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Atomic GIS: The use of Geographical Information Systems at Dounreay Nuclear Establishment

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Four key statements

The paper describes the background and history of the Dounreay site and illustrates how GIS is being utilised for the environmental management and decommissioning of a Nuclear Facility.

The diversification and expansion of GIS at Dounreay is illustrated, from data acquisition through to the development of virtual reality models.

The paper discusses the delivery of diverse geographical information to a diverse audience (ranging from senior personnel through to regulatory bodies such as the Nuclear Installations Inspectorate and Scottish Environmental Protection Agency and the public).

Numerous tables and diagrams are included in the paper to illustrate the variety of applications for which GIS has been used. These include tables of data sets, maps and three-dimensional illustrations.

Abstract

Dounreay Nuclear Establishment, situated in a geographically isolated, coastal location in the north of Scotland has, over the past 46 years, been a pioneer in the development and demonstration of nuclear fast reactor technology. However, the fast reactor programme has shut down and the challenge now is to decommission the three reactors and their associated facilities, the management of the waste and the remediation of the site.

GIS was introduced at Dounreay in 1999 to assist with two of the main decommissioning projects; Environmental Monitoring and Site Restoration. Initially the primary use of GIS was for map production, however, its role has subsequently expanded and diversified, to encompass data collection (through the use of mobile GIS and GPS), analysis, visualisation and management.

The inherent flexibility provided by GIS to integrate diverse sources of data explains the significant growth in the number of users and applications of the system at Dounreay. Environmental projects have benefited greatly from this ability, with data accessed ranging from side-scan sonar images, to gamma probe point data to CCTV video footage dynamically linked to a drainage-network. Visualisation of site restoration projects in two, three and four dimensions using the GIS has also provided new and varied ways of examining spatial data, including the data describing the site decommissioning programme and radioactive waste inventory.

Resulting from the growth of GIS at Dounreay, the distribution and presentation of geographical data to personnel, senior management and the regulators has progressed from traditional reports and diagrams to interactive html maps, animations and 3D models. Four-dimensional Virtual Environments are currently on the horizon, as is the delivery of GIS on the site Intranet.

1 Introduction

1.1 A Brief History of Dounreay

Dounreay was selected in 1954 as the UK site for the development and demonstration of nuclear fast reactor technology. Geographical isolation, a coastal location and the airfield (originally owned by the Admiralty, although by then disused) were some of the factors influencing the location. Construction of the site commenced by 1955 and the first reactor was operational in 1958.

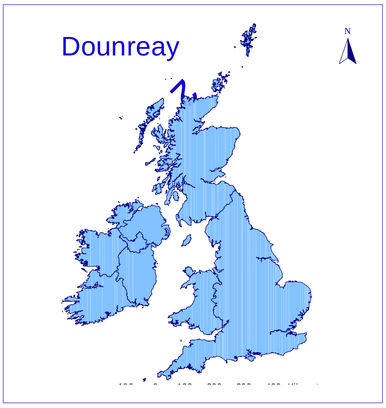


Figure 1 Dounreay Location Plan

Three reactors have been constructed and operated at the site:

- the Dounreay Material Testing Reactor (DMTR), operational in 1958, for the irradiation testing of materials;
- the Dounreay Fast Reactor (DFR), operational in 1959, to demonstrate the principle of a liquid-metal-cooled fast reactor
- the Prototype Fast Reactor (PFR), operational in 1974, to test fuel, coolant and equipment on a scale appropriate to a commercial electricity generating station.

The purpose of the Fast Breeder Reactor Programme was to demonstrate the feasibility of the system that would substantially increase the effective use of uranium fuel (one of the principal reasons for the development of this programme being the prospect of uranium becoming increasingly scarce and expensive). However, in 1992 the UK Government decided that a fuel shortage was unlikely to occur in the foreseeable future due to the discovery of additional natural sources and consequently it was announced that fast reactor research would cease in 1993 and PFR would close in 1994 (DMTR and DFR had closed in 1968 and 1977 respectively).

The tasks at Dounreay now are to decommission the reactors and associated facilities, to manage the radioactive waste and the treatment of nuclear material left over from site operations, the production of source materials for medical purposes and environmental remediation. These activities provide numerous areas where the use of a Geographical Information System (GIS) is proving to be beneficial.

1.2 A Brief History of the use of GIS at Dounreay

GIS was introduced at Dounreay in January 1999 with the purchase of two complementary systems. One was a specialised 3-Dimensional modelling system to be used for visualising geological and subterranean features and the other was an industry-standard, vector-based GIS, initially purchased to assist with the management and analysis of Environmental Data and subsequently to illustrate the Dounreay Site Restoration Plan.

The first stages of GIS development involved establishing the base data for the site (

Table 1).

Ordnance Survey (OS) Data Landline Vector (Map library) 1: 10,000 & 1: 50,000 Raster (Image Catalogues) HISTORIC BASE MAPPING - 1872, 1876, 1906, 1907 OS Land-Form Profile	Imagery Satellite Data - Spot Panchromatic - Spot Multi-spectral Photographs from aerial surveys (pre- and post-site construction) Side-scan Sonar Data, Bathymetry
Site CAD Model cm accuracy site survey performed in 1996, provides building, road, service and topographic data Model updated regularly	Databases Property Database Decommissioning Programme Dounreay Radioactive Waste Inventory Contaminated Ground Investigation
Environmental Data Including... Rainwater Seawater Sheep Faeces Grass/Soil Goat's milk Drain-survey data Contaminated Land Gaseous & Liquid Discharges ISO14001 Environmental Compliance Scottish Natural Heritage Datasets Highland Council Datasets	Geological Data Sedimentary Logging Bedrock Structure Borehole Logs Geophysical Seismic Surveys Groundwater Head Groundwater Chemistry Off-shore Geology Field Mapping British Geological Survey Data Solid & Superficial

Table 1 Data utilised within the GIS

Since the initial establishment of the system, GIS has developed from an experimental level to the stage where customised solutions are being implemented. Its use extends across a wide range of applications including project specific data analysis and visualisation, Virtual Reality modelling, data management, and data capture using Mobile GIS/Differential GPS.

An increased user base - more desktop licences, free GIS viewers, and the delivery of geographical data via the Intranet/Internet has ensured a greater awareness of geographic data across the site and highlighted the benefits of using GIS. Output from the system is now used to provide information to site personnel, senior management, regulatory bodies and the general public.

Specific uses of GIS at Dounreay ranging from Environmental to Decommissioning applications are discussed below.

2 Environmental Projects

GIS is being utilised extensively in environmental projects that are being carried out as part of the Decommissioning Programme. A selection of these are discussed below.

2.1 Aerial Survey

In 1998 an airborne survey covering a total area of 128 km^2 was conducted in the vicinity of Dounreay in order to establish levels of naturally occurring and artificial radioisotopes within the environment. The survey was performed using a helicopter with a gamma-ray spectrometer, flying along lines at a regular spacing and at an altitude of 90m.

GIS was subsequently utilised to produce maps for each of these radioisotopes with surfaces being interpolated from the point data (Figure 2). Results were then combined with 1:50,000 OS maps and satellite coverage to examine the influence of topography and land-use on the radiological signatures. A combination of 2-Dimensional and 3-Dimensional techniques were used for this analysis.

Different concentrations of natural radioisotopes were seen to occur in cultivated farmland when compared with the surrounding peatland. For the artificial isotope Caesium 137 (^{137}Cs), increased concentrations were observed in river valleys. This distribution suggests that it may have been transported by water run-off from the surrounding hills. Laboratory analysis of the data confirmed that most of the ^{137}Cs observed in the results could be attributed to contamination deposited from the fall out from atomic bomb testing in the 1950s and 60s and from the Chernobyl accident in 1986.

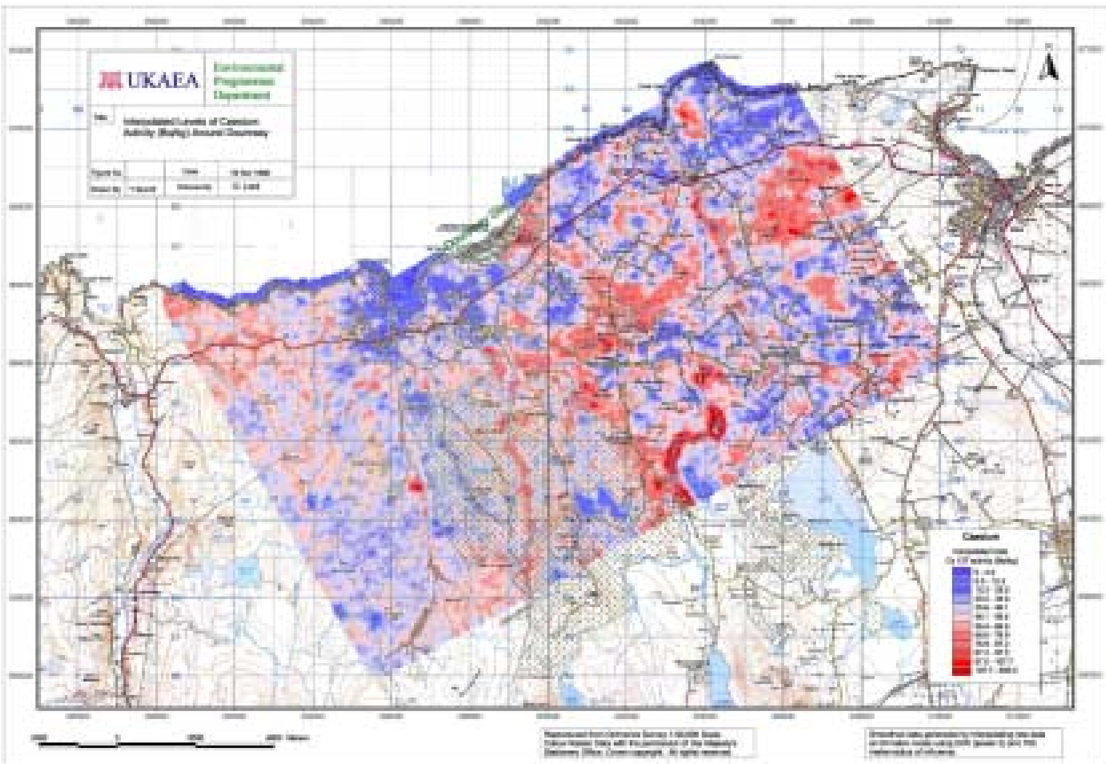


Figure 2 Illustration of Aerial Survey Data

2.2 Offshore Surveys

Particles of irradiated fuel similar in size and weight to a grain of sand (Figure 3) have been found during routine coastline monitoring at Dounreay. These particles originate from the milling of fuel elements in the 1960's –1970's. The most probable route for their migration into the marine and coastal environments is thought to have been through historical release to the low active drain, which discharges to the sea through a diffuser, 600m offshore (Figure 4).

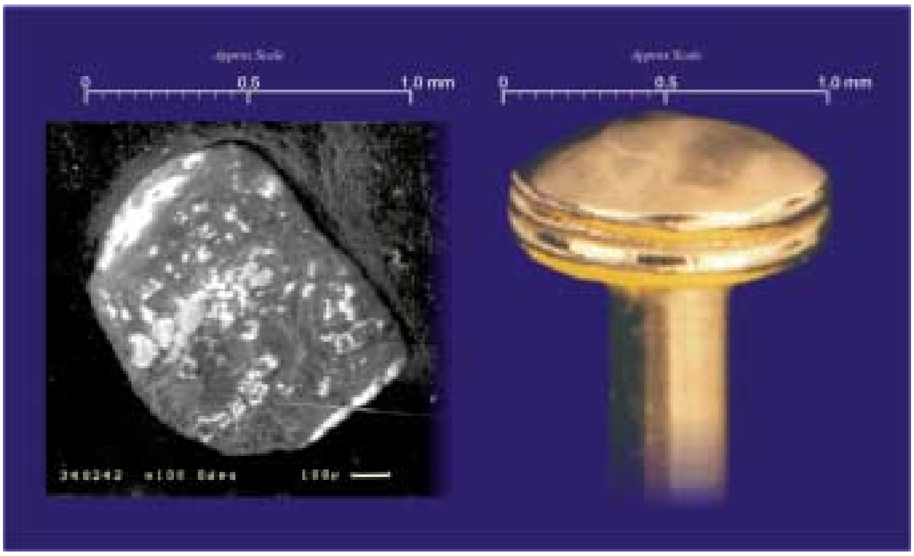


Figure 3 Irradiated Fuel Particle and a pin-head, viewed at the same scale

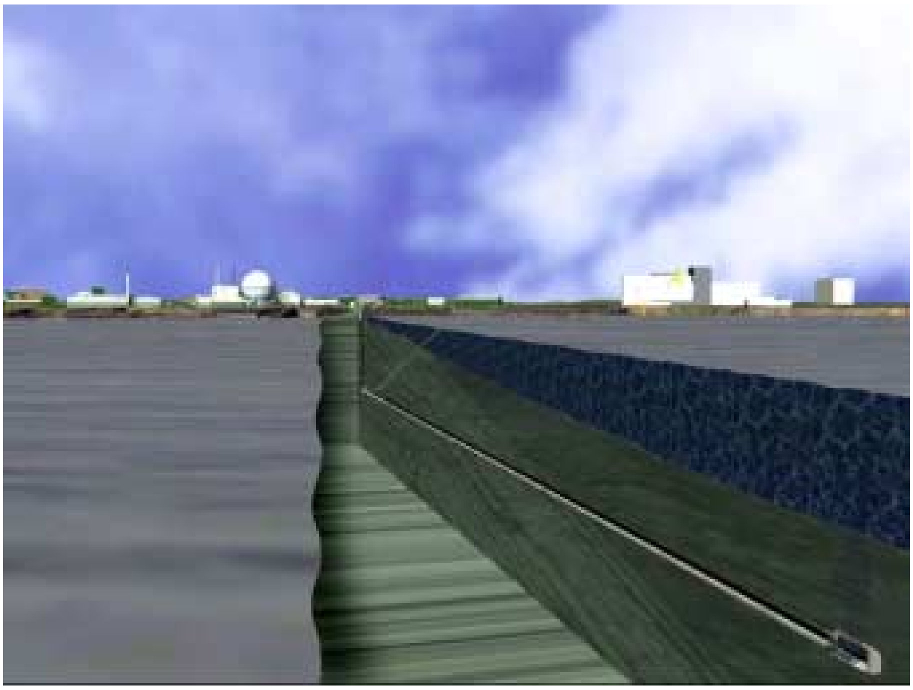


Figure 4 3-Dimensional model of the Dounreay Tunnel and Diffuser

As a result of these particle finds, several off-shore surveys have been performed along the Dounreay coastline in order to gather bathymetric, geological (superficial deposits and bedrock), and radiological data. Various techniques have been utilised to collect this information, including side-scan-sonar, towed gamma detectors, and manually collected dive data, including sediment sampling, hand-held gamma probes and video recorders.

The side-scan-sonar surveys have been used to produce a geo-referenced image of the seabed topography and an interpretation of sea-floor features (rock and superficial deposits) (Figure 5).

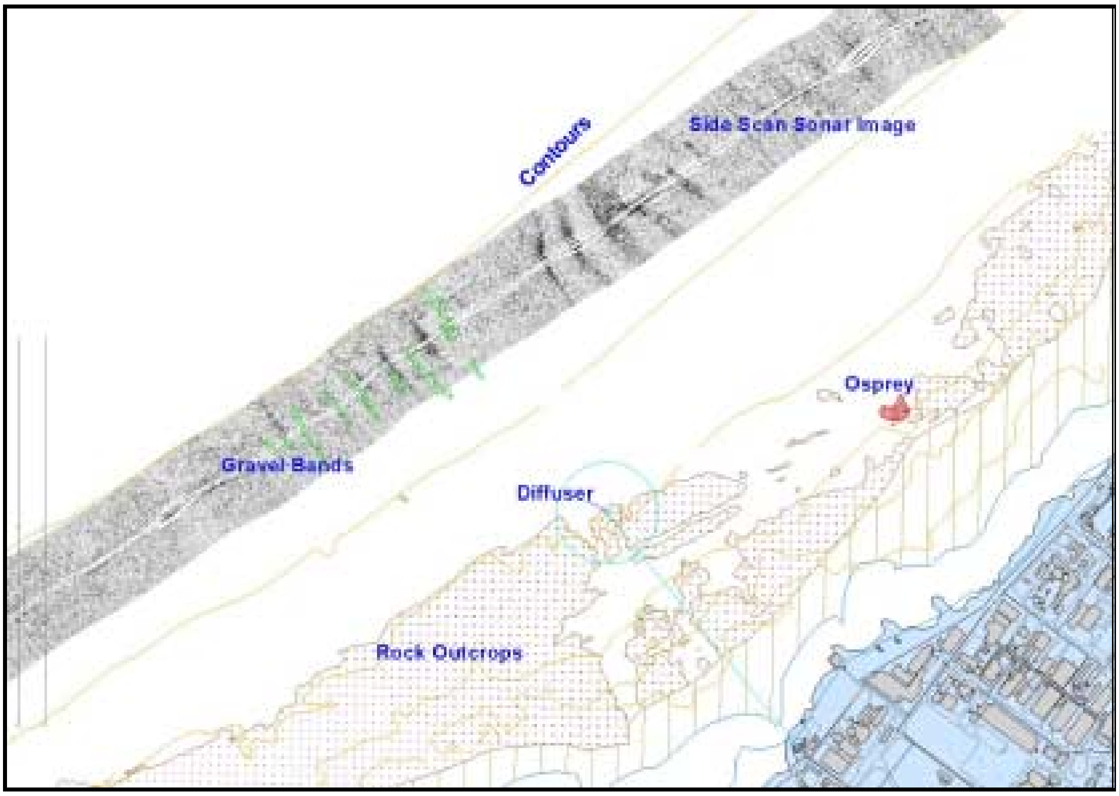


Figure 5 Sea-Bed Topographic Features & Side Scan Sonar Image

The towed-gamma detector survey was performed to collect gamma activity data for the seabed. This data was processed and combined with positional data (gathered using a Differential Global Positioning System (GPS)) and from this, a database including speed (typically 1-2 ms^{-1}), position and peak gamma activity every second was derived.

Walkover surveys of areas of the seabed have also been conducted by divers carrying gamma spectrometers (Figure 6), sediment samplers and helmet-mounted video cameras. They have recovered particles from the seabed and the location of these, along with the video-surveys have been incorporated into the GIS.

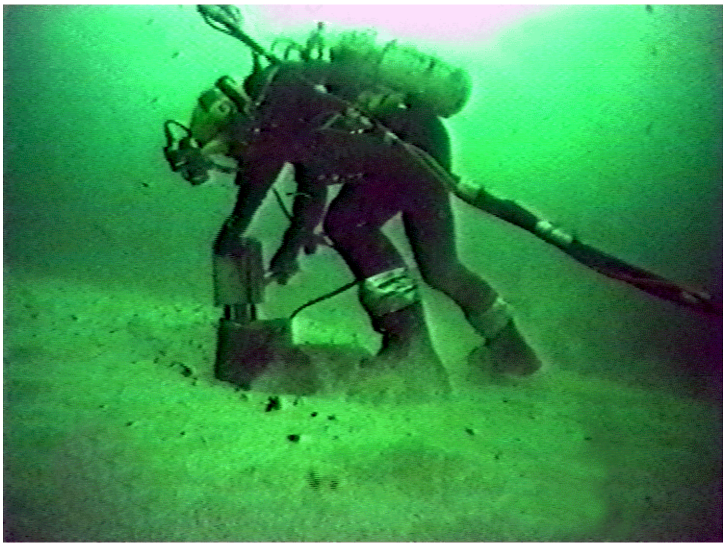


Figure 6 Diver Monitoring Sea-Bed

Preliminary spatial analysis of this off-shore data has included comparisons of the towed radiological data (some quarter of a million data points) with topographic data, sea-floor features and the manually collected dive-data.

Results of this early analysis highlighted a correlation between some radiological features and some seabed features, although it was unclear at this stage as to which features could be attributed to particles and which were due to naturally occurring background radiation. A requirement was therefore identified to process the data further, using geo-statistical techniques.

The gamma point data was processed in 100 metre grid areas using a rolling mean technique. This enabled natural high background readings to be differentiated from those high readings statistically likely to correspond to a particle. From the results of this data-processing, several anomalous discrete peaks were identified.

The processed data was subsequently displayed as a ratio of the number of readings satisfying the statistical likelihood of a particle, over the total number of readings per grid square. This was then compared with dive area locations that were displayed according to the number of particles found per dive. A clear correlation was identified between the areas where the gamma data indicated there could be particles, with areas where particles had been recovered (Figure 7).

Additionally, geo-referenced video coverage of the sea-floor has recently been acquired and can be accessed through the GIS (see also Drain-Network-Survey, below).

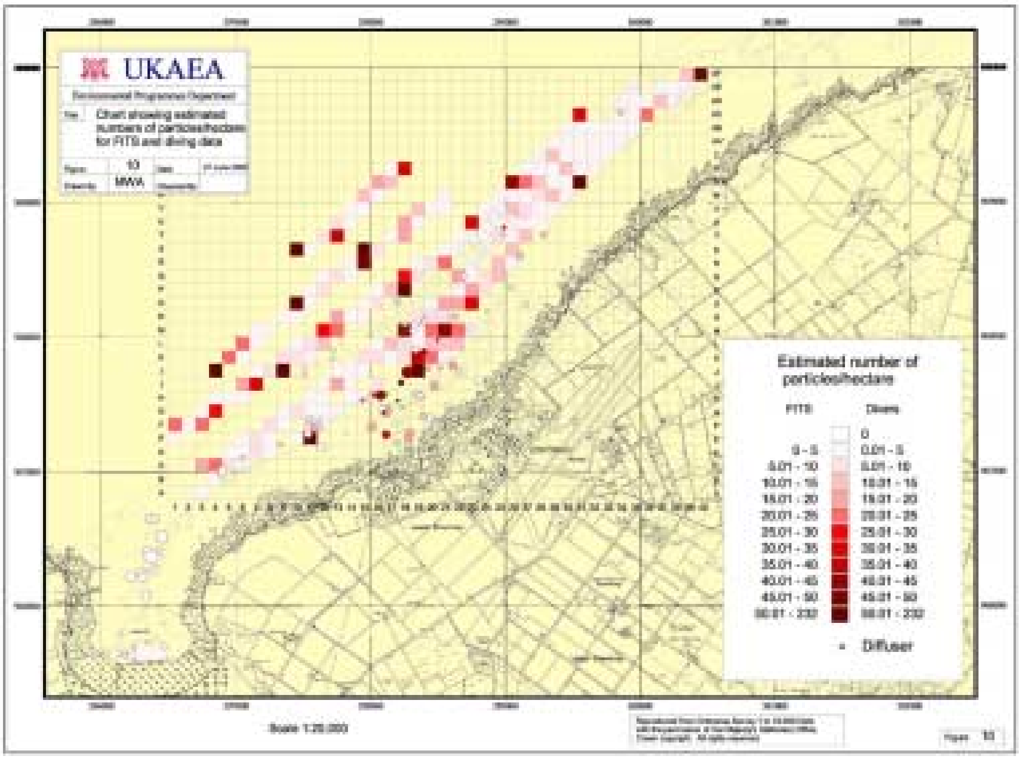


Figure 7 Diagram illustrating spatial analysis of off-shore data. The key shows how the intensity of colour represents increasing number of likely particles (FITS) and actual particles found (divers).

2.3 Environmental Monitoring Programme

The Environmental Monitoring Programme at Dounreay includes the collection and analysis of organic samples from specific terrestrial and marine monitoring points. It also comprises of ongoing radiological surveys of the site and local beaches, for which different types of radiological detectors are used.

One system utilised, "GroundHog™", combines a gamma probe coupled to a GPS and this enables large areas of spatially referenced monitoring data to be collected either on foot, or from a vehicle. In 1998, the system was utilised to demonstrate the effective remediation of the ground around the Dounreay Castle. The Castle is a site of historical importance, which was contaminated through diffusion experiments conducted in the 1950's. Plots produced in GIS from the Groundhog™ data, obtained prior to and post-remediation, demonstrated to the regulators the work had been successfully completed.

2.4 Drain Network Survey

In 1996 a survey was performed of the drain network on site to collect radiological point survey data and CCTV survey footage using a remotely operated vehicle. Six lever-arch files of point data and 150 hours of video footage were collected.

To enable the data to be viewed and analysed geographically, a dynamically segmented network was created from the existing digital drain-survey drawing. Since data was collected in both upstream and downstream directions (due to blockages in pipes etc.), two networks had to be produced in order for the data to be plotted correctly.

CCTV data was converted into a digital format and geo-referenced to the drain network. An interface has been developed for the GIS to interact with the video data, which enables the user to view the video data for each drain section. The progress of the camera along the section is also displayed in the GIS as the video runs (Figure 8).

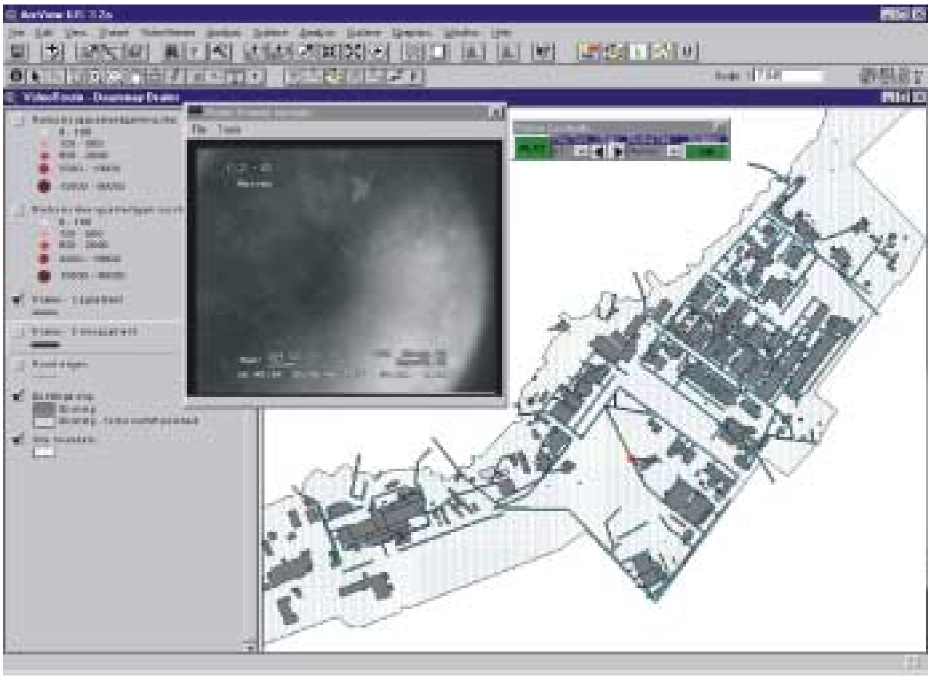


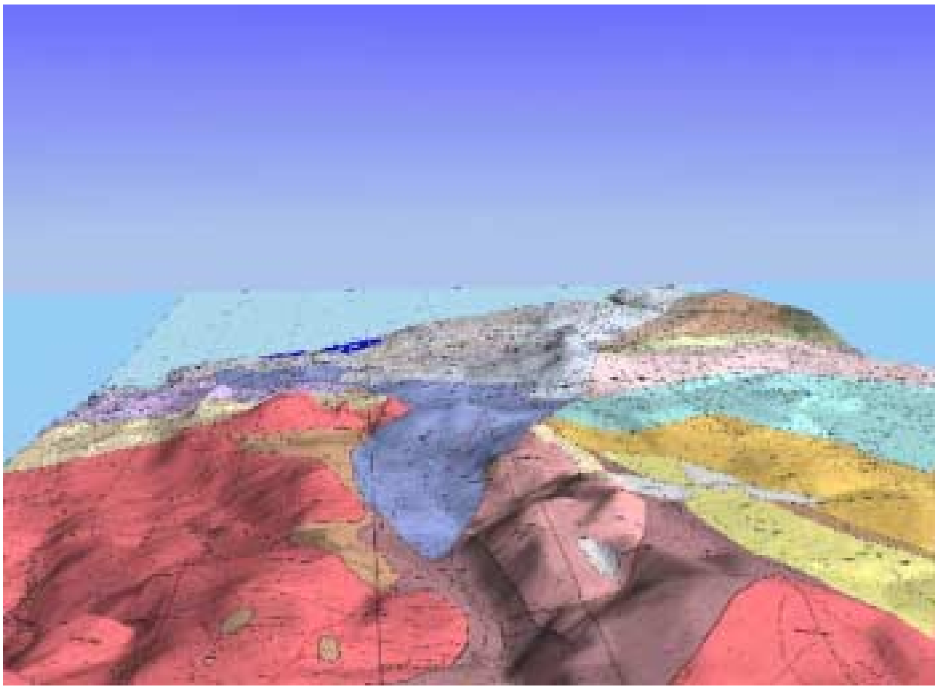
Figure 8 Screen-shot of GIS and Geo-referenced Drain Video

2.5 Geological Mapping & Modelling

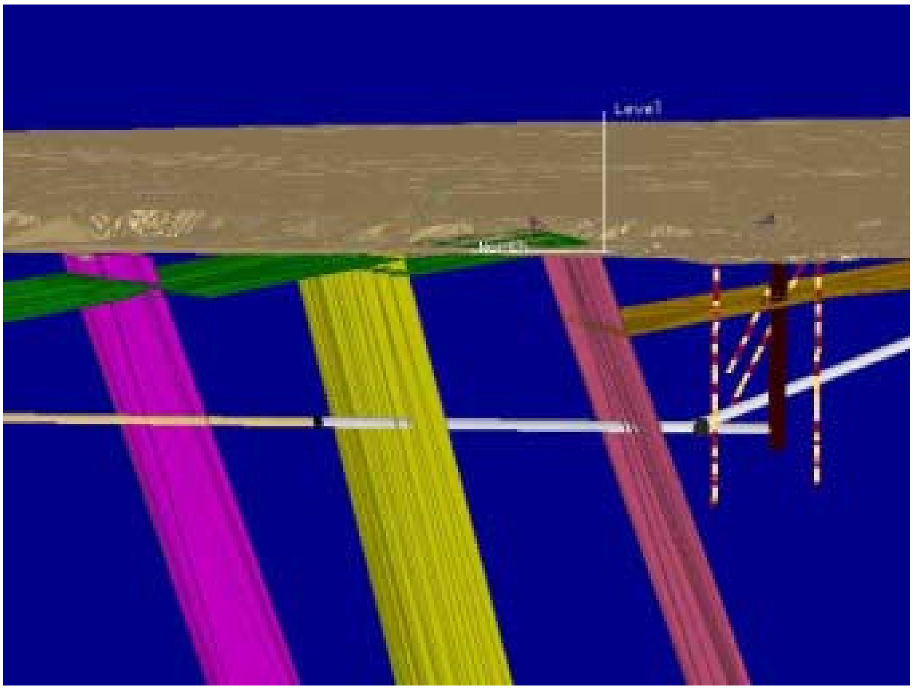
During the construction of the Dounreay Site in the 1950's, a 60 m deep shaft was excavated to assist with the removal of spoil from the construction of a sub-sea tunnel. This tunnel was to be used as the conduit for the Low Active Drain, carrying it to the off-shore diffuser 600 m north of the site from which authorised discharge to the marine environment could take place (see Offshore Section and Figure 4).

Upon completion of the Shaft, Tunnel and adjoining Adit, the Shaft was no longer required and it was deemed to be a suitable location for a licensed disposal facility for nuclear waste arising from the site's work. This practice continued routinely until 1971, when a new purpose built facility took over as a storage area, although there were occasional deposits made into the shaft until 1977. The shaft remained a licensed disposal facility until 1999 when the decision was made to retrieve the waste material from within the shaft and remediate the surrounding area. This process will involve the construction of new facilities around the shaft.

For the Shaft Radioactive Waste Retrieval project, Geological Data is required to provide information on the geological and hydrogeological conditions likely to exist beneath the site. An extensive selection of local and regional, two and three dimensional Geological information has been gathered and integrated within the GIS, including mapping, sedimentary logging, borehole and geophysical (seismic and logging) data (Figure 9). It is planned that geological output from the GIS will be utilised in numerical models for the prediction of groundwater flow around the shaft for example.



(i) Geology of the area around Dounreay draped over a DTM



(ii) Boreholes and the Geology around the Shaft, Tunnel & Adit

(iii) The geology and fault lines around Dounreay

Figure 9 (i-iii) 3D Geological Modelling of the Dounreay Environment

In addition, geological data collected for the shaft project will be of value for the decommissioning of other facilities having extensive substructures, since ground conditions will require assessment, prior to their removal. Natural Groundwater flow, for example, will have been deviated as a result of these substructures penetrating beneath the water table.

Geological data held within the GIS has subsequently been disseminated to a wider audience through a compilation of web-pages, which includes interactive and static maps, animations, vrml models, 3D scenes, tabular data and reports (Figure 10).

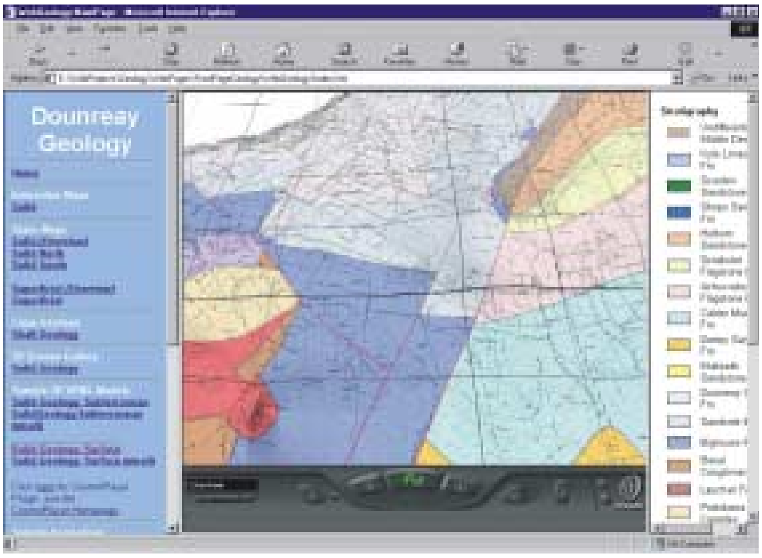


Figure 10 Web-Page delivery of GIS data

3 Decommissioning Projects

3.1 The Decommissioning Process

Decommissioning of the Dounreay Site has already commenced and is due to last for approximately 60 years.

A custom-built 'Timetool' extension for the GIS has been developed to assist with the Decommissioning process by linking to output from the Site Programme. Four-dimensional sequences illustrating current programming strategy such as the proposed demolition and construction of facilities have been produced and can be used to highlight potential conflicts within the programme (

Figure 11).

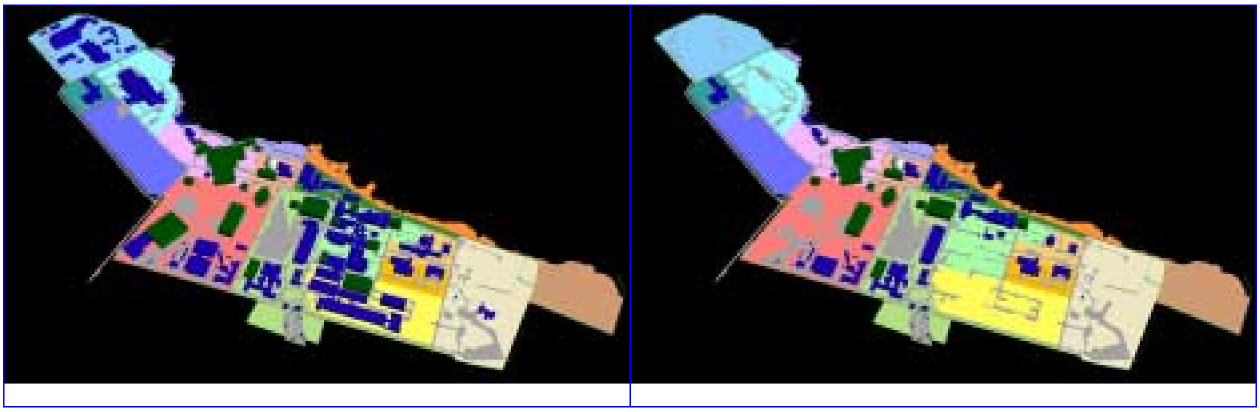


Figure 11 Decommissioning Sequences produced within the GIS

3.2 The Impact of New Facilities

As part of the site restoration procedure, new facilities are required to handle the waste from the decommissioned facilities. GIS has been used to illustrate potential locations of these new facilities and to highlight potential conflicts in their location with, for example services, existing facilities, contaminated ground, etc. Additionally, the visual impact of these proposed new facilities has also been examined, by placing them in a 3D environment to compare different types of constructions and to perform line-of-sight-analysis.

3.3 Virtual Reality

Over the past two years, visualisation has progressed from 2-Dimensional maps, through simple 3D block diagrams, to the development of a photo-realistic 3-Dimensional model of the site which has been used at presentations to public bodies and international technical gatherings (Figure 12).