CONTAMINATED LAND MANAGEMENT: DEFINING AND PRESENTING A ROBUST PRIORITISED PROGRAMME USING INTEGRATED DATA MANAGEMENT AND GEOGRAPHICAL INFORMATION SYSTEMS

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ABSTRACT

The long industrial history of many UK nuclear licensed sites has resulted in a legacy of contaminated land issues, which require resolution before such sites can be restored or made suitable for re-use. At UKAEA Dounreay the approach taken has been to address all potential risks posed by chemically and radioactively contaminated land to humans and the wider environment, in order to ensure sound environmental management and regulatory compliance. A best-practice Phase One contaminated land desk study methodology has been integrated with a bespoke data management and Geographical Information System (GIS), to enable interpretation of soil and water quality data and provide a tool for visualisation of issues flagged by the study. The Phase One study is one element of the ongoing management of the land restoration process and is the focus of this paper.

The integrated approach outlined in this paper has demonstrated the significant advantages that can be obtained by combining a Phase One study with data management and visualisation tools. Risks have been assessed and prioritised in the data management system and presented using live connections to GIS. The result is a live system that provides a dynamic management tool to ensure that not only is new data captured in a logical and structured fashion, but that the basis of decisions, actions and the management programme are recorded, accessible and auditable. Furthermore, the ability to visualise the location and status of issues and drill down to source data will enable improved communication to regulatory bodies and other stakeholders.

INTRODUCTION

UKAEA Dounreay opened in 1955 and pioneered the development of fast reactor technology in the UK through the construction of three reactors - Dounreay Materials Test Reactor (DMTR), the Dounreay Fast Reactor (DFR) and the Prototype Fast Reactor (PFR). All are now closed and being decommissioned. The reactors, fuel fabrication and recycling facilities and associated infrastructure represent an historical legacy of contaminated plant and land which, as part of responsible site operation and decommissioning, and also under statutory requirements, require effective recording and management (1).

This paper deals with the process in place at Dounreay for managing contaminated land and recording land quality, and summarises the recent Phase One project undertaken. The remainder

of this introductory section describes the UK regulatory context for the management of contaminated land on nuclear sites, and goes on to describe UKAEA's corporate software tools used to record land quality information. The term 'land quality' recognises that, whilst land may contain anthropogenic chemical or radioactive substances, it may not meet statutory definitions of 'contaminated land' and may not constitute an unacceptable risk to human health or the environment.

The remaining sections of the paper outline the traditional approach to Phase One studies in the UK, and describe its limitations that have led to the development of the approach used for the Dounreay Phase One. This Phase One project has integrated traditional desk study techniques with UKAEA's software tools, to ensure that all potentially significant contamination issues are identified and suitably recorded. Existing qualitative and quantitative data held within the software tools have been reviewed along with information from various other sources to characterise, assess and prioritise the contamination issues. This has resulted in a best practice Phase One project which is easily accessible and amenable to ongoing supplement and update, and which can significantly aid stakeholder engagement by providing a simple means of interpreting and communicating land quality information and demonstrating the decision making process.

Regulatory Controls

UKAEA Dounreay is a Nuclear Licensed Site, under the Nuclear Installations Act, 1965 (as amended): this is the principal statutory instrument used to regulate the on-site processes, as it is primarily concerned with the safe operation of the site. The Site Licence makes certain management requirements, which have an attendant cost to implement. If, in the future, the site licence holder wishes to reduce this cost through reducing the area of the licensed site, and cease to be responsible for nuclear liability on a part of the site, that part must undergo a process of delicensing. The UK Health and Safety Executive (HSE) have issued guidance on the delicensing process (2) which states that, in order for an area to be delicensed, there has ceased to be any danger from ionising radiations on that area. Implicit in this requirement is that appropriate records of land condition on nuclear licensed sites are made. It is also appropriate that the licence holder maintains a record of the risks associated with land contamination, so that a live assessment of the progression towards delicensing may be made, if this is in fact the defined objective of the site.

Other regulatory regimes are in place to manage other aspects of the site operations and environmental impacts, and those with a specific potential application with regard to land quality are briefly summarised below:

- Radioactive Substances Act: regulating the storage and use, and accumulation and disposal, of radioactive substances. Land contaminated with artificial radioactivity may be viewed as an accumulation of radioactive material;
- Contaminated Land Regulations: regulating land contaminated with non-radioactive chemical contamination;

- Ionising Radiations Regulations: controls the aspects of working with radioactivity relevant to the protection of human health;
- Potential additional liability under Control of Pollution and Water Quality legislation.
- Integrated Pollution Prevention and Control: this regulatory regime seeks to minimise releases to environmental media as a consequence of new industrial processes.

As a consequence of these regulations, there is a requirement to identify and understand the quality of the land occupied by the site, and to make records of land quality. These may be used to assess the risks associated with contamination, and to measure progress towards a relaxation in regulatory requirements.

UKAEA Software Tools to Support Land Quality Management

UKAEA have embarked on a corporate strategy to use a bespoke Information Management and Geographical Evaluation System (IMAGES) for land quality management. IMAGES is a relational database, built on an ORACLE architecture, that assists the process of land quality data capture, storage, interpretation and presentation. Component modules within IMAGES include invasive survey, water quality, buildings history and land assessment. Core to the IMAGES application is the ability to standardise data capture, revision control information and provide a structure from which to formulate land quality management decisions. The database modules combine to integrate land quality information and management processes on the site.

Key to the interpretation and presentation of data within IMAGES is a coupling of standard database operations with the spatial analytical capabilities of a Geographical Information System (GIS). The GIS used by UKAEA is ArcGIS, which enhances traditional database information by enabling spatial searching, analysis and map-based presentation of data in two and three dimensions. Data held within IMAGES is supplemented by information held within a file-based GIS structure for base mapping, and externally provided data including geology and remote sensing.

At UKAEA Dounreay, the combined use of IMAGES and GIS has become firmly established since the introduction of both systems for use in contaminated land management in 1999. IMAGES and GIS are now integral to the contaminated land management process and have been used in this Phase One study to analyse existing land quality data and provide the mechanism to update, report and visualise results.

CONVENTIONAL PHASE ONE STUDIES

Standard UK Approach

The standard UK approach to researching and documenting the identification of potential and actual contaminated land issues has recently been formalised in a set of 'Model Procedures'

issued by the Environment Agency (3). The Model Procedures adopt a similar approach to the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (4), and term the initial phase of identification of potential contaminants the 'Preliminary Risk Assessment'. The context of preliminary risk assessment is the adoption of a tiered approach, whereby succeeding tiers involve a more complex evaluation of the potential risks associated with a site, progressing from preliminary (qualitative) risk assessment, through generic (quantitative) risk assessment to detailed quantitative risk assessment.

This approach is often translated into practice by UK land contamination consultants through the medium of a 'desk study' or 'phase one' report, terminology which precedes the Model Procedures and refers to previously documented approaches to the assessment of land contamination. These progressed from Phase One (Identification) through Phase Two (Characterisation) to Phase Three (Remediation). The findings of each phase informed successive phases of work, representing a more chronological progression as opposed to the current Model Procedures, which represent the progression of characterisation knowledge and thus strength of the resultant risk assessment in the context of achieving mitigation of the risks.

Limitations of Standard UK Industry Practice

A standard consultant's methodology for undertaking a Phase One involves inspecting the site in question, considering the available data and constructing the most appropriate Conceptual Site Model (CSM) for the site. All of these stages of work are then reported to the client within a written report.

The principal drawback with this approach is that, for clients with large or complex land contamination liabilities, a significant time/cost investment must be made by the client, on the receipt of the consultant's report, to review and synthesise the report into a forward programme of works. There is also the contention that, through wholly relying on consultants' reports, the client never fully takes ownership of the knowledge developed through the identification work, and so remains at least partially dependent on the consultant in the future management of contamination issues. Whilst this represents a possible recourse to insurance in the event of deficiencies, it does not engender confidence on the part of the regulatory bodies that the problem owner is fully engaged in managing the issues.

THE PHASE ONE INTEGRATED APPROACH AT UKAEA DOUNREAY

The approach to the Phase One contaminated land assessment at Dounreay has been developed by utilising published guidance on contaminated land industry best practice, in addition to nuclear-sector specific guidance from interest groups such as SAFEGROUNDS and regulators (5 & 6). The Dounreay Phase One project has reviewed and supplemented information within IMAGES in order to identify two types of issues:

- Potential sources of contamination
- Impacted areas affected by contamination (known and potential areas)

The Phase One was undertaken by specialist environmental consultants, Entec UK Ltd., to ensure that the approach and findings were consistent with industry best practice. A collaborative approach between consultant and client was taken to ensure that the technical methodology and software system were successfully meshed (as shown by Figure 1), aiding analysis and presentation of information.

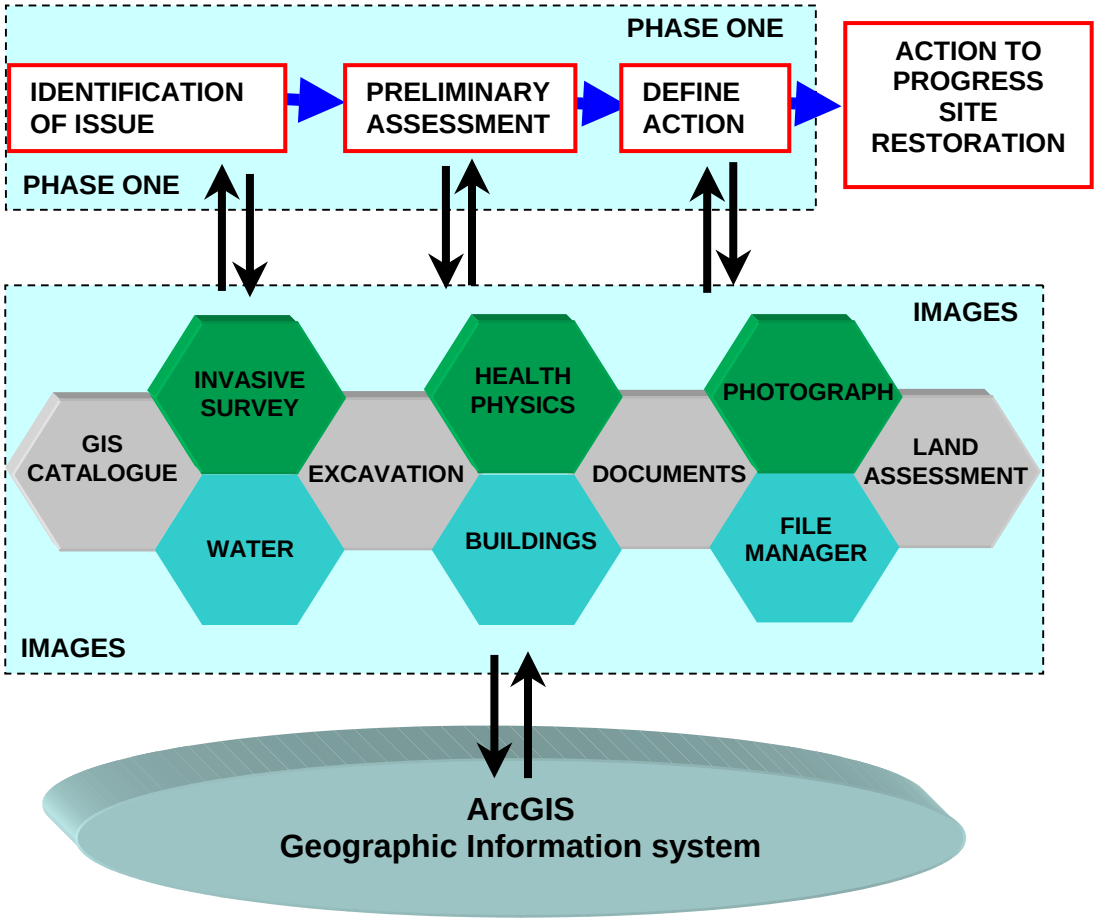

Fig. 1. Process diagram of Phase One project and interaction with IMAGES/GIS system

Historically, Phase One studies at nuclear sites have often focussed on radioactive contamination as this was seen as posing the greatest risk, or constituting the greatest liabilities. However, many nuclear sites do store and use large volumes of common and specialist industrial chemicals, and consequently there is the potential for significant risks to be posed to the environment by non-radioactive contaminants. In line with contaminated land industry best practice, the Dounreay Phase One has assessed all potential contaminants, i.e. both radioactive

and chemical, not only on the nuclear licensed site, but also on land outside this boundary either currently or historically used or owned by UKAEA.

Review of Existing Information within IMAGES

Investigations at Dounreay have historically focussed on the assessment of discrete contamination issues, but have also included a significant amount of opportunistic sampling, as well as a comprehensive programme of environmental monitoring. Site investigation and environmental monitoring data has been, and continues to be entered into the Invasive Survey, Water and Health Physics modules of the IMAGES database through standard data capture templates. Importantly, each sample within IMAGES has a XY location, typically collected using Global Positioning Systems (GPS) to enable samples to be plotted using GIS. Sample data also include ancillary information such as soil logging details, chain of custody information and analytical results. On logging into the database, a series of automated routines exist to standardise analytical units and present data in an open format suitable for further analysis in GIS or spreadsheet packages. An innovation introduced to the templates as part of the Phase One was the ability to mark sample data as being for 'issue characterisation', 'waste characterisation' or for 'remedial verification'. This will ensure that the system provides an accurate inventory of contaminated land remaining on-site at any time.

In order to assess existing data within IMAGES and use it to identify any Impacted Areas, the results of laboratory analyses stored within these modules can be compared with screening criteria, and exceedances displayed via the GIS. As part of the Phase One, soil quality data were compared with UK published generic screening criteria, exceedances of which were used to identify impacted areas on site. At present, the generic (i.e. Tier 1) screening criteria have been selected based on conservative assumptions regarding site conditions and intended end use of the site. Should these assumptions change, it will be easy to up-date the GIS-layers with alternative screening criteria. Likewise, if site-specific screening criteria have been developed, these can be used to undertake a more customised and detailed risk assessment.

One of the key features of the connection to GIS is the ability for decision-makers and analysts to be automatically updated pictorially on the current level of exceedances in any particular area of the site (as shown on Figure 2 below). This is made possible through the live linking between database and GIS so, as new samples are added to IMAGES, any that exceed the predefined thresholds are flagged up on screen, giving a clear indication of current land quality.

The GIS layers showing screening criteria exceedances for a wide variety of contaminants have been used to identify Impacted Areas. For each Impacted Area and Potential Source, a record was created within the Sentencing Module of IMAGES, which acts as a 'register' of contamination issues that will require some further investigation or assessment.

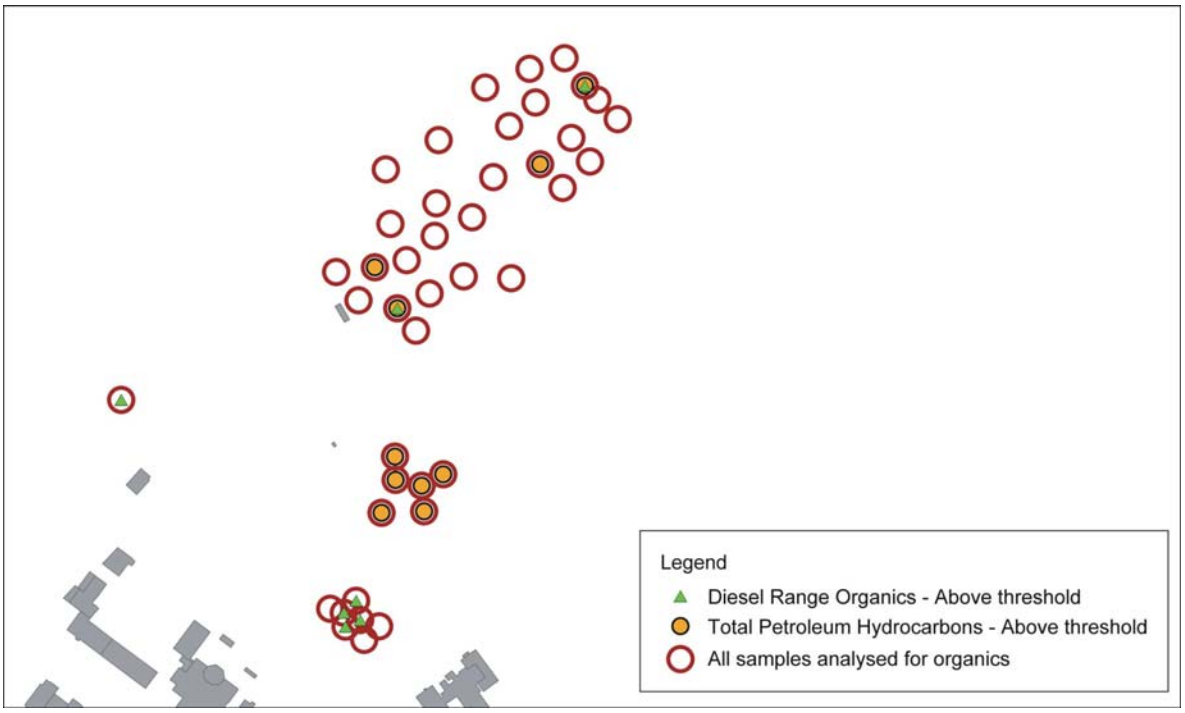

Fig. 2. Display of Contaminants above Screening Criteria

Potential Sources

Information relating to potential sources of contamination was structured on the basis of the individual buildings (or outdoor structures/areas) in which they occurred. Details of the hazardous substances historically and currently used or stored in each building were obtained from interviews with key personnel, from relevant documentation and from site reconnaissance visits. This information was entered into individual building records within the IMAGES database. The organisation of this information on an individual building basis will enable the details of historic and current activities carried out within each building to be readily accessed by other parties who may need this information for purposes other than contaminated land management. For example, details of historic activities are required by regulators before a demolition permit is issued.

Records to reflect the contamination issues identified for each building were created within the Sentencing Module of IMAGES for each of the potential sources identified. Separate issues were created for different potential sources, or groups of potential sources with similar characteristics e.g. historic chemicals used in the building, current chemicals stored in bulk with similar containment measures.

Impacted Areas

Impacted areas were identified from anecdotal and documentary evidence of contamination events provided by current and former personnel, from observations made during site reconnaissance visits and by using site investigation data. Impacted areas included those where

waste disposal activities took place, and known or suspected leaks and spills of hazardous substances occurred. Where Impacted Areas were associated with particular buildings, appropriate information was added to the individual building records within the Buildings Module.

RISK ASSESSMENT AND PRIORITISATION OF ISSUES

Each contamination issue (Potential Source or Impacted Area) has been subject to a qualitative risk assessment to enable the prioritisation of the large number of issues identified. By assigning Priority Categories to contamination issues, this will ensure that the most significant risks to human or environmental receptors are dealt with first. The risk assessments are based on the established source-pathway-receptor model, universally used for contaminated land assessment (3). The receptors have been identified to include both human and environmental receptors. With respect to human receptors, these have been initially divided into two groups which will have significantly different exposure scenarios: decommissioning workers and the general public. Environmental receptors comprise surface waters, groundwater, flora, fauna, buildings and services.

The aim of the risk assessment was to assign a Priority Category to each potential pollutant linkage (source-pathway-receptor interaction) associated with a contamination issue. The Priority Category definitions were adopted from UK regulatory guidance (CLR6: reference 7), defined in Table I:

Table I. Priority Category Definitions from CLR 6

Priority Category 1	• Site probably or certainly not suitable for present use and environmental setting • Contaminants probably or certainly present and very likely to have an unacceptable impact on key receptors • Urgent action needed in the short term
Priority Category 2	• Site may not be suitable for present use and environmental setting • Contaminants probably or certainly present, and likely to have an unacceptable impact on key receptors • Action may be needed in the medium term
Priority Category 3	• Site considered suitable for present use and environmental setting. • Contaminants may be present but unlikely to have an unacceptable impact on key receptors • Action unlikely to be needed whilst the site remains in present use or otherwise remains undisturbed.
Priority Category 4	• Site considered suitable for present use and environmental setting • Contaminants may be present but very unlikely to have an unacceptable impact on key receptors • No action needed while site remains in present use and remains undisturbed

In order to provide clarification on the meaning of some of the subjective terms within the Priority Categories, a risk assessment matrix has been developed by Entec, adapted from ones commonly used by the contaminated land industry (Table II).

Table II. Risk Assessment Matrix Used for the Assignment of Priority Category Ratings

Consequences if pollution linkage occurs	**Likelihood of pollutant linkage occurring** (Indicative Probability Range)			
	Almost certain (95-99%)	**Likely** (55-94%)	**Possible** (45-54%)	**Unlikely** (5-44%)
Severe – Significant harm to designated receptor	1	1	2	3
Moderate – Harm likely to designated receptor	1	2	2	3
Mild – Harm could arise to designated receptor, but likely to be mild	2	2	3	4
Negligible – Presence of hazard does not give rise to potential to cause significant harm	2	3	4	4

NB 'Harm' is defined in statutory regulations (8) as 'harm to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes harm to his property'.

The matrix is used to assign individual Priority Categories to each pollutant linkage. An overall Priority Category is assigned to each contamination issue, based upon the highest category assigned to any component pollutant linkage. The results of the risk assessments are entered into a GIS database table that can be used to generate tables (as in Table III) for each individual contamination issue within the Sentencing Module. If further information on a pollutant linkage becomes available, the risk assessment can be revised easily in GIS, and new Priority Categories assigned**.**

It is apparent that some positions within the above matrix, may be interpreted as applicable to more than one Priority Category, due to their subjective definitions. Where this is the case, the position has been assigned to the highest applicable Priority Category, ensuring a conservative approach. This accounts for the fact that more positions within the matrix are Category 2, than for the other categories.

The matrix provides a basis for assigning the Priority Categories consistently; however, it is acknowledged that there will always be an element of subjectivity in the risk assessment process. The effects of this subjectivity were minimised by ensuring that appropriately qualified and experienced personnel were used to undertake the Phase One project, working closely together, who have developed their professional judgement by undertaking similar projects on non-nuclear contaminated sites.

Table III. Risk Assessment Data Associated with Issues

Potential Pollutant (source)	Potential Receptor	Potential Pathway to Receptor	Associated Hazard	Consequences if pollution linkage occurs	Likelihood of pollutant linkage occurring	Priority Category
30,000-litre tank containing contaminant X. Tank of single skin construction, over shallow bund. Tank and bund integrity not tested.	Humans (decommissioning workers)	Direct contact, inhalation ingestion	Toxic, irritant, chemical burns	Mild	Possible	3
	Humans (general public)	Access to site is restricted	-	-	-	-
	Perched Groundwater	Infiltration/ Migration	Groundwater contamination	Moderate	Possible	2
	Deep groundwater	Infiltration through rock profile	Groundwater contamination	Mild	Unlikely	4
	Surface waters	Migration via groundwater, surface run off surface drainage	Surface water contamination	Negligible	Unlikely	4
	Buildings and services	Direct contact, infiltration/migration	Degradation of services and building materials	Mild	Possible	3
	Flora and fauna	Direct contact, uptake from groundwater,	Phytotoxic, toxic, irritant, chemical burns.	Mild	Unlikely	4

The above example shows that the individual pollutant linkages have been assigned Priority Categories ranging from 2 to 4, and thus the overall Priority Category for that issue is 2. It is acknowledged that the risk assessments are conservative, but this approach was considered appropriate due to the long industrial history of the site, and often a lack of immediately available information about a specific issue. The same approach has been used in the assessment of all issues; i.e. the relative ranking of issues is robust.

ISSUE ANALYSIS AND VISUALISATION USING GIS

The IMAGES and GIS system has been integral to the storage and assessment of existing land quality data used in the Phase One study. It also provides the mechanism for storage, analysis and visualisation of the results of the study and is the tool by which UKAEA will demonstrate progress in contaminated land management throughout the period of site restoration to the site regulators and other stakeholders.

In order to fulfil this role the system has to hold risk assessment data and location information for each issue, in such a form that the data and the location information can be combined and interrogated using ArcGIS software, shown in Figure 3. A geodatabase is an appropriate solution for this task as it holds information relating to geographic features - including both their spatial characteristics and other attribute information - so that GIS software, such as ArcGIS, can access the information to display feature locations and attribute data.

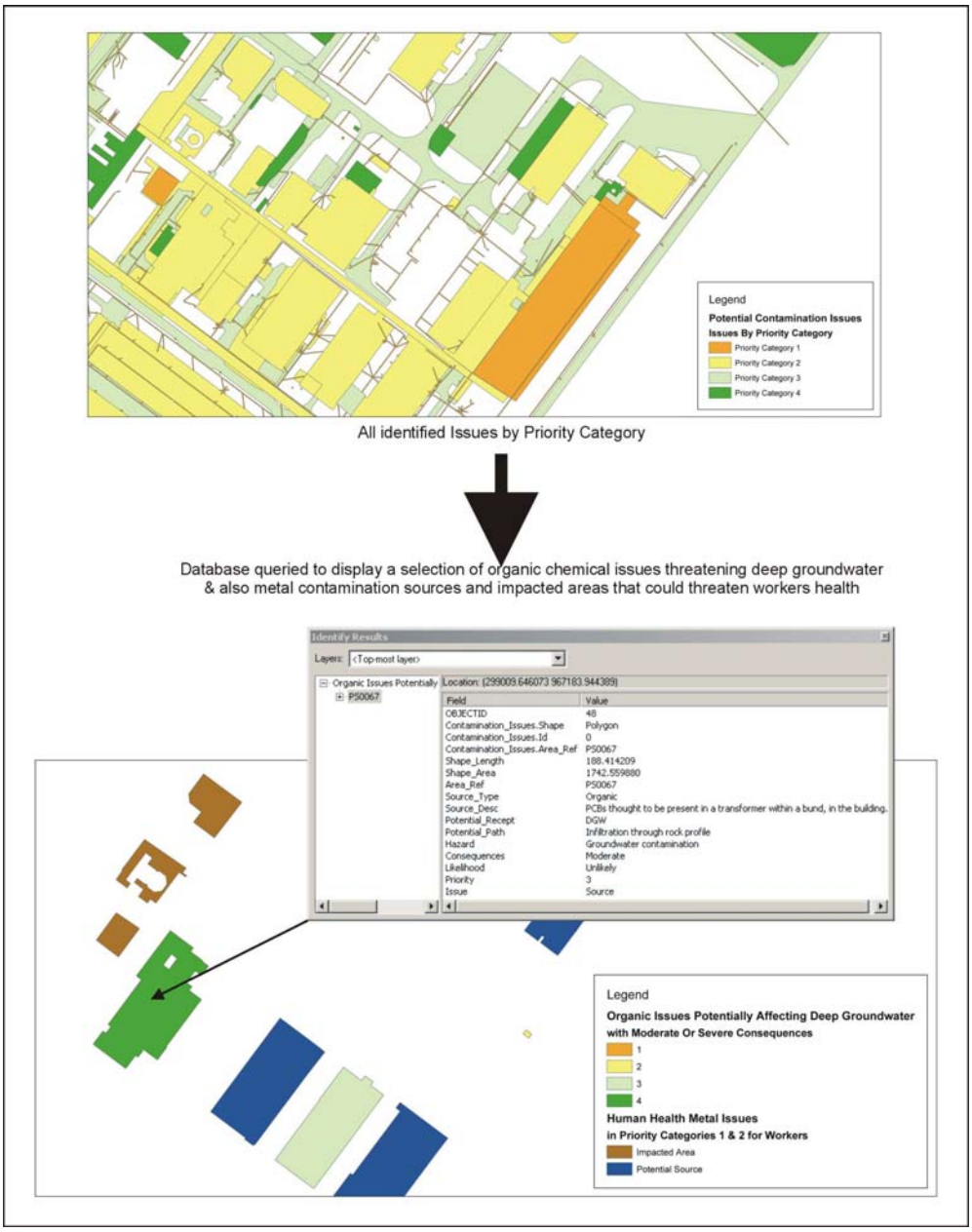

Fig. 3. Analysis and Visualisation of Issues using GIS

Risk assessment data is stored in the IMAGES system in a single database table structured as in Table III. Each record is stored along with its area reference number. The database table is the authoritative source of information that drives any document output that might be necessary for wider distribution of the information. The database table is accessed using ArcGIS, and risk assessment data are added or updated directly within the table. The database allows the contents of fields within the table to be constrained to administrator-defined pick lists ensuring

consistency and quality of data, and ease of input. When an existing record is updated in any way an archived copy of the record is created with a date stamp thus allowing the status of issues to be analysed at any point in time covered by the risk assessment data. This is an important tool in demonstrating the progressive reduction in the severity and number of contamination issues on the site.

Spatial data for each contamination issue are held as polygon feature data in a separate table within the IMAGES and GIS system. Each polygon represents either a Potential Source such as a building, or an Impacted Area such as an area of contaminated soil. The attribute information for each polygon feature consists of an issue reference number and the area and perimeter length of the issue. The latter spatial data are managed automatically by ArcGIS.

In order to view the risk assessment data in its spatial location using ArcGIS, the spatial polygon feature data are related to the tabular risk assessment data using the area reference number field that is common to both tables. In this way all the risk assessment data for each issue are readily available and issues can be symbolised on the map according to their priority category, the issue type and so on. More complex queries can be written within the database software using Structured Query Language (SQL), and the results of these can then be viewed and interrogated in GIS. In this way, any combinations of issue type, potential receptor, priority category can be built up within the database and then delivered into GIS for symbolisation and spatial analysis as shown in Figure 3.

GIS layer files are used to store commonly used queries or combinations of symbology for viewing data. The files themselves hold the query or symbology details and load the relevant data from the database. The layer files are accessible to the Contaminated Land team at Dounreay, and can be quickly dragged and dropped into ArcGIS software for visualisation of issues alongside other layers of GIS data - such as existing infrastructure, or planned work areas. In this way, the information can be used for displaying the location and status of issues from the point of view of contaminated land management, or used by skilled personnel to rapidly evaluate potential issues associated with site decommissioning activities allowing them to provide appropriate advice.

FORWARD PROGRAMME

Characterisation

The potentially significant land contamination issues on the Dounreay site have been identified and ascribed a priority classification. This priority classification has been used to construct a programme of further characterisation that is defensible and risk/receptor-based, thus making the most effective use of a limited budget. The UK Government's Paper of 1995 placed all human and environmental receptors on an equal sensitivity footing (9), and so the prioritisation of contamination issues on the Dounreay site is across all potential receptors. In defining the forward programme, a qualitative assessment of the relative magnitude of issues has been made in order that they may be prioritised appropriately within class. Actual characterisation activities will be carried out in accordance with relevant guidance; for example, the SAFEGROUNDS project (5).

Iteration and Analysis

Risk assessment is not a static process. The assessment of risks arising from land contamination must include a wide variety of parameters, many of which will change or will be developed with time. For example, further characterisation of a land contamination issue invariably changes the CSM for that issue, by developing aspects of the source, pathway or receptor characteristics. Consequently, the continual assessment of risk arising from land contamination is an implicit part of ongoing contaminated land management.

At UKAEA Dounreay, this ongoing risk assessment process has been termed 'Integrated Review'. The review process integrates the assessed priority class into the following review cycle:

- Priority Class One issues: reviewed annually;
- Priority Class Two issues: reviewed every two years;
- Priority Classes Three and Four: reviewed every three or four years or as appropriate.

This approach yields some flexibility whilst still ensuring that issues are regularly reviewed as befits the environmental risks they pose. The integrated review process considers all aspects of the CSM for each issue, in addition to any work carried out since the last review, in determining the likely environmental risks and resultant priority category. Over a period of several review cycles, the prioritisation profile of the site will change, as issues are downgraded through improved characterisation or actual remedial activity. This will provide a convenient metric to financial stakeholders on progression towards a site which is a viable candidate for delicensing. Furthermore, as the land quality record is maintained as a live database, it may be easily updated, re-prioritised and progress defined and presented to decision makers using GIS.

Information flow into this iterative process is provided by an ongoing programme of characterisation, structured around the prioritisation classes. This will permit updates of each issue's CSM to be made, thus informing and developing the prioritisation process as illustrated in Figure 4.

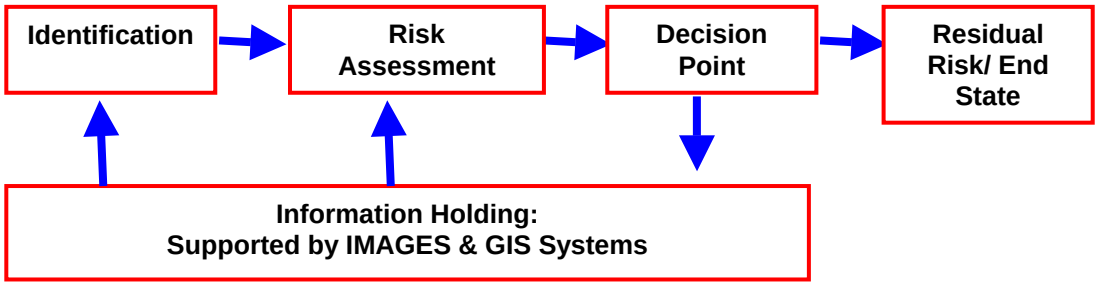

Fig. 4. Iterative Land Quality Management Process

Overall, this integrated approach to land quality management provides a dynamic tool that underpins the contaminated land programme at UKAEA Dounreay. The use of GIS tools as a

medium for stakeholder communication has ensured that information is transferred in a manner that is understandable and easily interpreted by both technical and non-technical personnel. The software tools used in this study have been applied to other areas of the UKAEA site restoration process and could easily be transferred to other projects both within the nuclear industry and in other sectors.

CONCLUSION

In conclusion, this paper has shown that:

- A comprehensive Phase One has been undertaken on and adjacent to the Dounreay site, to identify all potentially significant radioactive and chemical contaminated land issues. The collaborative approach to the Phase One adopted by UKAEA and their multi-disciplinary environmental consultants (Entec UK Ltd) ensured the application of best practice.
- The Phase One was fully integrated with UKAEA's existing state-of-the-art contaminated land management and GIS systems. This has the following benefits over standard Phase One assessments:
  - The Phase One risk assessment data is readily available to multiple UKAEA users for analysis in electronic format.
  - The data can be accessed either in raw form through a standard tabular database format, or by using GIS graphical user interface tools to map issues by their location on site and categorise them on any of their attributes.
  - The combination of database and GIS software allow database queries to be written and rapidly accessed to display any subsets of the data required.
  - The Phase One can be readily updated by the addition of new risk assessment data as new or previously unidentified issues are discovered and investigated.
  - Existing risk assessment data can be readily updated as further characterisation or remediation work is undertaken and risk assessments therefore change.
  - Changes in the status of the land will be recorded over time providing UKAEA with the mechanism to display improvements in the quality of the land.
  - The presentation of the data to external bodies using GIS generated graphical formats will result in a higher level of stakeholder engagement.
- The Phase One, and the systems implemented to store and display the information provide the technical basis on which future contaminated land management decisions can be made at Dounreay. The Integrated Review process will be based on these systems and data.
- The technical approach to the Phase One, and UKAEA's contaminated land management tool (IMAGES), combined with GIS technology represent highly transferable technologies which can be easily applied to any site or contaminated land issue.

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