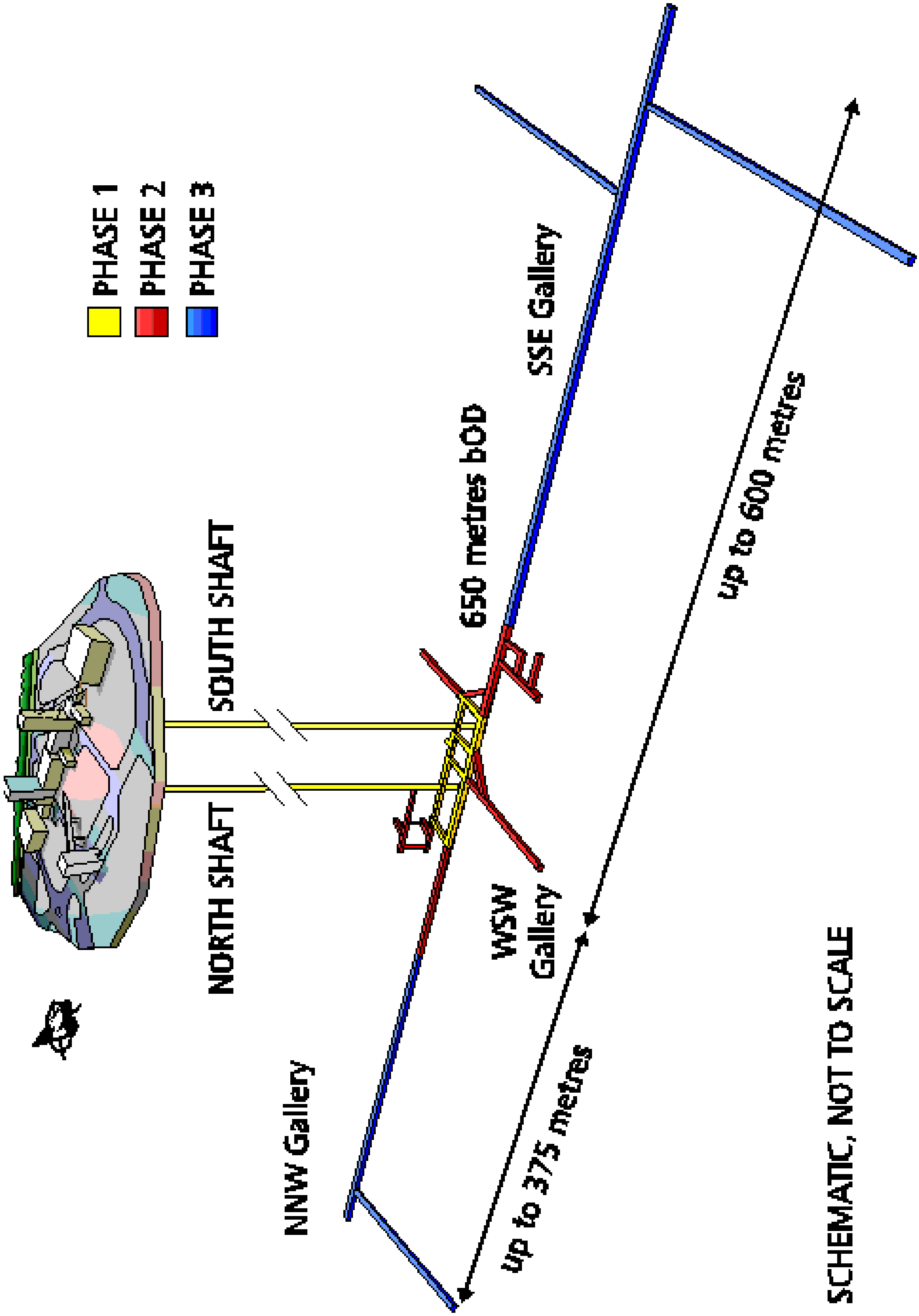

Fig. 2: RCF phases and design

tual and numerical models relevant to developing the necessary assessment of the post closure performance of the site. This requires a range of information to be obtained from the RCF in order to test the predictions made from these models. Particular emphasis will be placed in establishing appropriate methodologies to enable Nirex to acquire the requisite information (Mellor and Davies, 1996).

Purpose of RCF Data Management

Well managed data are high quality, maintained and protected over their life cycle, and easily accessible to professionals who add value to data through processing and analysis (Johnson, 1995). The purpose of the RCF Data Management function is to provide a centralised project service (Figure 3) to receive, catalogue, store, protect, organise, distribute,

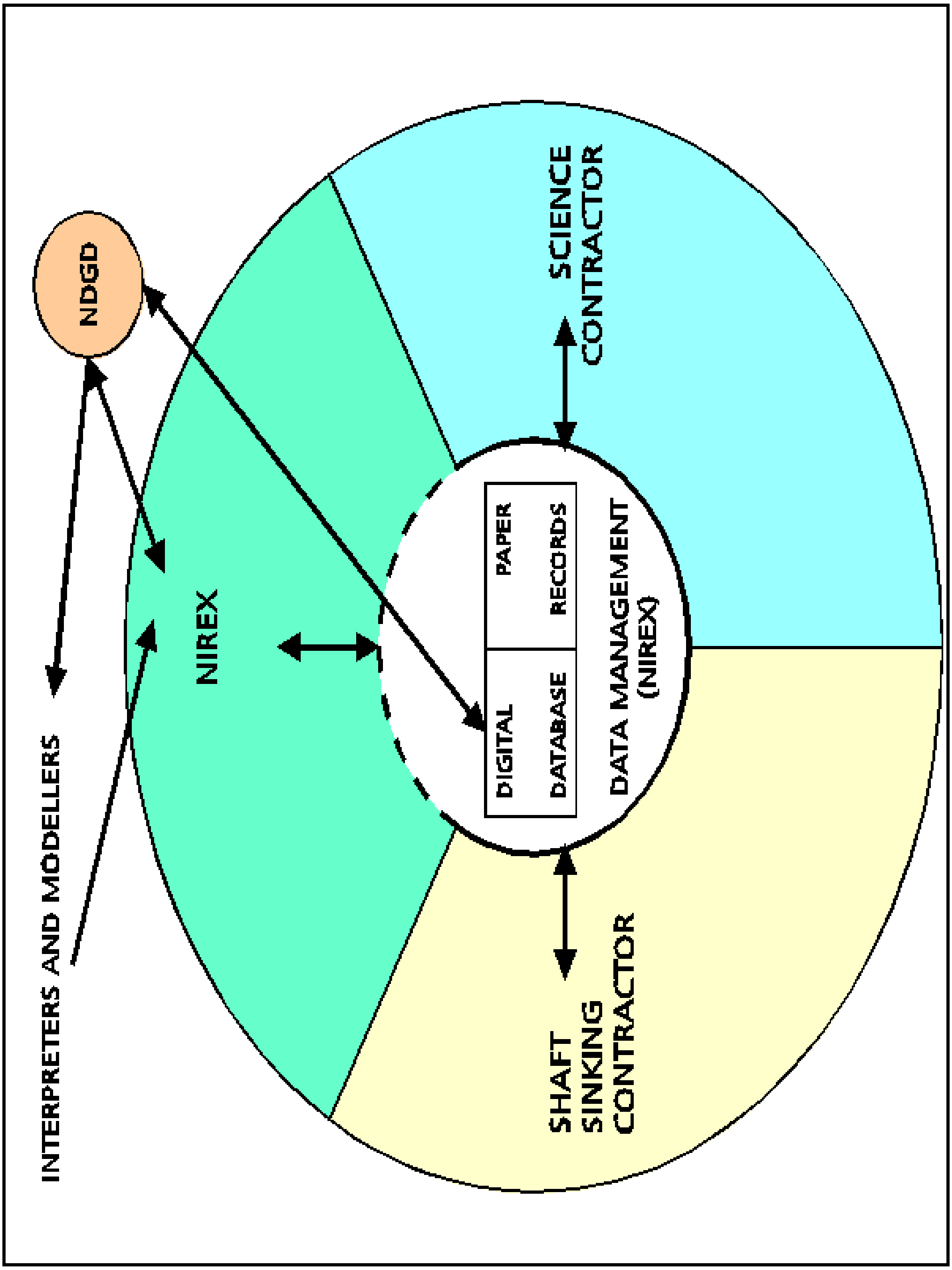

Fig. 3: RCF Data Management overview

check, and report (as required) all data acquired from the RCF, for Nirex's requirements. Nirex's scientific interpreters will access approved subsets of the data through the separate Nirex Digital Geoscience Database (NDGD).

It is generally accepted that, in the absence of effective data management, earth scientists spend 60-70% of their time looking for and preparing data (Johnson, 1995). The Data Management function will minimise time spent in locating and integrating disparate datasets by ensuring all RCF data are catalogued from the outset through a single integrated source.

Centralised data management is employed by other underground Laboratories Such as the Äspö Hard Rock Laboratory (SKB, 1996) or the Canadian Underground Rock Laboratory (Simmons, et al, 1992).

The RCF Data Management function does not include the planning or execution of data acquisition, or making predictions from models.

RCF data streams and their integration

The data acquired from the RCF in response to the Scientific requirements will be generated both by dedicated Scientific activities and by construction activities. The latter generally underpin the former by providing background data needed to explain results. In some cases the construction activities are part of the experiments, such as measuring water and humidity extracted from the shaft against time, compared with that introduced, to derive the volume of groundwater make. In either case records are required to provide a sound audit trail for the scientific data.

Scientific data

Vulcan (a UNIX-based 3D geological package - Maptek, 1995) will be used for visualisation, checking, and handling of most of the Scientific data. Vulcan will be linked to a relational database using Oracle. Oracle and Vulcan are trade names of the Oracle Corporation, and of Maptek, respectively.

Underground mapping will take place from a specially designed sinking stage consisting of two platforms slung below the main shaft sinking stage. The lower platform will allow an image of the shaft wall to be taken of the most recently blasted section (termed round) of the shaft. The platform above will allow geologists and geotechnical engineers to map the structure and rock mass conditions onto the image taken of the previous round. Specialist mapping will also take place at predetermined sections on particular areas of interest (Mellor and Davies, 1996). The image may be digital for reasons of timeliness, ease of processing and manipulation, and cost (photographic processing facilities and staff, cost of reproduction - Weider, 1996). Combination of the digital images and a survey of the shaft profile would result in a geometrically corrected image basemap (an orthophoto) for the mappers to work from where required. Removal of distortion before mapping removes the need for subsequent geometric correction of the mapping (therefore saving time), and allows the photomosaics to have a minimum of edge mis-matches that would otherwise be caused by relief distortion in an uncorrected mosaic.

The shaft image mosaic, the shaft profile, and the underground mapping will be integrated with the rest of the RCF data by location against the Shaft Sinking Contractor's survey data, in Vulcan.

The geological mapping itself forms a reference for other data, such as borehole, and sample locations, to allow interpreters to build up their 3 dimensional understanding of the geology, in comparison with predictions and observations from existing boreholes.

Hydraulic measurements will take place as an integral and continuous part of shaft and gallery construction. These will provide observational information on changes in the groundwater pressure on the groundwater pressure monitoring system in nearby boreholes, inflows of groundwater to the shafts and galleries, groundwater samples from flow zones and from underground boreholes, hydraulic testing of fractures intersected in underground boreholes, and monitoring during construction for groundwater ahead of the shaft by testing the Shaft Sinking Contractor's probe holes (Mellor 1995).

Geotechnical data will be acquired on rock mass quality, rock support monitoring, and measurement of the excavation disturbed zone (EDZ) (Davies and Mellor, 1996).

A variety of instruments may be used to obtain the requisite data. Some boreholes will have several instruments installed, or instruments with a number of sensors. The types of instruments that may be used are likely to include Multiple Point Borehole Extensometers (MPBXs), straddle packers, convergence arrays, geophones/accelerometers, and triaxial strain cells (Mellor and Davies, 1996). In addition flow of water from devices to collect water entering the shaft (Mellor, 1995) may be logged either manually or digitally.

Figure 4 shows an example of an instrumented borehole from the Canadian Underground Rock Laboratory (URL) in Pinawa, Manitoba. The photograph shows pressure gauges and wiring to signal conditioners as part of an automated data acquisition system (ADAS).

Construction monitoring and as-built records

A wide variety of construction monitoring and as-built records will be acquired as part of the normal monitoring of the construction performance against the design. Many of these data will be integrated with the scientific data as they will be an element of the physical and temporal context of the scientific data. Data will be acquired on the hydrostatic lining, rock bolts, sprayed concrete (shotcrete), ventilation, grouting, probe drilling, shaft profile, and blasting. The survey of the works forms the spatial framework upon which most other RCF data will be located.

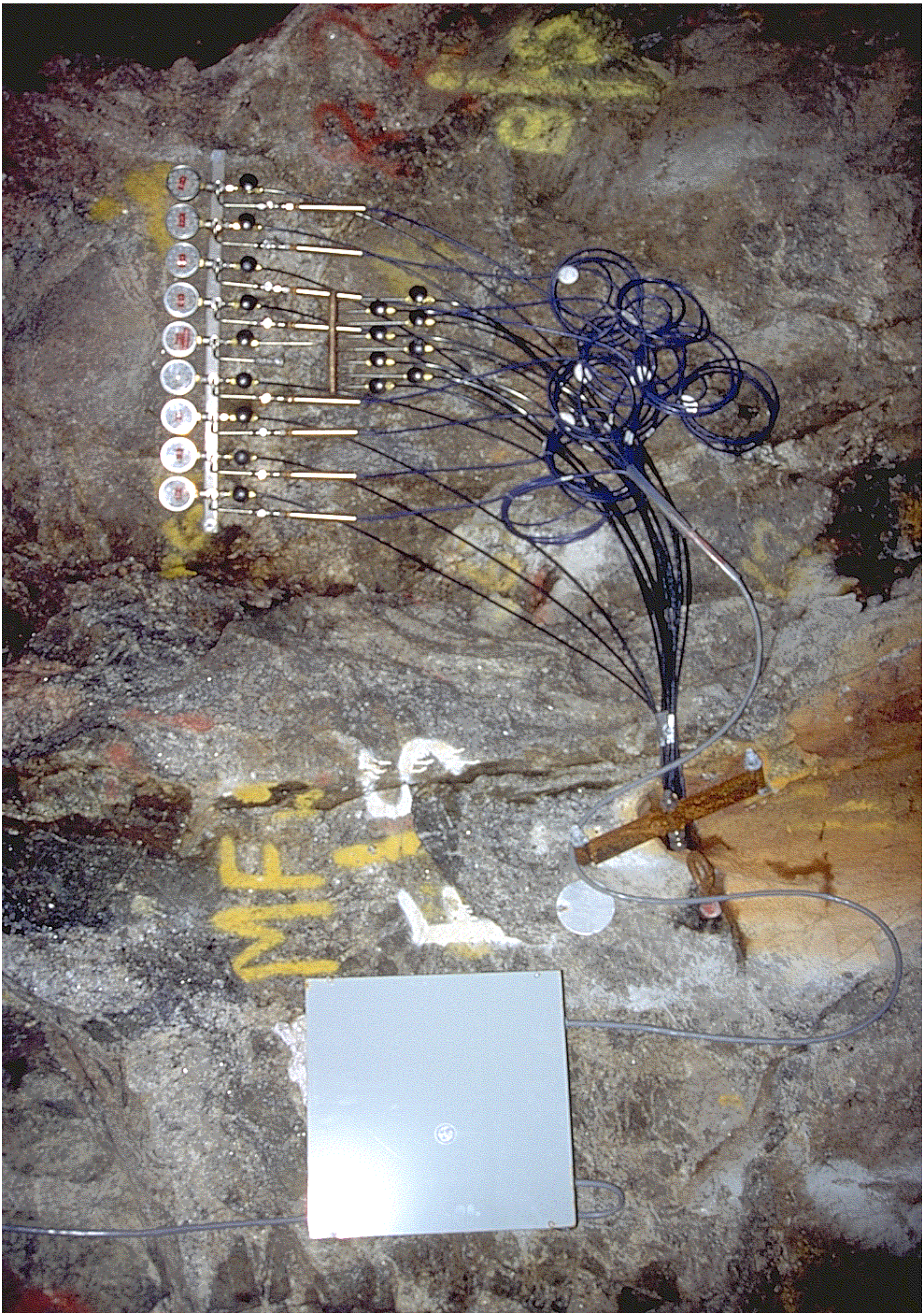

Fig. 4: An instrumented borehole in the Canadian URL

Data collection

Data generated in the RCF will be contained in a variety of media. Some of the data will arrive at the database via an automated data acquisition system (ADAS). Portable data loggers will be used to transfer other data to the surface based ADAS control for calibration where necessary, and then onto the database.

If a digital camera is used then the shaft photographs will be downloaded to a workstation. Modern 35mm digital cameras produce full colour, very high resolution images (3060 x 2036 x 36bit, ie 27 megabytes - Kodak DCS-460). The full detail may be required for stereo interpretation, and copies of the images may be subsampled before they are digitally mosaiced in Vulcan by registering to the shaft profile. In this way a distortion-free image mosaic can be generated rapidly without the use of processing chemicals, a dark room, or glue.

Some datasets will arrive on diskettes, or on other computer media such as tapes, depending on the instrumentation used. These will probably be handled through the surface based ADAS control, but some may be loaded directly into the database, as appropriate.

A proportion of the RCF records are likely to be paper based. The simplicity and reliability of a paper forms, especially in underground conditions, suggests this will be the medium of many of the more simple records. Paper records will be handled one of two ways: the data will be digitised if the information contained in the record underpins some scientific data, or if it is sensible and practical to do so; otherwise the document will be logged into Nirex's document control system and filed, accessible through a unique number.

It is important that the where data on forms are to be entered into the database there should be a one-to-one relationship between items on the paper form and items on the digital form. This will remove ambiguity, therefore minimising errors, and speeding up the process of data entry.

There will be a variety of samples for both scientific and construction purposes. The current intention is to log samples with a unique number and store information in the database about the sample against the unique number. Sample storage will vary according to the nature of the sample and the purpose for which it was taken, and this is outside the scope of the paper.

Integration of the data streams

In the sections above I have illustrated the variety of data that may be generated from the RCF. The validation of any one model may require data from many instruments, and also may require a range of different construction data to provide an audit trail, and for background data. Similarly a single type of data may be required for the validation of more than one model. This is known as a "many-to-many" relationship. Where models require more than a single dataset the integration of the datasets becomes necessary. It is essential that spatial datasets are represented in the same space, and temporal datasets in the same time.

An important part of data management is the checking of data. Such checking is for transcription errors, for completeness, and for faithfulness to the original, rather than an assessment of the validity of the data. Experience has shown that such errors are hard to detect in tables of numbers, but represented graphically in conjunction with cospatial or cotemporal data, they are much easier to detect. Visualisation is therefore an important quality control measure, in the hands of a suitably qualified user.

For these reasons, a single integrated relational data model for the RCF Database will be developed, linked to a 3D visualisation front end. The database will be developed from the data model using Computer Aided Software Engineering (CASE) tools and Oracle Relational Database Management System (RDBMS). Oracle has been chosen largely for its compatibility with other Nirex databases. Oracle alone, however, will not represent integrated spatial data in a form that is readily understood, neither does it have the toolsets for standard modelling and manipulation of earth science data. Vulcan has been chosen by Nirex to perform these tasks, and to be the visualisation and manipulation front end for the RCF Database.

Vulcan currently uses its own database, which is proprietary and not relational, so a link must be developed between Oracle and Vulcan. Linking via the transfer of files provides limited flexibility so is inconsistent with the strategy of managing RCF data (section 4). A link is required between Oracle and Vulcan to enable multi-user access to the same data pool, and to allow interactive query of the RCF data in the Geographical Information System (GIS) paradigm.

Management of data acquistion: sector test plans

Nirex recognises that it is prudent to plan and manage the RCF on the basis that changes in the underground layout and/or the detail of the scientific activities are likely. This practical need for flexibility is a recurring theme in similar programmes elsewhere (Simmons, et al, 1992, Olsson, 1994, SKB, 1994).

The approach that Nirex has adopted for providing a flexible method of managing data acquisition activities in the RCF is to divide the shafts and galleries into discrete sectors. Each sector has an Outline Sector Test Plan setting out the requirements for activities and experiments which are to be undertaken. The Outline Sector Test Plans will be upgraded to 'Firm' status to confirm activities and experiments to be carried out in any particular sector. The Firm Sector Test Plans will pass into the final category, 'Implementable Sector Test Plans', a matter of weeks before excavation of the particular sector. This presents a final confirmation of tests and experiments to be undertaken. This rationale allows the Shaft Sinking Contractor to be informed progressively of the input to the data acquisition and experiment programme that is expected. This input, in terms of time, logistics, support, and personnel is essential to the effective implementation of both the experimental programme and shaft sinking. Results and experience in completed sectors will be used iteratively to adapt work programmes and detailed design in successive sectors (Mellor and Davies, 1996).

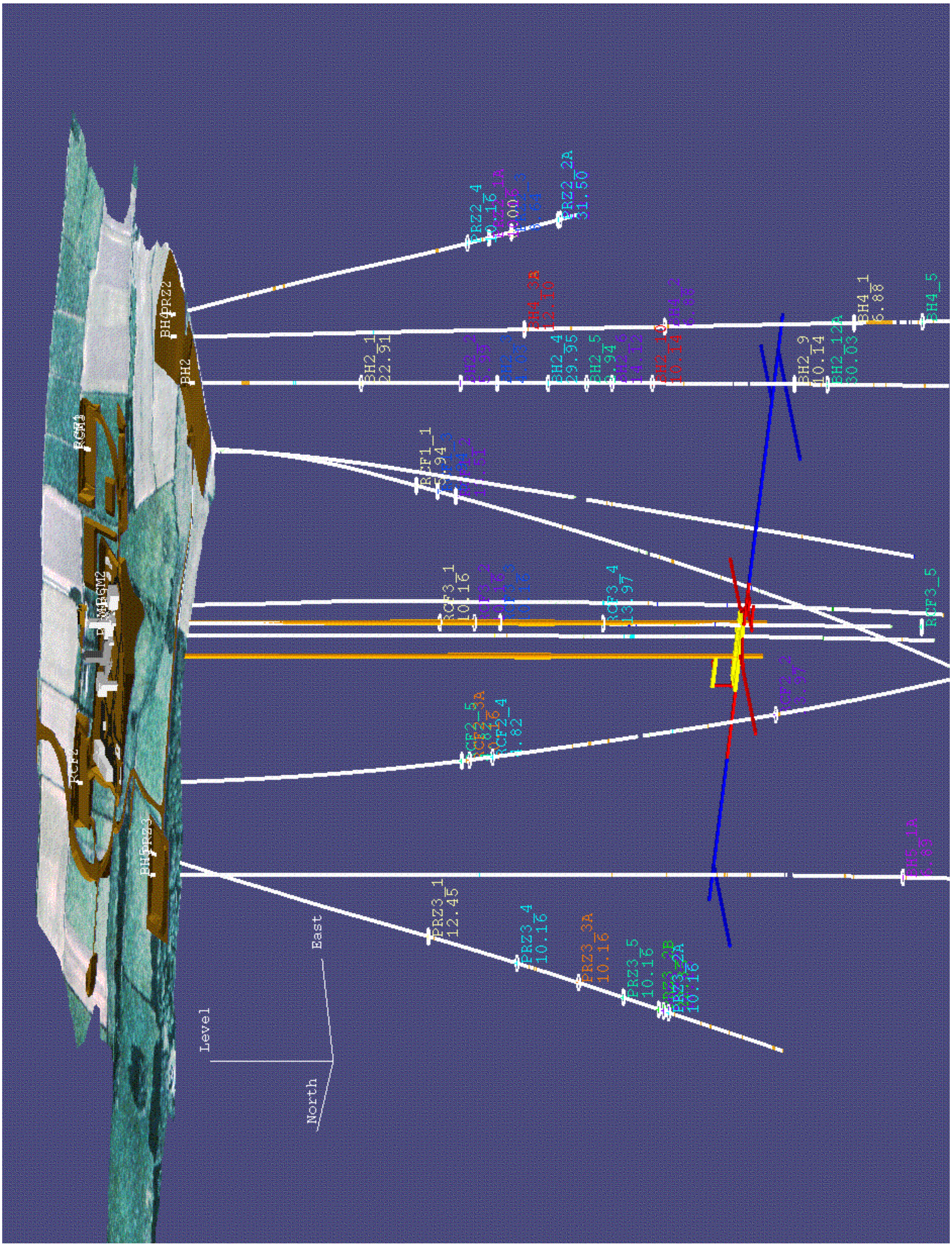

Fig. 5: View of RCF vicinity with existing borehole trajectories and DET information.

This approach means that the RCF Database and the arrangements for managing data must retain flexibility to adapt to any changes in the work programme and detailed design. The strategy for retaining flexibility in the RCF database comprises five key measures:

- a simple, robust data structure;
- a flexible means of access to the data along the GIS (intelligent picture) paradigm;
- not storing data in proprietary format where practical;
- close working with the Science Contractor, the Shaft Sinking Contractor, and the users of the data;
- combining the often sequential roles of designer/developer/database administrator (DBA) into one role throughout the lifetime of the project, with backup cover.

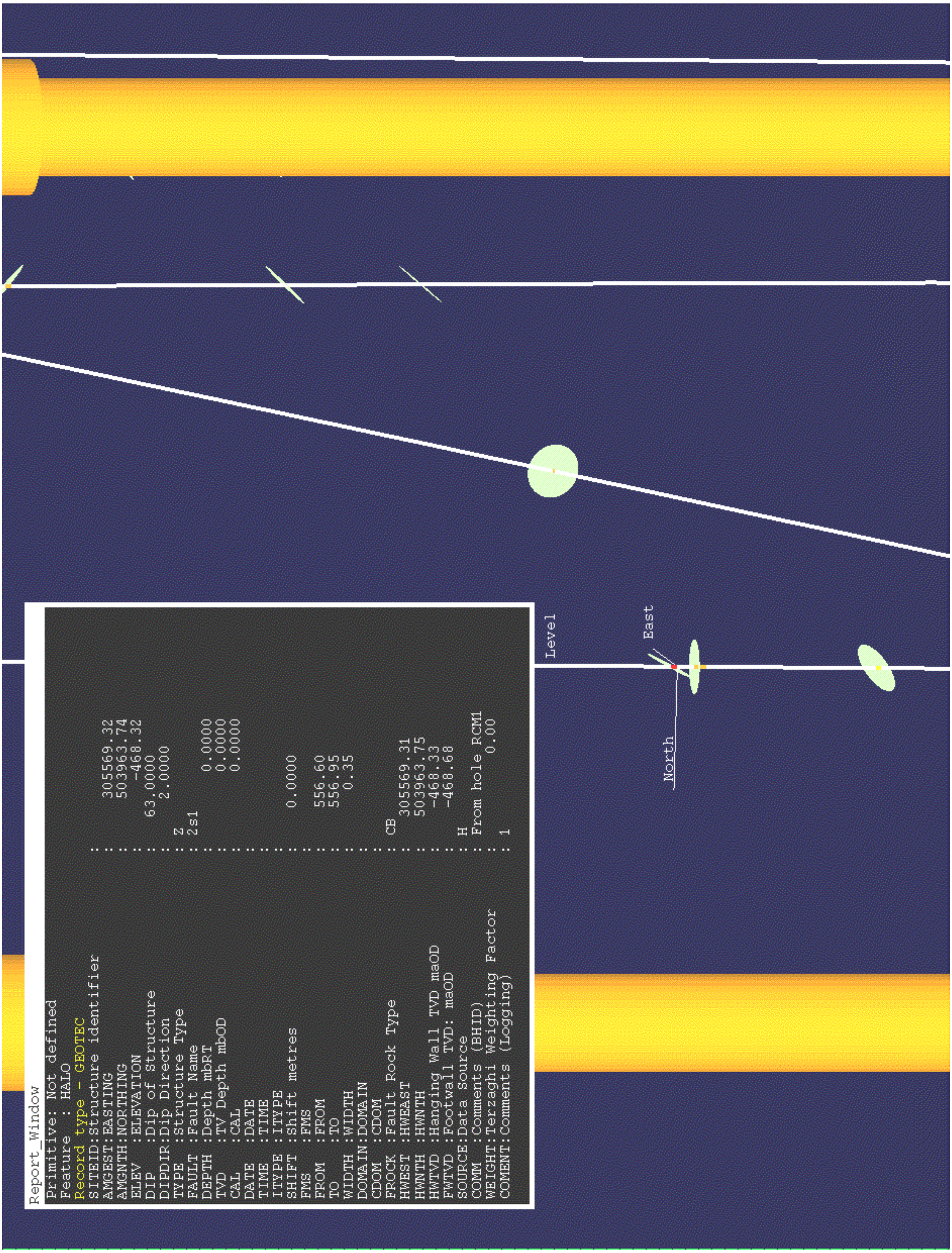

Fig..6: View of existing discontinuity data between planned RCF shafts.

The first two measures are explained in more detail below.

A simple, robust database structure

A simple robust logical data model at the core of the database is essential for efficient operation of the database, and in order for the data structure to be modified efficiently at a later date if required. Although flexibility is required to adapt to changes in the work programme and detailed design, it is possible to define a nearly complete "menu" of parameters that *may* be recorded in the RCF and to define provisional formats and ranges. The database design will start with a definition of provisional and assumed requirements comprising the current view of the superset of data items to be recorded from the RCF during Phase 1. It is essential that the database will work with *or without* (Chew, 1995) many of these parameters as the project progresses.

The database design and development will be refined as instruments and methods are selected. On instrument selection the formats and ranges of data from the instrument shortlist will be supplied to the database designers. Once instruments are tested, the test datasets will be used for refining and testing the database. Forms used in the acquisition will be designed in conjunction with the Data Management team to ensure efficient data entry and to ensure that definitions are both understood and are sufficiently unambiguous (Chew, 1995).

Some datasets that are logically fairly self-contained, or may require special tools for use/visualisation (such as some borehole logs), may be stored separately and only pointed to by the database.

The database structure will be developed using integrated CASE tools such as the Oracle Designer/Developer 2000 toolsets. In this way high level changes in the logical data structure can more easily be incorporated in the physical database structure. This also helps bind the design with the application which assists in the quality assurance of any design changes.

Flexible data access (the intelligent picture)

This section shows how the GIS (intelligent picture) paradigm will provide a flexible means of access to, and visualisation of, integrated RCF datasets. This approach is a component of the flexible data management strategy for RCF data. This facility will be available to modellers for building their understanding and predictions, such as described by Murray, 1996. The flexible, interactive display that Vulcan provides, coupled with the suite of tools for reporting, sectioning, triangulating, gridding, graph and stereonet plotting, means that relatively little effort is required to adapt to changes in the work programme and detailed design that may occur between Sectors.

Visualising existing data.

Figure 5 shows a Vulcan view of the vicinity of the RCF, showing the existing borehole trajectories and an illustrative RCF surface and underground layout, with locations of packers used in Hydrogeological testing of the boreholes. The text window shows the result of a query by clicking the mouse on a packer location. The query has returned the details associated with the packer, with data from a Discrete Extraction Test (DET).

Figure 6 shows a view of the existing boreholes between the planned North and South shafts of the RCF. In this example logged faults are displayed as discs in the orientation of the observed fractures, and the data for one of these is displayed in the text window.

Simulated RCF data

The following examples are based on simulated data: the views and functionality described are real, but in advance of actual RCF data being available the underlying data have been simulated. The instrumentation data are simulated MPBX data with arbitrary assumptions about rock mass relaxation with time. Figure 7 shows an overview of the simulated data, looking at the shaft from the outside, including mapped discontinuity traces and fictitious MPBX boreholes (long holes) along with fictitious instrumented rock bolts and convergence pins.

Mapping

A special feature of mapping shafts is that a 2D sheet is used to represent 3 dimensional geometry. Vulcan allows us to digitise shaft data from a 2D “field” map representing the “unwrapped” shaft wall as shown in figure 8. The data can be attributed and reported in this view, and dip/strike and other data added as required. The same data can also be viewed in their true 3D geometry as shown in the figures 7 and 9.

Figure 9 shows a “geologists eye view” of the same data that is shown in figures 7 and 8. The benefits for checking and comparing the data are obvious.

Instrumentation

The following figures illustrate simulated MPBX data (section 3.1), but the principles apply to other time series data.

Figure 10 shows a view down a shaft including the simulated mapped geology and a display of data identifying a fictitious extensometer instrument.

Figure 11 shows the result of querying the database in Vulcan for the first 100 days of measurements for 5 anchors in an MPBX borehole, and plotting the results as a graph, in Vulcan. The Y axis is displacement (mm), and the X axis is time (days). The different traces show the results for anchors at increasing distances from the shaft wall as the displacement decreases.

Such time series data would be exported from the underlying data in required formats, eg Microsoft Excel, for processing and interpretation.

Figure 12 shows a perspective view of Acoustic Emission (AE) data and the drill and blast tunnel for the Zone of Excavation Disturbance EXperiment (ZEDEX), in Äspö, Sweden. The excavation pulls have been coloured to highlight them, and the AE data have been coloured by the day of the event. The labels show variously the event number, the date, or the magnitude of the events. Figure 13 shows a cross section through the same data as shown in figure 12. AE will be used to monitor excavation response during shaft sinking (Mellor and Davies, 1996).

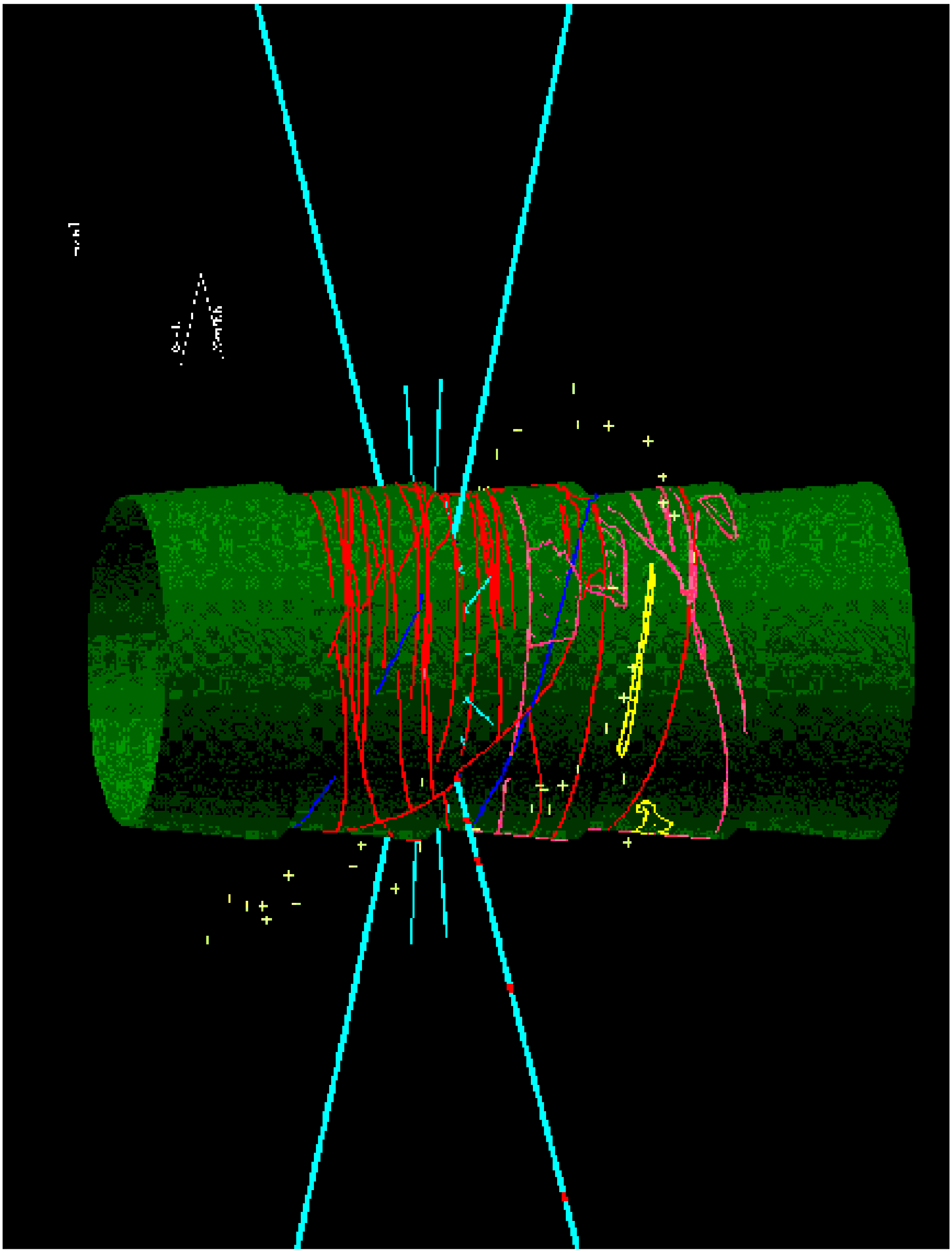

Fig. 7: Overview of simulated RCF dataset

Construction data

The figures above show geology registered to a 3 dimensional shaft wall, which would be built up from shaft profile surveys registered to the general survey of the works. The same techniques for querying and displaying MPBX data shown above could be used for blast vibration data, a further example of the flexibility in the intelligent picture approach.

Figure 14 shows a simulated blast pattern for cautious blasting of the RCF shaft in the BVG. This facility can be used for comparing the blast design with the actual blast pattern.

Links with other Nirex databases

Nirex's central database of contractor-verified data is called the Nirex Digital Geoscience Database (NDGD). This is operated by the British Geological Survey for Nirex. The intention is to replicate approved data from the RCF database to the NDGD for these data to be accessed for processing, interpretation, and modelling.

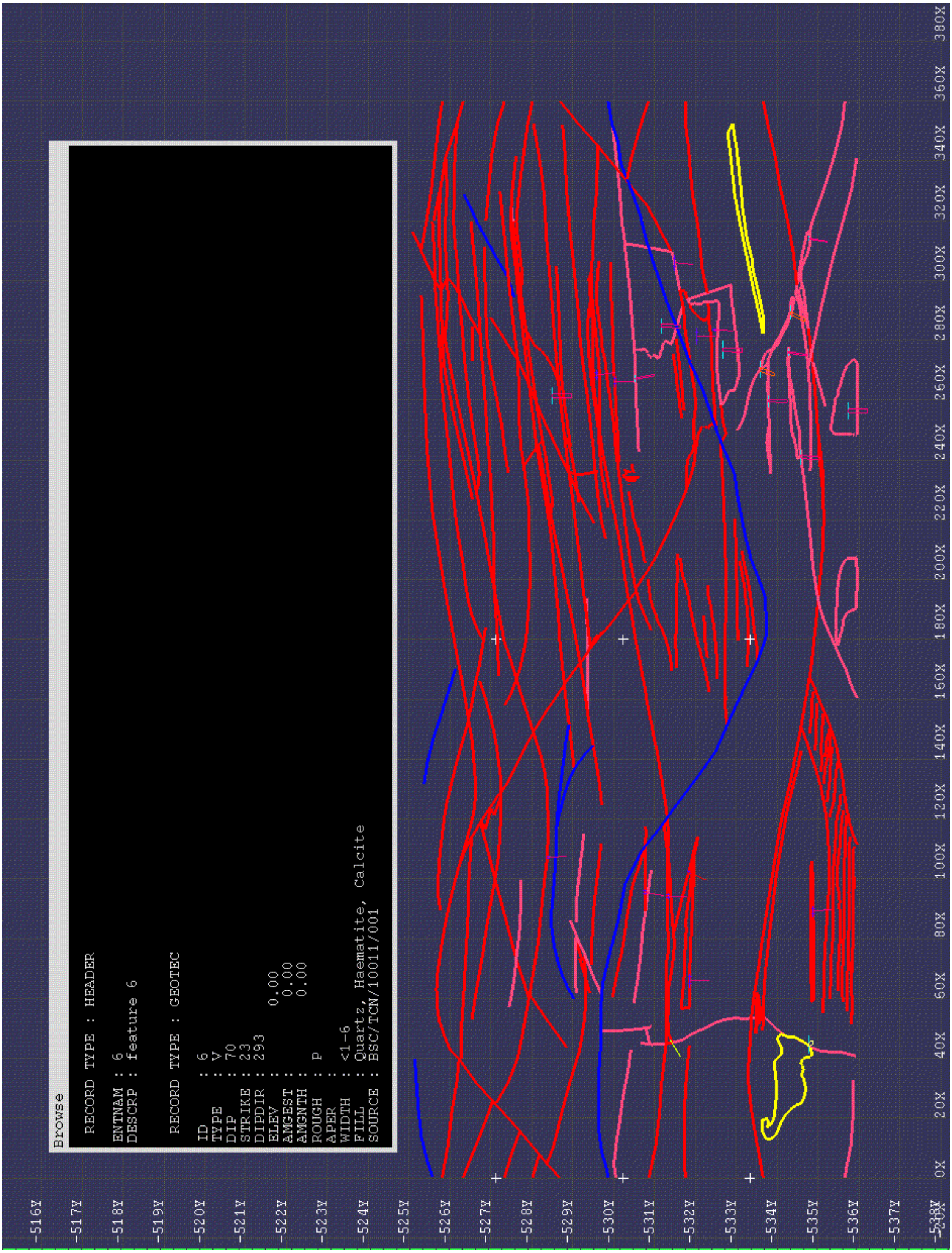

Fig. 8: Unwrapped simulated shaft mapping data

Nirex has a database of hydrogeological monitoring data currently in Cumbria, working in Oracle. The current concept is for a replication of key fields to occur from this database into the RCF database so the monitoring data can be viewed alongside the RCF data. This will allow the two parts of the RCF data (the intra- RCF data and the simultaneous monitoring of the boreholes around the RCF) to coexist for easy and rapid comparison.

Disaster prevention and planning

An essential aspect of data management is the protection of the data. It is not the intention to describe the measures in detail here, but a number of measures for disaster prevention and reduction will be instituted. These include:

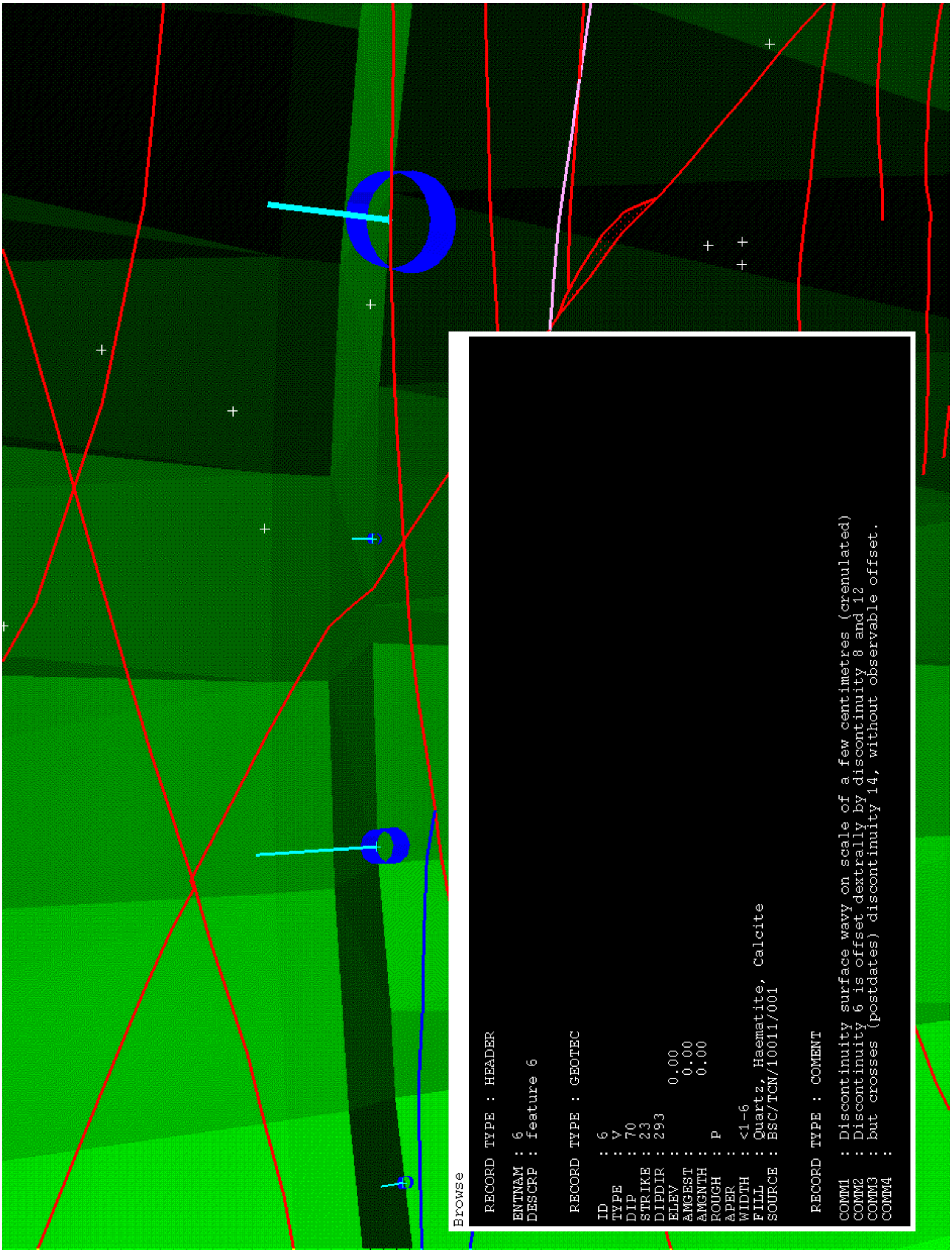

Fig. 9: "Geologist's eye view" of simulated shaft mapping data

- Siting water tanks and pipes away from the Data Management /ADAS areas in the office building
- Controlled access to the data management area
- Comprehensive backup procedure, including off-site backup
- Journal archive onto CDs to avoid magnetic media management problems
- Hardware and software maintenance
- Disaster planning
- Spare processing capacity
- Duplicated storage (disk mirroring/RAID)
- Uninterruptible Power Supplies

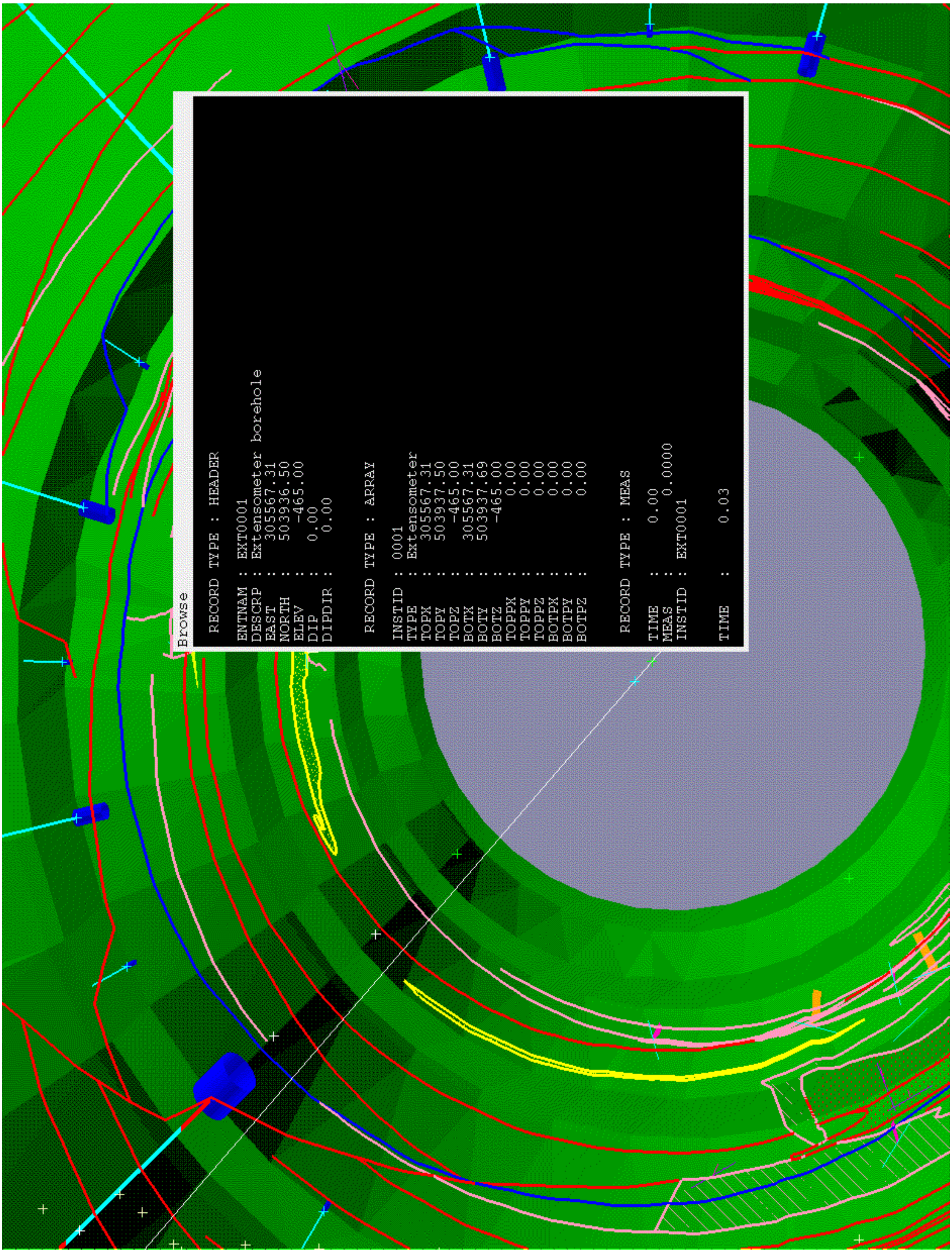

Fig. 10: View down a shaft showing simulated data and database listing for an extensometer

- Privilege Management / controlled access to data
- Anti virus measures
- Software in Escrow
- Protection of documentation
- Training and motivation
- Documented procedures

These measures feature in MACE (1993).

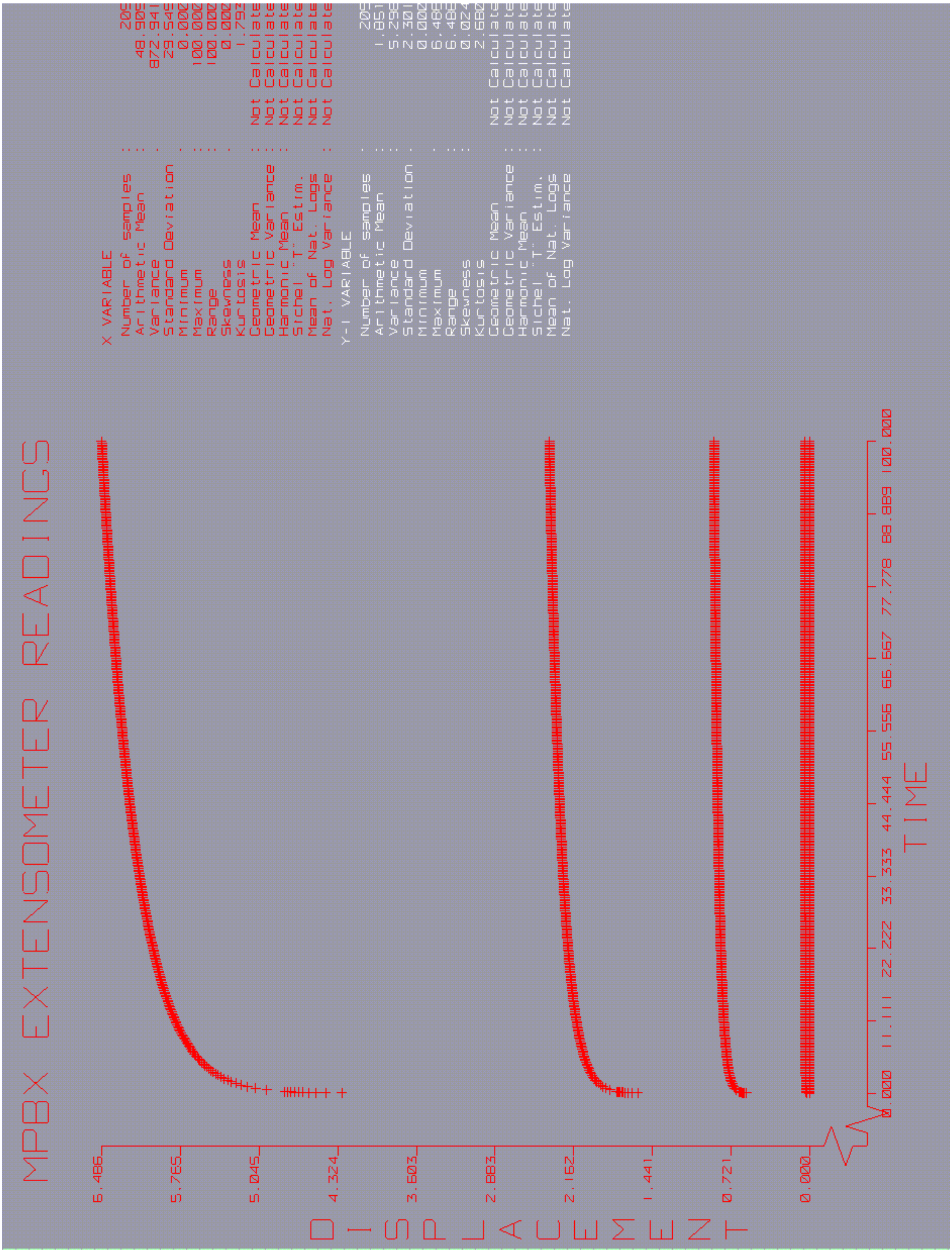

Fig. 11: Simulated MPBX data showing decreasing displacement on anchors further from the shaft wall.

Conclusions

Nirex recognises that it is prudent to plan and manage the RCF on the basis that changes in the underground layout and/or the detail of the scientific activities are likely. The approach that Nirex has adopted for providing a flexible method of managing data acquisition activities in the RCF is to divide the shafts and galleries into discrete sectors. Results and experience in completed sectors will be used iteratively to adapt work programmes and detailed design in successive sectors (Mellor and Davies, 1996). This approach means that the RCF Database and the arrangements for managing data must retain flexibility to adapt to any changes in the work programme and detailed design. The strategy for retaining flexibility in the RCF database comprises five key measures:

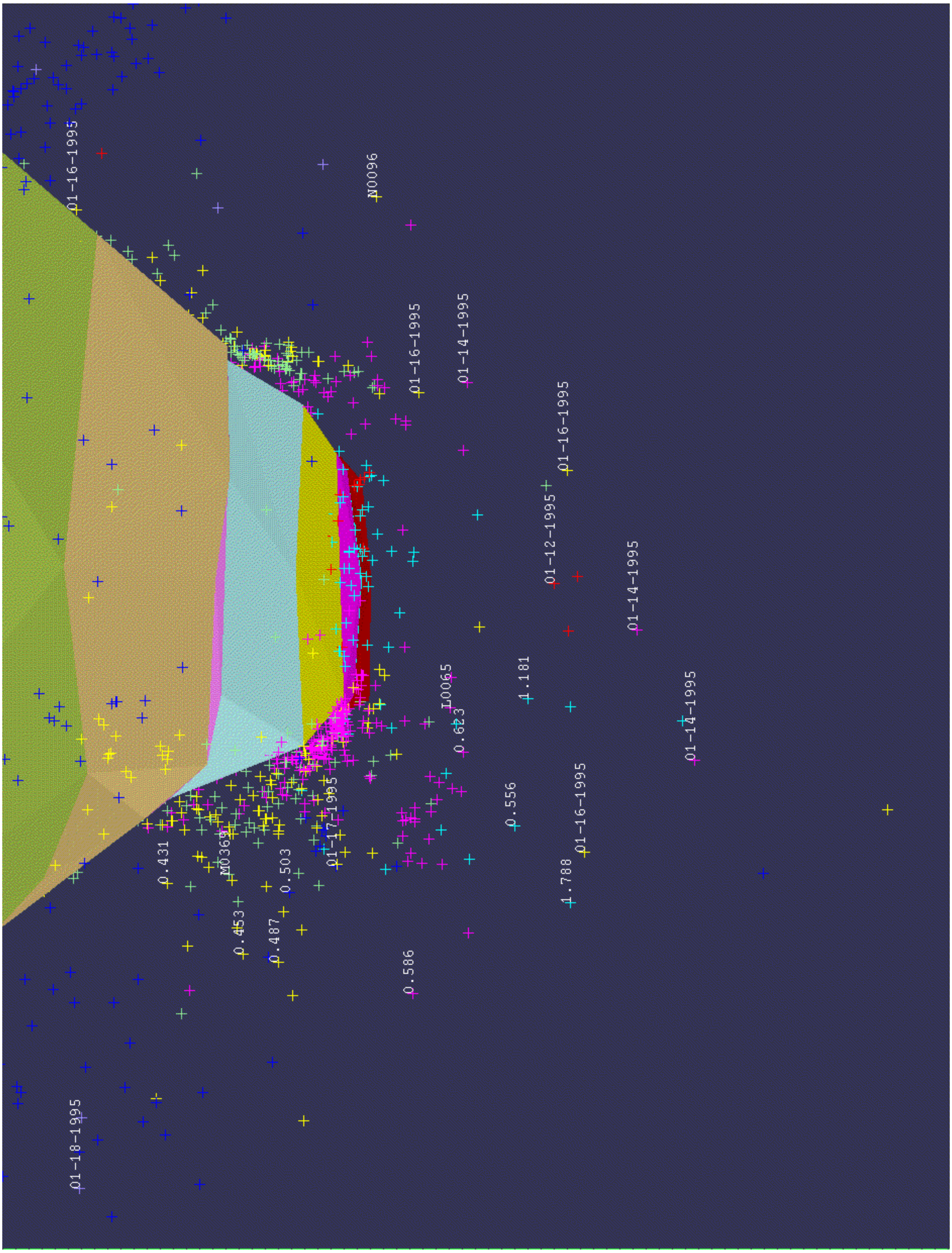

Fig. 12: Perspective view of tunnel and acoustic emission data from ZEDEX, Äspö, Sweden.

- a simple, robust data structure;
- a flexible means of access to the data along the GIS (intelligent picture) paradigm;
- not storing data in proprietary format where practical;
- close working with the Science Contractor, the Shaft Sinking Contractor, and the users of the data;
- combining the often sequential roles of designer/developer/database administrator (DBA) into one role throughout the lifetime of the project, with backup cover.

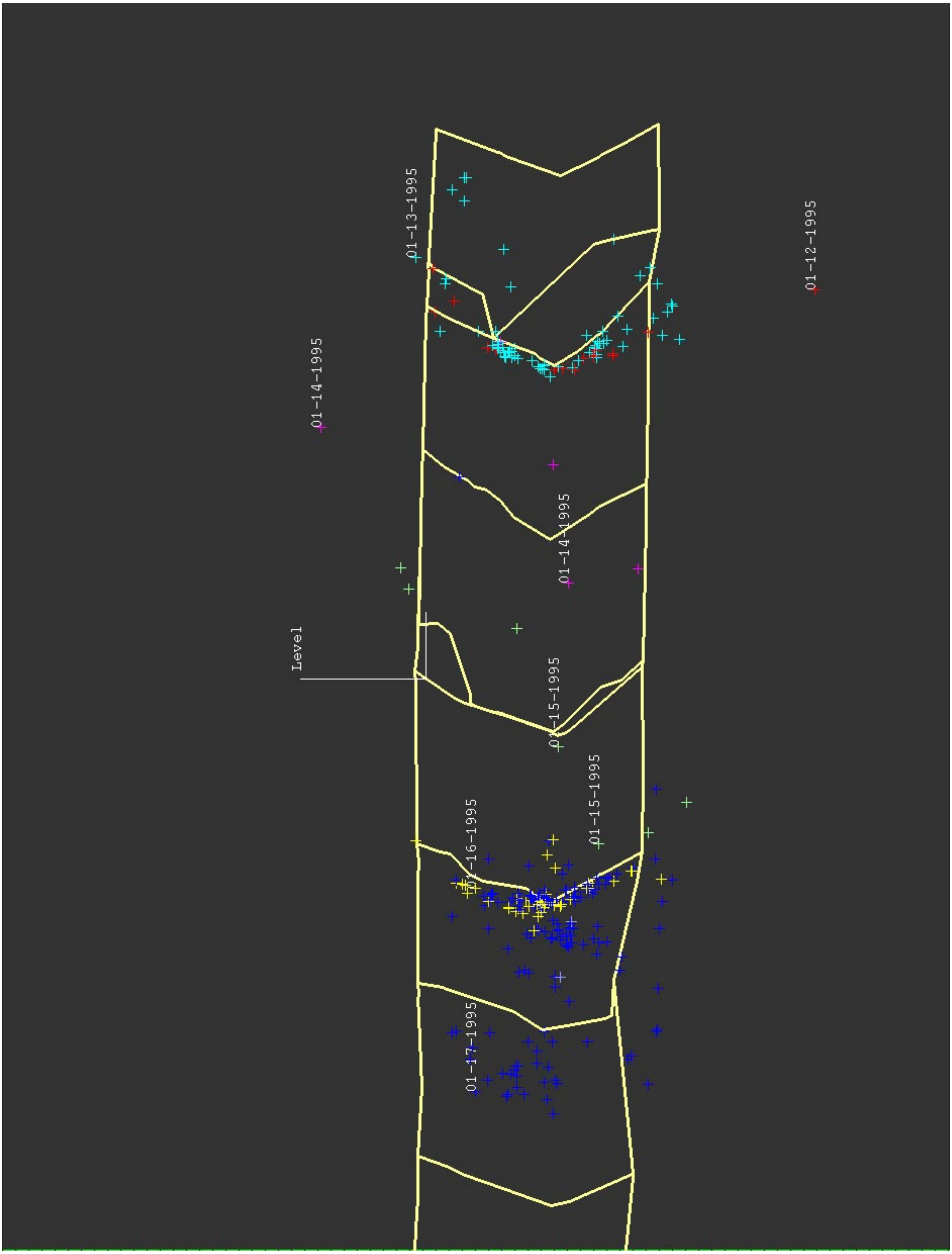

Fig. 13: Cross section through ZEDEX tunnel and acoustic emission data

The GIS (intelligent picture) paradigm will provide a flexible means of access to, and visualisation of, integrated RCF datasets. This approach is a component of the flexible data management strategy for RCF data, providing a powerful tool for checking, integrating, examining, and understanding acquired data.

Acknowledgements

Elements in this paper are derived from work by individuals other than the author. The author wishes to thank D Vreugdenburg (Maptek) G Power (consultant) J Conway (Subterra Engineering) R Whittle (GeoScience) T Murray

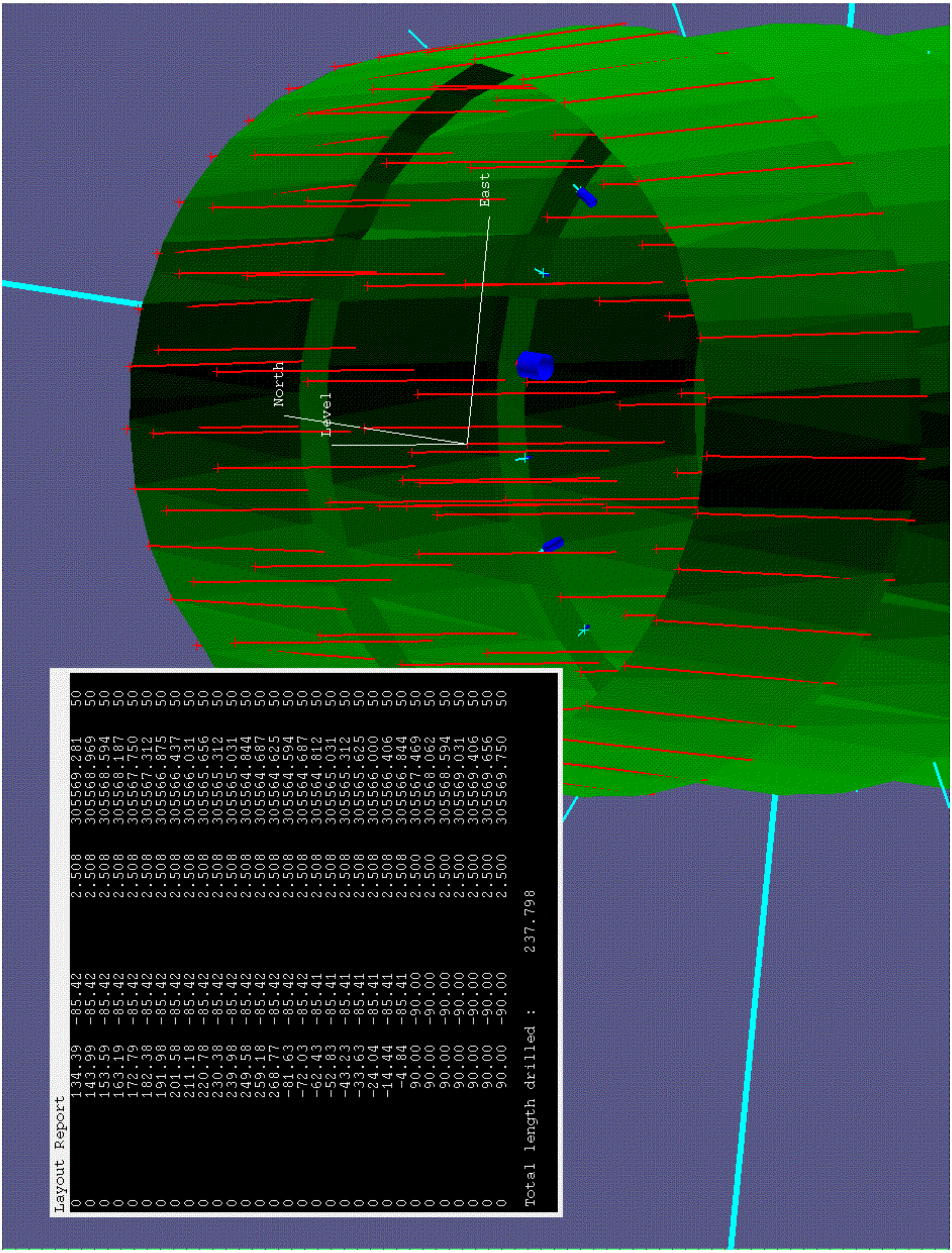

Fig. 14: Simulated blast pattern and blast report

(Nirex), A Bowden (Nirex), P Chernis (Atomic Energy of Canada Limited, Underground Rock Laboratory, Pinawa, Manitoba, Canada).

Oracle and Vulcan are trade names of Oracle Corporation and Maptek respectively.

References

Chew, K. J. 1995 “Data modelling a general purpose petroleum geological database” in “Geological Data Management” Giles, J. R. A. (Ed), Geological Society Special Publication No. 97, Geological Society, London.

Davies, N and Mellor, D W. 1996. “Proposed geotechnical investigations in the Nirex Rock Characterisation Facility” in “Rock Mechanics and Techniques” Volume 2 of Proceedings of the 2nd North American Rock Mechanics Symposium: NARMS 96, Montreal, Canada, 19-21 June 1996.

Hickford, G., and Billington, D.E., 1994. NUCLEAR ENERGY - Journal of the British Nuclear Energy Society, February 1994, Volume 33 Number 1; pp 19-24, Special Issue - The Nirex Repository.

Johnson, A. 1995. “Effective data management provides a competitive advantage” World Oil, v216, No10, p151 (1), October 1995.

M.A.C.E, 1993. “Computer disasters and recovery planning (in the British Isles and Eire)” August 1993, M.A.C.E., Ansy, West Sussex.

Maptek, 1995. “Vulcan Envisage User Reference Manual, Core” Maptek Pty Ltd incorporating KRJA Systems, Perth, Western Australia.

Mellor, D, and Davies, N, 1996. “Incorporating the excavation disturbed zone (EDZ) into the design of the Nirex Rock Characterisation Facility (RCF)”, Proceedings of the International Conference on Deep Geological Disposal of Radioactive Waste, Winnipeg, 16-19 September 1996, *in press*.

Mellor, D. 1995. “United Kingdom Nirex Limited Rock Characterisation Facility, Longlands Farm, Gosforth, Cumbria: Proof of evidence of Dr D W Mellor BSc, MSc, PhD, CEng, CGeol, FGS, MIMinE ‘The role of the RCF’” PE/NRX/16. App ref: DB/CD 8.5.1, LPA Ref: 4/94/90011, DOE Ref: APP/H0900/A/94/247019.

Murray, T. 1996. “Computer modelling of Sellafield geology”. Proceedings of Geological Society Information Group Meeting on Geological Visualisation - the intelligent picture?, October 16th 1996, British Geological Society, Keyworth, Nottingham, UK (same as comprises this paper).

Nirex, 1992; Nirex Report No. 327 - “A Rock Characterisation Facility Consultative Document”, 21 October 1992.

Olsson, O. 1994. “Test plan for ZEDEX - Zone of Excavation Disturbance Experiment.” Äspö Hard Rock Laboratory Release 1.0, February 1994.

Simmons, G.R., Bilinsky, D.M., Davison, C.C., Gray, M.N., Kjartanson, B.H., Martin, C.D., Peters, D.A., Keil, L.D., Lang, P.A. 1992. “Programme of experiments for the operating phase of the Underground Research Laboratory”; page 2; Atomic Energy of Canada Limited. -10554, COG-92-280, AECL, Pinawa, Manitoba. September 1992.

SKB, 1996. “Äspö Hard Rock Laboratory Status Report, January - March 1996” Progress report HRL-96-13

SKB, 1994. “Äspö Hard Rock Laboratory Annual Report 1993”; page 22; SKB Technical Report 94- June 1994.

Weider, J. 1996. “Delivery of a building-wide scientific imaging center” Advanced Imaging, v11, No 6, June 1996.

Nirex reference: R1/PAP/1, R1.16.30