Gasworks remediation in the UK – a remediation contractor's perspective

JAMES BAYLIS[1] & DOUGLAS ALLENBY[2]

[1] *Edmund Nuttall Limited, Camberley GU15 3XW, UK. (e-mail: James.Baylis@edmund-nuttall.co.uk)*
[2] *Edmund Nuttall Limited, Camberley GU15 3XW, UK. (e-mail: Doug.Allenby@edmund-nuttall.co.uk)*

Abstract: The destructive distillation of bituminous coals to produce coal gas, coke, coal tar and ammoniacal liquor has left many of our towns and cities with heavily contaminated gas production and storage sites.

Contaminants range from long chain hydrocarbons in the form of viscous tars, to the much shorter chain highly volatile hydrocarbons. Polycyclic aromatic hydrocarbons can form a significant proportion of gasworks waste and some are carcinogenic. Inorganic contaminants include compounds of cyanide, sulphur, ammonia and heavy metals. Each site poses a significant risk to human health, groundwater and the surrounding environment demanding major remediation before its full potential as a brown field development site can be realized.

The paper will examine a number of gasworks sites and describe the processes of remediation beginning with the legislative driving force, site investigation, contaminant identification and the formation of a remediation strategy to satisfy both regulatory authorities and clients. Also discussed will be the significant control measures necessary to manage hazards and protect both on site and off site receptors during the remediation process.

The authors will summarize with an overview of gasworks remediation, future developments and the options available for the many contaminated sites present in the United Kingdom.

Résumé: La distillation destructive du charbon bitumineux pour la production de gaz de houille, de coke, de goudron de houille et d'eau ammoniacale a laissé, dans un grand nombre de nos villes, des usines de production et stockage de gaz fortement contaminées.

Ces contaminants vont d'hydrocarbures à chaîne longue, sous forme de goudron visqueux, à des hydrocarbures très volatils à chaîne beaucoup plus courte. Les hydrocarbures polycycliques aromatiques, certains desquels sont cancérigènes, peuvent constituer une proportion importante des déchets des usines à gaz. Parmi les agents de contamination inorganiques, on trouve des composés de cyanure, soufre, ammoniac et métaux lourds. Chaque usine pose des risques graves pour la santé de l'homme, la nappe phréatique et l'environnement, et nécessite des travaux d'assainissement considérables avant de permettre la réalisation de son potentiel comme site recyclable.

La présente communication examine un certain nombre d'usines à gaz, et décrit les processus d'assainissement, de la dynamique législative jusqu'à l'examen du site, à l'identification des agents de contamination et à la création d'une stratégie d'assainissement satisfaisant à la fois les exigences des organes de réglementation et celles des clients. Cette communication se penche également sur les mesures de contrôle importantes qui sont nécessaires pour la gestion des risques et la protection des récepteurs intérieurs au site et extérieurs à celui-ci, au cours du processus d'assainissement.

Les auteurs résument la communication avec un aperçu général sur l'assainissement des usines à gaz, les développements futurs, et les options disponibles pour les nombreuses usines contaminées au Royaume-Uni.

Keywords: Contaminated land, site investigation, hazardous waste, groundwater contamination, remediation.

INTRODUCTION

From the late eighteenth century up until the 1970s coal gas production provided the rapidly expanding domestic and industrial markets with heating, lighting, fuel, and the raw chemical by-products for a wide range of manufacturing processes. The process, illustrated in Figure 1, required bituminous coal to be heated in the absence of air inside purpose designed retorts. The resulting vapour products were collected and passed through a purification process typically comprising tar traps, air- and water-cooled condensers, washers, scrubbers and purifiers to remove the coal tar, ammoniacal liquor, sulphur, and cyanide. Purified coal gas, principally comprising hydrogen 48% and methane 32%, but with ethylene, carbon monoxide, carbon dioxide and nitrogen, was then pumped into gas holders for distribution into the gas main. Traditionally the coke produced within the retorts was recovered and used to fire the gas-manufacturing retorts.

Throughout the period of coal gas production major advances took place in the cleaning and purification of the coal gas to optimize coal tar and ammoniacal liquor recovery for the chemical industry. Slightly different processes were also introduced for oil gas, producer gas and carburetted water gas production.

During the late 1950s and early 1960s a number of coal gas producing sites converted part of their generating capacity to the production of high- Btu oil gas, i.e. gas from oil, this ceased in the late 1970s.

To date there are no gasworks in operation in the UK, as all domestic gas is natural and sourced offshore.

Contamination was inevitable not only from the coal gas production process itself, but also from the substances imported for the purification process and their decomposition or reaction products. These may typically include, DOE (1995).

- hydrocarbons such as aromatics, polycyclic aromatic hydrocarbons, hydroxy phenyls
- inorganic compounds such as sulphuric acid, sodium hydroxide, cyanides, ammonium
- metals such as arsenic, cadmium, lead, mercury, and
- asbestos

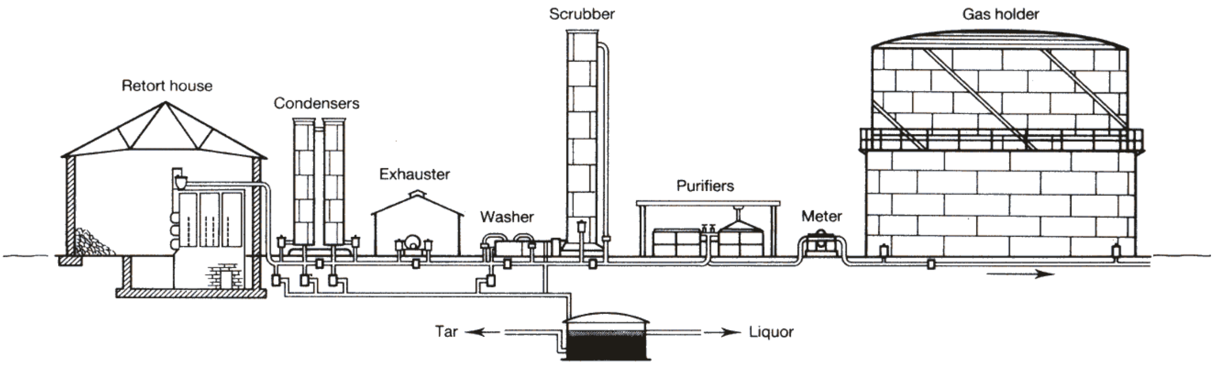

Figure 1. Coal gas production process, Leach & Goodger (1991)

THE LEGACY

During peak coal gas production there were some 2000 gas producing and gas storage sites across the UK, Leach & Goodger (1991), ranging in area from less than 1ha to 200ha, with a number of major works strategically located alongside industrial complexes producing coke, smokeless fuel and by products for chemical industries, for example The Avenue Coking Works, Chesterfield.

Plant decommissioning generally preceded the era of environmental awareness and was variable, concentrating more on the recovery of salvageable metals, saleable process products and materials than on remediation.

For example, the numerous pipe runs, culverts, surface and underground tanks, pits and chambers illustrated in Figure 1 were drained of their coal tar and ammoniacal liquors leaving contaminated residues and sludges. Surface pipe runs, plant and structures were then dismantled with scant regard to spillage.

Underground gas mains were filled with water to avoid the accumulation of potentially toxic gases, sealed and their valve chambers and access points backfilled with site sourced material. The roofs of underground chambers, tanks and near surface culverts were exposed, broken into and backfilled. Backfill material typically comprized inert demolition materials such as bricks, pipes, asbestos and wood. It was not uncommon for waste materials from the gas production process such as ash, catalysts and spent oxides including iron cyanide complexes to be used, Kjeldsen (1999).

Those gasholder bases with subsurface water-seal tanks were left structurally intact and backfilled. Many contain water and tar oils with the light non-aqueous phase liquids forming an oily layer on the surface of water while the denser non-aqueous phase liquids, comprising tar oils and tars, migrate and collect at the base of the structure. Water between these layers is often contaminated with metal complexes and dissolved phase hydrocarbons.

Recently exposed underground structures containing residues and backfill materials are illustrated in Figures 2 and 3. Figure 4 illustrates free tar in an exposed tar collection and storage tank.

Figure 2. A chamber containing a coal tar backfill mixture placed originally during plant demoliton.

Figure 3. A combination of pink-tinted phenolic liquor, water and backfill material within a subsurface chamber

Figure 4. Free tar within a subsurface tar collection or storage tank

THE LEGISLATIVE DRIVING FORCE

Over the past 25 years Government policy and legislation has been directed to promote the beneficial reuse of land damaged by industrial and related activities. Table 1 summarizes the key policy and legal developments.

Table 1. Key policy and legal developments

Mid 1970s	First recognition of the problem of redeveloping land previously used for industrial and related purposes. The Control of Pollution Act 1974
Early 1980s	Establishment of an interdepartmental advisory body (United Kingdom Interdepartmental Committee for the Redevelopment of Contaminated Land)
Mid to late 1980s	Development of technical guidance on contaminated land
1990	House of Commons Select Committee on the Environment Inquiry on Contaminated Land. Environmental Protection Act 1990
1991 – 1992	Consultation on proposals for the registration of potentially contaminated land based on past and current land use. The *Controlled Waste Regulations* 1991
1993	Initiation of UK Government review of contaminated land and liability. Publication of the European Commission *Green Paper* on Environmental Liability
March 1994	Publication of consultation papers as part of the Government review process. The *Waste Management Licensing Regulations*
November 1994	Conclusion of Government review and publication of UK policy paper, *Framework for Contaminated Land*
1995	Section 57 of the Environment Act 1995 (Part IIa of the Environmental Protection Act 1990)
1996	Publication of draft statutory guidance on Part IIa of the Environmental Protection Act 1990. *The Duty of Care – A Code of Practice*
1999	The Pollution Prevention Control Act
April 2000	Implementation of Part IIa of the Environmental Protection Act 1990 in England
2002	The Landfill (England and Wales) Regulations 2002
2005	The Hazardous Waste Regulations (England and Wales)

Under Part IIa of the Environmental Protection Act 1990 a new regulatory regimen for the identification and remediation of contaminated land was introduced. This regimen provides for the first time the following statutory definition of contaminated land which is based on risks of significant harm to human health and the environment, or pollution of controlled waters:

"Any land which appears to the Local Authority in whose area it is situated to be in such a condition, by means of substances in, on or under the land that;

- *Significant harm is being caused, or there is a significant possibility of such harm being caused;*
- *Pollution of controlled waters is being, or is likely to be, caused."*

The definition of ‘significance’ and its measurement are the subject of detailed Technical Guidance, much of which is still under development. Often legislation refers to ‘possibility’ and ‘likelihood’ which places the emphasis of enforcement on prevention rather than cure.

By adopting the principles of risk assessment and risk management Part IIa of the Environmental Protection Act 1990 ensures that contaminated land is managed effectively, based on its current use and environmental setting.

The lead regulator in respect to Part IIa of the Environmental Protection Act 1990 consultation is the Local Authority.

Statutory Remediation

Statutory Remediation stems from Environmental and Health and Safety Legislation. The primary legislation concerning contaminated land is Part IIa of the Environmental Protection Act 1990. In the definition of contaminated land, a site which is significantly harming, or has a significant possibility of harming the wider environment is under statute, ‘contaminated’ and therefore must be remediated. The three criteria to be satisfied are:

- a Source which has the potential to cause harm or pollution
- a Pathway, or route by which a receptor may be exposed to a contaminant, and
- a Receptor that could be adversely affected by a contaminant, eg a person, water body or ecological system

When a site is being assessed, the future drivers of risk need to be identified, even if they may not be an immediate statutory problem. For example, SecondSite Property (2003), Paragraph 13.2, Appendix 13, Section 11.0 states:

“Many sites contain below ground structures containing tar and other gasworks residues. While many of these are not leaking at present, virtually all are either past their design life (in some cases by more than 100 years) or were not specifically intended for that purpose (eg backfilled gasholder bases). Although the Environment Agency/Scottish Environment Protection Agency in many cases would regard these as representing a significant possibility of harm or as being likely to cause pollution of controlled waters, it could be argued that they do not meet the definition at present, for example, on the basis of their structural integrity.”

Non-Statutory Remediation

Often a contaminated site in an unused and derelict state does not constitute a threat as there are no onsite receptors to be considered. A change of use through sale or letting of the site would introduce new receptors, ie the site occupier and potentially cause the site to be statutorily contaminated. Thus non-statutory remediation may be undertaken prior to sale or lease to remove the longer term liability.

CONTAMINANT IDENTIFICATION AND THE FORMATION OF A REMEDIATION STRATEGY

The flowchart presented in Figure 5 overleaf illustrates the SecondSite Environmental Assessment Reporting Structure to be followed during the formation and execution of a remediation contract on one of their sites. Key stages in the process are as follows:

Desk Study

The desk study provides a rapid and relatively inexpensive method of establishing previous uses of the site and possible contamination. Main sources of information to be consulted are:

- previous occupant(s)
- Ordnance Survey Maps and aerial photographs
- town plans and fire insurance plans
- trade directories, journals, registers and archive reports including engineering records
- archaeology reports
- bomb incident reports
- geological records including mining and mineral plans, and
- hydrogeological records and more recently NRA Groundwater Vulnerability Maps

The desk study will identify short falls of information and detail the scope and content of the site investigation.

Site Investigation

This may be undertaken using a combination of boreholes and trial pits to determine the ground conditions on the site, including strata types and their horizons referenced to a site datum, groundwater table(s), subsurface structures and services. Continuous sampling is essential to determine the type and extent of contamination.

The site investigation report must make specific statements as to whether the site is considered contaminated land as defined by legislation, ie Part IIa of the Environmental Protection Act 1990. In addition the site investigation report must address the following:

- hazards to construction workers, users, occupiers
- chemical attack on building materials, ie sulphate attack
- identification of contaminated materials to be removed or treated
- information for the design of appropriate remedial measures
- outline of remediation proposals
- the possible end use(s) of the site, and
- the public interface

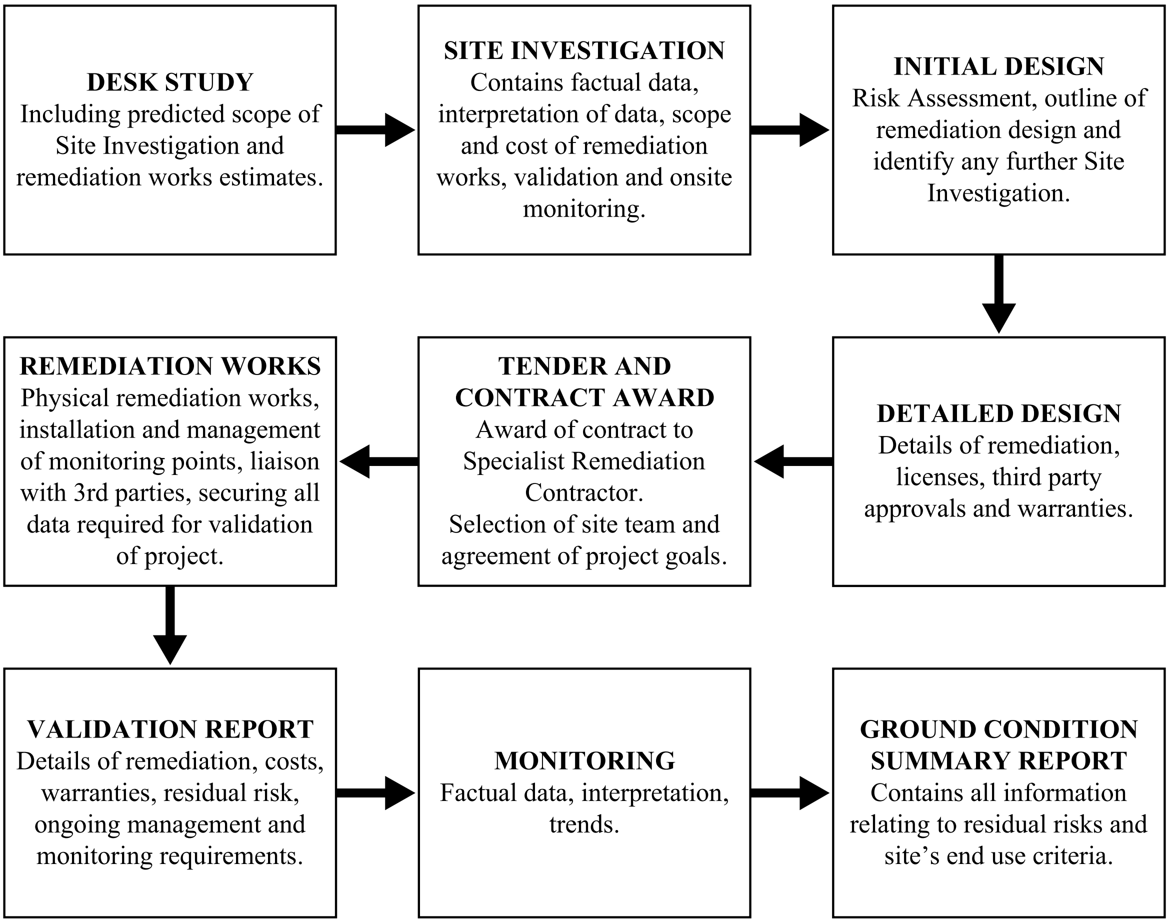

Figure 5. Environmental Assessment Reporting Structure, SecondSite Property (2003)

Initial Design

The initial design addresses the site liabilities associated with a continuation of the current use, or for a defined change of use. Proposals for remediation are based upon the Source-Pathway-Receptor linkages identified during site investigation.

A conceptual model is created, often as a schematic diagram, to allow main pollutant linkages to be highlighted. An example of a conceptual model highlighting pollutant linkages is shown in Figure 6.

Prior to a contract going to tender the Client or his representative will undertake a Quantitative Risk Assessment to determine site specific, risk-based remediation criteria. This allows remediation techniques to be evaluated against acceptable risk reductions and cost implications. The rationale behind the choice of remedial technique must be highlighted including the associated costs and uncertainties involved, or residual liabilities which may remain.

Detailed Design

Detailed design builds upon the initial design stage to establish the most appropriate remediation method(s) necessary to satisfy current legislation and bring the site to brown field status. This must be undertaken in consultation with experienced remediation contractors to take advantage of latest techniques, benefits from well proven practices. Realistic budget costs must be established to give the detailed design a practical bias essential for a timely and efficient remediation.

Utility providers must be approached to provide details of existing services and facilities to be maintained and to jointly establish the impact remediation will have on their operations, ie rights of way, maintenance requirements, diversions, etc.

Many sites of contamination are located within built up areas. It is therefore essential to assess the impact the proposed works will have on the local environment, residents, commercial activities, etc. For example it may be necessary to limit working hours and provide designated traffic routes to and from the site to satisfy environmental requirements and pressure groups.

Using the information collected to date the designer is able to take an overview and give a considered opinion as to the most appropriate remediation strategy. Detailed method statements, risk assessments, costings, licence applications, remediation and validation criteria, and programme are essential, together with an outline approvals procedure necessary to bring the site to brown field status.

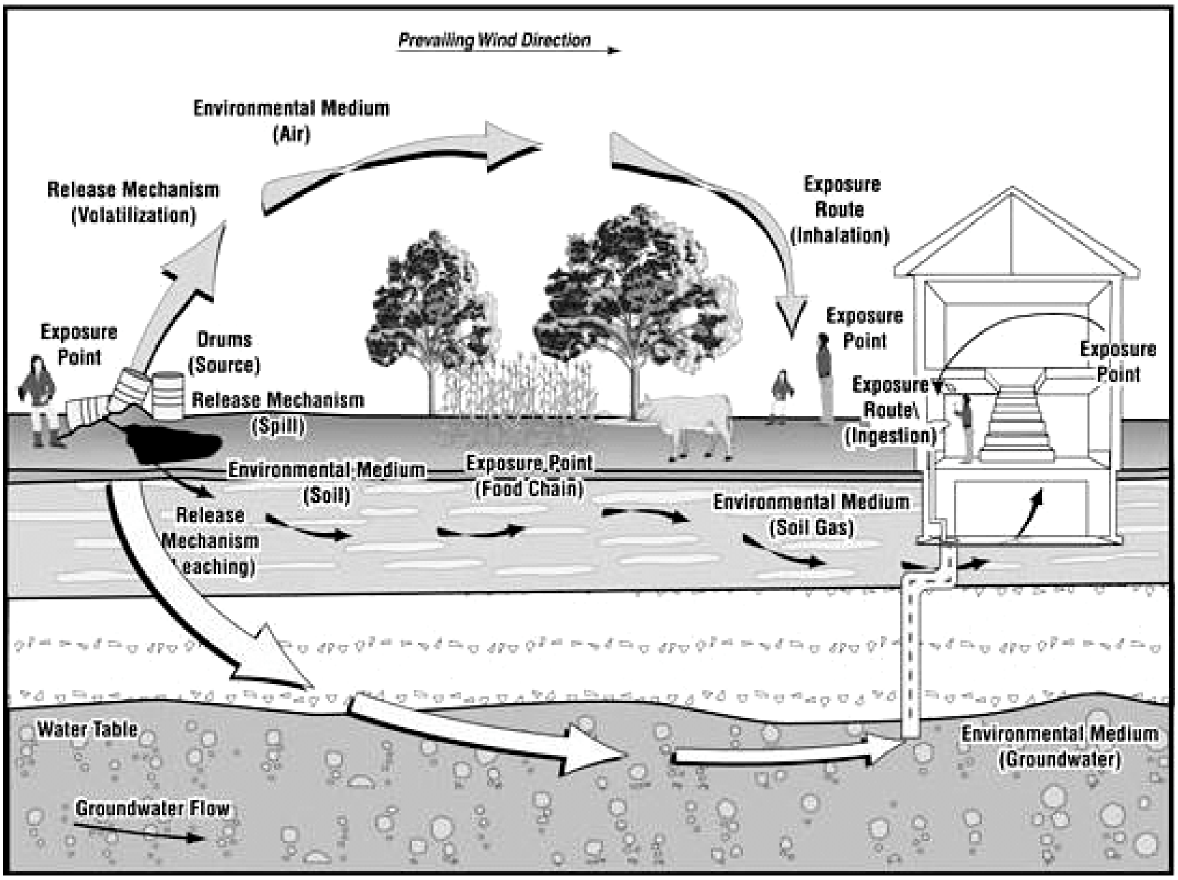

Figure 6. Example conceptual model (U.S. ATSDR)

Tender and Contract Award

Tender documents are prepared based on the detailed design, site owner's and legislative requirements. They should only be issued to contractors who have satisfied a rigorous prequalification process based on financial stability, proven track record, technical ability and the ability to manage and execute remediation works in a timely and efficient manner within budget.

All tenders submitted are assessed by the Client, or his representative, against predetermined criteria which principally include:

- cost, time and risk schedule
- method statements and associated risk registers
- health and safety, quality and environmental issues
- sustainability
- partnering, etc

Remediation Works

The physical works are the most important stage of remediation. They can also be the highest risk in terms of pollution to the environment, damage to human health, local amenities and cost escalation. Remediation contractors must execute the works with the highest regard to health and safety, quality, and the environment. Accurate programme and commercial restraints are also of importance, particularly where future development relies on timely completion. Preparation of risk assessments for each phase of the works is essential.

Project execution must be in accordance with ISO 9004:2000 Quality management systems – Guidelines for performance improvements, ISO 10005:1995 Quality management guidelines and BS 6079: 2002 Guide to project management. It should also meet the requirements of ISO 9001:2000 Quality management system and ISO 14001:1996 Environmental management systems.

Every gasworks site poses significant hazards. It is standard procedure to establish the site offices and welfare in a ‘clean’ main compound. The main site, plant and stores are located in the ‘dirty’ area where the remediation process(s) are taking place. Access to and from site must be through a decontamination unit and all operatives must wear the appropriate Personnel Protective Equipment. On restricted sites careful planning is essential to co-ordinate plant movements to and from material stockpiles.

Rigorous chemical testing prior to and during the works ensures all contaminated material is correctly identified in a timely manner. Some larger gaswork sites have had in excess of 1000 soil samples selected for analysis. This demands a rigorous management system for sampling, testing and recording of results. Crucial decisions relating to health, safety and the environment are based upon the analysis of these soil samples.

Daily environmental monitoring is essential to minimize risk and to prove compliance with site licences and consents, typical monitoring includes:

- emission to air, such as odour, vapour, dust
- emission to the environment, such as noise, light, vibration
- emission to controlled waters, such as surface water, groundwater, and
- asbestos fibre quantification

Gasworks sites are traditionally located in urban areas, often adjacent to residential properties, see Figure 7. Good public relations are essential when undertaking all remediation projects. Client, Contractor, Consulting Engineer and Local Authority must be actively involved in this process.

Figure 7. Aerial photograph of gasworks remediation adjacent to residential properties, Evans (2005)

The characteristic odour of tarry wastes is perceptible by the human nose at very low concentrations (threshold of about 2 ppb). During excavation it is essential to minimize the surface area of exposed wastes and to sheet stockpiles. Confined spaces including tanks, chambers and culverts are particularly challenging because they contain volatile hydrocarbons and ammonia and require extensive forced ventilation.

Odour and vapour monitoring is essential to protect the health and safety of site personnel and off site receptors. This can take the form of strategically sited monitoring stations which continuously sample, analyze and record contaminant levels against audible and visual warnings. Hand held absorption tube equipment, which give a contaminant level against a graduated colour change, must be regularly used during excavation, and operatives must carry portable detection equipment with built in audible and visual warnings at all times. Stringent procedures are to be followed when breaking into and working within confined spaces.

Operatives should wear organic vapour masks as part of their personal protective equipment. When monitoring indicates that concentration levels may exceed the protective capabilities of vapour masks operatives should be withdrawn until concentrations fall to safe limits. Alternatively positive pressure breathing apparatus can be worn.

Validation Report

Remediation validation is an ongoing process throughout the duration of the works and consists of a well planned range of observations and chemical tests.

The aim of remediation is to reduce risk to an acceptable level. The aim of validation is to show that remediation has been achieved. Therefore the validation strategy employs risk assessment as a measurement tool of residual risk against the Source-Pathway-Receptor linkages already identified. The reduction in environmental load of contaminants on the site and the consequent reduction in risks to receptors, ie humans, controlled waters and the environment must be demonstrated.

To demonstrate the success of remediation the validation report includes the remediation strategy, works undertaken, third party approvals, validation and quality assessments, environmental monitoring, final site conditions, options for redevelopment and residual risks assessments.

Monitoring

Following remediation ongoing monitoring can be a regulatory requirement and is typically restricted to groundwater monitoring over a prescribed period. A groundwater monitoring report details the objectives and timescale of the monitoring program, graphical representation of apparent trends and implications in terms of the conceptual model.

Ground Condition Summary Report

This report briefly summarizes in lay terms the findings of the validation report with a focus on the remediation process and the site's end use criteria.

REMEDIATION METHODS

The following remediation methods have been successfully used on former gasworks sites.

Excavation and Removal

The traditional solution to gasworks contaminated land of 'excavation and removal' has been challenged for a number of years, most seriously in the past two years as landfill gate tipping charges have increased dramatically in certain cases by a factor of 10. There is also growing concern that the practice removes the problem from one site onto another albeit in a more controlled environment, such as an engineered and licensed landfill site.

In the future 'excavation and removal' will have a role to play in the remediation of gasworks sites because certain materials have no financially viable alternative treatment, ie asbestos and contaminated filter cakes.

Soil Washing

Soil washing is a concentrating technique resulting in volume reduction by separating contaminated soils into two or more streams, clean and contaminated. Contamination tends to bind chemically and/or physically to fine soils including silts and clays, the fine soil in turn binds to more coarse sand and gravel. The washing process separates the contaminated fine soil from the more coarse sand and gravel fractions. Contaminants are extracted with the fine soils from the main mass of the soil being treated. Soil washing does not destroy contaminants, but instead aims to separate the contamination from the greater part of the material being treated.

This process aids the separation and removal of both organic and inorganic contaminants. Ideally the soil washing process should lead to a typical volume reduction of 90% treated material to 10% contaminated product which may require further treatment. Experience has shown soil washing is unsuitable for soils containing a high percentage of fine-sized particles <0.063mm in diameter.

Free phase coal tar does not lend itself to treatment by soil washing. Tar tends to 'ball' within the soil washing plant and can be transported over into the 'clean' sand and gravel fractions. Free phase tar encountered on a gasworks remediation site may have to be segregated for alternative treatment.

Bioremediation

Bioremediation uses micro-biological activity in a controlled environment to degrade contaminants, primarily hydrocarbons. Above ground this is carried out either in biopiles using forced aeration, composting techniques and nutrient addition, or in soil windrows where composting techniques and nutrient addition are used within a low-tech environment. Below ground bioremediation involves injecting nutrients to accelerate the process. This can stimulate the degradation of complex chemicals in the soil or groundwater into less hazardous compounds, and ultimately into residuals of water and carbon dioxide.

Mobilisation costs for bioremediation are significantly lower than those for soil washing. The process can also be used with soils containing a higher fines content. Treatment periods are dependant upon micro-biological activity, the degree of contamination and soil type.

Hydrocarbons such as polycyclic aromatic hydrocarbons found in coal tar, resist biodegradation which inevitably leads to extended treatment periods.

Thermal Desorption

Contaminated material is fed into a purpose designed rotary kiln in a controlled manner and is heated to between 250ºC to 900ºC to encourage contaminants to volatilize. The off-gas is transported to a thermal oxidizer where contaminants are incinerated at 1900ºC. Resultant flue gases are scrubbed to remove residual particles which are then collected for off-site disposal. The process is ideally suited to the treatment of hydrocarbon contaminants. Thermal desorption requires significant energy input and is therefore only suitable when site conditions preclude the use of other techniques.

Alternative Remediation Techniques

The authors recognize there are other remediation techniques suitable for gasworks contamination, for example Stabilisation/Solidification, Chemical Oxidation, and Air Sparging. These are not discussed in this paper.

EXAMPLES OF REMEDIATION CONTRACTS

Bury Gasworks, Bury, Greater Manchester

Project

To clear the site, demolish all buildings above ground level, undertake further site investigation and perform statutory remediation.

Challenge

Bury Gasworks posed a number of challenges, namely:

- the demolition of 2 buildings containing various forms of asbestos insulating materials
- the exposure and removal of liquid and solid contaminants from 3 underground gas holder bases and associated tanks
- the presence of live, high pressure, vibration sensitive, present-day gas distribution apparatus located directly adjacent to a 10m deep tar well excavation
- a live Transco depot requiring gas-service access to be maintained at all times
- a Victorian-aged fragile brick culvert located between a contaminated tar tank and a gasholder base, and
- a 12 week remediation programme

Solution

Significant planning and resources were invested before contract award, permitting the site team to fully develop the strategy for each specific challenge and commence site activities to programme. Site investigation and asbestos removal were performed concurrently. Wherever possible materials were recycled within the works, for example slates and metal were recycled, bricks were crushed for fill material. The existing surface water drainage system was sealed and surface water runoff routed to the town water treatment system. Existing boreholes were used for groundwater quality monitoring throughout the contract and for 6 months following completion.

The Victorian-aged culvert running through the centre of the site contained a swiftly flowing stream. This structure was beyond its design life and its stability was unknown. Following CCTV surveys and trial pits along the length of the culvert, excavation and backfill began in 5 metre sections removing as much contaminated material as practicable without compromising the stability of the culvert.

Air quality was monitored by 328 individual quantitative vapour measurements and 54 environmental dust samples. In excess of 36,000 tonnes of contaminated materials were remediated over a 2 month period prior to site handover for redevelopment. Contaminated materials were transported in high quality, well maintained self sheeting tipping lorries and emergency access was provided for the adjacent Transco personnel at all times.

Innovation

A specific challenge was presented by a tar tank containing severely contaminated material located directly adjacent to a vibration sensitive, high pressure gas distribution apparatus with integral monitoring instrumentation. The tank required remediation under statute, however the proximity to gas apparatus precluded normal techniques.

The solution was to install a secant piled wall between the active gas apparatus and the old tar tank. Scaffolding was erected to encase the gas apparatus and protect it from falling pile arisings, with an emergency access for Transco personnel. The piled wall construction material comprized a cement/bentonite mix to create an impermeable barrier and prevent leaching of contaminants into remediated ground.

Figure 8 shows the scaffold boarding protecting the gas apparatus and the brick instrumentation house at the top of the picture. Fencing panels were secured along the top of the secant piled wall. The brick lined tar well, typically 6m deep, is shown partially excavated. All materials were characterized and consigned to a licensed waste disposal facility.

Figure 8. Tar well partially excavated

Further remediation challenges were posed by the contents of one particular underground tank. To improve the handling of these contents trials were conducted adding a variety of substances including saw dust, wood shavings, brick dust, Pulverized Fuel Ash, cement, lime and a variety of polymers to increase viscosity. Polymers were chosen as the most appropriate viscosifier with a dosage rate of 1 part polymer to 80 parts contaminated material. The overall bulking effect was negligible. Following remediation the site was released for commercial development.

Garston Gasworks, Speke Garston, Liverpool

Project

To investigate, identify and remediate all gasworks residues and remove environmental liability. Existing structures included two large gasholders, high pressure gas lines and vibration sensitive pressure reducing equipment requiring access to be maintained at all times for Transco personnel. Adjacent properties included a church, residential buildings and local amenities.

Challenge

Principal challenges were to:

- maintain a live operational gas distribution site with 24 hour access for Transco personnel
- protect and maintain numerous underground and overhead live services
- remove heavy contamination
- identify contamination sources ie tanks, chambers, pipes, tar wells
- remove redundant services containing tar
- remove and treat perched waters and ammoniacal liquors, and
- protect vibration sensitive gas apparatus

Solution

To employ a holistic approach dealing with contamination across the site concurrently. A rigorous sampling regimen ensured contamination was accurately identified and remediated.

166 samples were obtained during the additional site investigation, a further 128 samples ensured accurate confirmatory waste characterisation. Following remediation 448 samples were taken to ensure validation criteria were met. Figure 9 shows the excavation of a gasholder water-seal tank. This gasholder was not initially identified as a major contaminant source, however additional site investigation highlighted the need for remediation due to adverse environmental impact.

Excavation of an 1890s brick built tar tank adjacent to vibration sensitive gas apparatus required careful excavation and monitoring to avoid movement of the structure, particularly during backfill and vibratory compaction.

The proximity to residential properties was of great concern during the works. Daily dust, odour and vapour monitoring was meticulously performed. Over 289 environmental samples were taken and analysed in addition to qualitative appraisals and weather monitoring.

In excess of 31,700 tonnes of contaminated materials were excavated for disposal at a licensed facility over a period of 43 working days, peaking at 1583 tonnes per day.

Figure 9. Excavation of a gasholder basin using a 50 tonne tracked excavator

Innovation

Edmund Nuttall, in conjunction with Parsons Brinckerhoff and SecondSite Property, conducted a coal tar bioremediation trial using a large upright bioreactor. The plant used bacteria to degrade polycyclic aromatic hydrocarbons and total petroleum hydrocarbons within a prepared coal tar/sand/gravel waste stream. Figure 10 shows the upright bioreactor tank. The process proved successful.

Figure 10. Bioreactor at Garston Gasworks

Imperial Wharf Gasworks, Fulham, London

Project

A 26 week contract undertaking statutory remediation and civils/services segregation prior to redevelopment of the site. Following the closure of the town gas production plant, the site had a number of previous uses including scrap yards and oil storage facilities.

Challenge

- variety of contaminants
- heterogeneous ground conditions
- adjacent River Thames receptor
- high groundwater table, and
- adjacent residential properties

Solution

Additional site investigation was undertaken to accurately identify contaminated materials thereby minimizing excavation and remediation costs. Large volumes of metal, brick and concrete were recovered from the site for recycling.

The authors believe that the Imperial Wharf Gasworks contract was the first bioremediation contract undertaken in the UK and involved the treatment of some 6000m^3 of contaminated material. Onsite bioremediation dramatically reduced the number of lorry movements compared with other remediation methods.

Environmental monitoring and assessment ensured offsite receptors were not adversely affected. A purpose designed groundwater treatment plant was established to treat contaminated water, removing fines, heavy metals and hydrocarbons, prior to discharge.

Figure 11 shows the extent of the Imperial Wharf Gasworks, with a number of gasholders shown at the top of the photograph and the River Thames in the foreground. The site is surrounded on 3 sides by residential and commercial properties.

Figure 11. Aerial view of Imperial Wharf Gasworks site

SUMMARY

Successful remediation demands a well considered and comprehensive desk study followed by a site investigation programme to:

- determine the ground conditions and hydrogeology
- identify live services and redundant structures, installations, etc
- identify contaminants together with their extent
- determine the scope of the remediation programme addressing the likely remediation processes and their impact on the local environment, and
- the residual risks

Current gasworks remediation processes do not destroy all of the heavy metals, such as arsenic, lead, cadmium or asbestos. These have to be identified, carefully excavated and transported to a licensed landfill facility. Similar problems occur on sites containing cyanide contaminated wood and spent-lime 'blue billy'.

Recent legislation is leading the drive towards on-site remediation, yet despite improvements to mobile remediation plants it would appear inevitable that there will always be a requirement for limited 'excavation and removal' for further on-site treatment or direct transport to a licensed landfill facility. Alternative remediation techniques ie soil washing, thermal desorption, and bioremediation are currently securing a greater share of the remediation market. Most of these techniques are amenable to conduct on-site, in situations where there is adequate operating space.

Emerging technologies offer exciting possibilities. For example, material containing tars, oils and creosotes can be fed into a chamber and bombarded with microwaves. The resulting temperature increase causes the contaminants to volatilize permitting them to be condensed at pre-determined cut-off points in a condenser for re-use, ie in the fuel chain.

To date, of the 2000 gas production and storage sites across the UK over half have been remediated using the techniques discussed in this paper.

Acknowledgements: The author wishes to acknowledge the assistance and encouragement of Edmund Nuttall Ltd in the preparation of this paper.

Corresponding author: Dr Douglas Allenby, Edmund Nuttall Limited, St James House, Knoll Road, Camberley, Surrey, GU15 3XW, United Kingdom. Tel: 44-1276-63484. Email: Doug.Allenby@edmund-nuttall.co.uk.

REFERENCES

DOE, 1995. Annex Potential Contaminants. In: *Gasworks, coke works and other coal carbonisation plants*. DOE, Ruislip. DOE Industry Profile, 15-16.

EVANS, F. 2005. SecondSite Property Holdings, Practical solutions in dealing with contaminated land.

KJELDSEN, P. 1999. Water, Air and Soil Pollution. Springer Science and Business Media, The Netherlands. 115, (1-4).

LEACH, B.A. & GOODGER, H.K. 1991. Appendix 3 Basic principles applied to specific types of site. In: *Building on Derelict Land*. CIRIA, London. Special Publication 78, 208-213.

SECONDSITE PROPERTY 2003 *Guidance for assessing and managing potential contamination on former gasworks and associated sites*, *Part 1, Environmental Assessment Guidance Version 3* Paragraph 13.2, Appendix 13, Section 11.0

U.S. ATSDR (Agency for Toxic Substances and Disease Registry), 2006, U.S. Department of Health and Human Services. (www.atsdr.cdc.gov/HAC/HAGM/images/figure6_2.jpg)