Review of Environmental Issues of Underground Coal Gasification – Best Practice Guide

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EXECUTIVE SUMMARY

This Guidance Document has been produced on behalf of the Department of Trade and Industry (DTI) and identifies best practice for the management of the environmental aspects associated with underground coal gasification (UCG) projects in the UK. The guidance is specifically aimed at the management of those aspects associated with UCG trials and semi-commercial operations involving the in-seam gasification of coal at depths of 600 to 1200m.

The guidance is applicable to UCG trial projects with gas production rates of about 25MWth, which are undertaken for the purpose of investigating: drilling techniques and technologies for installing the injection and production facilities; the sustainable control of the gasification reaction within the coal seam; and the sustainable and consistent production of a high quality gas. It is also applicable to semi-commercial operations with a gas production rate of up to 250MWth for the purpose of generating power using some form of gas turbine technology (possibly CCGT technology). Such a system would generate between 40 and 100MWel.

Advice is provided on the issues that should be taken into consideration throughout the lifetime of a UCG project (i.e. from site selection and design to cessation of operations and restoration of the site). This Guidance Document comprises the following Chapters:

- Site Selection and Investigation;
- Environmental Considerations Specific to UCG; and
- Standard Environmental Considerations

Many of the activities and aspects are applicable to both UCG trials and semi-commercial operations and as such, the environmental management techniques are equally applicable. There are however, instances in which best practice for the management of an environmental aspect differs between the two types of project - where this is the case, best practice for each project type is discussed.

In general, the potential environmental impacts of UCG can be minimised through:

- appropriate site selection;
- effective operational process control;
- adoption of an appropriate shutdown procedure;
- environmental monitoring.

Appropriate site selection involves:

- selection of suitable coal seam characteristics that will provide environmentally advantageous operational conditions;
- selection of a site where the geological and hydrogeological characteristics mean that the risk of groundwater pollution from the UCG operation is negligible; and
- choosing a suitable surface location that satisfies the various planning requirements that may apply to the operation.
Effective process control is the key to the efficient operation of the gasifier, and to minimise the generation and dispersal of potential contaminants. The priorities for operational control should be:

- minimisation of gas losses;
- maintenance of the thermochemical equilibrium;
- maintenance of the coal conversion/gas production rate; and
- maintenance of the product gas calorific value.

Real time gas analysis is the essential basis for operational control, since the crucial in-situ phenomena of groundwater ingress/gas losses to strata cannot be measured directly but can be inferred from the cumulative mass balance through the system.

Adoption of an appropriate shutdown procedure is very important in minimising contaminant production because the reactor zone will no longer exist once injection to the reactor has ceased, and contaminants produced in the pyrolysis zone will no longer be consumed.

The strategy at shutdown should therefore be:

- to minimise post-burn contaminant generation from pyrolysis products by accelerating the cooling of the cavities and preventing pressure build up post gasification;
- to maintain the flow of groundwater towards the cavities by pumping water from the cavities and hence maintaining a hydrostatic gradient towards the reactor areas; and
- to maximise the removal of potential organic and inorganic groundwater contaminants from the underground strata by pumping and treating contaminants;
- to restore reactor water quality to near baseline conditions.

Particular recommendations are:

- Authorisations from competent authorities will be required for gasification, power generation, storage of hazardous substances, construction of power lines and construction of pipelines. The determining authority or authorities will vary according to the nature and scale of the proposed development.
- Acceptance of the need to undertake a formal Environmental Impact Assessment for all schemes from the outset will increase public confidence in the technology and assist in achieving consents for the various elements of the development.
- A robust analysis should be carried out on the risk to groundwater presented by the underground reactor. This is required both for site selection and specific site investigation activities in order to provide sufficient evidence for the EIA/planning activities and to ensure best practice mitigation against the risk to groundwater. This assessment will be based on the geology and hydrogeology of the site and will require appropriate desk studies and site investigation methods. The boundaries and significance of the risk are likely to be defined by regulatory constraints, so liaison with the groundwater regulators and an understanding of the relevant legislation is a key part of the groundwater risk evaluation process.
Although operational activities can minimise the risk of gas escape during operations, due to the uncertainties involved it is likely that a ‘worst case’ scenario involving short term gas escapes will have to be evaluated as part of the analysis of risks to groundwater.

It may be possible to agree that the gasification reactor is located within a permanently unsuitable (PU) groundwater zone. Such an agreement will need to be based on site specific technical factors, which will cause them to be almost certainly hydrogeologically isolated from significant aquifers in the overburden. If this approach is adopted, then the extent of this strata zone will have to be agreed with the Regulator in order to gain authorisation for the process; again, close liaison is recommended. To do this, the site investigation/appraisal must gain sufficient hydrogeological data to allow a determination of the extent and nature of the block of strata containing the ‘permanently unsuitable groundwater’.

Significant surface subsidence is not thought to be likely from a trial or semi commercial operation, but this will have to be evaluated as part of the EIA/planning application. The potential impact of ground movement at depth (caused by caving of the reactor) on the permeability of strata and structures underground will also have to be evaluated as part of the assessment of the risk of contamination of groundwaters. Other man-made underground features, particularly abandoned mines, boreholes and mine shafts should also be included in the groundwater risk evaluation as these may present one of the most significant risks of contaminant migration at depth.

Groundwater monitoring both during and after operations will be required in order to ensure that there is a minimal impact to groundwater from the UCG operation. The requirements of the monitoring network will be site specific, but it is recommended that design is based on knowledge gained from the site investigation and appraisal of groundwater risk (i.e. it is ‘targeted’ towards potential risk areas).

The development of a UCG trial site would be the subject of a planning application submitted in accordance with the Town and Country Planning Act 1990. A semi-commercial operation would include electricity generation and could (if the capacity of the power plant exceeds 50 MWe) require consent from the Secretary of State for Trade and Industry under Section 36 of the Electricity Act 1989 as well as a separate application under the Town and Country Planning Act 1990 for the reactor. For projects which fall within Schedule 1 of the Town and Country Planning (Environmental Impact Assessment) Regulations 1999 the production of an Environmental Impact Assessment (EIA) is mandatory. The trial and semi-commercial operation both fall within Schedule 2. Having regard to the characteristics of UCG and its potential environmental effects it is highly probable that the determining planning authority would request that a formal EIA be carried out for both a trial and a semi-commercial operation.

The process of site development should evolve alongside a strong level of community consultation. This should involve the use of a communications strategy, which allows for the provision of information on the process involved (for the purpose of providing the public with an understanding of the
process), along with establishing broad agreement on the site selection criteria. Such consultation could be by way of public meetings or exhibitions.

- Full justification needs to be made for discounting sites with the same level of critical analysis as that applied to selecting the chosen site. The use of a matrix to assess sites against a range of criteria with attached weightings should be considered.

- As the UK legislation stands, both the trial and semi-commercial operation will fall under the Pollution Prevention and Control (England and Wales) Regulations 2000 as a Part A(1) Installation and the Pollution Prevention and Control (Scotland) Regulations 2000 as a Part A Installation. As such, the best available techniques (BAT) should be used to minimise impacts of the installation(s) on the environment. The EU IPPC Directive contains a research and development (R&D) exemption clause that was not fully implemented in Great Britain. Consultation on the R&D exemption is currently being undertaken across Europe. If the PPC Regulations 2000 and the PPC Regulations (Scotland) 2000 were to be modified to implement the R&D exemption, then the trial might be exempt from the full requirements of IPPC.

- The semi-commercial operation will also fall under the remit of the European Commission Directive on Greenhouse Gas Emissions Trading and, potentially, The Hazardous Substances (Control of Major Accident Hazards) Regulations 1999 (depending upon the capacity of the gas reception facilities).

- Surface activities undertaken during the construction, operation and restoration of UCG project sites give rise to environmental aspects similar to many other industrial sites in the UK. Standard industrial environmental management techniques should be used to control those aspects not subject to control under the Pollution Prevention and Control regulatory regime.

- The environmental impact assessment required as part of the planning application for the trial or semi-commercial operation would need to include an air quality baseline study and an assessment of the potential effects upon air quality. This should include a detailed atmospheric dispersion modelling study.

It is recommended that any proposed trial design should be based upon site-specific dispersion modelling incorporating a stack height sensitivity study. In the absence of gas cleaning during the trial, a temporary stack higher than the minimum good practice design may achieve substantial reductions in short term sulphur dioxide concentrations. The stack height will be subject to agreement by the Environment Agency and to approval by the planning authority.
CONTENTS

EXECUTIVE SUMMARY

1. INTRODUCTION 11
   1.1 Guidance Document Overview 11
   1.1.1 UCG and Pollution Prevention and Control 13

2. SITE SELECTION AND INVESTIGATION 15
   2.1 Coal Seam Characteristics 15
   2.2 Assessment of Groundwater Issues 16
      2.2.1 Regulatory Considerations 17
      2.2.2 Background to the Evaluation Process and Nature of the Hazards Involved 19
   2.3 Methods and Guidance on Groundwater Risk Evaluation 19
      2.3.1 General Approach 20
      2.3.2 Stages of Assessment 25
      2.3.3 Evaluation of Geological and Hydrogeological Characteristics 27
      2.3.4 Effects of Strata Relaxation and Proximity to Mineral Workings 32
      2.3.5 General Guidance on the Proximity of Pre-Existing Mineral Workings 33
   2.4 Site Exploration Requirements - Groundwater 34
      2.4.1 Desk Studies 34
      2.4.2 On Site Investigation Techniques 35
   2.5 Site Layout and Adjacent Land Use 38
   2.6 Planning Considerations 39

3. ENVIRONMENTAL CONSIDERATION SPECIFIC TO UCG 45
   3.1 Construction 45
      3.1.1 Drilling and Well Completion 45
   3.2 Operation 48
      3.2.1 Underground Process Control 48
      3.2.2 Gas Combustion and other Operational Surface Activities 49
      3.2.3 Environmental Monitoring Requirements 52
      3.2.4 Waste Water Management 54
   3.3 Shut Down and Site Restoration 59
      3.3.1 Venting, Cooling and Flushing 59
      3.3.2 Well and Lagoon Closure 63
      3.3.3 Options for Post Gasification Monitoring 63

4. STANDARD ENVIRONMENTAL CONSIDERATIONS 65
   4.1 Control of Dust 65
   4.2 Control of Noise 66
4.3 Prevention of Pollution of Watercourses and Groundwater from Surface Activities 67
4.4 Control of Traffic 72
4.5 Waste Management and Disposal 72
4.6 Contaminated Land Issues 73
4.7 Site Restoration 75
References 77

List of Tables
Table 2.1 - Summary of Potential Fluid (gas or liquid) Migration Pathways 22
Table 2.2 - Example Sources of Hydrogeological Information at the Desk Study Stage 35
Table 2.3 - Example Down-Hole Geophysical Methods 37
Table 3.1 - Potential treatment techniques (Developed from: Environment Agency: Effluent Treatment Techniques (1998)) 57

List of Figures
Figure 2.1 - Generic Risk Assessment Process 24
Figure 2.2 - Illustrative Overview of the General Hydrogeological Evaluation Process 29
Figure 2.3 - Example of Conceptual Potential Contaminant Transport Mechanisms 30

Appendices
Appendix A Nature of Potential Groundwater Contaminants from UCG
Appendix B Technical Guidance on Hydrogeological Investigation Techniques
Appendix C Technical Guidance on UCG Process Control
1. INTRODUCTION

1.1 GUIDANCE DOCUMENT OVERVIEW

This Guidance Document has been produced on behalf of the Department of Trade and Industry (DTI) and identifies best practice for the management of the environmental aspects associated with underground coal gasification (UCG) projects in the UK. The guidance is specifically aimed at the management of those aspects associated with UCG trials and semi-commercial operations involving the in-seam gasification of coal at depths of 600 to 1200m. However, much of it may be applicable to the management of projects that do not fall exactly within this description.

In particular, the guidance is applicable to UCG trial projects involving the gasification of a single gasification module, with a gas production rate of about 25MWth. Such a trial is likely to have an operational phase in the order of 9 months. The purpose of the trial would be to investigate: drilling techniques and technologies for installing the injection and production facilities; the sustainable control of the gasification reaction within the coal seam; and the sustainable and consistent production of a high quality gas. As such, the product gas would not be put to use, but be destroyed in a combustor.

Semi-commercial operations to which the guidance is applicable are likely to involve the gasification of 4 to 10 modules at any one time and generate product gas at a rate of up to 250MWth. The gas would be cleaned up to make it suitable for electricity generation using some form of gas turbine technology (possibly CCGT technology). Such a system would generate between 40 and 100MWt.

The nature of UCG projects means that the management and control of the environmental aspects and impacts associated with them needs to be addressed during the earliest stages of the project. Advice is provided on the issues that should be taken into consideration throughout the lifetime of a UCG project (i.e. from site selection and design to cessation of operations and restoration of the site). This Guidance Document comprises the following Chapters:

- Site Selection and Investigation;
- Environmental Considerations Specific to UCG; and
- Standard Environmental Considerations

The first Chapter provides guidance on those considerations that should be given to the nature of a potential UCG project site during the site selection process. These considerations will allow the environmental aspects associated with the project to be managed most effectively. They include the nature of the coal seam characteristics; the nature of the site in terms of the
risks posed to groundwater; and the nature of the adjacent land use and associated planning considerations.

The second Chapter of the Guidance Document provides guidance on best practice for the management of those aspects associated with the activities specific to UCG, for which no recognised best practice guidance currently exists. The Chapter is arranged in terms of the phases during which activities will occur:

- **Construction** – activities specific to UCG undertaken during the construction phase include drilling and well completion operations;
- **Operation** – activities specific to UCG undertaken during the operational phase include the gasification process and its control, the combustion of product gas, the management of water arising from the underground reactor and the monitoring of the environmental aspects associated with the UCG process; and
- **Shut-down and Restoration** – activities specific to UCG that will occur during the shut-down and restoration phase include the venting, cooling and flushing of the underground reactor, the closure of the injection and production wells and any lagoons and post gasification monitoring of the project site.

The third Chapter provides guidance on best practice for the management of those environmental aspects that are not just restricted to one phase of a UCG project but will require management during construction, operation and the eventual shut-down and restoration phases. These aspects include dust, noise, traffic, surface water run-off etc. and are associated with activities such as construction, demolition, surface water drainage system design etc., which are routine to most industry within the UK. As a result, a substantial body of best practice guidance already exists for the management of these aspects. Rather than this best practice being repeated here, the issues are outlined and users of this Guidance Document are directed to more detailed best practice guidance in existing sources.

In general, many of the activities and aspects are applicable to both UCG trials and semi-commercial operations and as such, the environmental management techniques are equally applicable. There are however, instances in which best practice for the management of an environmental aspect differs between the two types of project - where this is the case, best practice for each project type is discussed.

UCG projects will be subject to a wide range of regulatory regimes, which will control their planning, development, operation and ultimate shut-down. The regimes that will apply will depend upon the specifics of the UCG project and will need to be considered on a case by case basis. Detailed information on the regulatory regimes that could apply to UCG projects are provided in WS Atkins, 2003.
1.1.1 UCG and Pollution Prevention and Control

It should be noted at this stage that any UCG trial or semi-commercial project will be subject to regulation under the UK’s Pollution Prevention and Control (PPC) regimes (i.e. those prescribed by The Pollution Prevention and Control (England and Wales) Regulations 2000 and The Pollution Prevention and Control (Scotland) Regulations 2000).

As UK legislation stands, the UCG process, as undertaken in both the trial and semi-commercial projects, will fall into the activity description in paragraph e of Part A1 of Section 1.2 Gasification, Liquefaction and Refining Activities of Schedule 1 to the PPC (England and Wales) Regulations – i.e. producing gas from... carbonaceous material. This means that the underground reactor and any potentially polluting activity or plant that provides a direct service to the gasification process (e.g. an air separation unit, a waste water treatment system etc.) will form the “installation” that will be regulated under the PPC regime.

Similarly, the gas clean-up plant and power generating gas turbine plant employed in the semi-commercial project will fall into the activity description in:

- paragraph f of Part A1 of Section 1.2 Gasification, Liquefaction and Refining Activities of Schedule 1 to the PPC (England and Wales) Regulations – i.e. purifying or refining any product of any product of the activities falling within paragraphs (a) to (e); and
- paragraph a of Part A1 of Section 1.1 Combustion Activities of Schedule 1 to the PPC (England and Wales) Regulations – i.e. burning any fuel in an appliance with a rated thermal input of 50 megawatts or more, respectively.

Again, these pieces of plant and any potentially polluting activity or plant that provides a direct service to them (as well as the underground reactor) will comprise the installation that will be regulated under the PPC regime.

As such, the operator(s) of the installation will be required to apply to the relevant regulator (the Environment Agency (EA) or Scottish Environmental Protection Agency (SEPA)) for a permit to operate. To be granted a permit, the operator must satisfy the regulator that the design and operation of the UCG installation will be the best available techniques (BAT) to prevent and minimise pollution from the installation.

In essence, the BAT are those techniques (in terms of design, construction, maintenance, operation and decommissioning) that are most effective for protecting the environment as a whole and are economically and technically viable. As a guide to the level of protection expected, the regulators produce Sector Guidance that lays down indicative BAT standards and benchmark emission levels that would normally be expected to be achieved in that sector. The Sector Guidance is based upon Europe-wide studies (funded by the
European Commission) of available techniques for controlling pollution within the sector in question. The outcomes of these studies are published in Best Available Techniques Reference (BREF) Notes.

At the time of producing this Guidance Document, no BREF Note has been produced on the gasification of coal (above or below ground), nor on the refining or purification of gas. The BREF Note for combustion activities is only in its second draft. As a result, no Sector Guidance has been produced in the UK for these sectors.

Attempts have been made in this Guidance Document to anticipate the probable indicative BAT standards and benchmark emission levels that would be contained in the relevant Sector Guidance, once it has been produced. However, it should be recognised that once available, the relevant Sector Guidance will take precedence over any guidance offered in this document.

When planning the design of any PPC installation (whether for a trial or a semi-commercial operation) users of this Guidance Document should always refer to the local EA or SEPA inspector who will be responsible for the regulation of the PPC installation.

Atkins have prepared this report on the basis of information concerning UCG known at the time. In the event of changes in best practice, processes or legislation affecting UCG, and in any case following any UCG trials, this report should be reviewed. Atkins accept no liability for the use of this report in circumstances that do not conform to this requirement.

It should also be noted that the EU IPPC Directive contains a research and development (R&D) exemption clause that was not fully implemented in Great Britain. Consultation on the R&D exemption is currently being undertaken across Europe. If the PPC Regulations 2000 and the PPC Regulations (Scotland) 2000 were to be modified to implement the R&D exemption, then the trial might be exempt from the full requirements of IPPC.
2. SITE SELECTION AND INVESTIGATION

There are three key elements to selecting a site that is environmentally suitable for UCG development:
- selecting suitable coal seam characteristics that will provide environmentally advantageous operational conditions;
- selecting a site where the geological and hydrogeological characteristics mean that the risk of groundwater pollution from the UCG operation is negligible; and
- choosing a suitable surface location that satisfies the various planning requirements that may apply to the operation.

The factors that have to be considered in relation to these aspects and the site investigation methods that have to be adopted in order to select a site that satisfies these criteria are discussed within this Chapter.

2.1 COAL SEAM CHARACTERISTICS

The main coal seam characteristics to be considered at the site selection stage are:
- depth;
- seam thickness;
- coal rank;
- seam dip;
- degree of disturbance; and
- nature of adjacent strata.

The main influences of increased depth on UCG performance are:
- improved process control;
- increased gasification pressure, and its many attendant benefits;
- greater compaction of the reactor; and
- decreased permeability of coal and adjacent strata.

A balance has to be drawn between the improved performance and the increased cost with increasing depth. Current indications are that seam depths in the range 600m to 1200m are optimum.

Thicker seams (> 2 m) permit a greater area of coal to be gasified from a single pair of wells providing both economic and environmental advantages. Four characteristics of coal are fundamental to the gasification process:
- chemical reactivity;
- chemical analysis;
- swelling characteristics; and
- thermal decomposition characteristics (volatiles content).
With the present state of knowledge, low rank, high volatile, non caking bituminous coals within NCB classifications 700-900 are preferable; however, UCG has been successfully carried out in higher rank coals.

Shallow dipping seams are preferable. Such seams facilitate drainage and the maintenance of hydrostatic balance within the gasifier, and minimise potential damage to the down dip production well from strata movements associated with UCG. However, UCG has been successfully carried out in steeply dipping seams.

Areas of seams that are free of major faulting in the vicinity (<45 m) of the proposed gasifier, and which could potentially provide a pathway for water inflow or gas migration, should be preferentially targeted.

Seams where the immediate roof strata (defined as 5 times the seam height) cave readily, and where there are no overlying aquifers within a distance of 25 times the seam height, are preferable. Trials have been successfully carried out in seams in closer proximity to aquifers, but the potential risk of contamination is increased.

2.2 ASSESSMENT OF GROUNDWATER ISSUES

Although the underground environment at a suitable deep UCG site and the operational controls that are available mean that the risk of groundwater pollution should be very low, addressing the concerns over groundwater contamination remain one of the main considerations for a UCG operation. It is also one of the most technically challenging aspects of the environmental evaluation process. Because the potential impacts to groundwater are so specific to UCG, this aspect of the site selection and investigation process is described separately to the other issues.

This section provides a suggested framework for site selection and/or investigation and background information on geology and hydrogeology that will assist in using the framework. Guidance is also provided on desk study and site investigation methods.

Injection of produced waters to deep underground strata is common practice in oil and gas exploration and other forms of underground waste injection are commonly operated in other countries. However, there are a number of significant differences to UCG that mean standard practices in those industries are only useful for certain aspects of site selection and mitigation in UCG. The main considerations that separate UCG from these other industries are:

- UCG has to be targeted at an operationally suitable coal seam, which means that a UCG operation does not have the luxury to select suitably impermeable strata that is available to underground injection technologies;
- UCG involves gas production under pressure, which is not a common phenomenon in underground injection technologies; and
UCG involves the removal of strata that can lead to caving and strata relaxation above the reactor, which is not a common feature in underground injection.

An understanding of the mechanisms involved in contaminant transport and production is required before the site characteristics that are relevant to contaminant transport can be evaluated. The nature of the contaminants that are produced by UCG and the theory behind the various transport mechanisms are provided within Appendix A of this document and WS Atkins, 2003. It is strongly recommended that users of this document unfamiliar with these issues should read that appendix and report before carrying out a groundwater risk assessment for a potential UCG site.

The following sections provide information and guidance on assessing the groundwater risk factors that influence site suitability in terms of groundwater pollution. The methods described are presented on a generic basis in a form that should be flexible enough to be used for both higher level comparative site selections and for the main site investigation and regulatory authorisation process.

2.2.1 Regulatory Considerations

In the UK context, the parameters that define the purpose of the risk analysis are dominated by regulatory considerations. This section provides an overview of the regulatory considerations for groundwater and the mechanisms involved in the production and transport of contaminants from the UCG reactor.

It should be noted that the regulatory guidance contained within this section is based on preliminary consultations with the EA and does not constitute official ‘policy’ at this stage. Users of this guide are strongly advised to engage with the EA’s Groundwater Policy Unit to discuss the authorisation of the process at the earliest opportunity, if the proposed UCG site is within England or Wales. If the site is within Scotland, then users should similarly contact SEPA to confirm the validity and mechanisms of the approach.

The Groundwater Regulations 1998 (HMSO, 1998) prohibit the direct discharge of List I substances to groundwater and require indirect discharges of list I substances and direct and indirect discharges of list II substances to be authorised by EA or SEPA. Benzene, phenols, ammonia (and nitrate), boron and some of the other minor contaminants that are released from the gasification process via gas escapes or leaching are list II substances. Some of the trace inorganics that have been recorded within UCG reactors (such as cyanides, mercury and cadmium) are classed as List I substances, although the levels at which these are present are likely to be insignificant.

The main regulatory concern in terms of groundwater is the fact that List II substances produced by the reactor will almost certainly enter ‘groundwater’
in the immediate vicinity of the reactor. However, deep operations such as this do not necessarily represent a risk to the shallower aquifers that constitute water resources, as long as suitable site selection, technical analysis and mitigation measures are carried out.

The 1998 Groundwater Directive (Council Directive 80/68/EEC) (implemented in the UK by The Groundwater Regulations, 1998) allows exemptions for the discharge of List I and II substances provided that ‘investigation reveals that the groundwater is permanently unsuitable for other uses, presence of that substance does not impede exploitation of ground resources and conditions are imposed which require that all technical precautions are observed to prevent the substance from reaching other aquatic systems or harming other ecosystems’. This zone is referred to in the remainder of this document as the ‘Permanently Unsuitable’ (PU) groundwater zone.

The authors of this document are aware of one other authorisation based on this route, and it is considered to be feasible within UK regulation. However, this is by no means ‘standard practice’ and close liaison with the relevant regulator will be required to secure authorisation by this means.

The EA has indicated that pre-defined parameters are not appropriate for determining the extent of this zone for a UCG development in England or Wales. Any agreed zone will be based on site specific technical factors, which will cause the PU zone to be almost certainly hydrogeologically isolated from significant aquifers in the overburden. This means that the site investigation/appraisal must gain sufficient hydrogeological data to allow a determination of the extent and nature of the block of strata containing the ‘permanently unsuitable groundwater’. If this approach is adopted, then the extent of this strata zone will have to be agreed with the Regulator in order to gain authorisation for the process; again, close liaison is recommended.

Authorisation by this approach means that investigations will have to provide suitable proof that contaminants from the process will not escape from the defined ‘PU’ zone. The definition of ‘suitable proof’ will be site specific, but a robust risk based approach, such as the one described in this Document, should be acceptable to the EA. Because ammonia and nitrates are a List II substance and ammonia is contained within the gaseous emissions from UCG, this ‘suitable proof’ also applies to gaseous emissions from the reactor.

If the PU zone approach is used, then there are no additional regulatory implications in re-introducing process waters into the cavity, or in flushing the cavity once gasification has ceased.

Because the process will require authorisation from the EA or SEPA under the Groundwater Regulations, the operational and post operational monitoring will be required that conforms to regulation 8 of the Groundwater Regulations
by providing ‘requisite surveillance’. Monitoring requirements are discussed later in this Document.

2.2.2 Background to the Evaluation Process and Nature of the Hazards Involved

The risks to groundwater from the gasification reactor itself at any given site depend on whether the sub-surface characteristics of that site allow conditions to develop that will allow contaminants to be transported beyond the PU zone in significant quantities or concentrations.

As discussed in Appendix A, potential contaminants fall into four main categories:

- product gases during gasification;
- pyrolysis products (both aqueous and gaseous phase) during gasification, usually caused when product gases are ‘pushed’ through the pyrolysis zone;
- gases with potentially high contaminant loads during shutdown (usually caused by pressure build up if the reactor is not properly vented); and
- leaching and transport of aqueous phase contaminants post gasification (either from the reactor or from sections of strata that have received gas escapes during operations and therefore contain dissolved contaminants).

The risk of groundwater pollution being caused by these contaminants depends on natural site characteristics and factors such as gasification pressures and borehole design. The significance of various site characteristics is discussed later in this section. Operational and construction issues do not influence the environmental selection of the site per se and are discussed as mitigation measures in Chapter 3, rather than as part of the site selection/investigation.

The potential for high quality groundwater to be affected by naturally occurring poor quality groundwater as a result of UCG activities is discussed in Appendix A. Whilst this is a separate issue from that of pollution by contaminants produced by the reactor, the transport mechanisms (for aqueous contaminants) will be the same and no distinction is made in this section of the document between these two processes.

The pollution of groundwater by surface activities associated with UCG developments can be prevented through suitable engineering design and operating procedures (as discussed in Chapter 4) and are not a determining factor in the selection of a site.

2.3 METHODS AND GUIDANCE ON GROUNDWATER RISK EVALUATION

For the UK, UCG operations are proposed at a depth that should significantly limit the risk to groundwater. However, hydrogeological data at depth is expensive to obtain and it is often difficult to gain accurate measurements of in-situ conditions. Therefore, there will always be uncertainties about the
hydrogeological regime at a deep UCG site. In addition to this, there will be uncertainties about the response of the rock mass to the caving and thermal shock caused by the cavity. For these reasons, a risk based approach to groundwater evaluation is suggested in this document. Such an approach should not be regarded as a lenient option and it is likely that a very robust assessment will be required before regulatory and public concerns can be addressed.

The establishment and definition of the ‘Permanently Unsuitable’ (PU) zone of groundwater around the coal seam is very important to the assessment of risk in the UK. The definition and legal status of the PU zone has been discussed previously, but it is essentially defined as a block of strata where the water quality and/or yield are so poor that groundwater in that area cannot realistically be regarded as an environmentally or economically significant ‘aquifer’. The assessment of the pollution risk should be geared towards examining the possibility that significant quantities of contaminants will migrate beyond this zone to overlying (or even underlying) aquifers.

The risk based approach should be appropriate both in higher level site comparison/selection studies and at a more detailed level, when evaluating the potential impacts to groundwater at a selected site.

2.3.1 General Approach
The evaluation of the risk to groundwater posed by any particular site must take into account all factors relating to contaminant production, contaminant transport and assessment of migration pathways based on geological and hydrogeological evaluation. The significance of the risk can be described in the context of a general best practice approach to risk, as outlined below.

**Hazard** – The hazards are those posed to the groundwater by the gaseous emissions and leachate described previously, with a secondary hazard of ‘cross contamination’ of aquifers.

**Source-Receptor Pathways** – In a low risk environment, identifying specific pathways that can actually represent a specific risk of transmitting contaminants for significant distances in the underground environment is key to evaluating the risk posed by a UCG site. These are referred to as ‘contaminant migration pathways’ in this Document.

**Likelihood of occurrence** – This represents the probability that the contaminant in question will escape beyond the PU groundwater zone. This is heavily dependant on the existence of contaminant migration pathways, but the assessment of risk likelihood should incorporate connectivity between contaminant pathways, direction of groundwater/gas flow and timescales involved in contaminant migration.
**Consequence of occurrence** - This represents the impact that the contaminant will have if it does enter ‘sensitive’ aquifers. Generally speaking this will be an ‘absolute’ once the PU zones has been defined – i.e. a significant likelihood of migration beyond this zone is not acceptable. However, the risk consequence can impact on the definition of this zone and can help to determine the requirements that will be placed on the monitoring regime.

Of these considerations, it is the likelihood of contamination that will vary the most between sites. It therefore represents the most important factor for evaluation in site comparison, selection and investigation. This is based on the identification of contaminant pathways and the hydrogeological evaluation of the significance of those pathways, as discussed below.

It should be noted that a lack of information or uncertainties in migration or strata response assessment may in itself result in a more conservative assessment of risk – i.e. the risk assessment should identify and include the implications of any ‘knowledge gaps’.

**Contaminant Transport Pathways**

Contaminant transport pathways must be available for gaseous and aqueous contaminants to pollute ‘significant’ aquifers outside of the PU zone. Gaseous and aqueous contaminant pathways should, therefore, be assessed relative to major overlying aquifers (e.g. the Sherwood Sandstone or Carboniferous strata layers such as the Coventry Sandstone) prior to establishment of the PU zone.

Provided operational best practice is followed, gas escapes are likely to be short lived, but they are likely to move rapidly through joints and fissures in surrounding rock masses. This means that the rock matrix permeability of the surrounding strata is relatively unimportant except in strata with high matrix permeability (primarily sandstones in this context).

Migration of aqueous phase contaminants (leachate, dissolved gases etc.) will be affected by similar rock mass properties to gas flows, but is a longer term issue that will depend on the matrix permeability of the strata in which it is flowing, as well as fissures, joints and faults. The direction of transport of aqueous contaminants will be strongly affected by the direction of groundwater flow, unless flow rates are extremely low. Where this is the case, diffusion due to concentration gradients may be important. These issues are discussed later as part of the hydrogeological evaluation process.

Table 2.1. Provides a summary of the potential contaminant migration pathways that present a risk of gas escapes or aqueous transport beyond the PU zone.
Joints, cleats and slips
Encountered in coal seams (both target seam and others), these are significant potential gas migration pathways.

Permeable rock matrices
High permeability sands/gravels (consolidated or unconsolidated) can allow rapid transport of fluids. These are caused by weathering and structural deformation of rock masses. These are primary fluid transport routes in lower permeability strata.

Joints, fissures, fractures and bed separation
Encountered in any strata. Can be a barrier or can permit fluid flow in otherwise impermeable strata. May impact on the permeability of surrounding sedimentary structures or can be fissured themselves.

Faulting
Slow dissolution of rock structure by groundwater in limestone or evaporitic deposits can lead to major permeable pathways. Can affect any strata by causing stress relaxation. Can expand/extend existing pathways or create new fissures, fractures etc. Strata relaxation will be caused by caving of the reactor itself. Mines themselves also provide rapid fluid flow paths.

Igneous dykes and sills
Will promote very rapid movement of fluids if unlined, or lining has failed.

Table 2.1 - Summary of Potential Fluid (gas or liquid) Migration Pathways

Likelihood of Groundwater Pollution
Figure 2.1 outlines the type of approach that could be taken to assess the likelihood of contamination from leachate or gas emissions, which incorporates the hydrogeological evaluation presented later in this Chapter. Conceptually the approach is very simple. Because the risk is likely to be fairly low at most sites, a staged approach is suggested where the assessments starts at a simple level, but with conservative assumptions. If there appears to be a risk, then the detail of the risk analysis should be increased.

For many sites, the risk that contaminant pathways exist will be so low that a conceptual model combined with site investigation results will be sufficient to
prove a negligible risk of pollution. Some sites, however, could be more complex and require more detailed modelling and analysis.

The approach can be adapted to the various levels of the site selection and site investigation process. For a site selection/comparison phase, it is probable that an estimation of the extent of the PU zone and identification of potential contaminant transport pathways will be sufficient to undertake a comparative assessment. However, for the Environmental Impact Assessment / site investigation stage, close liaison with the Regulator will be required and more detailed analysis or modelling will be necessary.

*Consequences of Groundwater Pollution*

The concept of the PU zone effectively limits the importance of the consequence assessment. However, the extent of the PU zone can change from site to site, and may significantly influence site suitability. Initial estimates should be based on published reports of water quality and quantity in strata around the target coal seam. As noted previously, ‘known’ significant aquifers are likely to define the absolute potential boundary to the zone, but other factors may reduce its size to be closer to the target seam.

Any aquifer that has realistic potential as a water resource in future is likely to present a boundary to the PU zone. The definition of the zone should then be revised as information on water quality and quantity is obtained. Ultimately the extent of the zone will have to be agreed with the relevant regulator if authorisation for the process is to be obtained.
Carry out initial assessment of local aquifers and estimate the extent of the 'Permanently Unsuitable' groundwater zone

Carry out initial geological evaluation as per Figure 4.2. to determine if there are any potentially transmissive pathways connecting the reactor to outside of the PU zone

Are there any gas transmission pathways?
- No
- Yes/ uncertain

Evaluate the potential for gas escape during and post operation at the site, assuming suitable mitigation measures are taken

Evaluate and agree likelihood. Obtain more information if level of risk due to uncertainty is too high

Are there leachate transmission pathways with potentially appropriate driving head?
- Yes
- Uncertain
- No

Evaluate potential flow rates. Is the ‘time of 1st arrival’ timescale< defined threshold?
- Yes
- Uncertain
- No

Model contaminant transport – are significant concentrations of contaminant likely to escape PU zone?
- Yes
- Uncertain
- No

Evaluate and agree likelihood. Obtain more information if level of risk due to uncertainty is too high.

Figure 2.1 - Generic Risk Assessment Process
2.3.2 Stages of Assessment

Considerations in the Assessment of Potential Flow Paths

The first stage of the risk assessment process is to determine if any of the potential transmission pathways discussed previously exist at the site and can provide realistic gas or leachate contaminant transport pathways, given the assumption that gases and leachate will escape from the reactor. Typically this would include assessments such as:

- a review of the nature and extent of nearby faults and their susceptibility to dilation caused by strata movement associated with the reactor;
- identifying un-cemented or fractured sandstones and the likelihood that these would be intersected by the zone of caving associated with the reactor (as noted previously, such sandstones are relatively rare in Carboniferous strata);
- assessing the potential gas permeability of the target coal seam and the risk presented by up-dip flow from the reactor; and
- a review of the consistency and extent of mudrock layers and whether there are any zones of thinning strata that may allow contaminant transport between more permeable horizons.

Once these are identified, an iterative process of geological and hydrogeological assessment should be carried out to determine whether these pathways are likely to promote transport of contaminants to locally significant aquifers (beyond the ‘PU’ zone). Further guidance on the evaluation of geological and hydrogeological characteristics that can give rise to contaminant transport pathways are provided later in this Chapter.

It is very important to note that a lack of contaminant transport pathways must be ‘actively’ proven. It is unlikely that an assessment will be deemed to be satisfactory if the evaluation shows there are no potential pathways simply because structural and lithological information is unavailable for much of the geology in the area. If this is the case, further site investigations are likely to be required to provide the relevant information. Alternatively, a conservative approach could be used to assess the risks posed by these unknowns.

Further Analysis for Gas Migration

If potential gas migration pathways are identified, then it will be difficult to predict the likely extent of gas migration. Where this is the case, the assessment should be refined to include operational issues such as tighter gas monitoring and more stringent shut-down criteria if gas escape is detected. Alternatively, a ‘sense check’ may be carried out based on high level, conservative estimates of gas permeability, and maximum potential differences between operating pressure and hydrostatic head. It should be borne in mind that operational controls should limit the risk of gas escape, so even in this ‘worst case’ scenario, significant, long term escapes are not realistic. Very long sub-horizontal migration paths (e.g. >1km) may be
sufficient to convince the regulator that significant pollution due to gas escape is highly unlikely without having to attempt detailed modelling.

Estimation of gas permeability through water saturated networks is standard practice in hydrocarbon reservoir engineering. Mechanisms are different and concentrate on the relative permeability of oil/gas/water phases during pressure changes in the reservoir (generally speaking, gas will come out of solution, rather than be created and dissolve into the water phase). However, interpretation of methods from standard texts such as Dake (1994, 1998) may be useful if estimates of gas permeability are required in sandstone bodies.

In extreme circumstances, empirical site investigation methods for gas permeability may have to be devised. These will tend to be bespoke methods based on the particular parameters of the site under investigation and are likely to provide uncertain results. If this stage of assessment is required then the site may well be unsuitable for selection.

Further Considerations for Aqueous Phase Contaminant Transport

If potential leachate migration pathways exist at a site and the hydrogeological regime is such that once baseline (or near baseline) conditions are reinstated, groundwater flow is likely to be towards upper aquifer horizons, then further modelling or operational constraints may be required.

The most simple form of modelling will be to determine whether the speed of groundwater flow through contaminant transport pathways is sufficient to transport groundwater originating near the reactor to beyond the PU zone within ‘meaningful’ timescales. This will give a good approximation for the time of first arrival of the contaminant beyond the PU zone (albeit at potentially insignificant concentrations). If this shows there is still a potential risk then the option of contaminant transport modelling may be explored, or operational and monitoring constraints discussed with the Regulator.

The most obvious constraint would be to use the hydrogeological information already gained to derive a post-gasification reactor pumping strategy that will ensure that groundwater flow will be maintained towards the reactor. Agreed constraints on monitoring and reactor/local groundwater quality may then have to be met before pumping ceases.

Alternatively, modelling of the transport of the contaminants that allows for retardation may show that there is a negligible risk of significant quantities of contaminants migrating beyond the PU zone within ‘realistic’ timescales. Further guidance on contaminant transport modelling is provided later in this section.
2.3.3 Evaluation of Geological and Hydrogeological Characteristics

Because the likelihood of contamination from UCG is based on the presence of potential contaminant migration pathways and a hydrogeological regime that will promote movement of gases and leachate through those features, evaluation of geological and hydrogeological characteristics is key to assessing the risk.

In simple terms, the evaluation of geological and hydrogeological characteristics requires analysis of two main driving factors:

- identifying the main potentially transmissive features and whether they could link up to provide a continuous transmission pathway beyond the permanently unsuitable zone; and
- determining whether hydrogeological conditions are likely to promote transmission of contaminants through potentially transmissive features.

Guidance on the mechanisms of gas and liquid transport is provided in WS Atkins, 2003. For gas transport, there are two key factors that need to be borne in mind:

- flow is likely to be up-dip or vertical - the groundwater flow regime is largely irrelevant, but the hydrostatic head in various strata layers during operations is important; and
- calculation of flow rates etc. is likely to be extremely difficult because of the nature of gas transport through the geosphere - a risk based approach based on the presence of low permeability, relatively unfaulted and un-fissured rocks is advised.

The analysis of aqueous phase contaminants will be more time dependant. Flow will be dictated by hydrostatic conditions, rather than by buoyancy. This means that the assessment may require estimates of:

- The amount of drawdown caused by the removal of groundwater during the process in the coal seam and the impact on key permeable horizons
- the rate of recovery of hydrostatic conditions after operations have ceased and the potential impact of post operation cavity pumping
- groundwater flow rates through key permeable horizons and other transmissive features once equilibrium conditions have been restored.

It should be noted that groundwater flow rates after restoration of equilibrium may not be the same as those prior to gasification, due to the potential fracturing, bedding plane separation and fault activation caused by the reactor caving.

An overview of the suggested evaluation procedure is given within Figure 2.2. The quality of the evaluation will depend on the data available and it should be iterative, so that it can be updated as more information becomes available.
The overall concept behind the evaluation is to look for geological structures that can lead to contaminant transport (and potential continuity between these pathways) and buoyancy/pressure or hydrogeological conditions that may promote migration through these pathways to overlying aquifers. In addition, the impact of reactor operation and caving on potentially transmissive pathways should be assessed along with third party risks such as abandoned boreholes and mine workings. A conceptual example of the type of issues that may be encountered is provided in Figure 2.3. below.

Various aspects of the evaluation process such as geological considerations, and the impact of strata relaxation are detailed within the following Chapters of this document.

‘Sense checks’ are very important when evaluating potential contaminant transport pathways. For example, if there is an aquifer overlying a fault that potentially links underlying poor quality groundwaters to the aquifer, then hydrochemical analysis should be able to demonstrate whether the fault is in fact providing that hydraulic link. If there is no evidence of a link prior to gasification, there will be no reason to suppose that the fault will provide a hydraulic link for UCG contaminants, unless, of course, the caving of the reactor causes fault dilation.
1. Evaluate the existing hydrogeological regime to determine:
   - Hydrostatic pressure in key horizons, particularly in the coal seam and immediate overburden
   - Direction of horizontal flow in key horizons
   - Evidence of vertical continuity between strata layers
   - The possible influence of faults
   - Potential rates of inflow to the UCG reactor

2. Look for potentially transmissive features, either pre-existing, or that might be caused by the strata relaxation described in Step 3:
   - Transmissive sandstone bodies/strong layers of strata potentially affected by bed separation
   - Areas of coal that are likely to be transmissive due to high densities of cleats
   - Faults/fractured fault zones
   - Igneous intrusions/karstic limestones/dissolution cavities in evaporites

3. Evaluate the extent of strata relaxation caused by the creation of the cavity and determine the impact this has on:
   - Fracture/joint/cleat propagation
   - Bed separation
   - Fault activation
Check that the extent of the bed separation does not impact on any areas of strata not evaluated in Step 2. Re-evaluate if necessary

4. Determine the impact that dewatering (pre or post operations) could have on the hydrogeological regime, including:
   - Potential drawdown rates in the coal seam and immediate overburden
   - The areal extent of this drawdown and the potential influence it may have on overlying aquifer horizons
   - The resulting impact this may have on flow regimes

5. Evaluate potential pathways by:
   1. Examining the potential connections between potentially transmissive features (e.g. a fault zone intersecting the coal seam and a sandstone body up dip of the reactor)
   2. Comparing these with flow regimes (or the distribution of piezometric heads in the case of gas escape)

Figure 2.2 - Illustrative Overview of the General Hydrogeological Evaluation Process
The presence of potentially transmissive contaminant transport pathways at a proposed UCG development site will depend upon the nature of the geology. WS Atkins, 2003 provides guidance on the potential transmissivity of the various types of geology and geological structures that may be associated with the PU zone around a site.

### Guidance on Geological Structures

The presence of potentially transmissive contaminant transport pathways at a proposed UCG development site will depend upon the nature of the geology. WS Atkins, 2003 provides guidance on the potential transmissivity of the various types of geology and geological structures that may be associated with the PU zone around a site.

### Hydrogeological Considerations

It is impossible to generalise the type of hydrogeological regime that may be present at a site, but it is worth noting that evaluations of deep hydrogeology can be difficult and can demonstrate features that are not found in more ‘conventional’ hydrogeological assessments.

When evaluating deep hydrogeology, there may a number of distinct groundwater ‘zones’ where the rate and vertical component of flow differs. Often this will consist of a relatively rapid moving upper aquifer zone that interacts with surface recharge and discharge, and a slower moving zone beneath that with minor flows. Where distinct layers exist, then there will often be hydrochemical differences in the various groundwaters.

Where flow rates are distinct, then potential head differences can arise in different layers of strata. This may not be significant due to hydraulic...
separation of strata layers, however it can be important in fault zones where increased permeability can allow movement between otherwise distinct ‘zones’.

The suggested methods for hydrogeological evaluation in terms of the overall risk assessment have been discussed previously and suggested sources for desk studies and suitable site investigation techniques are discussed in later Chapters of this document.

**Considerations for Contaminant Transport Modelling**

There are a number of issues presented by a deep UCG site that should be taken into account when attempting to ‘prove’ that there is negligible risk of contaminant escape from the PU zone. These include the fact that:

- vertical and horizontal heterogeneity will have to be taken into account within and between the various strata layers;
- the long term nature of the contaminant source is not well understood; and
- the environmental attributes of a deep site are generally anoxic with low microbial activity.

Guidance on concentrations of key contaminants from the reactor source during and immediately after gasification is really only available from empirical data obtained from previous trials. The ‘source’ of leachate represented by the reactor depends on the balance between leaching and adsorption within the coal around the reactor. Available concentrations from this source will decline over time, but the rate and mechanisms for this cannot be accurately quantified.

Although there is a reasonable amount of information available about the environmental (chemical and biological) degradation of the types of contaminants involved, this relates to near surface vadose zones or aquifers. Therefore, whilst information on environmental half-lives in standard texts (e.g. Howard *et al*; Montgomery) will be of some value, some estimation will have to be used.

Transport and retardation can be modelled using modified advection-dispersion equations. There are a number of packages and techniques available for modelling contaminant hydrogeology, ranging from the simple, conservative EA P20 spreadsheet, to full 3D modelling packages (Swift, MT3D etc.). The selection of the package will depend on the level of risk and the investigating team’s own experience and preferences. However, the most significant factor is likely to be the level of information available for the site (including the quality of the conceptual hydrogeological model) and the resulting assumptions that have to be made where information is not available. Where additional investigation is identified, site investigators should be aware of the high cost of obtaining in-situ information at depth and should be reasonably confident of the benefits of the information.
Because of uncertainties over the decay in concentrations at the source and environmental degradation rates of the contaminants involved, conservative approaches to modelling based on simple (analytical) models may be advisable. It may be necessary to assume that there is very little biological degradation at depth and retardation is mainly based on chemical reactions, dispersion and sorption.

If contaminant transport modelling is required, then an estimate of the maximum concentration at source will be required. Results from previous trials are entirely inconclusive for reasons discussed in WS Atkins, 2003. This means that a fairly conservative assessment may be necessary, possibly up to 500 mg/l of the major organic contaminants (phenols, benzenes etc.) within the pyrolysis zone itself. Reduction in contaminant concentration in the pyrolysis zone is difficult as no investigations of this aspect relevant to deep trials were available for this document. Based on previous studies, an effective concentration half life of 10 years may be realistic, but differences between previous shallow sites and deeper UK sites need to be considered. Further information on past experience is provided in the Final Report to this project.

For contaminants associated with gas escape (sulphides, ammonia etc.) it is suggested that estimates of concentrations of contaminants left in areas effect by the gas escape are made based on the solubility of the gas, the maximum estimated pressure differential between the gas and the groundwater and the duration of contact between the gas and the groundwater. As discussed previously, gas escapes should be short lived even in the ‘worst case’ scenario, so contact times based on operational ‘awareness’ (i.e. how long before operators are aware of a gas escape) of gas escapes should be appropriate. Heavy metals and other minor contaminants will be at much lower concentrations, it is suggested that 1ppm is a realistic upper limit.

If contaminant transport modelling is required as a key element of the risk analysis, then it is advisable that important assumptions are discussed with the regulator at an early stage to ensure that final results will be supported.

### 2.3.4 Effects of Strata Relaxation and Proximity to Mineral Workings

Man-made influences can have a large impact on the risk posed by the geology and hydrogeology at the site. Man-made influences that can affect hydrogeology at depth include:

- mineral workings and resource extraction activities such as Coal Bed Methane extraction;
- the collapse of the UCG reactor itself; and
- deep site investigation boreholes.

The removal of coal at depth, whether by conventional longwall methods or by unconventional methods such as UCG, will cause the unsupported
overburden to collapse into the cavity left in the coal. At the depths proposed for UCG in the UK, caving will almost certainly occur. Depending on the width of the cavity, the seam thickness, and its depth, caving may cause subsidence at the surface, but it will also cause stress relaxation in the strata within the overburden above the caved zone. This strata relaxation can lead to opening and extensions of joints, fissures, fractures etc. in the overburden rocks. Methods for assessing the extent of the impact caused by caving and the impact that this has on certain strata types are provided below.

Nearby mineral workings can have other impacts that are relevant to UCG operations and these are also discussed in this section.

**Assessing the Impact of Strata Relaxation on the Risk to Groundwater**

Overall the impact of the caving of the UCG reactor on surrounding strata and the resulting risk to groundwater will depend on the following factors:

- the width and number of reactors involved;
- the location of strong, competent strata layers that may arrest upward development of strain and create ‘subsidence’ effects beneath them;
- the location, nature and geometry of faults; and
- the proximity of strata deformation to assessed potential contaminant migration pathways.

Any assessment of the impact that caving has on the risk of contaminant escape therefore has to be considered in relation to the wider geology and risk assessment at a site. The following section provides various methods for assessing the extent of ground disturbance associated with caving of the reactor and the resulting impact on strata permeability. No specific recommendations are made as knowledge in this area is not definite and a degree of judgement will be required. Generally speaking, it is advised that a conservative approach is adopted to determine the maximum extent of the impact (e.g. using 1mm or 0.5mm limiting strain criteria, or rules of thumb associated with mine inrushes if they require greater strata thickness). Those evaluations can then be used to make a ‘best guess’ of the significance of the reactor caving in combination with the wider hydrogeological knowledge of the site.

Technical guidance on the evaluation of strata relaxation is provided in WS Atkins to this document.

**2.3.5 General Guidance on the Proximity of Pre-Existing Mineral Workings**

Where there are existing mine workings, ‘rules of thumb’ for the zone of extensional stress caused by caving may be appropriate as a first estimate of the extent of the impact. This may reduce site investigation requirements. In general, the zone of extension extends upwards and outwards from the edge of the workings to the surface at an angle of approximately 35°. The de-stressed zone around mine workings extends for up to 200 m above and 70 m below the workings (Creedy,1991) and for a distance of about 20 m
horizontally from the workings (Dunmore, 1969). Because the proximity of large faults to the mine workings can lead to the concentration of subsidence along the fault plane and extended associated joints, more detailed analysis are recommended where mine workings interact with faults near to the UCG reactor.

As well as affecting the transmissivity of strata, coal operations up-dip of the UCG may change the groundwater regime. Operational coal mines are de-watering Coal Measures so that the reduced piezometric head extends well beyond the mine workings, but negative pressure exerted on the mining system for ventilation purposes only extends as far as the zone of mining influence around the workings Coal Bed Methane (CBM) operations also modify groundwater levels but only within the area that is local to operations themselves. Abandoned Mine Methane (AMM) operators apply only relatively low negative pressures at the surface vents, and these effectively reduce with increasing distance from the vent because of frictional losses. Water levels in abandoned mine workings are rebounding within the extensive areas that were historically de-watered.

Although coal mine and AMM operations apply negative pressures to the system the effects are limited to the zones of influence extending to an envelope of approximately 200 m x 70 m x 20 m around the workings. Coal mine and CBM operators actively reduce the hydrostatic pressure around their operations to extents that are presently undefined and evaluation of this extent would have to form part of the UCG site investigation. Interaction agreements between the coal operators will be required following site specific investigations and the identification of factors that might result in one of the operation’s effects impinging on another’s.

2.4 SITE EXPLORATION REQUIREMENTS - GROUNDWATER

The hydrogeological investigations in relation to UCG should be designed to support the form of groundwater risk assessment that is being carried out. Site selection will usually only involve desk studies (although site investigation data from previous coal prospect investigations may be available) as the main aim of the risk analysis is to compare the suitability of sites. The site investigation phase undertaken as part of the PPC permit application process will require sufficient information to convince the regulators that the site does not pose a risk to groundwater.

2.4.1 Desk Studies

Desk studies are important whether sites are being assessed for a comparative analysis at the site selection stage, or whether they are the initial stage in the production of an application for a PPC permit. For the comparative assessment they should provide all of the necessary information. For the PPC permit application they should be used to carry out a ‘first’ pass assessment of the conceptual hydrogeology and risk at the site that can be
used to determine what physical site investigation methods need to be employed.

There are a wide variety of information sources that can be used for a UCG desk study in the UK. These include the information sources summarised in Table 2.2 below.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Possible Sources of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological Memoirs</td>
<td>British Geological Survey (BGS), Geological Society (Hydrogeological Group) etc</td>
</tr>
<tr>
<td>Geological and hydrogeological maps</td>
<td>BGS, Geological Society (Hydrogeological Group)</td>
</tr>
<tr>
<td>Borehole records, coal mine investigation reports, abandoned mine shafts and plans</td>
<td>BGS National Geological Records Centre (NGRC), Coal Authority Mining Records Office (Mansfield)</td>
</tr>
<tr>
<td>Hydrogeological reports and</td>
<td>Local EA/SEPA, local Water Undertaker, CEH Wallingford, BGS (NGRC and</td>
</tr>
<tr>
<td>hydrogeological information</td>
<td>local mineral planning authorities, university libraries. Local hydrocarbon extraction facilities.</td>
</tr>
<tr>
<td>Geophysical Surveys</td>
<td>BGS NGRC (coal prospect investigations), Local EA/SEPA, local developers</td>
</tr>
</tbody>
</table>

Table 2.2 - Example Sources of Hydrogeological Information at the Desk Study Stage

Analysis of previous coal prospect investigations or other deep site investigation data is likely to be very important for locating faults and determining the lateral extent and nature of Carboniferous strata at the site. In some cases this will include previous in-situ hydrogeological data and detailed seismic data, but simple drilling logs can prove very valuable to an experienced Coal Measures geologist.

Desk studies should be planned in advance to determine the purpose of the study; information requirements may change depending on whether a comparative assessment is required or whether the desk study is aimed at determining what site investigation techniques will be required. The guidance contained on risk assessment and geological evaluation discussed earlier in this report provides a good idea of the issues that need to be considered by the hydrogeological desk study.

2.4.2 On Site Investigation Techniques
Site investigations are likely to be partly opportunistic and partly based on the desk studies. This second phase may include both invasive and geophysical
investigation techniques and should be integrated with the geological investigations and production drilling works. Where practicable, two production holes should be predrilled in smaller diameters for the geological and hydrogeological investigations. In addition a third hole will be drilled to provide monitoring of the production phase. These three holes should form the basis of the hydrogeological investigations.

Any hole drilled to 1000 metres in depth will involve substantial effort and time, and could create a flow pathway from the UCG chamber horizon to surface. Any holes should therefore be carefully planned with installations and back grouting undertaken to high standards. The drilling of additional, multiple and observation holes is, therefore, discouraged without thorough justification because of the expense and contamination risks that such holes may create.

Conventional pumping tests with multiple piezometer boreholes are also inadvisable. In many cases permeabilities will be too low to make such pumping tests viable in any case.

In each borehole there are three parameters that need to be measured, these are:

- the water pressure, and particularly its deviation from a hydrostatic profile;
- the transmissivity (permeability multiplied by the thickness of a particular unit); and
- water quality (principally as measured by the total dissolved solids/conductivity).

The vertical profile for each of these three parameters alongside the geological profile, represent the key parameters from which the components of the hydrogeological model can be established. In practice, measurements will be at discrete zones rather than as a continuous profile. Further guidance on the technical investigation of these parameters is provided in Appendix B to this Document.

Down-hole geophysical methods will provide useful supporting data to these techniques. The standard test methods that may be useful in interpreting the strata, along with some of the applications of those methods, are summarised in Table 2.3. below. Guidance on interpretation can be found in a number of standard texts such as Driscoll, 1986.

<table>
<thead>
<tr>
<th>Method</th>
<th>Possible Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borehole Resistivity/SP</td>
<td>Can demonstrate occurrence of sand with water and clay bands. Where saline waters exist then apparent resistivity needs to be analysed along with SP.</td>
</tr>
<tr>
<td>SP Potential Logs</td>
<td></td>
</tr>
</tbody>
</table>
Gamma logging  
Detection of clay/mudrock layers 

Neutron logs  
Indicator of total porosity 

Temperature logs  
(discussed below) 

Calliper logs  
Can be useful in detecting large 
fissures/fracture zones 

Acoustic/optical (CCTV, 
optim viewers etc.) methods  
Fracture location and investigation 

| Table 2.3 - Example Down-Hole Geophysical Methods |

Lateral variations in properties are likely to be limited in a sedimentary 
environment, except where there has been significant faulting or intrusions. 
Such variations may be indicated and tested by the second and third holes. 
Testing in these further holes should be used to confirm, infill and upgrade the 
data from the initial hole.

Conclusions relating to lateral continuity should be supported by desk study 
information, including geophysical (primarily seismic) investigations carried 
out for previous coal prospect investigations. Where there is little data 
available, further seismic exploration will probably be required in any case to 
assess the operational viability of the site. This data can be used to confirm 
lateral continuity and thickness of strata layers.

**Identification of Faults and Fault Hydrogeology**

Desk study techniques to determine fault permeability do not provide certain 
solutions and can only be tested with detailed hydrological studies involving 
monitoring points close to any critical fault. Where water is pumped from 
strata an idealised cone of depression develops; when this cone reaches a 
fault zone it may either be recharged from a permeable fault or terminated. 
Monitoring points on the remote side of the fault will show little reaction. 
Monitoring points between the pumping site and the fault will either show an 
increased change of pressure (impermeable fault) or a reduced change of 
pressure (permeable or recharge zone). These changes are relative to the 
idealised development of the cone of depression, usually considered as a 
deviation from the theoretical Theis curve on a log time versus log drawdown 
plot.

Faults can be located by surface geophysical and morphological means. 
Whilst these methods do not define the hydrogeology of faults, they are likely 
to be an effective identifier of fault locations for planning in situ 
hydrogeological testing.

The more useful geophysical methods are electrical resistivity and seismic 
refraction. Electrical resistivity is based on passing a current through the 
ground between two electrodes, the electrical potential created in the area is 
measured on varying arrays and used to interpret ground conditions. Such 
methods have practical limitations on the depth of penetration due to the
practicality of limiting currents. For deeper penetration the seismic refraction method creates a shock wave (usually created by a small explosive charge or specialised heavy plant) and the time of travel of the shock waves measured on an array of sensors. Waves are reflected and refracted by the underlying strata and vary with rock types.

Morphological methods should be included at the desk study stage. In its simplest form the technique can be used to suggest where faults have left weaknesses in the earths surface which have been exploited by eroding rivers. Fookes (1997) has considered the geomorphological models and the methodology in some detail.

The overall role of the hydrogeology of faults and modelling their behaviour is described in some detail by Galson Sciences (1999 report to UK Nirex).

2.5 SITE LAYOUT AND ADJACENT LAND USE

The Office of the Deputy Prime Minister (ODPM) has produced draft guidance Consultation Paper on On-shore Oil, Gas and Coalbed Methane Development and it is understood the guidance will in due course include UCG. In terms of land use planning the process of on shore gas and coal bed methane development is similar to UCG. The guidance is therefore relevant in respect of best practice on how to ensure that the development of UCG resources can take place in accordance with the full and proper protection of the environment and the local community.

In addition guidance on consideration of mineral proposals is given in Minerals Planning Guidance (MPG) 1 and MPG 2 as well as in Planning Policy Guidance 1 (PPG 1) (DTLR, 1997). MPG2 advocates early consultation with the Minerals Planning Authority prior to any application being made. Such pre-application discussions should also make clear the exact nature of the development being proposed (e.g. a trial, which would be temporary in nature, or a more long-term semi-commercial operation).

Site selection for a UCG trial or semi-commercial project should, as a matter of policy, generally follow a sequential approach. Having established a case for the development and a general area of search having been defined (based on availability of appropriate coal seams), it is then appropriate to establish criteria for identifying specific sites for the project.

A sequential approach should employ suitable criteria against which viable sites can be considered. It may be necessary to attach weighting to the criteria to reflect their relative importance. It would be appropriate to assess the sensitivity of the receiving environment and the magnitude of the potential impact in order to arrive at a robust score for each criteria.
It would be inappropriate to establish a rigid set of criteria for specific areas, though the suitability of a location in terms of the following factors should be included

- landscape/visual;
- surface water and groundwater;
- dust;
- air quality;
- noise;
- ecology;
- land quality;
- cultural heritage;
- planning policy;
- road network capacity;
- socio-economics; and
- contaminated land.

The robustness of the selection criteria will be an important factor in determining the suitability of any chosen site.

Any proposal for UCG should set out a reasoned justification for the facility, a description of the extent of the coal seam able to support the facility together with a map of the area where the facility could be located. The proposal should then set out the criteria adopted for assessing sites within the identified area. The planning application should include a supporting statement which covers relevant aspects of national energy policy e.g. cleaner coal technologies, self sufficiency.

### 2.6 PLANNING CONSIDERATIONS

As a minerals development, a UCG trial operation and all works associated with it will require planning consent under the Town and Country Planning Act 1990 (HMSO, 1990a). Planning applications will need to be submitted to the relevant minerals planning authority. The mineral planning authority is:

- the county planning authority in respect of a site in a non-metropolitan County;
- the local planning authority in respect of a site in a metropolitan district or London Borough or unitary district; or
- the National Park Authority.

Section 36 of the Electricity Act 1989 (HMSO, 1989) states that a generating station shall not be constructed, extended or operated except in accordance with a consent granted by the Secretary of State for Trade and Industry. This requirement does not apply to a power generating station whose capacity does not exceed the permitted capacity of 50 megawatts. Section 62 allows the Secretary of State for Trade and Industry to cause an inquiry to be held in any case where he considers it advisable to do so.
Whilst the power generation aspects of the semi-commercial proposals will be determined under the Electricity Act if the proposed generation capacity is to exceed 50MW, the process of application to the Secretary of State for Trade and Industry should follow best practice planning procedure for major infrastructure developments. PPG1 (ref. DTLR, 1997) sets out guidance on the general policy and principles for new development. Application via the Electricity Act should not be seen as a way of circumventing full and proper planning and environmental considerations.

The gasification aspects of the semi-commercial proposals would continue to be viewed as a minerals development and could not be considered as ancillary to the power generation aspects. Planning applications will therefore, need to be submitted in the same manner as for the trial operation.

If the proposed generation capacity of the semi-commercial project is not to exceed 50MWe, a planning application would be needed to be made to cover both the gasification and power generation aspects, with the latter being considered as an industrial process. The application would be determined by the local authority.

In respect of power lines associated with the semi commercial operation for power generation. Permission for this can be obtained by making an application under S37 of the Electricity Act 1989 to the Secretary of State for Trade and Industry. It is normal practice for the National Grid to obtain this consent on behalf of the developer. The submission of an environmental impact assessment (EIA) for all S.37 transmission lines is mandatory under The Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000 (HMSO, 2000a) or The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2000 (HMSO, 2000b). An assessment of the visual impact of transmission lines and the unsubstantiated threat from electromagnetic radiation will be critical to a S.37 application.

Under the Pipelines Act 1962 (HMSO, 1962) a Pipeline Construction Authorisation (PCA) is required to construct an underground pipeline for the supply of gas to a site or transfer from wellhead to power plant. An application for planning permission to construct the pipeline would also be required and ‘no valid objection’ status is required before a PCA is given by the DTI. If gasification agents were delivered to the UCG trial site by road a PCA would only be required for the importation of natural gas. It is therefore anticipated that a PCA could be required for both the trial and the semi-commercial operation.

Applications made under Acts of Parliament need to be made to the relevant Secretary of State. Applications take the same form as would a planning application and should contain all information which would be submitted for a
planning application. Local authorities are consulted on such applications and the relevant Secretary of State may call an inquiry if there is objection to the proposal.

Under the Planning (Hazardous Substances) Act 1990 (HMSO, 1990b), a hazardous substances consent is required for the presence of a hazardous substance in an amount at or above its controlled quantity. It is likely that quantities of hazardous substances present at certain times during the semi-commercial operation would be above the levels in Schedule 1 of The Planning (Hazardous Substances) Regulations 1992 (HMSO, 1992) as amended by the Planning (Control of Major Accident Hazards) Regulations 1999 (HMSO, 1999). A hazardous substances consent would therefore, be required for the semi-commercial UCG operation.

The hazardous substances authority (the planning authority) is required to consider whether the proposed storage or use of a significant quantity of a hazardous substance is appropriate in a particular location, having regard to the risks associated with the persons in the surrounding area and the wider implications for the community.

Applicants should submit a prescribed form and must publicise the application. The hazardous substances consent application should run concurrently with the planning application as they are inter-dependent. The authority is required to consult with the Health and Safety Executive (HSE) and the EA. Where consent is granted, the authority must set up a consultation zone within which proposals for future development are referred to consultees to consider public safety.

It is important in the introduction of new technologies that public confidence is maintained in the development of such facilities.

The whole process of site development should evolve along side a strong level of community consultation. This should involve the use of a communications strategy, which allows for the provision of information on the process involved (for the purpose of providing the public with an understanding of the process), along with establishing broad agreement on the site selection criteria. Such consultation could be by way of public meetings or exhibitions.

Early agreement should be made to undertake a full EIA, ideally employing an iterative approach to development proposals. Acceptance of EIA for all schemes from the outset will increase public confidence in the technology and assist in achieving consent for the scheme.

Due to the numerous components of UCG, identification of the appropriate EIA regulations and their appropriate application is open to some interpretation.

- The Town and Country Planning (Environmental Impact Assessment) Regulations 1999 (from here on in referred to as the Planning EIA Regulations).
- The Electricity Works (Environmental Impact Assessment) Regulations (England and Wales) Regulations 2000 (S.I. 1927) (from here on in referred to as the Electricity EIA Regulations).
- The Pipe-line Works (Environmental Impact Assessment) Regulations 2000 (from here on in referred to as the Pipeline EIA Regulations).

For the EIA, developers should seek a formal scoping opinion from consultation bodies to define the key issues to be considered in the Environmental Statement. The consultation bodies for a scheme submitted under any of the EIA Regulations include:

- the relevant planning authority;
- the Countryside Agency;
- English Nature; and
- EA (Not mandatory for a S.37 consent).

Under the Planning EIA Regulations it would be necessary to consult with any body that the relevant planning authority is required to consult as specified in article 10 of the Town and Country Planning (General Development Procedure) Order 1995 (HMSO, 1995). The additional consultees from which a scoping opinion should be sought will depend on site context but could include:

- local highway authority;
- English Heritage;
- Department for Environment, Food and Rural Affairs; and
- Health and Safety Executive.

For an Electricity Act application an EIA scoping opinion from the additional consultees specified in article 10 of the aforementioned Order, may be necessary.

With an “EIA Development” the local planning authority has 16 weeks rather than 8 weeks to determine the application. The applicant has a right of appeal if the application is not determined within the 16 week period.

The EIA process requires the consideration of alternatives, including the do nothing alternative. Consideration should also be given to alternative processes for electricity generation as justification for the chosen technology, as well as alternative site layouts and designs. Consideration of alternative sites consideration should then follow the sequential approach outlined above. Full justification needs to be made for discounting sites with the same
level of critical analysis as that applied to selecting the chosen site. The use of a matrix to assess sites against a range of criteria with attached weightings should be considered.

The EIA should consider the significant impacts arising during the construction/operational and decommissioning phases of the project. Such impacts maybe direct/indirect, positive and negative. The EIA should also consider cumulative effects. The scope of the EIA should be determined through a formal scoping exercise (DETR, 1999).

Early discussions with the local planning authority with regard to consultation and legislative requirements should be entered into. Such discussions should confirm the need for hazardous substance consent. Discussions should also include proposals for shutdown, restoration and after care. Satisfactory proposals for restoration and aftercare are critical to the approval of mineral applications and need to be taken into account in the development of the proposals.

In respect of a trial or a semi-commercial operation it will be necessary to evaluate a scheme against the planning policy framework. This will involve an assessment of the scheme’s consistency with national, regional and local planning policy. Where a scheme or elements of that scheme contravene the provisions of the development plan, it will be necessary to identify those material considerations that justify a departure from development plan policy.
3. ENVIRONMENTAL CONSIDERATION SPECIFIC TO UCG
This Chapter provides guidance on best practice for the management of those aspects associated with the activities that are specific to UCG, for which no recognised best practice guidance currently exists. It is arranged in terms of the phases during which these activities will occur: construction, operation and shut-down and restoration.

3.1 CONSTRUCTION

3.1.1 Drilling and Well Completion
Drilling operations have the potential to contaminate groundwater with drilling fluids or cause cross-contamination of aquifer horizons present in the overburden. Drilling operations will also generate solid and liquid wastes requiring disposal.

The various wells must be designed and constructed to ensure their integrity during the life of the well to eliminate the leakage of injection agents or product gases.

Environmental Issues During Drilling
During drilling of vertical wells, the hydrostatic head within the borehole should be greater than that of the formation, to ensure stability of the borehole, prevent groundwater inflow and hence aquifer cross contamination. Under balanced drilling should be used when drilling horizontal holes in coal seams.

The type of drilling mud used depends on a number of factors including the nature of the strata formations, in particular the existence of any aquifers, the depth of the well and the angle of deviation. Water based muds are preferred over oil based muds on the basis of both environmental protection and cost. The EA have expressed a preference that water based muds should be used when drilling through significant aquifers (particularly the Sherwood Sandstone).

A basic water based mud will comprise:
- water;
- bentonite, to increase viscosity;
- barite (barium sulphate), to increase density;
- sodium hydroxide/soda ash, to control pH; and
- potassium chloride, to inhibit the degradation of formation clays.

The main constituents (bentonite and barite) do not represent significant environmental concerns as they are essentially chemically inert. pH control and potassium chloride are also not a concern unless this results in a drilling fluid that is chemically significantly different from groundwater within the aquifers. Other additives may need to be used for specific purposes and
potential underground impacts from these should be assessed on a case by case basis.

Drilling operations will generate two principal waste streams:
- solid wastes, principally drill cuttings contaminated with mud additives; and
- liquid wastes, mainly drilling fluid contaminated with fine drill cuttings.

Drill cuttings are generated continuously during the drilling process and should be separated from the drilling fluid by the rig’s solids control equipment. The drilling fluid should be re-used. The separated cuttings will require disposal. Drill cuttings contain too high a water content to be disposed of to landfill without further treatment. Therefore, two options exist for the disposal of drill cuttings:
- stabilisation with pulverised fly ash (PFA) and disposal to a licensed landfill; or
- re-injection into an exhausted gasifier.

Re-injection is likely to be the preferred option on both environmental and cost grounds. If the cuttings were re-injected into the formation from which they were derived they would not be classified as landfill. However, as the gasifier is not strictly the formation from which the cuttings were derived, the EA’s approval should be obtained for this. There are precedents, for example BP Wytch Farm. Re-injection would involve slurrying the cuttings with water on an approximate 50:50 basis by volume.

DTI guidelines on cutting disposal allow cutting re-injection to boreholes under the Landfill Directive (DTI, 2003). This may therefore be an option in UCG where one or more of the operational boreholes are filled post gasification, however guidelines on suitable sealing of boreholes following closure (discussed later) should be adhered to. Since cuttings will not have a sufficiently low permeability, disposal using this methods may be limited to the lower portions of abandoned boreholes.

Off-site landfill will require that waste management is carried out in accordance with the waste management legislation including Duty of Care for waste handling and waste licensing if appropriate. Guidance on the classification of muds according to the Hazardous Waste Directive (Council Directive 91/689/EC) is provided in a joint EA/SEPA guidance note (Environment Agency etc., 2003). Water based drilling muds are normally barium sulphate based, which is not a dangerous substance. However, a substantial number of inorganic and organic substances are supplied to the offshore industry as drilling mud additives (Environment Agency, etc., 2003) and the cuttings themselves may also contain hazardous substances, particularly relating to category H14 (ecotoxin). Muds and cuttings should therefore be categorised and disposed in accordance with all current
legislation if they are classed as hazardous, otherwise they may be dealt with as inert waste.

On completion of drilling, the drilling fluid should be recovered from the well. Two options exist for disposal:
• stabilisation with PFA and disposal to a licensed landfill; or
• removal of the solids, e.g. by filtration, and consented discharge of the waste water to a watercourse or sewer.

The solid waste will comprise 30% to 60% drilling fluid additives, predominantly barite, and the remainder will be drill cuttings.

Storage of drilling muds and cuttings depends on the type of substances involved. If they are considered to be hazardous (as discussed previously), then on-site storage should be in suitably impermeable lagoons or storage tanks (often referred to as ‘reserve pits’) in accordance with the relevant waste handling legislation. Otherwise the only environmental considerations are to prevent sediment runoff entering nearby water courses (i.e. suitable storage size, bunding and drainage is required).

Well Construction
The major environmental requirement for well construction is that the wells should be suitably lined and cemented through permeable horizons to ensure that contaminants from the reactor zone do not infiltrate overlying aquifers and aquifer cross-contamination does not occur. Hence the number of aquifers will substantially influence the cost of construction of the vertical section of each well.

Environmentally, the only requirement is that any aquifer is protected by an outer cemented casing. However, operationally there may have to be more then one ‘intermediate’ outer casing in the upper parts of the well which will have to be sized for in the well design.

Well Integrity
Well construction materials, both casing and cement, need to be capable of withstanding the elevated temperatures, pressures and corrosivity caused by the injected fluids and product gases, particularly CO₂. This needs to be considered at the design stage by:
• selection of a cement appropriate for the process conditions (pressure, temperature and type of gas, particularly CO₂);
• specification of corrosion resistant alloy steels suitable for the high temperature/pressure conditions; and
• specification of gas-tight couplings.

To confirm that the desired well integrity has been achieved following construction, initial mechanical integrity testing should carried out, comprising:
• a pressure test; and
• cement bond logging

Integrity monitoring should also be carried out during operation, due to the possibility of damage to the casing from the burning of pure oxygen at the injection well, and from the excessive temperatures at the production well. This will involve the installation of sensors to measure temperature, pressure and mechanical integrity. As the instrumentation will be attached to the casings, this needs to be planned at the drilling stage.

Emergency procedures should be defined to shut down the injection and/or production if high temperatures are detected along the casing.

Both integrity monitoring and emergency procedures need to be combined with the wider groundwater monitoring requirements (discussed later) to ensure an integrated approach that will minimise the risk of significant gas/contaminant escape during operations.

Well Completion
On completion of the drilling and construction phase, the wells should be left cased, cemented and capped, with liners in place. The design of the inner sections is primarily related to operational control rather than environmental issues, although down-hole instrumentation is a key part of operational control and monitoring.

3.2 OPERATION

3.2.1 Underground Process Control
It should be emphasised that with deep UCG there is no risk of the gasification process ‘running out of control’. Coal can be neither gasified nor burned in the absence of oxygen and, in deep coal suitable for UCG, the only available oxygen is that introduced via the injection well. Hence, when oxygen injection is terminated, gasification ceases and the system progressively cools down. An additional safeguard is provided by the facility for injecting process water in addition to, or instead of, nitrogen to quench the gasifier.

Effective process control is the key to the efficient operation of the gasifier, and to minimise the generation and dispersal of potential contaminants. The priorities for operational control should be:
• minimisation of gas losses;
• maintenance of the thermochemical equilibrium;
• maintenance of the coal conversion/gas production rate; and
• maintenance of the product gas calorific value.

Real time gas analysis is the essential basis for operational control, since the crucial in-situ phenomena of groundwater ingress/gas losses to strata cannot be measured directly but can be inferred from the cumulative mass balance.
through the system. The thermochemical conditions in the reaction zone can also be inferred from the product gas analysis and temperature (before sparging, at the base of the production well).

Further information on the objectives, methods and instrumentation required for effective process control is presented in Appendix C.

3.2.2 Gas Combustion and other Operational Surface Activities

Control of Emissions to Atmosphere
As described in the introduction to this document, both the UCG trial and semi-commercial operation would fall within the scope of the Pollution Prevention and Control (England and Wales) Regulations 2000 (PPC Regulations 2000) and the PPC (Scotland) Regulations 2000. Operation of the process would be conditional upon obtaining an PPC permit from the EA in England and Wales, and from the SEPA in Scotland.

Furthermore, as stated in Chapter 4 of this Guidance Document, an environmental impact assessment is likely to be required as part of the planning application for both a trial and a semi-commercial operation. An environmental statement would need to include an air quality baseline study and an assessment of the construction and operational effects upon air quality. This should include a detailed atmospheric dispersion modelling study.

The air quality implications of the planning and regulatory regimes in terms of the control of emissions and the approach to air quality assessments are considered below.

Planning and Regulatory Requirements
Government policy guidance to local authorities on local air quality management states that the land use planning system is integral to improving air quality (DEFRA, 2003a). It states that any air quality consideration is capable of being a material planning consideration, in so far as it affects land use. Where a proposed development is likely to have significant air quality impacts, close co-operation between local planning authorities and those with responsibilities for air quality and pollution control will be essential. It advises that the impact on ambient air quality is particularly important, however:

- where the development is proposed within, or adjacent to, an AQMA;
- where the development could in itself result in the designation of an AQMA or the extension of an AQMA;
- where the development, or associated traffic, is likely to result in predicted levels of air pollutants close to a breach of the Air Quality Objectives; or
- where to grant planning permissions would conflict with, or render unworkable, elements of the local authority’s action plan.
This document refers to PPG23 Planning and Pollution Control (DoE, 1997), which discusses the relationship between the land use planning and pollution control systems. A consultation draft of PPG 23 was published which reiterates the earlier advice that the planning authority should not give weight to objections on matters which are properly subject to the pollution control regime and which do not have land-use planning implications (ODPM, 2002). It states that it should not generally be necessary to use planning conditions to control the pollution aspects of a development that are subject to prior approval by a pollution control authority.

The consultation paper lists matters for consideration in development plan preparation and individual planning applications including the following:
- existing, and likely future, air quality in an area, including any AQMAs or other areas where air quality is likely to be relatively poor;
- compliance with any statutory environmental quality standards or objectives (including the air quality objectives prescribed by the various Air Quality Regulations (HMSO, 2000c; HMSO, 2000d; HMSO, 2000e)); and
- the potential effects of climate change.

As discussed previously, the gasification process for the trial and the semi-commercial operation is likely to be covered by Section 1.2 of Schedule 1 of the PPC Regulations 2000 and PPC (Scotland) Regulations 2000. For the semi-commercial process, the gas utilisation activities are likely to be covered by Section 1.1 of the regulations. As stated, authorisation under PPC requires the application of BAT to minimise emissions. The PPC permit would include emission limits to air derived from achievable releases based on BAT.

For the semi-commercial operation, the current technical guidance is IPC Technical Guidance Note S3 1.01, (Environment Agency, 2000). This updates earlier guidance and includes information to assist with the application of PPC. This describes achievable releases for sulphur dioxide and oxides of nitrogen. It also gives specific advice regarding oxides of nitrogen limits for gas turbines of various configurations.

In addition to the above there is general guidance for PPC. Reference is made in various EA guidance documents to the need for stack height calculations for authorised processes. The stack height calculation is carried out using the procedure described in the HMIP Technical Guidance Note D1 (HMIP, 1993). The stack height obtained should be regarded as a minimum requirement, and local factors such as topography should be considered. The acceptability of the stack height should be confirmed by means of the detailed dispersion modelling study forming part of the planning application and the PPC application.

In determining emission limits for the PPC authorisation the EA will have regard to the Air Quality Regulations, the Large Combustion Plant Directive
and the Waste Incineration Directive as appropriate to the specific application. Carbon dioxide emissions will also be considered and overall energy efficiency is relevant to BAT.

**Guidance on Modelling Emissions**

Guidance on modelling emissions to the atmosphere is contained in the Environment Agency Air Quality Modelling and Assessment Unit (AQMAU) report (Environment Agency, 2002). The AQMAU report provides a concise guide to the structure of a dispersion modelling study and includes recommendations that they regard as good practice.

Modelling of vehicular and industrial emissions is also addressed in technical guidance from (DEFRA, 2003b). This guidance is intended to assist local authorities with their duties to review and assess air quality. However, it is of more general application as an indication of good practice. Annex 3 of the document addresses modelling with the express purpose of promoting good practice. The guidance notes that estimation of secondary pollutant formation is outside the capability of practical models at the moment. Oxides of nitrogen should be modelled rather than attempt to estimate nitrogen dioxide formation.

Detailed dispersion modelling studies will be required for both the proposed trial and semi-commercial operation. Ground level pollutant concentrations will be a consideration both in the context of the planning application and with regard to the PPC application. Ideally, the same detailed study should be appropriate for both purposes. In practice, the EA may require more technical discussion, whereas for the planning forum the same results may be presented with a wider readership in mind.

It should be noted that a recent study (WS Atkins, 2003) included a dispersion modelling study for the UCG trial using the minimum stack height calculated using the Technical Guidance Note D1 (HMIP, 1993). It concluded that “substantial reductions in short term sulphur dioxide concentrations were found to result from doubling the stack height to 26 m. Any proposed trial design should be based upon a site specific dispersion modelling study incorporating a stack height sensitivity study”.

For planning and regulatory applications the PPC sector benchmark emission concentrations should be used as the basis of the pollutant emissions rates modelled. The trial and semi-commercial operation should be modelled as operating at their maximum design loads.

The detailed modelling studies should include complex effects such as building downwash and the effect of terrain. Hourly sequential meteorological data should be used. It is noted that the EA require the use of five years data. Receptor grids should be of sufficient resolution to provide a good estimate of maximum concentrations. The EA recommend a grid
resolution equal to one and a half times the stack height and the DEFRA guidance suggests that resolution should be in the order of 25 to 50 m.

The model results need to be interpreted in the context of existing background concentrations. Annual average pollutant concentrations are available on national maps in the Air Quality Archive. Allowance may be made for pollutant concentrations in future years following DEFRA advice.

3.2.3 Environmental Monitoring Requirements

It is likely that many of the aspects arising during the operation of a UCG trial or semi-commercial project would require some form of monitoring or measurement. Specific consideration is given below to monitoring groundwater in the vicinity of the gasification reactor, monitoring ambient air quality (to provide a baseline for planning purposes) and monitoring emissions to atmosphere.

**Groundwater Monitoring**

As noted previously, authorisation from the EA or SEPA under the Groundwater Regulations will have to conform with regulation 8 of the Groundwater Regulations by providing ‘requisite surveillance’ during and after operations (similar requirements will be made under the Water Framework Directive). Any monitoring regime will, therefore, need to be site specific and agreed with the regulator in order to gain authorisation.

Monitoring should be geared towards checking that contaminants are not migrating from the ‘permanently unsuitable’ zone, rather than simply measuring contaminant movement away from the cavity. The monitoring regime as installed would need to identify potential problems with contaminant movement before it escaped beyond the confines of the ‘permanently unsuitable’ zone. Monitoring requirements should, therefore, be based on identified potential migration pathways. They are unlikely to require specific monitoring boreholes within the target coal seam, other than the injection and production wells, but again this will be site specific and dependant on the regulator. Other monitoring boreholes may be required, but these may be opportunistic, based on existing monitoring points. The EA or SEPA should be consulted on the presence of groundwater monitoring systems already in the area.

During operations the primary concern is likely to be gas escape. If gas escape is a potential concern, then the regulator may require installation of monitoring wells in permeable horizons above the reactor or in fault areas and a sampling regime that will provide an early warning of gas escape. Because gas escapes are often characterised by a drop in pH, pH meters may be a suitable monitoring method that will provide immediate indication of a gas escape. Temperature or conductivity meters may also give suitable ‘early warning’ of gas escape, but care should be taken (especially in the case of conductivity readings) to ensure that natural variations in baseline conditions
are not incorrectly mis-interpreted as gas escapes. Any monitoring system should be integrated with the process pressure/mass balance monitors that are being used to monitor gas escape from the reactor or boreholes in order to avoid erroneous interpretation.

As a general guideline, attempting groundwater monitoring in very low permeability strata is not advised due to the problems in obtaining sufficient samples and the highly variable special response that may be present in such strata. It is, therefore, advised that monitoring points concentrate on known permeable strata regions.

The monitoring regime should include suitable baseline quality investigations. These are discussed elsewhere in this document.

The regulator may require specific constraints on the PPC authorisation that mean the process has to be shut down if significant gas escapes are encountered within a specific borehole (or boreholes). In this case the notification procedure should be agreed with the regulator in advance.

Major contaminants such as ammonia, sulphides or aromatic hydrocarbons (phenols, benzene) can characterise also gas/contaminant escape during operations, but this will require groundwater sampling and laboratory analysis, which will take days to carry out. Although groundwater samples are not particularly useful as ‘early warning’, major contaminants should be sampled for from monitoring wells at key points during the operation and shutdown and compared against baseline characteristics to determine groundwater changes caused by the UCG operation.

It is important to note that any monitoring well that is constructed in addition to the main site investigation/operational wells should be suitably cased to avoid contaminant migration or aquifer cross contamination.

**Baseline Air Quality Monitoring**

Baseline air quality assessment is an integral part of an EIA. As a component of a dispersion modelling study it enables a view to be reached regarding the acceptability of the incremental change in air quality due to a development. As air quality will be a material planning consideration, the local authority review and assessment reports may need to be supplemented by additional monitoring in the local area. This will be particularly important where the proposed UCG trial or semi-commercial plant is within or adjacent to an AQMA. Most AQMAs are designated due to nitrogen dioxide concentrations potentially breaching the annual mean Air Quality Objective.

Nitrogen dioxide monitoring using diffusion tubes should be carried out for an extended period in the area influenced by the discharge. A minimum of six months monitoring is recommended as providing a reasonable estimate of annual average concentration. The choice of monitoring locations should be
made in the light of a dispersion modelling study and with regard to potentially sensitive receptors in the area.

**Monitoring Emissions to the Atmosphere**

Monitoring of stack emissions to demonstrate compliance with emission limits will be a specific requirement of the PPC authorisation for the UCG trial and semi-commercial plant. The authorisation for the semi-commercial plant will also meet the requirements for continuous monitoring of the Large Combustion Plant Directive (Directive 2001/80/EC) as relevant to the proposed plant design. The Directive sets limits for sulphur dioxide, oxides of nitrogen and particulates. There are monitoring requirements regarding averaging periods and a statistical indicator of compliance for the various time scales for which discharge limits are specified.

In addition to the above pollutants, IPC Guidance Note S3 1.01 quotes achievable releases to air for carbon monoxide and hydrogen chloride. Were these substances to be subject to emission limits specified in the PPC authorisation, it is likely that the EA would require a similar regime of continuous monitoring.

Given the potential sulphur dioxide emissions from the UCG trial, it is likely that continuous monitoring of acid gases and flue gas characteristics would be a requirement throughout the trial. The EA may also require spot measurements of trace elements in the flue gas. However, as the purpose of the trial is to investigate the viability of the technology, it would be likely that a thorough investigation of product gas composition and the resultant flue gas composition would be an integral part of the project.

### 3.2.4 Waste Water Management

In order to determine the appropriate water treatment technologies that should be used for a UCG trial, it is first necessary to understand the nature of the wastewaters produced by UCG.

**Process water** - during the process, it is anticipated that most of the water generated as the steam condenses can be returned to the cavity, so wastewater treatment as such may not be required. There may be the need to monitor for organic contaminants such as phenols, and ammonia, sulphides and salts may also be an issue. If these contaminants do build up they could compromise equipment due to either depositing as scale or corrosion. Consequently, a series of in-line treatment options may be required to ensure operational problems are not encountered. Selection of such systems is a process engineering issue and many equipment manufacturers will specify the appropriate treatment technologies for wastes produced.

However, the volume of wastewater generated during operation will be much higher, and may become an issue, if there is excessive infiltration of ground water during the operation. Because of the contaminant production methods
discussed in Appendix A, these produced waters can be very high in contaminants. The type of values that can be expected in such waters is very uncertain, but the following values have been recorded previously for such wastewaters:

- 500 ppm+ phenols;
- 1000 ppm+ ammonia; and
- 6000 ppm+ COD

There is anecdotal evidence from previous UCG trials to show that contaminant levels (particularly phenols) could be even higher. No reliable guidance has been found on the levels of sulphides and sulphates, but a few thousand ppm is not unrealistic. Contaminant concentrations can also vary considerably over time, resulting in contaminant ‘spikes’ at key points of the operation. Monitoring change is important as, though it may not significantly impact on the treatment process selected, it may be significant in determining how the treatment process is operated.

**Gas treatment wastewater** - as there is the potential to generate pollutants in the gaseous form, \( \text{H}_2\text{S}, \text{HCl}, \text{NO}_x \), a process will need to separate them. This process is likely to produce some wastewater. These wastewaters could be odorous, and may need treatment on site to avoid odour or toxic environments, but these are part of the engineering design of the process and are not considered further here.

**Cavity flushing/pumping water** - if cavity pumping is used as a remedial activity (even if it is just to maintain groundwater flow towards the reactor), then washwaters will have to be treated and disposed of. These tend to be significantly lower concentrations than condensate produced during gasification due to dilution effects within the caved reactor. Water used to flush the cavity on completion of operation is expected to be the most contaminated of any cavity washwater due to continued production of organics immediately after operations have ceased. Once operations have ceased, further pumping/washing of the cavity may also be selected, which may also contain significant contaminant loads.

The objective of the BAT assessment for wastewater treatment would be to determine the appropriate treatment techniques to prevent chemicals in the discharge from UCG installations breaching the relevant Environmental Quality Standards or to meet the relevant consent conditions set by the Sewerage Undertaker.

**Overview of Environmental Quality standards**

The EC Dangerous Substances Directives set limit values for discharges and Environmental Quality Objectives (EQOs) for receiving waters: the UK complies with the Directives through statutory EQSs based on the EC EQOs. These quality standards are enforced in England through the EA. The EA will either set the discharge consents for wastewaters, or treated effluent from the
site or they will set consents for the sewage works if the UCG wastewaters are discharged to sewer.

**Disposal to Sewer**

The sewer and associated sewage treatment works is owned and operated by the sewerage undertaker appointed under the Water Act 1989 (now re-enacted in the Water Industry Act 1991). As such they are obliged to provide, operate and maintain the public sewerage system and sewage treatment works. Discharge consents are issued by the sewerage undertaker to permit industries to discharge waste water and storm water to their sewerage system. Such consents normally place restrictions on the content of such discharges. The consent must contain permission to discharge the substances that are known to be in the wastewater. The concentrations of the substances permitted by the sewerage undertaker will be dependent on the dilution available in the sewer, the type of sewage treatment process operated, the size and type of surface water that the sewage works discharges and the limits set on the sewerage undertaking by the EA.

**Selection of Wastewater Treatment Techniques**

Wastewater treatment is part of the process and should be designed within the BAT principles discussed earlier in this Document. Due to the potential nature of the contaminants involved, the treatment of waters produced during gasification and waters produced after gasification require different assessment methods.

If there are minor groundwater inflows during the process, then the best environmental disposal method is simply to re-inject the wastewater, although operational considerations should be accounted for (e.g. monitoring quality to present damage to pipes or equipment). However, if there is a risk of excessive groundwater inflow, then some allowance will have to be made to dispose and treat of any waters that are produced.

There are a number of considerations that need to be taken into account when designing treatment systems for excessive wastewaters produced during gasification:

- volume and concentrations will be very difficult to predict;
- concentrations can fluctuate rapidly based on below ground factors that cannot be predicted given the current level of understanding; and
- the rate of infiltration into the cavity may fluctuate considerably (although it should generally increase during the process) and rapidly.

Post-gasification treatment should involve lower, more constant concentrations of contaminants. Ideally, samples should be taken to characterise the waste before the treatment plant is designed. This may not be possible due to time constraints if groundwater risk mitigation requires that the cavity is pumped shortly after operations have ceased.
There are many process vendors with either unique or specialised variants of generic treatment approaches. It is impossible to review each and every technology, but Table 3.1 indicates the types of technique that may be used to treat the pollutants. Further details of the generic processes are available in Environment Agency, 1998b.

*Biological treatment methods may not be suitable due to operational difficulties, particularly a potential lack of BOD in the effluent stream.*

Table 3.1 - Potential treatment techniques *(Developed from: Environment Agency: Effluent Treatment Techniques (1998))*

For sulphides (not listed in the table), ferric chloride is potentially suitable for sulphide removal and H₂S can be removed via ozonation or air stripping (although this can cause odour issues).

When selecting a process in accordance with BAT principles, detailed consideration should include the following:

- energy usage;
- waste generated (e.g. sludges, contaminated carbon, wastewaters, carbon dioxide);
- use of materials (acid, alkali, precipitants and adsorbents) these may have health and safety implications or wastes may be special category and require disposal to licensed land fill;
- space available;
- air emissions (odour, safety for confined species, occupational exposure limits);
- potential spills (including fire water);
- failure and back up systems (may require emergency storage lagoons);
• training of operators, maintenance; and
decommissioning.

Detailed selection may require bench or pilot scale tests to demonstrate that the appropriate treatment performance is achievable. Generally speaking, membranes, chemelec deposition and supercritical oxidation are very expensive and consume large amounts of energy, although they may be required for flexibility. The selection of other techniques will depend on the balance between cost, flexibility, the ability to treat the contaminant concentrations and the environmental BAT issues discussed above.

It should be noted that disposal to sewer is contained within this assessment. This will require the same wastewater characterisation as treatment, but will require disposal consent from the sewage undertaker (as described previously), rather than treatment design. Tankering and disposal off site may be considered, however, this is often expensive and environmentally unsound due to noise, fuel use and spillage risks.

The form of the treatment technology selected will largely depend on the anticipated risk of excessive groundwater influx that will produce wastewater during gasification. Due to the uncertainties involved, any process wastewater treatment system designed before gasification commences will have to be flexible and fairly precautionary. The hydrogeological evaluation should be able to give an indication of the likelihood of significant inflows.

If there is a significant risk, then some form of storage lagoon or pond is likely to be required (to ‘blend’ concentration peaks), combined with those processes that are capable of dealing with the higher concentration contaminants. These are likely to involve the oxidation and coagulation (i.e. chemical dosing) treatment techniques. Disposal to sewer may be an option for process waters, but this will require careful discussion with the sewerage undertaker and it is anticipated that some form of balancing pond will be required at the very least to avoid concentration spikes.

If there is a low risk of excessive groundwater, then it may not be necessary to design for process waters. In this case the lower cost technologies such as adsorption or disposal to sewer may be feasible to treat the cavity pumping/washwaters. There is likely to be a residual risk that process waters will be unexpectedly created during the gasification, so a contingency plan should be made to deal with this. This could, for example, involve the provision of ponds or wastewater storage facilities that will allow off-site tankering in the initial phases, followed by bringing in suitably sized, skid mounted chemical dosing facilities.

Best practice for temporary waste water storage is likely to be a lagoon, the embankments and base of which are lined with a 1 metre thick strata of clay (with a permeability of 10⁻⁹m/s) that is, in turn, lined with an impermeable geo-
textile membrane. For semi-commercial projects (where lagoons will be expected to have a substantial lifetime) consideration should also be given including a leak detection system beneath its base to provide a means of monitoring its impermeability. The lagoon should be sized so that it is able to contain the maximum volume of wastewater likely to be generated in a suitable defined operational time period as well as rainfall in the lagoon. Lagoon embankments should be high enough to provide a reasonable amount of freeboard (usually >0.5m) when the lagoon is full to its maximum capacity. Unless specifically design for that purpose, lagoons should not receive significant amounts of surface run-off and, if necessary, provision should be made for diverting surface water around the pond. More detailed guidance on the design and construction of lagoons is provided in Mason, et al, 1997a.

3.3 SHUT DOWN AND SITE RESTORATION

Site restoration is largely a generic issue (i.e. not specific to UCG) and is discussed in Chapter 4. This section details best practice for issues specific to UCG. Wastewater treatment may be required as part of the cavity flushing and remediation processes, but this should be assessed within the same framework as provided in the previous section.

3.3.1 Venting, Cooling and Flushing

The chemical and physical processes involved in contaminant production post gasification have been discussed in Chapter 2 of this document. This section should be read in order to gain an understanding of why the operational practices contained in this section are recommended.

At the end of the operational phase, the gasification process is stopped by halting the injection of reactants. The gasification circuit is then depressurised by gradually releasing the gas from the system (“venting”). As the pressure within the circuit is reduced, the flow of groundwater through the reactor walls and into the reactor will increase. The impact that this increased groundwater influx will have depends on the rate of inflow that will occur. If flows are reasonably high, then this can have the effect of “quenching” the reactor (thus preventing the continued pyrolysis of coal in the reactor walls) and flushing pyrolysis products from the reactor walls into the reactor. In locations where groundwater flow is not likely to be high enough to cool the reactor quickly enough to limit pyrolysis, water may be injected from the surface. Finally, the reactor may be “flushed” to remove potential groundwater pollutants from the reactor by injecting water into it, via the injection well. The flush water is recovered via the production well. After flushing the gasification module will remain full of water with dilute concentrations of pyrolysis products and leachate that may still exceed pre-burn concentrations. If natural restoration processes prove insufficient to subsequently restore reactor water quality to baseline conditions, then an
active restoration process may need to be activated by pumping the reactor waters to surface and treating them.

The best practice guidelines for venting, cooling and flushing are derived from the relevant experiences from previous UCG trials, particularly the “Clean Cavern Concept” developed in connection with the RM1 trial, Hanna, USA, but suitably amended for application to UCG at great depth.

**Shutdown Objectives**
In line with the ‘clean cavern’ concept, the objectives of the shutdown process are:
- to minimise post-burn contaminant generation from pyrolysis products by accelerating the cooling of the cavities and preventing pressure build up post gasification;
- to maximise the removal of potential organic and inorganic groundwater contaminants from the underground strata by pumping and treating contaminants;
- to maintain the flow of groundwater towards the cavities by pumping water from the cavities and hence maintaining a hydrostatic gradient towards the reactor areas; and
- to restore reactor water quality to near baseline conditions.

**Shutdown Strategy**
Because the reactor zone will no longer exist once injection to the reactor has ceased, contaminants produced in the pyrolysis zone will no longer be consumed. This means that the immediate post-injection phase can be very important in minimising contaminant production.

The strategy at shutdown should therefore be to cool the reactor as quickly as possible to minimise the post gasification formation of organic pollutants, as follows:
- terminate oxygen injection;
- maintain water injection, unless shutdown has been compelled by excessive groundwater ingress; and
- open the choke valves on the production wellhead towards their maximum to depressurise the reactor as quickly as possible, and also to maintain gas lift (of water) conditions within the production well.

**Venting**
As noted in Chapter 2, the heat from the rubble region will enter the coal and continue to expand the char and dry coal regions. This will generate additional steam and pyrolysis products. Gas production will therefore continue during depressurisation, but the gas quality will decline and in the later stages will contain elevated proportions of CO₂, steam (and ultimately liquid water) and un-decomposed organic pollutants. Depressurisation might typically take approximately one week for a successful experimental reactor; and probably considerably longer for a commercial system.
Appropriate venting should prevent the reactor pressure from exceeding hydrostatic pressure during shutdown. This is very important, as high pressures will expand the pyrolysis zone even further and could ‘push’ pyrolysis products and poor quality gases into the surrounding coal and strata. On the other hand, maintenance of a pressure less than hydrostatic pressure by reactor venting will allow water influx to cross/cool the reactor side wall and consequently limit the production of post-burn pyrolysis products. Heat within the post-burn reactor should not be sufficient to exceed hydrostatic pressure if it is suitably vented.

Care needs to be taken whilst venting as previous trials have shown that groundwater will tend to pond at the base of the reactor whilst steam forms in the caved strata above the base of the reactor. Where the production well has been used to vent post process gases, towards the end of the venting phase the rising water level may effectively isolate the well from the gases in the cavity and prematurely stop the venting process. This potential blockage may avoided or removed by exhausting the water accumulating at the well bottom by a gas lift system (injection of nitrogen in the annulus of the production well and producing the gas / steam / water mixture through the production tubing). However, it may be more appropriate at this stage to circulate water to flush the reactor.

In deep locations it should be possible to maintain gas lift conditions within the production well with reactor gas pressures well below hydrostatic to either prevent pooling at the base of the production well, or to delay pooling until the reactor is effectively quenched (the injection of CO₂ is an option here).

**Cooling and Flushing**

During venting, groundwater influx will increase as the difference between hydrostatic pressure and the reactor pressure increases. The impact that this increased groundwater influx will have depends on the rate of inflow that will occur. If flows are reasonably high, then this can have the effect of “quenching” the reactor (thus preventing the continued pyrolysis of coal in the reactor walls) and “flushing” pyrolysis products from the reactor walls into the reactor.

In locations where groundwater flow is not likely to be adequate to cool the reactor quickly enough to limit pyrolysis, water should be injected from the surface (although steam has been used in shallower trials, this is not considered a viable option at depth due to the high temperature of the steam and the fact that a pressurised steam generating plant would be specifically required for the task).

At the conclusion of depressurisation, the reactor will be filled with water and the system will have returned essentially to the geothermal temperature. There will then be the option of circulating the system to flush residual
contaminants. The use of a dilute hydrogen peroxide solution to oxidise any remaining organic pollutants is also an option, but the effectiveness of this procedure has yet to be tested, and is only really necessary if contaminant concentration levels are high.

**Restoration**

After the venting, cooling and flushing and operations are completed, the gasification cavities will remain full of water with dilute concentrations of pyrolysis products and leachate that may still exceed pre-burn concentrations.

The objectives of the restoration process will be (i) to remove residual UCG generated contaminants from cavities and quickly re-establish a stable groundwater system, and (ii) to treat the waters removed so that they are environmentally suitable for discharge to the surface.

In previous trials, natural restoration processes have been shown to restore reactor water quality to near baseline conditions with time. However, as noted in Chapter 2, biological processes may not have a significant impact at the depths proposed for the UK, so the slower physical (dispersion and adsorption) and chemical activity may be the predominant mechanism for restoring groundwater quality.

Dependent on the initial residual concentrations and their rate of decline, an active restoration process should be considered. This could involve pumping the reactor waters to surface and treating them in suitable surface plant before discharge. The number of reactor volumes of water to be pumped to surface will depend on the rapidity with which contaminant concentrations in the cavities recover baseline values.

Restoration may be complicated by the fact that contaminants are entrained within coal cleats and may only really move in slower flowing groundwater conditions via the process of diffusion. This means that flushing the reactor may only remove a proportion of the available contaminants. It is not clear at this stage whether this is a realistic concern at depth, but monitoring contaminant trends in the flooded reactor should give some indication of the mechanisms that are occurring at depth. Care should be taken when interpreting results to determine whether groundwater is still flowing towards the reactor. If flow is simply through the reactor as part of a generalised flow regime then there is no reason to suppose that contaminant levels will increase, even if there are still appreciable levels of contaminants left in the pyrolysis zone.

Repeated flushing of the reactor will have the added benefit of ensuring that groundwater flow is still towards the reactor, which will limit leachate migration post-gasification. Flushing, combined with water quality monitoring can therefore significantly lower the risk of leachate migration if there are concerns over long term groundwater risks at a particular site.
3.3.2 Well and Lagoon Closure

Any wells that are not being used for long term monitoring purposes will have to be abandoned after operations. On abandonment, wells should be plugged with cement for their entire length to prevent potential contaminant migration within the well bore.

Proposals for the abandonment of wells have to be agreed with the HSE Oil and Gas Directorate (OSD) at the design stage and the OSD must be notified of the intention to abandon a well at least 21 days in advance of any abandonment operation. The normal responsibility of the OSD is to ensure that oil and gas wells are left in a safe condition and standard procedures are documented\(^1\) for removal of casing, sealing and cement bond logging.

The OSD do not however, cover environmental hazards occurring after drilling and completion of the in-well processes, or at a distance from the boreholes. These are matters for the planning process and the EA. The EA is therefore the key authority in defining and monitoring abandonment arrangements.

Depending on the type of bottom hole completion and the position of the well in relation to the gasifier, plugging may require the setting of a packer at the bottom of the casing prior to filling the well. Satisfactory filling must be demonstrated, generally by filling in sections and then loading the each plug by lowering the drill string onto it.

On site storage lagoons should be emptied and sediments should be tested to determine landfill options, as discussed for drill cuttings disposal. Lagoons should then be filled with appropriate local materials (possibly site bunds etc.) for final closure.

3.3.3 Options for Post Gasification Monitoring

Groundwater monitoring requirements have already been discussed earlier in the operational section of this Document. Longer term monitoring should be geared towards potential leachate transport rather than gas escape, so sampling and testing should consist of the major contaminants already identified in this document.

Timescales and frequency of monitoring will be dependant on the perceived risk from the site.

As well as checking the quality of groundwaters, it is recommended that any of the operational wells that are left open for monitoring purposes that directly intercept the reactor are periodically tested for mechanical integrity to avoid contamination by leakage. The US Environmental Protection Agency recommends that mechanical integrity tests are carried out every year on

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\(^1\) UKOOA guidelines for suspension and abandonment of wells
internal well casing and every 5 years on the outer casing for hazardous injection wells. However, practical monitoring methods for external integrity tests are very problematic and there is no standard test. Internal integrity tests such as the ones described for well construction may therefore be the only realistic option.
4. STANDARD ENVIRONMENTAL CONSIDERATIONS

The following Chapter identifies best practice for the management of environmental aspects associated with those activities likely to be common to more than one phase of a UCG trial or semi-commercial UCG project. The relevant environmental aspects and the best practice controls that should be applied to them are identified below, along with the activities likely to give rise to the aspects and the phases during which these activities are likely to be undertaken.

The relative importance of the environmental aspects and the degree to which the controls should be applied will depend upon both the nature of the UCG project (i.e. whether it is a trial or a semi-commercial project) and the sensitivity of aspects of the surrounding environment (e.g. the proximity to residential areas, the quality of local watercourses etc.). The aim of this Chapter is to highlight those practices that should be considered for application to both UCG trials and semi-commercial projects.

4.1 CONTROL OF DUST

Emissions of dust from UCG projects are likely to be most significant during the construction and drilling phase and the eventual site restoration phase. The principal source of these emissions will be earth works and soil stripping activities undertaken to construct the infrastructure necessary for a UCG project e.g. drilling pads suitable for locating heavy drilling equipment; maintenance areas for the maintenance of plant and the storage of consumable materials; foundation works for gas clean up plant and turbine halls etc.

During the construction phase, water spraying should be used to control emissions of dust from surfaces exposed during soil stripping operations and other excavation activities (including stockpiling of top-soil, other excavated materials and demolition rubble). The rate of application of water should be such that the surface remains damp but the dust is not washed off the surface into local water courses. Emissions of dust may also be reduced through the erection of wind fences on the site perimeter.

Activities involving the movement of soil, other excavated material or demolition rubble, should be kept to a minimum and carefully planned so that they are not undertaken unnecessarily. Stockpiles of such materials should be created away from sensitive boundaries (i.e. those up wind of sensitive receptors such as residential areas). The drop height should be minimised when loading dust laden or dust creating materials into trucks or onto stockpiles.

Stockpiles should be of similar heights and should be located in areas where they are protected from the prevailing winds by topographical features or
existing vegetation. Where possible, stock piles should be aerodynamically profiled in relation to the prevailing wind. Top soil and other excavated materials that are to be used for reclaiming the site at the end of the project should be constructed so that they can be seeded to prevent them from giving rise to emissions throughout the duration of the project.

During both the construction phase and the operational phase, the effect of large numbers of heavy goods vehicles on site access roads may also cause substantial emissions of dust. Site roads - particularly those that will be used frequently by road tankers delivering raw materials (e.g. oxygen, water and other consumables) during the operational phase of a UCG trial - should be hard-surfaced. Un-surfaced roads that are subject to frequent traffic movements should be routed away from sensitive receptors or where this is not practicable, they should damped down during periods of dry, windy weather. Vehicle speeds on un-surfaced roads should be limited to less than 10mph.


4.2 CONTROL OF NOISE

The construction and demolition phases of a UCG project will involve the use of a number of pieces of plant that could make a substantial contribution to noise levels on and off the project site. Such plant is will include earth moving equipment, excavators, piling plant, drilling rigs, cement and concrete mixing plant, concrete crushing plant and heavy goods vehicles for the delivery of aggregates etc.

Where practicable, noisy plant and operations that do not have to be undertaken in specific locations (such as unloading and stockpiling aggregates) should be located away from noise sensitive receptors. However, the location of many noisy activities will not be flexible and in all such instances, some form of noise barrier should be erected to shield noise sensitive receptors from these noise sources.

The construction of earth bunds along strategic lengths of the site perimeter may be appropriate. Where the availability of bunding materials is limited, acoustic screens should be considered as an alternative. A range of acoustic screens are available and the most appropriate design will depend upon site specific factors such as the location of the noise source with respect to the sensitive receptor and the level of noise emitted from the source.

Noisy construction activities and the operation of noisy construction or demolition plant should be undertaken during normal working hours (rather than at night) and be switched-off when not in use. However, this may not always be feasible.
It is likely that drilling operations will be undertaken continuously over a period of several days. Since noise can have a greater impact on sensitive receptors during the night, consideration should be given to the erection of acoustic screens around the drilling pads and other areas where particularly noisy stationary plant such as the diesel powered generators and compressors needed for drilling operations will be located. Alternatively, the compressors and generators could be enclosed in one or more suitably ventilated acoustic sheds.

Detailed guidance on the assessment and control of noise from construction and demolition sites can be found in BS 5228: 1997, Parts 1, 2 and 4.

The PPC regulatory regime will require the best available techniques to be used to control emissions of noise from a UCG installation. Within an operational UCG trial installation, the main sources of noise will include the gas combustor and emergency flare. The air separation unit, gas clean-up plant and gas turbines will be the main sources of noise during the operational phase of a semi-commercial project. In both trial and semi-commercial projects, the production well head (from which gas will be drawn off at velocities of greater than 100m/s) will also be a significant noise source.

Well heads, combustors and product gas clean-up plant will need to be enclosed in acoustic sheds or behind acoustic screens capable of abating low frequency noise (<50Hz). Means of minimising the velocity of gas entering a combustor or flare should be considered as much of the noise arising from combustion of gas is related to the turbulent flow caused by high gas velocities. In a semi-commercial project, the turbine hall should also be constructed to ensure that suitable abatement is provided for the operational noise of the turbines. It may also be necessary to install silencers or acoustic louvers on stacks and exhausts.

The control of noise should be considered at the design stage as it will prove difficult to address any problems after construction. Substantial guidance on the BAT for controlling noise from PPC installations is provided in Environment Agency etc., 2002a, Environment Agency etc., 2002b and BS 4142: 1997.

4.3 PREVENTION OF POLLUTION OF WATERCOURSES AND GROUNDWATER FROM SURFACE ACTIVITIES

There are a wide variety of surface activities associated with the UCG trial and semi-commercial project, which could result in the pollution of watercourses and/or groundwater. The following controls should be used to prevent the pollution of watercourse and groundwater.
During construction and demolition phases, levels of silt, dust and other sediments contained in surface water run-off should be minimised by minimising the amount of exposed ground and soil or stockpiles of soil, excavated material and rubble. Where it is necessary to stockpile soil or rubble, silt fences should be erected from geo-textile membranes to reduce silt levels in the run-off.

Where practicable, effluents should be prevented from arising from construction and demolition activities. In particular, water should be prevented from entering excavations through the use of “cut-off” ditches (designed to collect rainwater run-off and divert it around an excavation) or the use of physical subsurface barriers to prevent groundwater entering the excavation. Masters-Williams et al, 2001 provides detailed guidance on a range of techniques available for preventing effluent from entering excavations.

In many instances rainfall, groundwater levels and other factors outside the control of the construction manager or contractors, make it impossible to prevent effluents from being generated. Where this is the case, effluents should be managed in accordance with the principles outlined below.

Where possible, effluents arising from construction etc. activities should be discharged to the public sewer, rather than to local water courses. All such discharges need to be made with the consent of the sewerage undertaker responsible for the operation of the public sewers in that area and in accordance with all conditions stipulated in the certificate of consent. In circumstances where it is not possible to discharge effluent to a public sewer, it will be necessary to apply to the EA or SEPA for consent to discharge effluent to local a watercourse or to the ground via a temporary soakaway. Discharges to watercourses or the ground will need to be made in accordance with the conditions specified by the EA or SEPA in the certificate of consent.

In applying to the sewerage undertaker or the EA for consent to discharge effluent to the public sewer, watercourse or ground, it will be necessary to provide a prediction of the quantities and rates of flow of effluent, as well as its likely quality. This information will depend upon the ground conditions specific to the location of the UCG trial or semi-commercial project and should be derived from the results of ground investigations.

To ensure compliance with the conditions of the relevant discharge consent, it may be necessary to treat effluent arising from construction etc. activities prior to its discharge. Effluent loaded with silt, dust or other sediment will most likely need to go through some form of settlement prior to discharge. Masters-Williams et al, 2001 provide guidance on the use of a number of techniques for treating effluent arising from construction sites, as well as a method for calculating retention times and storage volumes for the settlement of sediments.
Effluent arising from excavations in land contaminated with chemicals or other hazardous materials is likely to require more advanced treatment before it can be discharged to public sewer or a local watercourse or the ground. In such circumstances, it may be less costly to contain the effluent in a holding tank and have it removed from site by road tanker. Effluent disposed of in this manner should be disposed of in accordance with the guidance provided in the section below on *Waste Management and Disposal.*

Means of controlling run-off and disposing of effluent arising from construction etc. activities should be identified during the early construction planning stages and the advice of the EA or SEPA and the sewerage undertake should be sought at least six months in advance of the work starting (the process of making an application for consent to discharge can take at least four months).

In England, the storage of oil, fuel and other substances in above ground (fixed or mobile) containers with a capacity of 200 litres or more is regulated under the Control of Pollution (Oil Storage)(England) Regulations 2001 (HMSO, 2001). Similar legislation is due to be introduced in Scotland in the near future (Environment Agency etc., 2001a). The requirements of the 2001 Regulations will apply during all stages of the UCG trial and the semi-commercial project and should be regarded as standard practice in those areas of the UK where they do not apply. There is a substantial amount of guidance available on the storage of oils, fuels and other consumable liquids. In particular, the following guidance should be referred to when considering the storage of such materials: Environment Agency etc., 2001a; Environment Agency etc., 2001b; DEFRA, 2001; Mason *et al,* 1997b.

Surface water that drains from access roads, delivery yards and other areas in which plant and equipment will be used, will be contaminated with oil, fuel, dust and other contaminants picked up from the surfaces of these areas. The following techniques to prevent surface water becoming contaminated should be considered for incorporation into the design of the surface water drainage systems serving both the UCG trial site and the site of the semi-commercial operation:

- Uncontaminated rainwater from roofs should be segregated from any rainwater from capped ground likely to become contaminated during the course of the project (e.g. access roads, plant and machinery yards and other areas where oil drips may accumulate over time).
- Uncontaminated rainwater from roofs should be discharged from down-pipes directly into the surface water drainage system via direct drain points or sealed top, side entry gullies. Open gullies and grates should not be used to collect roof water from down pipes as they provide an entry route for contamination.
- Areas used for loading and unloading liquids (oils, fuels, solvents etc.) should be roofed to minimise the amount of contaminated surface
water they give rise to. These areas should be isolated from the surface water drainage system using ramps, roll-over bunds or stepped access. Any surface water arising from these areas should be discharged to the site effluent treatment system or the public sewer.

- **Class 1 (as defined in European Standard BSEN 858)** full-flow oil separators should be installed at appropriate locations within surface water drainage systems serving site access roads and those yards where no substantial quantities of oil, fuel etc. are stored, unloaded or used.

- **Class 1 or 2 (as defined in European Standard BSEN 858)** by-pass separators and/or penstock valves should be installed in surface water systems serving areas in which substantial volumes of oils and/or fuels are to be stored or used. N.B. the use of oil separators to treat surface drainage contaminated with a substantial oil spill could require the oil storage capacity of the separator being equivalent to that of the original oil container (perhaps a 20m³ oil tanker) and that the installation of separators of this sort of capacity will involve high costs. An alternative approach may be to construct a remote secondary containment system (see below). Further information on the use of oil separators and methods of sizing full retention and by-pass separators are provided in Environment Agency etc., 1996.

- **Gully pots** should be installed in surface water systems providing drainage for site access roads and yards. Gully pots require frequent maintenance and should be cleaned at least once or twice a year or directly following any incidents and accidents in which they are likely to have become contaminated (Osborne *et al*, 1998). Waste arising from the cleaning and emptying of gully-pots should be dealt with in accordance with the guidance provided in the section below on *Waste Management and Disposal*.

- **UCG trial sites** will not require a substantial remote secondary containment system. The installation of penstock valves in the surface water drainage system is likely to be sufficient, providing that all primary containment is provided with appropriately designed and maintained local secondary containment such as bunds and drip trays. A semi-commercial UCG site is likely to require a more substantial remote secondary containment system. In particular, the system should be designed to contain the quantity of fire water run-off likely to be generated in response to fires in the gas treatment plant and the power generating plant. It is likely that the most cost effective means of incorporating a remote secondary containment system into the site of a semi-commercial project would be to design sufficient extra capacity into lagoons or tanks to be used to collect process water. It should be recognised however, that this will require substantial changes to the design and management of such holding facilities from that of facilities used for holding process effluent only.
In both cases, the final decision as to the design of a remote secondary containment system should be based upon an assessment of the consequences of all incidents identified by HAZOP studies or similar hazard identification and assessment processes. Where a system is to be used to contain fire water, the local fire service should be consulted during the design phase, as to the nature and likely quantities of the fire water that would be generated in response to predicted fires. Substantial guidance on the design and operation of remote secondary containment systems is provided in Environment Agency etc., 1999 and Mason, *et al.*, 1997a.

The nature of the UCG project and the sensitivity of its location will determine which of the controls identified above should be employed in any one UCG project. For example, it is most likely that a semi-commercial UCG operation sited in a sensitive location would require a site surface water system that effectively isolates the site from the rest of the water environment (i.e. local water courses and groundwater). The site surfaces should be constructed of impermeable concrete with sealed joints, laid on an impermeable geo-textile membrane, and the surface water systems be engineered to contain all rainwater that falls onto them, as well as to prevent off-site surface water flowing onto the site. If necessary, the surface water drainage system could be designed so that it routinely diverts all surface water run-off to an effluent treatment plant. It should also be installed with remote containment systems designed to contain liquids arising from all likely foreseeable incidents (including fire-water). A similar design of site surface water drainage system is employed by BP for its on-shore oil well sites at its Wytch Farm development in Dorset.

Whilst the design of site surface water drainage system described above should be considered for a semi-commercial operation (which would be expected to operate for approximately twenty years) the level of cost and engineering involved is likely to prevent it from being appropriate for a UCG trial (with a predicted operational phase lasting only nine months). A less substantial surface water drainage system is likely to be more appropriate for the UCG trial, but its final design will depend upon the level of protection required for the surrounding environment. However, it should be noted that the relevant regulator (the EA or SEPA) should be consulted as to the design of site surface water drainage system for any UCG project.

UCG trials and the semi-commercial projects should have a pollution incident response plan that includes a list of key contact numbers for emergency response co-ordination staff, emergency services, the relevant environmental regulators, the local sewerage undertakers, the Health and Safety Executive and specialist clean-up contractors. Incident response procedures should also be included within the plan to cover those incidents identified as being most likely to occur (e.g. leaks, spills, fires etc.). Further guidance on pollution incident response planning is provided in Environment Agency etc., 2000.
4.4 CONTROL OF TRAFFIC

The substantial quantities of raw materials, engineering plant, consumables etc. required by a UCG trial or semi-commercial project means that there will be a considerable number of vehicle movements to and from the project site. Traffic is likely to have a significant impact during the construction and demolition phases of a semi-commercial project and during all three phases of a trial project (the operational phase of a trial project is likely to involve frequent road tanker movements to supply water and oxygen to the site). It is therefore, important that traffic and its environmental impacts are given consideration in the planning and management of such projects.

Traffic or certain vehicles (particularly construction vehicles, heavy goods vehicles and road tankers) associated with UCG sites should be restricted to specific routes that will minimise the number of sensitive locations likely to be affected. Where it is not possible to identify routes without any sensitive locations, consideration should be given to restricting the hours during which traffic may travel to and from the UCG project site (local planning authorities would control traffic movements on and off-site by placing restrictions on the site’s hours of operation). This may include the prohibition of traffic being allowed on or off the site during night time, weekends and times during the day when local traffic conditions are likely to be most affected. Again, this is particularly applicable to deliveries made by heavy goods vehicles, which, because of their size, speed and associated noise levels, are likely to contribute most to traffic impacts.

It may also be appropriate to limit the size and speed of vehicles travelling to and from the site, particularly if the highways to be used comprise minor roads. In areas where minor roads have to be used and depending upon their level of pedestrian use, it may also be appropriate to provide street lighting and widen the footways. Where traffic and vehicle noise is likely to be an issue, consideration should be given to the provision of temporary or permanent noise barriers. However, it should be recognised that in many circumstances, the accompanying visual impact of noise barriers may restrict their feasibility.

The impacts of dust and dirt on roads and surrounding areas should also be controlled. Haulage vehicles carrying aggregates, rubble, concrete, spoil and other potential sources of dust should be covered. Wheel washing facilities should be provided for vehicles leaving the site, particularly during the construction and site reclamation phases.

4.5 WASTE MANAGEMENT AND DISPOSAL

Producers of solid wastes such as rubble, spoil, soil etc. arising from the site clearance, excavation, construction and other activities undertaken during the construction phase should store these wastes on site in such a manner that
they do not emit dust into the air or cause dust or sediment to be carried into local water courses. Waste liquids such as waste oils etc. should be stored in suitable containers with a suitable secondary containment.

Construction and demolition wastes should only be removed from the premises at which they were produced by a waste carrier registered under the Control of Pollution (Amendment) Act 1989 and The Controlled Waste (Registration of Carriers and Seizure of Vehicles) Regulations 1991. Waste should only be transferred to a carrier with a transfer note, as required by the Environmental Protection (Duty of Care) Regulations 1991. Detailed guidance on procedures for disposing of wastes is provided in DETR, 1996.

The transfer of wastes with certain hazardous properties is controlled under The Special Waste Regulations 1996. The 1996 Regulations require that transfers or consignments of “special waste” are made with a special waste consignment note. Detailed guidance on the identification and consignment of special waste is provided in Environment Agency, 2001.

All wastes (special or otherwise) should only be transferred to licensed waste facilities or facilities that undertake waste management activities exempt from waste management licensing. Facilities used to undertake exempt waste management activities should be registered with the regulating authority.

Certain activities involving the storage, treatment or disposal of wastes may be undertaken on the UCG project site as part of the construction process (e.g. the storage of crushed concrete or the use of similar materials to back fill excavations). It is likely that such activities would be viewed as waste management activities and would require a waste management license or registration as exempt activities. Where such activities are planned, the local regulatory authority should be consulted as to whether licensing or registration is necessary.

The operation of the UCG installation and the eventual reclamation of the site of the installation (be it an installation involved in a trial or a semi-commercial project) will be controlled under the Pollution Prevention and Control Regime. It is likely that the permit issued to the operator under this regime would specify the quantities and types of wastes permitted to be disposed of from the installation and the treatment or disposal route by which they should be disposed of. The operator will be obliged to comply with the conditions of the permit as well as the regulatory requirements described above.

### 4.6 CONTAMINATED LAND ISSUES

In those instances where the proposed location of a UCG project is a previously developed site, consideration needs to be given to the possibility that the past uses have caused the site to become contaminated with hazardous substances. This is of particular concern for the design of sub-
surface construction work during the semi-commercial project, where it is likely that substantial ground improvement work such as piling (to create suitable conditions for the location of a gas treatment plant and turbine hall) could be required. There are number of potential hazards associated with the development of contaminated sites, including:

- the exposure of site workers and the general public to hazardous substances as a result of the work during the construction phase;
- the creation (as a result of piling and other penetrative ground work) of preferential pathways for contaminants to migrate through impermeable strata, into underlying aquifers;
- the displacement of contaminating substances into aquifers;
- the creation (as a result of piling and other penetrative ground work) of preferential pathways for gaseous contaminants (landfill gas, soil gas, solvent vapours etc.) to migrate upwards through impermeable strata, to the surface;
- the direct contact of underground structural work (concrete, steel etc.) with corrosive and otherwise degrading substances; and
- the exposure of site workers and (less likely) the general public during the operational phase of the project.

To be able to manage these hazards effectively, it will be necessary for the developer to determine the type and extent of any contamination present in the site before the construction work starts (or even during the site selection process). All site surveys should be planned and undertaken by suitably qualified and experienced personnel and performed in accordance with recognised Codes of Practice such as BS 10175: 2001 and BS 5930: 1999.

The results of the site surveys should be used to characterise and evaluate the risks posed by the proposed work in relation to each of the hazards identified above. The various risk assessments needed to do this and their results should be presented in a Foundation Works Risk Assessment Report, which should accompany any application for planning permission.

The Foundation Works Risk Assessment Report should provide the local planning authority, Minerals Planning Authority or DTI (depending upon the planning process) and the EA or SEPA (as consultees in the planning application process) with sufficient information to be able to assess whether they are satisfied that the proposed development works will not pose an undue risk to underlying aquifers, site workers or the general public.

Further guidance on managing the risks associated with penetrative ground works on contaminated sites and the production of a Foundation Works Risk Assessment Report may be found in Westcott FJ, et al, 2001.
4.7 SITE RESTORATION

The restoration of a UCG project site on cessation of operations will be controlled under both the planning regime and the Pollution Prevention and Control regime. Any planning permission provided for a UCG project will impose conditions requiring the site to be restored and provided with sufficient aftercare to make it fit for beneficial after-use or enhance the overall quality of the environment (in accordance with Government policy).

As discussed in Chapter 2, there is no guidance for Minerals Planning Authorities specific to UCG developments. However, a draft guidance note providing a policy framework for considering planning applications relating to on-shore oil, gas and coal bed methane development, has been issued for consultation by the Office of the Deputy Prime Minister. Most relevant to restoration of UCG project sites, the draft guidance note specifies the actions that should be agreed by the DTI and the operator in an abandonment programme for the abandonment of a coal bed methane development. These actions are likely to be similar to those placed upon the operator of a UCG project prior to its abandonment and include: sealing the entire length of all well bores with cement; cutting the well casing two metres below ground level and sealing the remaining casing with a welded steel plate; backfilling the excavation required to accomplish this work; and the complete removal of all production equipment and security fencing etc. The design of the equipment and site should therefore, be such that their removal and restoration may be easily achieved.

The site should then be cleared of all hard standing (e.g. drilling pads, maintenance yards etc.) and crushed stone and the top-soil and sub-soil re-spread and treated to relieve compaction. Finally, the site should be restored to its original condition through a period of after-care management. Further information on the restoration of sites subject to mineral planning can be found in Minerals Planning Guidance 7.

Regulation 11(3) of the Pollution Prevention and Control Regulations 2000, places a requirement on operators of PPC installations to take the necessary measures “to avoid any pollution risk and to return the site of the installation... to a satisfactory state”. In effect, this requires the operator to return the site of the installation to the condition it was in prior to the PPC permit being granted.

The condition of the site of the installation prior to the issue of the permit should be determined by the operator in the “Application Site Report”, required as part of the permit application process. The Application Site Report should cover all the land on which the installation and its activities are based and identify the nature and extent of any contamination within the site. The nature and extent of contamination within the land should be identified.

On definitive cessation of the operation of the installation, the operator will be responsible for surrendering the PPC permit. Once the regulator has accepted the surrender of the permit, it will cease to have effect. However, the regulator will only accept the surrender of the permit if there is no pollution risk and nothing more is needed to return the site to a satisfactory state.

To satisfy the regulator that these conditions have been met, the operator should submit a “Closure Site Report” that describes the condition of the site and identifies any changes from the condition described in the original Application Site Report submitted with the permit application. Where pollution of the ground is known to have occurred during the operation of the installation, the operator should first undertake the appropriate remedial work to ensure that there is no pollution risk and that the condition that the site will be left in will be satisfactory to the regulator (i.e. the site is returned to the condition identified in the Application Site Report).

It is suggested that discussions with the regulator as to what remedial work is necessary, should be undertaken prior to the installation ceasing operation and certainly before the Closure Site Report is produced. The regulator is likely to want to see the following remedial work:

- the removal, treatment or immobilisation of any pollutants;
- the remedying of any harm caused by the pollution; and
- the mitigation of the effects of that harm.

In the event that no polluting incidents occurred during the operation of the installation and this can be demonstrated to the satisfaction of the regulator through the use of a robust incident reporting and recording system, then the regulator will not require any remedial works. However, this should be confirmed with the regulator before the Closure Site Report is produced.

The interaction between the PPC regime and the planning regime is likely to be subject to negotiation between the relevant regulators of the two regimes. For example, where the removal of certain items of equipment on cessation of operations is not specified in the planning conditions, their removal may be required by the PPC regulator, either as a condition within the PPC permit at the time of issue or through permit surrender discussions with the operator during the permit surrender process.
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