ICRCL Guidance Note 17/78
Eighth Edition
December 1990

INTERDEPARTMENTAL COMMITTEE ON THE REDEVELOPMENT OF CONTAMINATED LAND

Notes on the development and after-use of landfill sites

ICRCL

Recycled Paper

Eighth Edition
December 1990

INTERDEPARTMENTAL COMMITTEE ON THE REDEVELOPMENT OF CONTAMINATED LAND

Notes on the development and after-use of landfill sites

ICRCL

£2.25p

INTERDEPARTMENTAL COMMITTEE ON THE REDEVELOPMENT OF CONTAMINATED LAND

NOTES ON THE DEVELOPMENT AND AFTER-USE OF LANDFILL SITES

SUMMARY

Landfill sites present particular problems for development and after-use, especially where the construction of buildings is proposed. The principal hazards are the presence of biodegradable materials which release flammable and explosive gases (landfill gas) as they decay; the geotechnical properties, which may be unsuitable for building and construction purposes; and the presence in the soil of toxic substances or of chemicals which attack building materials.

Because of these hazards landfill sites are generally unsuitable for 'hard' forms of development (eg buildings or structures) unless appropriate remedial treatment is carried out before construction begins: such treatment is very likely to be technically complex and correspondingly costly. Where there is landfill gas, there should be a very strong presumption against development which involves construction of traditional types of housing (ie houses with gardens) which would require particularly stringent precautions such as the provision of high rates of sub-floor and cavity ventilation and the installation of gas detectors and alarms. The difficulty of guaranteeing the safe operation of such systems over the gassing lifetime of a site is such that on safety grounds developments of this type should not be located within an area affected by landfill gas emissions. Blocks of flats, offices, supermarkets etc may be less difficult to protect because the sub-floor ventilation requirements can be provided, for example, by raising the building clear of the ground - a form of construction which is unsuitable for traditional types of housing development - and other means of meeting ventilation requirements which are more capable of being subjected to quality assured management. Similarly, the provision of alarm systems and other protective measures can be more readily accomplished in blocks of flats etc. Protective measures should also be afforded to any associated outbuildings such as garages, sheds etc.

In general, restoration and re-use of the sites for purposes other than building and construction is considered to be a preferable and less expensive method of returning the land to beneficial use. No form of re-use should, however, be commenced without first considering the possibility of contamination and/or gas emissions and then, if necessary, investigating the site to find out whether it is suitable for the proposed use.

This note has been prepared to assist those considering the development of landfills in ensuring that the site is properly evaluated and that all actual or potential hazards are accounted for in the design of their schemes. In preparing this latest edition of ICRCL 17/78 the opportunity has been taken to incorporate new information, and to expand the sections dealing with landfill gas hazards to complement information available elsewhere. The note also describes other principal hazards such as the presence of toxic substances in the soil at landfill sites, and the difficult geotechnical properties which may make such sites unsuitable for construction purposes. It goes on to advise on planning and building control aspects, site assessment requirements, and remedial measures.

I INTRODUCTION

1. Landfills are sites where waste materials are deposited on to or into land for the purposes of final disposal. The method is at present the most widely used disposal route in the UK for household, commercial and industrial waste. The nature and chemical composition of these wastes is varied and therefore a very wide range of contamination is possible; Table 1 shows the typical composition of UK household waste.

TABLE 1: TYPICAL COMPOSITION OF UK HOUSEHOLD WASTE

	Range (% by weight)
Paper	22 - 36
Plastic	5 - 12
Textiles	1 - 5
Miscellaneous combustibles	3 - 6
" non-combustibles	1 - 7
Glass	6 - 11
Putrescible matter	16 - 24
Metals	1 - 8
Fines below 10 mm size	6 - 33
Moisture content	27 - 37

2. Because of the likelihood of contamination, landfill sites can be hazardous to develop, particularly for the purposes of building and construction. The hazards may include:

i presence of harmful substances which can affect human health, plant growth, animals;

ii combustibility of fill materials (eg household waste, paper, plastics);

iii chemical attack on building materials, including service pipes and cables;

iv emission of flammable, toxic, asphyxiant or corrosive gases;

v ground stability problems; and

vi problems associated with odour, site drainage, leachate production, and surface run-off.

3. The importance of each of these hazards differs according to the immediate and longer term requirements of the site. It also depends on the intensity of the contamination. The form of development best suited to a particular site cannot therefore be decided until the condition of the land has been properly assessed. It is primarily the developer's responsibility to satisfy himself that the site is safe and suitable for the intended use. Advice on the preparation and handling of the planning aspects of contaminated land is given in DOE Circular 21/87 (Welsh Office Circular 22/87) Development of Contaminated Land (HMSO 1987)(1) (see also paragraph 5). No

form of re-use or development should commence before the possibility of contamination has been considered. An adequate investigation of the site should be carried out to assess the importance of the relevant hazards. A suggested procedure for investigating and assessing landfill sites is given in this paper (see section IV and Annex II). General guidance on the assessment and redevelopment of contaminated land is given in ICRCL 59/83 Guidance on the Assessment and Redevelopment of Contaminated Land (see back cover).

4. Waste disposal by landfill is at present governed by Part I of the Control of Pollution Act 1974 (COPA). Sites which accept controlled wastes must be licensed for the purpose: the licence should specify inter alia the types, quantities and other particulars of the wastes to be deposited including, for certain defined categories of waste, the general location of the waste within the site. A licence can only be issued where the site has, or does not require, planning permission for the land to be used for waste disposal. Thus for landfills which have operated since the COPA site licensing procedure was introduced in 1976, information should be available on the nature and contents of a particular site. Such information will help to identify which hazards may need to be considered. For sites which were operated prior to disposal licensing it is unlikely that any reliable records of usage, waste types or quantities will exist: such information will therefore have to be obtained from, or supplemented by, an investigation of the site.

Planning considerations

5. The presence of contamination, including the possibility that gas may be generated and emitted from landfill sites or that it may affect adjacent land, is a material planning consideration which needs to be taken into account whenever it is proposed to reclaim or redevelop such sites (1). A recent Joint Circular from the Department of the Environment and the Welsh Office, (DOE 17/89; Welsh Office 38/89) "Landfill Sites: Development Control" (2) advises that local planning authorities should exercise due caution in granting permission for development or redevelopment on or near landfill sites, and that permission should not be granted unless reliable arrangements can be made to overcome the danger of migrating gas. Under the General Development Order 1988(3), paragraph 18(1)(w), local planning authorities are required to consult with Waste Disposal Authorities on proposals to develop sites within 250m of land which:

i is or has, at any time in the 30 years before the relevant application, been used for the deposit of refuse or waste; and

ii has been notified to the local planning authority by the Waste Disposal Authority for the purposes of this provision.

It is the developer's responsibility to demonstrate that safe development is possible at sites to which the General Development Order applies.

Further guidance of relevance to the development of former landfill sites is contained in Planning Policy Guidance: Development on Unstable Land (4).

Building control

6. The Building Regulations 1985 (Schedule 1 Part C) require precautions to be taken to avoid danger to health caused by substances found on or in the ground to be covered by a building. Approved Document C of the Regulations contains guidance on relevant actions which may be considered to deal with various types of contaminants including gases (including methane and carbon dioxide). Relevant actions include:

- i removing contaminants;
- ii limited excavation, filling and sealing;
- iii sealing service entries;
- iv eliminating voids; and
- v sealing or effectively ventilating voids which cannot be eliminated.

Because the Building Regulations relate only to the ground to be covered by the building, it will be necessary to consider what actions should be taken to deal with contamination including gases on other parts of a site under development.

II TYPES OF CONTAMINANTS

7. The following types of contaminants may be present in a variety of physical forms including liquids, solids, sludges and gaseous emissions:

- i metals, including arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel and zinc;
- ii non-metals, including cyanides, chlorides, sulphides, and sulphates;
- iii acids and alkalis, for example hydrochloric, phosphoric, and sulphuric acids; caustic solutions, and ammoniacal liquors;
- iv organic substances, including oils, tarry wastes, solvents, and PCBs;
- v putrescible and biodegradable matter, eg household waste, food and vegetable residues, and paper packaging;
- vi asbestos; and
- vii miscellaneous wastes, including glass and rubble and materials which may have become contaminated with very low levels of radioactive substances during handling procedures.

8. The following information may assist in providing some idea of the likely range of problems and an early indication of the likely scope of further investigations:

i The type of waste present:

(a) biodegradable materials, such as household waste, produce flammable and asphyxiant gases and thus require special precautions to be taken during any site investigation and subsequent development;

(b) some industrial wastes may contain high concentrations of toxic or chemically aggressive substances or may interact with water or other wastes to produce toxic materials, and site investigation will need to be conducted under the supervision of a professional chemist; appropriate supervision and protection will also need to be provided during any subsequent development work on site and materials of construction/services will need to be resistant to attack from such substances;

(c) hazardous waste deposits: depending upon the method of site operation, hazardous waste may be present in one area of the site, in a number of areas, or interspersed throughout the fill; failure to find hazardous waste during a site investigation does not mean its absence can confidently be assumed, unless the intensity of the site investigation is sufficient to ascribe high confidence limits; site history is one of the better ways of establishing whether or not problems are likely to be encountered with hazardous waste deposits;

ii The depth of fill and the method of deposition: modern landfill techniques produce high initial fill densities which, although settlement does still occur, tend to reduce differential settlement compared with some older sites; very shallow, poorly compacted sites may be largely aerobic and although not producing significant quantities of methane, may produce hydrogen and may be prone to subterranean fires aided by the higher decomposition temperatures;

iii The age of the site: generally in older sites gas production should be declining or may even have been completed; however, lack of, or low rates of, gas production are not by themselves an indication that biodegradation has started or permanently ceased and it is not uncommon for an old site to be activated by disturbance caused by the construction of foundations and for gas production to start or be reactivated; in addition, the older the site, the more likely that the records of the wastes deposited there will be incomplete and the existence of toxic or chemically aggressive wastes may be unknown; and

iv the local geology, hydrogeology and hydrology (including site engineering): containment sites and sites in high rainfall areas may produce gas at a higher rate than "dry" sites, which may only be producing gas at minimal rates (although there may be considerable potential for production); site engineering measures may be affecting the impact of a site on its environment (eg artificial liners to protect groundwater, or artificially depressed leachate levels within the site); changes in groundwater flow patterns or rise in standing water levels could result in higher leachate levels within some sites and consequent increases in gas production or possibly the onset of gas production.

III POTENTIAL HAZARDS

Presence of harmful substances

9. Some contaminants are, in trace quantities, essential to the health of crops and animals, eg zinc, copper, iron, molybdenum and manganese. Others, such as lead, cadmium, mercury, nickel, arsenic and cyanide, may be harmful at relatively low concentrations. For most metals, the concentration difference between levels at which beneficial effects or toxic effects occur is relatively small. However, the presence of metals does not normally represent a hazard to site workers or buildings during the operational lifetime of a landfill site. Subsequent users or occupants of a site, including animals and plant life, may be at greater risk because they may be exposed to the hazards in various ways over a longer period.

10. Uptake of contaminants by crops and translocation to the edible parts could increase the concentrations of certain toxic metals (eg cadmium, lead and mercury) in the food chain leading to man. The amounts taken up depend upon the "availability" of the metals to the plants; this in turn depends on complex interactions between several factors, including soil structure and pH, crop species and cultivars, and chemical speciation of the elements in the soil. Cadmium is relatively easily taken up by plants but only very slowly released from human body tissues, and is therefore of particular concern. Lead and mercury are less readily taken up by most crop plants. Substances which are phytotoxic (toxic to plants, eg copper and zinc) are less likely to get into the food chain because of their adverse effects on plant growth.

11. For developments which incorporate gardens, landscaped areas or agricultural uses there is also the possibility of direct ingestion of contaminated materials. Grazing animals may ingest up to 20-30% by weight of soil with the vegetation they consume. All young children will ingest some soil, and a minority suffer from the condition known as pica (the habitual ingestion of non-food materials which can include soil). The outer leaves of some edible plants (eg cabbage, lettuce) can be contaminated by airborne particulate matter or by soil splashing.

12. Other contaminants may be harmful by direct contact with the skin or by inhalation, for example:

- i dilute or concentrated acids and alkalis present as either free liquids or in the form of sludges etc;
- ii phenolic substances;
- iii vapours produced by the evaporation of organic solvents and similar substances;
- iv asbestos; and
- v waste oils.

Potential combustibility

13. Landfill sites should be investigated for their potential combustibility since many of the wastes present are combustible, for example household waste, paper, plastics, and rubber. Wherever combustible matter is present below ground a fire may start and propagate below the surface. The disposal of flammable liquids such as oils, increases the risk of combustion of other materials. Because the supply of oxygen at depth is limited, subterranean fires usually propagate slowly by smouldering. Should they break through to the surface, flames may appear, but most frequently the zones of active combustion tend to remain at depth. Slow combustion may proceed for long periods with little outward sign; often the only external evidence is the occasional emission of wisps of steam and smoke. Subsidence may result as the combustible material is consumed: the consequent undermining of buildings already erected may be difficult and expensive to repair and there are hazards to people and vehicles through the possibility of the collapse of burned out voids. New development on the site may also be difficult.

14. Subterranean fires are often extremely difficult to extinguish. In their early stages when the area affected is small, digging out, accompanied by the application of water, may extinguish the fire. If left too late, this process may increase the air supply causing the fire to advance faster than the digging. The digging of isolating trenches or installation of barriers to prevent the fire from spreading is expensive and can be difficult if the area of the fire is extensive or the combustible material deep. In some cases grouting techniques can be used to limit the spread of combustion.

15. To assess the combustibility of materials, several tests are available: samples taken from the site can be examined to determine, for example, ash, moisture content, volatile matter, and fixed carbon. As in the case of conventional solid fuels, such properties are often inter-related. The most widely used criterion is calorific value (CV) which is the quantity of heat that can be released from unit mass of a sample after complete combustion in excess oxygen. Without information of the amount of air (oxygen) that is available for combustion, a knowledge of CV alone is insufficient for a prediction of the heat that will be released by a material as it burns below ground with a limited air supply.

16. Samples with high CVs, low ash contents and high carbon contents are possibly more likely to be combustible than others. Studies at the Building Research Establishment's Fire Research Station have shown that smouldering can propagate in samples with CVs similar to those of soils which did not smoulder under the same test conditions (a typical loamy soil has a CV of about 1.7 MJ/kg). These preliminary findings suggest that samples with CVs of above 10 MJ/kg are almost certain to sustain smouldering whilst those with CVs below 2 MJ/kg are less likely to do so. Within this range of values there is likely to be a large number of potentially combustible materials. More recent work at the Fire Research Station has concentrated on the development of a reliable test for determining the potential for combustion.

17. Further information on the fire hazards of contaminated land is given in ICRCL Guidance Note 61/84 (see back cover); information on subterranean fires is given in the proceedings of a research colloquium held in 1989(5).

Chemical attack on building materials and services

18. Some chemical contaminants attack building materials. Sulphate and acid attack on concrete are the most common effects, but there may also be enhanced corrosion of metals and deterioration of plastics. Certain plastics materials used for example in water pipes, protective coatings to metals, '0' rings, etc are particularly susceptible to damage by oily substances; permeation of plastics pipes by certain organic substances can lead to tainting of water supplies. Guidance on the corrosivity of soil is provided in British Standard Code of Practice 1021:1973 on "Cathodic Protection". The need to protect water supplies from contamination may require that service trenches be backfilled with clean fill material and protected to prevent ingress of contaminated liquids. At some sites water supply pipes have been placed inside an oversize conduit, and distribution and connecting mains made from specially resistant materials. Where such measures are likely to be needed, the undertakings responsible for water supply, drainage, electricity, telephone and gas services should be consulted at an early stage in the design of the proposed development. Further guidance on the effects of soil contaminants on water supply materials and on installation of pipelines in contaminated land is available in reports from the Water Research Centre (6, 7, 8).

Emissions of toxic or flammable gases

19. Organic matter deposited in landfills is decomposed by the action of micro-organisms. Decomposition usually begins before the organic matter is deposited. Initially it is due to the activity of aerobic (oxygen - requiring) micro-organisms and the products include carbon dioxide (CO_2) and water. As decomposition proceeds the release of these gases prevents the ingress of air and decreases the supply of oxygen available to the micro-organisms. Eventually, aerobic activity ceases and organisms capable of surviving under anaerobic (oxygen-deficient) conditions become dominant. Other decomposition processes then commence. During the early anaerobic phase CO_2 production increases and some hydrogen (H_2) is produced. Later the gases generated under anaerobic conditions are usually dominated by methane (CH_4), which is flammable, though the presence of other constituents such as CO_2 and residual nitrogen (N_2) may modify the properties of the gas mixtures. Such mixtures are known as "landfill gas". Figure 1 illustrates the different phases in gas generation.

20. The properties of landfill gas depend on its composition, and its behaviour is particularly dependent on the ratio of CO_2 and CH_4 (which controls its density and modifies its flammability), and the rate of emission and dispersion (which affects the tendency for flammable gas mixtures to accumulate). Mixtures of landfill gas and air should be regarded as potentially flammable and explosive. Methane itself forms explosive mixtures with air in the range 5%-15% by volume. These properties are modified by the presence of CO_2: as the proportion of CO_2 increases, the flammability of the mixture decreases, until no mixture of methane with an atmosphere composed of air and 25% or more of CO_2 is capable of propagating flame far from the source of ignition. If the ratio of CO_2: CH_4 is greater than 3.5, mixtures of CH_4 and CO_2 will not be flammable if mixed with air in any proportion; this ratio is known as the "limiting safe mixture" (LSM). However, such mixtures may be seriously deficient in oxygen and may present an asphyxiation hazard.

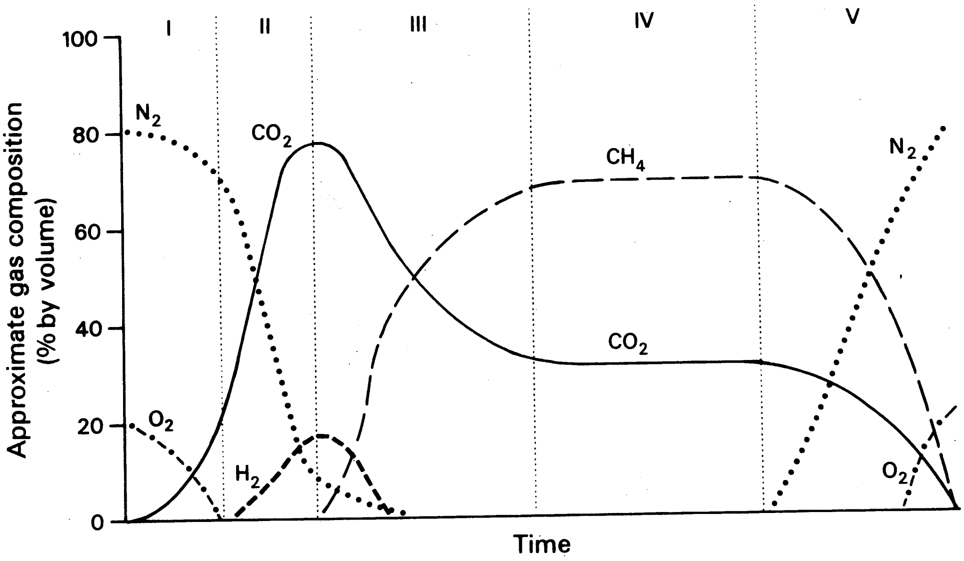

Figure 1 Phases in landfill gas generation

Phase I — Aerobic decomposition of biodegradable materials: entrained atmospheric oxygen is converted to carbon dioxide.

Phase II — Anaerobic decomposition commences as oxygen is used up: carbon dioxide concentration increases and some hydrogen is produced: no methane is produced at this stage.

Phase III — Anaerobic methane production commences and rises to a peak: concentration of carbon dioxide declines: hydrogen production ceases.

Phase IV — Steady methane and carbon dioxide generation in proportions of between 50-70% and 30-50% respectively.

Phase V — Steady decline in generation of methane and carbon dioxide: gradual return to aerobic conditions.

21. The CO_2: CH_4 ratio in landfill gas varies from values of less than unity to values which exceed the LSM ratio. The manner in which landfill gas accumulates in confined spaces and buildings depends on the CO_2: CH_4 ratio and the rate of entry. For all compositions, if the entry rate is very low, dispersion of the gas by molecular diffusion can prevent its accumulation at least in the short term. However, in small, poorly ventilated spaces a flammable mixture can accumulate even at slow rates of entry. For higher rates of entry, accumulation in stratified layers is more probable. When the CO_2: CH_4 ratio is greater than 0.87 the gas mixture has neutral buoyancy and the layers tend to accumulate close to the point of entry, usually near floor level in the containing space. If the CO_2:CH_4 ratio is less than 0.87, stratification tends to occur at higher levels in the space. Higher rates of ventilation are required to prevent the formation of stable stratified layers than are needed when entry of gas is balanced by dispersion by diffusion.

22. Almost without exception landfill gas will be produced at all landfill sites which have taken biodegradable wastes, which include all putrescible wastes, animal and vegetable matter, paper and any type of woody material such as shrubs and trees including timber products. Gas generation is particularly likely at sites which have taken household or commercial wastes, although gas has also been found at sites which were supposed to have taken only "inert" wastes. The characteristic features of gas emissions from different types of sites and the consequences for development are summarised in Table 2.

Table 2: Characteristics of emissions and sites

Emission characteristics	Examples of sites	Consequences
Gas produced continuously, usually released at low rates. Concentrations of flammable constituents may exceed lower explosive limit (LEL) values.	Natural materials eg silts, peat, coal seams, marshland. Older landfills containing minor amounts of biodegradable matter.	Building development may be possible with passive protection systems and suitable design allowances (eg ventilation of structure and elimination of voids where possible).
Production and release may be intermittent but emission rates and concentrations can be high.	Some abandoned mine workings.	Possibility of short- term hazard: development for non-sensitive uses such as public open space may be possible.
Gas emitted rapidly in large volumes under pressure, causing vertical and lateral movement. Methane often present at high concentrations together with other gases which may modify its behaviour eg CO_2.	Landfill sites containing a high proportion of biodegradable material eg household waste; infilled docks or watercourses	Traditional housing development is not suitable. Other forms of hard development are best avoided until emission ceases. If such development has to proceed carry out thorough investigation and then design active protection systems eg gas collection/extraction wells; gas detectors and alarm systems. Monitor effectiveness of precautions before, during and after development.

23. When landfill gas is mixed in air flammable or explosive concentrations can be produced ("flammable" refers to gas mixtures in the open atmosphere; "explosive" is used when the mixture is contained within a space such as a building). There may also be a noticeable odour, due to the presence of trace components such as organic sulphur compounds in the gas. There is also the possibility that wastes with high sulphate contents may on anaerobic decomposition produce hydrogen sulphide (H_2S), which is odorous and highly toxic as well as being flammable. The main hazards from landfill gas are:

i flammability (see Annex I);

ii asphyxiation; and

iii adverse effects on plant growth (usually by depletion of oxygen in the root zone).

24. Once production and emission of gas begins the activity may increase rapidly to a maximum and then decline equally quickly, but at some sites emissions may continue at a steady rate for many years. The local conditions must therefore be taken into account at each such site before it can be concluded that gas production either will not occur or has been completed. If it is absolutely essential and unavoidable to develop such land while emissions are still occurring, a thorough investigation of the site (see Annex II) by or on behalf of the prospective developer is essential before seeking planning approval. Provided that traditional housing development (ie houses with gardens) is not envisaged it may be possible to protect the proposed development but it could be unduly expensive to do so. Information on the gas composition and concentrations, emission rates, and their variations with time, will show whether precautionary measures are feasible. If they are not, the site should not be developed for hard end uses.

25. Information collected by Her Majesty's Inspectorate of Pollution (HMIP)(9) has shown that some 1400 active and closed landfill sites in the UK may pose a potential risk because of landfill gas emissions. Over half of these sites are within 250m of existing housing or industrial development and fewer than 30% of them had any gas control measures installed.

Site drainage and stability

26. Control of drainage and surface run-off from landfills is needed to reduce the risk of water pollution. This is more likely to affect surface watercourses than underground aquifers, but with appropriate precautions the hazards can be minimised and should not represent a major constraint on development. Leachate produced by the infiltration of rainfall through the fill can be a source of pollution to ground or surface waters, and this will be more difficult to prevent or control as well as possibly constraining the methods of construction. The advice of the National Rivers Authority (NRA) should be sought whenever landfill sites are to be developed.

27. Settlement of landfill material takes place gradually over a long period of time. Most household wastes increase in density with time principally due to the long term compaction of the fill under its own weight and that of any other overlying material. In addition, organic materials decompose while metal containers corrode and collapse. The heat generated by chemical and biochemical reactions may raise the temperature of some materials sufficiently for localised

spontaneous combustion to occur. All these processes could create voids within the fill. The rate of settlement may change if there are alterations in the level of the water table or changes in the moisture content of the fill. Some sample calculations of settlement are in Appendix 6a of Waste Management Paper No 26(10).

28. The precautions needed for site stability and suitability for structural purposes will depend on the local conditions, such as geology, hydrogeology waste input and method of operation. The British Standard Code of Practice for Foundations (CP 2004) states that 'All made ground should be treated as suspect, because of the likelihood of extreme variability'. A geotechnical investigation (11) of the site will usually be required before foundations or other structures can be designed. It should be noted that piled foundations may provide a pathway for gas movement.

IV SITE ASSESSMENT

29. The main objectives of site assessment are:

i to identify any buildings or other structures both above and below ground which may be present on the site;

ii to identify the extent of the site in terms of depth and area;

iii to identify the various types of materials present within the landfill and to ascertain their distribution over the site area;

iv to obtain information on the extent and degree of contamination both on and below the surface;

v to determine whether gas emissions are taking place and if so which gases and at what rates; and

vi to identify the existence and operational status of current pollution and gas control measures within and surrounding the landfill site.

30. The information thus obtained can be used to assess the suitability of the site for various possible forms of development. A detailed site investigation should always be carried out unless comprehensive knowledge of the site history and ground conditions already exists, or except for certain low-grade end uses (such as hard cover for vehicle parking) which would not require extensive remedial measures to make the site suitable although it will still be necessary to check for possible groundwater contamination and for the presence/migration of landfill gas. The scope of the investigation required depends upon the proposed end use and on the principal hazards likely to affect that use (12) subject to there not being an overriding need to deal with any particular contamination which may cause significant pollution or hazard to the environment. Site surveys and investigation of landfill sites with regard to provision of gas control and monitoring systems are dealt with in Waste Management Paper No 27 (14).

Preliminary stages

31. The first stage in the location and assessment of a former landfill site should consist of the collection and examination of available maps, plans, aerial photographs and other relevant records. Since 1976, waste disposal sites have been licenced under Part I of the Control of Pollution Act 1974. The issue of such licences is administered by Waste Disposal Authorities (County Councils* in England, District Councils in Wales) and these bodies should be able to provide information on the types and quantities of waste materials deposited at licensed sites. The water companies and the NRA may have information on the geology and hydrogeology of the sites, and may also have information on the location and nature of sites operating prior to 1976. In Wales use should be made of the Welsh Office survey of contaminated land (13).

32. Having obtained such information as is available, a site visit should be made by appropriate experts in order to correlate the documentary evidence with the conditions actually existing at the site. Particular attention should be paid to the surface topography and site layout, the absence or presence and condition of plant cover etc.

Chemical testing

33. Once the general site layout and history is known, the next stage of assessment is to identify or confirm the wastes and other materials present and to establish the pattern of contamination. This requires the collection and analysis of samples of fill from the surface and from varying depths, depending on the proposed end use of the site.

34. At most sites, a systematic ground survey will be required. The sample locations should be based on a grid pattern, the grid spacing being chosen to give sufficient samples for the size of the site under investigation (see reference 12). On large sites, typical grid intervals of 50m or 100m may be adequate, while closer spacing (eg 10m or 25m) may be needed on smaller sites or selected areas of larger sites intended for sensitive end uses such as the construction of buildings. However, it is not possible to lay down hard and fast rules for sampling, and survey procedures should be tailored to meet the specific requirements of individual sites.

35. When the number and locations of sampling points have been decided, samples should be collected from either trial pits or boreholes of the immediate surface layers and of each layer of the sub-surface materials, or if no change is discernible, at varying depths, for example, 0-0.10/0.15m; 0.5m; 1.0m etc. The use of trial pits excavated by a wheeled mechanical digger permits samples to be taken at depths down to about 3-4m, and allows visual observations of the sub-surface ground conditions to be made readily, including the nature of the materials present and the levels at which water is encountered. All excavations and trial pits should be tested for toxic, asphyxiant and flammable gases.Entry into excavations for purposes of inspection, sampling etc should be avoided because of the risk of collapse: full safety procedures are necessary before entry can be

---

* District Councils in the areas of the former Metropolitan Counties and the London Waste Regulation Authority in London.

permitted and a minimum of two-man teams is required. For sampling at depths greater than about 4-6m use of boreholes is necessary. Detection and mapping of subterranean fires may be aided by use of thermal imaging techniques.

36. Comprehensive analysis of all samples collected for investigation of a site can be costly and time-consuming, and for some end uses may not be necessary. To avoid unnecessary time and expense, the analyses to be carried out should relate both to the previous and proposed uses of the site. Where the construction of buildings is envisaged, the principal hazards to be considered are likely to include:

i emission of toxic and flammable gases;

ii chemical attack on construction materials and subsidence;

iii human health effects, including the safety of workers on the site during clearance and redevelopment, and the health of future users or occupiers; and, where domestic gardens or agricultural areas etc form part of the development:

iv phytotoxic effects.

For these hazards the priority contaminants are: sulphate, sulphide, chloride and soil pH; potentially combustible materials; oily, tarry and phenolic substances; methane and carbon dioxide (this will, in general, require the monitoring of emission rates and CH_4 and CO_2 concentrations over a period of up to 12 months); and metals, especially cadmium, lead and zinc. In addition a careful watch for the presence of asbestos should be kept, and an assessment should be made of the general ground engineering properties of the fill material.

37. Where it is proposed to restore the site for 'soft' after-uses (eg recreation, public open space, agriculture, allotments) or where domestic gardens form part of the development, the following contaminants may also need to be determined: arsenic, boron, cadmium, copper, lead, mercury, nickel, zinc, pH. It should be noted that although copper, nickel, and zinc are the elements usually considered when assessing phytotoxicity, many other contaminants are also toxic to plants.

38. While the above lists include most contaminants likely to be important in the majority of cases, local knowledge and conditions should be considered as appropriate and the choice of analyses modified accordingly, taking into account the proposed use of the site. The scope of the investigation should also be related to the type of development envisaged and the stage it has reached: a pre-purchase survey may not need to be so comprehensive as one intended to provide data on which detailed plans for remedial treatment and subsequent development will be based, but it is important and prudent that developers assume the worst unless or until it is proven otherwise.

Assessment of findings

39. To interpret the analytical results for soil and water samples obtained from a site investigation, the concept of "trigger concentrations" (see ICRCL 59/83) should be used. This

concept identifies two significant concentration values for each contaminant: a lower, or threshold value, and an upper or action value. They serve to divide the range of concentrations in which a contaminant may occur on a site into three zones: the significance of the contaminant then depends upon the zone corresponding to the concentration at which it is found.

40. For most contaminants it is not possible to specify concentrations that would have to be regarded as unacceptable, such that action to reduce the hazards would automatically have to be taken. Each site needs to be judged on the basis of all the available data. The assessment needs to take into account the end use to which the site is to be put and the exposure routes for those likely to be at risk. However, if the site investigation has been carried out according to the above sequence, enough information should have been obtained to assess the degree and general distribution of contamination. Consideration can then be given to the remedial measures needed to make the site suitable for the proposed end use, or those measures which would be required for some alternative end use. If necessary, particular areas of the site can then be investigated in greater detail to define 'clean' areas or regions of excessively high contamination.

41. No landfill site or site within an area likely to be affected by landfill gas should be developed without an adequate investigation for gas emissions (see Annex II). Until such an investigation has been carried out it is not possible to define the extent of gas migration which depends on local conditions and as such will be unique to each site. Should the findings of the investigation indicate that some form of hard development other than traditional housing may be possible even though gas is present, there are two principal courses of action:

i devise protective measures aimed at preventing the gas from reaching the proposed development; and/or

ii assume that the gas cannot be prevented from reaching the proposed development, and design the buildings to prevent the ingress and accumulation of dangerous concentrations of gas inside buildings and associated enclosed void spaces.

If development is to take place on land subject to gas migration it must be remembered that gas can be produced for typically up to about 30 years and precautionary measures should be guaranteed for at least this length of time. Also that whilst the buildings may be made safe the surrounding land may still be affected by gas, thus any associated or subsequent construction (ie garages, sheds etc) must conform to the same standards.

If none of these strategies is feasible the site should not be developed for hard end uses and alternative forms of development should be considered. There may, however, be a need for some form of remedial action to prevent the gas from moving into adjacent land where it may pose an immediate hazard (14).

V REMEDIAL MEASURES

42. The main methods currently employed (other than for gaseous emissions) are containment on site or removal. The approach to be adopted in any particular case depends on the nature, extent and significance of contamination, and can vary within a given site.

43. The depth of the fill also affects the choice of remedial measures. Where the fill is comparatively shallow and limited in extent, removal may be economic: some clearance of waste materials from the site surface may in any case be needed before development or redevelopment can proceed. However, removal of contaminated material on any substantial scale is undesirable: it tends to be expensive, uses up scarce landfill capacity elsewhere which may be needed for more essential purposes, and amounts to transferring a problem from one site to another without solving it, in order to gain a local advantage. Moreover, removal can create problems of nuisance, noise, odour, dust etc. If any contaminated materials are to be removed from the site for disposal elsewhere, the local Waste Disposal Authority and the local planning authority should be consulted. Appropriate precautions should be taken to minimise risks of ground and surface water pollution during disturbance of material. Highly contaminated material may require detailed documentary procedures as 'special waste' under the provisions of Section 17 of the Control of Pollution (Special Waste) Regulations 1980.

44. Where the quantity of contaminated material present is such as to preclude its removal, it will usually be necessary to retain it on the site and to isolate it beneath a sufficient depth of clean added cover material: it may be necessary in some instances to install vertical barriers to prevent lateral migration of contaminants. Liquid and semi-solid wastes can break out through some covering materials due to the effects of excessive loading through compaction or as the result of disturbance. Rather than allowing such wastes to remain on site and covering them over, it is preferable to remove them during site clearance operations. Appropriate precautions should be taken to minimise risks of ground and surface water pollution: advice should be sought from the NRA on the measures to be used.

45. For sites where hard development is proposed it is usually necessary to provide sufficient depth of cover to enable all services to be installed within the clean material. If however it is necessary to excavate service trenches through contaminated ground, the trenches should be cut oversize and filled with clean material before installation of the services. When this procedure is used, the appropriate precautions should be taken to minimise risks of re-contamination caused by any subsequent excavation of the service trenches. The statutory undertakings, and the water supply company, should be consulted about their special requirements, if any. Some water undertakers have special provisions concerning the installation of mains through contaminated land. It is considered that in some circumstances, such as a burst water main, backsiphonage could occur, resulting in the introduction of polluting substances into the water supply. Advice on pipeline installation in contaminated land is available from the Water Research Centre (7).

46. To reduce the hazards from emission of flammable or asphyxiant gases, additional precautions will normally be essential. The general principles of these precautions will be to collect and extract the gas so as to prevent it reaching the proposed development, and/or to design the development so that ingress and accumulation of dangerous concentrations of gas are

prevented even if the gas were to reach it. Either or both these methods may be used but the actual remedial measures adopted will be site-specific, depending on the rate of emission, the gas composition and concentration, and the intended use of the site.

47. Protection systems can operate either passively or actively. At some sites, a combination of both types may be required but care is needed to ensure that the measures adopted are not prejudicial to neighbouring properties or developments.

i *Passive systems* utilise the tendency for gas to migrate along paths of lower resistance either by introducing a preferential flow path along which it is safe to allow gas to migrate or by placing a barrier to flow to prevent gas migrating in a particular direction. It is important to note, however, that the use of vertical barriers in isolation will rarely provide satisfactory control. Examples of such systems are:

(a) peripheral cut-off trenches filled with permeable granular material, which intercept the gas as it moves outwards from the site and provide a preferential path for it to escape to the atmosphere away from the area intended to be developed. However, experience in practice has shown that the construction of such trenches is difficult to monitor effectively to ensure correct installation, and that they can become blocked with debris and vegetation.

(b) vertical barriers, for example bentonite filled trenches, compacted clay bunds or artificial membranes, which prevent the gas from moving away from the site and thereby force it to escape directly from the surface: the possibility of sideways or downwards deflection should not be overlooked and suitable provisions made to deal with this if necessary.

ii *Active systems* control or influence the movement of gas directly and continuously by the use of, for example a pump to provide a pressure differential between the body of the fill and a gas collection system. Such systems usually take the form of a network of horizontal and vertical collection pipes installed within the fill material, and connected to a series of boreholes or wells from which the gas can be pumped off. Guidance in the current edition of Waste Management Paper No 27(14) is that in any sub-surface probe or borehole outside the area of influence of any gas control system or the area of the wastes, whichever is greater, the flammable gas concentration from the landfill should not exceed 1% by volume in air and the concentration of carbon dioxide should not exceed 0.5% by volume in air (currently under review). Where the yield of gas is sufficiently high and its quality is suitable, it may be economically viable to extract and recover it as a fuel. Commercial utilisation of gas is discussed in Waste Management Paper No. 26(10). In other cases the gas may be burnt through a properly designed flare stack. The rate of pumping and extraction must be closely matched to the rate at which gas is generated. Over-pumping may draw oxygen into the fill and cause methane production to slow down or stop, so giving the impression that emission has ceased: if pumping is then stopped methane generation may restart and give rise to hazards; there is also the risk that over-pumping may lead to the development of explosive gas-air mixtures in pipelines and pumping equipment. On sites with both active and passive control systems there is the possibility that air may be drawn into the site through vent trenches. Under-pumping is also undesirable, as too low a rate of collection and extraction may allow gas to migrate away from the site into adjacent land.

48. If the alternative strategy is adopted of designing the buildings to prevent ingress and accumulation of dangerous concentrations of gases, the main objective of the protective measures described above should be to reduce the likelihood that dangerous accumulations of gas will occur in or around the buildings. The objective of building design and construction techniques must be to ensure that within buildings gases are maintained below specified concentrations throughout the gas producing life of the landfill. Preliminary advice and guidance on critical gas concentrations (for both methane and carbon dioxide) and on building design and construction techniques have been prepared by the Building Research Establishment (15). Measures which can be adopted include the following:

i Designing foundations to avoid the possibility of unventilated spaces within or beneath the buildings;

ii Providing gas traps or other special precautions at the points of entry of essential building services, especially water supplies, drains and electricity cables etc; and

iii Providing adequate internal ventilation for both below-ground and above-ground parts of the buildings, with monitoring alarm devices to respond to any potentially hazardous build-up of flammable gases.

49. The professional advice of structural engineers, foundation design specialists and ventilation experts should be obtained before specifying the precise form of a protection system. Their opinion on what is practical may influence decisions on what forms of development are possible: for example, it may well prove simpler to attempt to protect one large building from landfill gas than several smaller ones. Traditional types of housing development (ie houses with gardens) require particularly stringent precautions which should include the provision of high levels of sub-floor and cavity ventilation and the installation of gas detectors and linked alarm systems. However, the problems likely to be encountered in ensuring maintenance and guaranteeing the safe operation of such systems over the gassing lifetime of a site, and the implications for effective insulation as a consequence of high ventilation rates, strongly militate against construction of traditional housing within an area affected by emissions of landfill gas. Blocks of flats, offices, supermarkets etc may be less difficult to protect: for example the sub-floor ventilation requirements may be met by raising the building clear of the ground - a form of construction which does not lend itself to traditional types of housing development - and other means of meeting ventilation requirements which are more capable of being subjected to quality assured management. Similarly, the provision and maintenance of detection and alarm systems and other protective measures can be more readily accomplished in flats or commercial premises. The form of development and the design of protection systems should take account of any gas control systems already installed at landfill sites: the operation of such systems should not be compromised in any way by the proposed development.

50. Various attempts to control landfill gas in order to protect buildings are described in published papers. These include case studies and discussion of case histories of housing and

industrial redevelopment on former landfills (16, 17, 18, 19), provision of gas control adjacent to existing housing (20), consideration of the factors involved in the design of a motorway service station on a landfill site (21), and specialised construction techniques and monitoring procedures (22). The control of the migration of landfill gas by grouting to protect residential development has also been described (23). Other examples are to be found in Reference 15.

51. Whatever remedial measures are adopted the aim should be to ensure that they are durable, ie continue to be effective for the required time period, and robust, ie practical and not over-dependent on close control of design features. Responsibility for safe development and secure occupancy of the site rests with the developer (1).

ANNEX I

PROPERTIES OF LANDFILL GAS

1. Landfill gas is a complex mixture of several constituents. The principal components are: methane (55-65%) and carbon dioxide (35-45%). Other constituents may include hydrogen sulphide (up to 100ppm (0.01%) but occasionally much higher), water vapour (1-1.5%) and other hydrocarbons (1%).

2. *Methane* (CH_4) is a colourless, odourless, asphyxiant gas whose density is less than that of air. It is flammable, and will burn when mixed with air in certain proportions which define the limits of flammability (or explosibility). The lower explosive limit (LEL) for methane in air is normally 5% by volume; the upper limit (UEL) is 15% by volume. Any mixture of methane in air within these limits will burn if ignited. When the proportion of methane exceeds the UEL value the mixture should still be regarded as hazardous, since if it were to be diluted with clean air the composition might then fall within the flammable range. Furthermore, somewhere around the body of such a mixture of gas is a volume which will be in the explosive range and will therefore be hazardous. Only mixtures containing less than the LEL proportion of methane should be considered non-flammable: it is normal to allow a safety factor of at least 5, ie the methane concentration should not exceed 1% by volume in air (20% LEL).

3. *Carbon dioxide* (CO_2) is also colourless, odourless and asphyxiant. It is non-flammable and denser than air. The Health and Safety Executive (HSE) recommended short-term exposure limit (10 minutes) for CO_2 is a concentration of 1.5% by volume in air and the long-term limit (8 hours) is 0.5% by volume; it is normally present in air at a concentration of 0.03% by volume.

4. *Hydrogen sulphide* (H_2S) is colourless and highly toxic with a strong unpleasant odour of bad eggs at low concentrations. It is flammable in air, with a LEL value of 4.3% and UEL of 45.5% by volume in air. Its principal hazard is one of toxicity, however, with the toxic effects becoming more severe as the concentration increases. The HSE short-term exposure limit is 15 ppm and the long-term limit is 10 ppm; death can occur within a few minutes at concentrations of around 700 ppm. Potentially hazardous concentrations of hydrogen sulphide may not be detectable by smell due to olfactory fatigue after only seconds of exposure.

5. The practice of capping landfill sites with impermeable clay materials during restoration can result in a build-up of gas pressure within the site. If the top of a site is capped and the sides and base are not lined gas may migrate underground from the site under pressure and produce hazards on adjacent land. When the landfill site has been capped with impermeable materials, or covered by buildings or other structures which effectively seal off the surface of the fill, or the surrounding ground is particularly permeable, movement of gas can take place for distances up to several hundred metres. The presence of underground fissures or cavities such as old mine workings, service trenches etc may assist such movement. In addition certain climatic conditions such as hard frosts or heavy rainfall may temporarily seal the surface of a site, so forcing the gas to migrate laterally through the surrounding ground instead.

6. It has been estimated that over a 13 year period one tonne of household waste will decompose to produce a total of 130m^3 of landfill gas of which approximately 80m^3 will be methane. Other sites which contain, or are underlain by, natural organic materials, eg peat, may also release methane: examples are riversides, marshlands, dock areas. Land in coalfield areas, particularly that associated with shafts or with fractured or porous rock above seams and workings, may have methane problems. The concentrations of methane and the rates of gas emission from such sites are, however, generally lower than those from landfills although relatively high amounts may come from recently abandoned coal mines where water levels rise after pumping has ceased. Where there is uncertainty over the source of gas, analysis of the composition of gas samples by gas chromatography should be used to help establish its origin. Where it is still not possible to distinguish landfill gas from gas from other sources then carbon dating is probably the only satisfactory technique which can be used provided the gas is not a mixture from different sources. Appendix VIII of Waste Management Paper No. 26(10) gives typical analyses of gases other than landfill gas.

7. The initial release of gas from filled sites containing biodegradable materials may not occur until several years after completion of filling. This is because the numbers of methane-generating bacteria increase only slowly until the moisture content and temperature within the fill material reach the values needed to initiate and sustain gas production. The rates of gas production depend on the composition, depth and degree of compaction of the putrescible materials. Comparatively recent fill (less than 20 years old) which has been deposited in densely compacted layers in deep, wet pits or quarries is more likely to produce gas than older, loosely compacted material. Samples of fill material can be taken from various positions in the site and analysed by appropriate methods to attempt to estimate the potential for future gas generation.

ANNEX II

ASSESSMENT TECHNIQUES ON SITES EMITTING LANDFILL GAS

I GENERAL CONSIDERATIONS

1. Whenever the production, emission and movement of gas may occur, reliable techniques for its detection, measurement and monitoring are needed to assess the hazards prior to seeking planning approval. It may then be possible to incorporate any necessary precautions within the application or to suitably amend the proposed development. Thus it is essential that a site being considered for development is investigated thoroughly and comprehensively. Recommendations for investigation of potentially contaminated land are given in ICRCL Guidance Note 59/83 and in a BSI Draft Code of Practice (12). Strategies for sampling and monitoring sites subject to gas emissions have also been described (16, 18, 24, 25, 26). Important initial information can be obtained by first carrying out a comprehensive "desk study". In the case of a former landfill this should include information on, for example, the volume of the landfill, the types and quantities of waste disposed of and the period during which they were placed. Detailed information on the topography and geography of the site and the geology and hydrogeology of the area should also be obtained, by investigation if necessary.

II CHOICE OF GAS DETECTOR

2. The correct choice of suitable techniques and instruments for determining the gases present on a site is very important. No one instrument is likely to be suitable for all purposes (24) although recent research has shown that the use of coupled thermal conductivity/catalytic detectors (see paragraph 5) greatly reduces the influence of various interfering factors (25). All measurements taken with portable instruments should be confirmed by laboratory analysis of gas samples.

3. The main types of commercially available instruments for site monitoring are:

- i catalytic flammable gas detectors (explosimeters);
- ii thermal conductivity detectors;
- iii infra-red gas detectors; and
- iv flame ionisation detectors.

4. *Catalytic detectors* respond to the presence of any flammable gas or vapour, but must be calibrated for the composition of the gas or mixture they are intended to measure. Some instruments of this type give ambiguous results when used in atmospheres which are deficient in oxygen or enriched with the flammable gas. Their performance deteriorates with age through "poisoning" of the catalyst and needs to be calibrated regularly against a gas of known composition. Some trace constituents of landfill gas, especially halogenated organic compounds, silicones and organic compounds of phosphorus and lead, can accelerate this poisoning.

5 *Thermal conductivity detectors* measure the thermal conductivity of the sample gas. They can be used to detect the presence of any gas whose thermal conductivity differs sufficiently from that of air, but are best suited to determining the gas for which they have been calibrated. The presence of other gases in the sample may affect their accuracy. Some instruments of this type (known as binary gas analysers) can determine two components of a gas mixture provided the difference between their respective thermal conductivities is sufficiently large. Catalytic and thermal conductivity detectors can be combined in a single instrument. This enables several different measuring ranges, eg 0-10% LEL, 0-100% LEL and 0-100% by volume in air to be used. Improved performance in oxygen-deficient and fuel-rich atmospheres is also possible.

6. *Infra-red (i-r) detectors* measure the absorption of radiation in the i-r region of the electromagnetic spectrum. Provided that the gas to be determined absorbs this type of radiation, it is possible to determine its concentration in a sample by measuring the absorption. By suitable choice of i-r wavelength and detection system, highly selective response can be obtained for a wide range of gases including methane and carbon dioxide. Infra-red instruments are sensitive to the presence of water in a sample and it is advisable to dry the gases before they are passed through the analyser.

7. *Flame ionization detectors* respond to the passage of organic material(s) through a hydrogen - air flame. Although very sensitive, they respond to the presence of any organic materials, and, in addition, most instruments of this type use the air drawn in with the sample to provide the oxygen to support the flame. They require a minimum amount of oxygen in the sample to operate correctly, and will not be suitable for sampling where oxygen may be in low concentration or be absent. These instruments should not be used in an explosive atmosphere because the sensor incorporates a flame. The main use for this type of instrument is likely to be in the early stages of a site investigation to indicate where gas may be emitting from the ground ie for "sniffing" the open air above the site.

III MEASUREMENT OF EMISSION RATES AND CONCENTRATIONS AND THEIR VARIATIONS WITH TIME

8. Gas emissions can vary with changes in atmospheric pressure such that large variations have been recorded at the same sampling point at different times at most sites. Barometric pressure should therefore be recorded prior to and during monitoring of sites, and a record kept of the height of the water table. Care is necessary when measuring water table levels that the level recorded is not a perched table within the filled material. The air temperature is only significant for very shallow sites where in warm weather the wastes are heated sufficiently to increase microbial activity and therefore increase gas production: in the majority of sites this factor will be insignificant.

9. A single sampling investigation using portable detectors does not provide enough information to assess the hazards adequately. Not only does the performance of these instruments depend upon the type of detector and the suitability for the particular application, but the release of gas from the site is, as noted above, affected by climatic and hydrogeological factors which change with time. Even if portable detectors give a negative response during the initial survey of a

site, it is still possible for gas to be produced at some time in the future. The implications of an erroneous conclusion could have significant consequences for the safety of any proposed development of the site. To reduce the likelihood of reaching such a conclusion, it is preferable to carry out regular sampling or monitoring using fixed sampling points installed in the fill material over a sufficiently long period of time, eg at least 12 months, to define the full range of gas composition and emission rates.

10. One type of instrument for measuring gas emission rates is the hot-wire anemometer. This device operates on the principle of thermal conductivity and is normally calibrated to measure air velocities. Since the thermal conductivity of landfill gas is very different from that of air, erroneous conclusions may be drawn regarding gas emission rates and it is therefore necessary to calibrate the instrument for the particular mixture and concentration of gases present on site. It is also advisable to provide wind-shielding of the anemometer to prevent errors in measurement due to turbulence (25). Before using a hot wire anemometer, the user should check that the instrument is safe to use in a flammable gas stream. Other techniques for measuring emission rates are the use of a bubble flow meter or a pitot tube connected to a manometer. However, these methods are unlikely to be suitable on sites with low emission rates.

11. A simple short-term method for measuring and monitoring the gas composition in shallow soil or fill material is to sink a rigid hollow probe into the ground to a depth of 0.5-1.0m, and connect it to the gas detector with a flexible tube. After inserting the probe, the hole is sealed at the surface and the gas sample drawn from the connecting tube.

12. For monitoring over a longer period a semi-permanent type of sampling point is required, for example a sealed borehole provided with perforated lining walls to allow the soil gases to enter, together with means of drawing off samples for analysis or measuring the volume collected in a given time. In addition sample probes may be installed in back-filled trial pits which will also provide information on conditions at various locations on site and will enable solid samples to be taken at different depths down to the limit of the trench.

13. Monitoring should be carried out at regular intervals. Methane concentrations measured with shallow probes are usually low because it is difficult to obtain a good seal at the surface and air is drawn in during sampling. Further, the amount of anaerobic activity is less at shallow depth because of the availability of oxygen. It is possible, therefore, that shallow monitoring may give erroneous results. On the other hand, at greater depths the conditions may be such as to produce methane in relatively high concentrations and the results are likely to be much more reliable and consistent.

REFERENCES

1. DEPARTMENT OF THE ENVIRONMENT AND THE WELSH OFFICE. DOE Circular 21/87 (Welsh Office 22/87) Development of Contaminated Land. HMSO 1987, price £1.90.

2. DEPARTMENT OF THE ENVIRONMENT AND THE WELSH OFFICE. DOE Circular 17/89 (Welsh Office 38/89) Landfill Sites: Development Control. HMSO 1989, price £1.40.

3. Article 18 of The Town and Country Planning General Development Order 1988. Statutory Instruments 1988 No. 1813 Town and Country Planning, England and Wales. HMSO. Price £6.80.

4. DEPARTMENT OF THE ENVIRONMENT AND THE WELSH OFFICE. Planning Policy Guidance: Development on Unstable Land. PPG 14. 1990. HMSO. Price £3.50.

5. BUILDING RESEARCH ESTABLISHMENT. Incidence and control of subterranean fires: note of a meeting held at the Fire Research Station. BRE Occasional Paper. April 1990.

6. The effect of soil contaminants on materials used for distribution of water. Water Research Centre Report PRD 1452 - M/1 1987.

7. Pipeline installation in contaminated land. Water Research Centre Report ER 319E 1988.

8. Effects of soil contaminants on materials used for distribution of water. Water Research Centre Report ECI 9268. 1990.

9. HER MAJESTY'S INSPECTORATE OF POLLUTION. First Annual Report, 1987-88, HMSO 1989, price £10.95.

10. DEPARTMENT OF THE ENVIRONMENT. "Landfilling Wastes" (Report of the Landfill Practices Review Group). Waste Management Paper No 26, HMSO 1986. Price £15.00.

11. BRITISH STANDARDS INSTITUTION. Code of Practice for Ground Engineering Investigations. BS 5930: 1981.

12. BRITISH STANDARDS INSTITUTION. Draft for Development. Code of Practice for the Identification of Potentially Contaminated Land and its Investigation. DD 175/88.

13. WELSH OFFICE. Survey of contaminated land in Wales. August 1988. ISBN 0 86348 825 5.

14. DEPARTMENT OF THE ENVIRONMENT (HER MAJESTY'S INSPECTORATE OF POLLUTION). The Control of Landfill Gas, Waste Management Paper No 27, HMSO 1989 price £6.80.

15. BUILDING RESEARCH ESTABLISHMENT. To be published.

16. Carpenter, R.J. 1988. Building redevelopment on disused landfill sites - overcoming the landfill gas problem? ISWA 88. Proceedings of the 5th International Solid Wastes Conference, September 11-16, 1988, Copenhagen, Denmark. Vol 1. Andersen, L. and Moller, J. (eds). Academic Press. London. 1988, pp153-160.

17. Emberton, J.R. and Parker, A. 1987. The problems associated with building on landfill sites. Waste Management & Research, 5, 473-482.

18. INSTITUTE OF WASTES MANAGEMENT. Monitoring of landfill gas. September 1989.

19. Gross P.A. 1990. Assessment of landfill gas migration onto a site in Dartford. Polluted and Marginal Land - 90. Engineering Technics Press, Edinburgh, pp53-58.

20. McKendry, P.J. 1990. Pollution containment and gas extraction/flaring adjacent to housing. Polluted and Marginal Land - 90. Engineering Technics Press, Edinburgh, pp133-146.

21. Jones, D.L., Crowcroft, P. and Pritchard, B.N. 1988. Design of a motorway service station on a landfill site. Proceedings of the GRCDA 11th International Landfill Gas Symposium, March 21-24, 1988, Houston, Texas. Publication number GLFG-0016, GRCDA, PO Box 7219 Silver Spring, MD 20910, pp 32-45.

22. Lingwood, P. and Tankard, J. 1988. Safety on risky land. Surveyor 20 October 1988, 16-18.

23. Raybould, J.G and Anderson, D. J. 1987. Migration of landfill gas and its control by grouting - a case history. Quarterly Journal of Engineering Geology, London, 20, 75-83.

24. BUILDING RESEARCH ESTABLISHMENT. Measurement of gas emissions from contaminated land. BRE Report 1987, ISBN 0 85125 246 X. Available from BRE, Garston, Watford WD2 7JR. Price £8.00.

25. Research on Landfill Gas - Monitoring Equipment and Investigation Techniques. WS Atkins & Partners, Woodcote Grove, Ashley Road, Epsom, Surrey KT18 5BW. Report to DOE November 1988.

26. Campbell, D. 1988. Detecting the dangers. Surveyor 20 October 1988, 14-15.

ICRCL Guidance Notes in this series:

ICRCL 17/78 Notes on the development and after-use of landfill sites
ICRCL 18/79 Notes on the redevelopment of gasworks sites
ICRCL 23/79 Notes on the redevelopment of sewage works and farms
ICRCL 42/80 Notes on the redevelopment of scrap yards and similar sites
ICRCL 59/83 Guidance on the assessment and redevelopment of contaminated land
ICRCL 61/84 Notes on the fire hazards of contaminated land
ICRCL 64/85 Asbestos on contaminated sites
ICRCL 70/90 Notes on the restoration and aftercare of metalliferous mining sites for pasture and grazing

Copies of the publications listed above may be obtained from:

Department of the Environment
Publication Sales Unit
Building 1
Victoria Road
SOUTH RUISLIP
Middlesex HA4 0NZ

Requests for further general guidance on the problems of contaminated land should be addressed to:

The Secretary
Interdepartmental Committee on the
Redevelopment of Contaminated Land
Department of the Environment
Room A228 Romney House
43 Marsham Street
LONDON SW1P 3PY