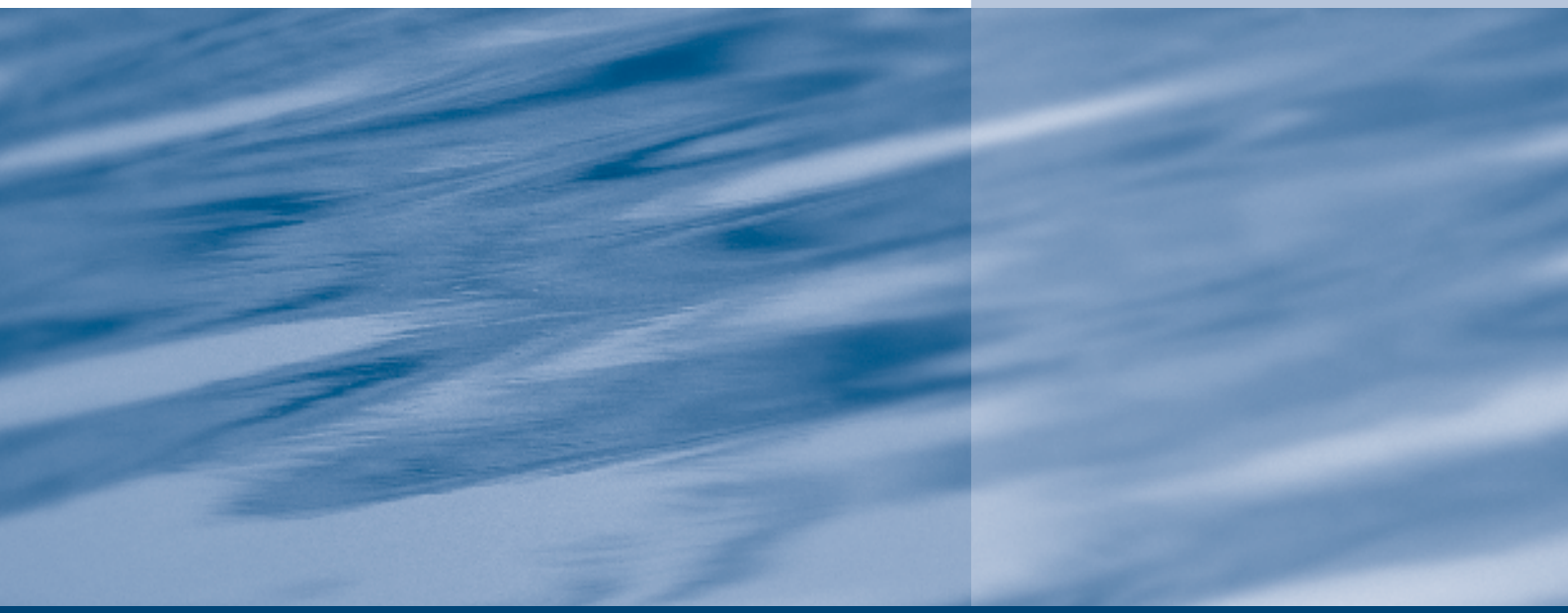

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Potential groundwater pollutants from cemeteries

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Professor Mike Depledge Head of Science

Executive Summary

This report provides background information on the likely types and concentrations of potential groundwater pollutants that may arise from the practice of human burial after death. It is intended as an update of a previous Agency report (P223) and is for anyone who may need to consider the potential for groundwater pollution from new or existing cemetery developments.

The report considers the components of the grave including organic and inorganic body constituents and reviews the likely processes of decay which will liberate these body constituents into the surrounding soil and groundwater. The likely timescales for degradation are presented.

The information should help in the preparation of a groundwater risk assessment for a particular site through providing background data to feed into that assessment.

Contents

1. Introduction

1.1 Scope

This report is intended as an aid to those involved in the development and management of human burial sites and in particular medium to large-scale cemeteries. The document provides an updated review of the potential pollution issues for groundwater associated with such sites which may in turn feed into any risk assessment for considering the environmental implications of a site. It follows on from, and replaces, an earlier report (Environment Agency, 1999) and builds on some of the additional research which the Agency has carried out with others in the intervening years (Trick, J, *et al*, 2002).

The report does not provide a detailed assessment for individual sites but rather is a point of reference for anyone who may regulate, manage or indeed own such sites.

This report also does not consider animal burials in detail either in large scale incidents, such as the disposal of carcasses following the outbreak of Foot and Mouth disease (FMD) nor for the more prosaic, but increasingly common pet cemeteries. For the latter one might consider that many of the issues and processes would be similar to human burial sites though the precise details of, for example, body sizes, numbers per hectare and time to skeleton will be different.

1.2 Context

The human body is made up of a multitude of elements and complex organic substances. After death, these components return to the wider environment either through the natural processes of decay or through human intervention for example in cremation. This document is intended to consider the potential groundwater pollution risks from areas of land used for multiple burials. Such areas are increasingly known by a variety of names including cemeteries, graveyards, burial grounds and so on. A scheme for the definition of such terms has been proposed (Rugg, 2000) but readers should be mindful that the pollution risks to groundwater are based on the geophysical and biogeochemical setting of the site and the source term involved rather than the title or description on the gate. For our own part we have mostly used the term cemetery intending to convey the impression of a planned site of burial for several to many bodies.

Several authors have commented that the cemetery in effect represents a specialised form of landfill (Dent and Knight, 1998) and the practice of burial does come very close to some current terminology in the arena of waste management. However, this comparison is not entirely helpful and should be used with care, particularly in public discussions. Certainly, there are some significant differences in the nature of a cemetery and the concept that most readers may have of a landfill. In particular, the relative volume of soil to waste and the liquid content are likely to be very different. Nevertheless, for existing landfills at least the sites do share the common aspect of being a final resting-place for organic and other material that has the potential to degrade and be transported in the subsurface. Moreover, the attention paid elsewhere to the regulation of crematoria and the atmospheric emissions from such establishments (Anon. 2001) shows that the potential environmental impacts from the disposal of human bodies may need to be carefully considered. Our focus is on the groundwater which may exist under a cemetery.

2. Review of burial conditions and associated decay processes

2.1 Burial practices and sites

Though it may initially seem that the existing arrangements and practices for the disposal of the dead are completely established and unchanged for many years, this is not necessarily the case.

For the great majority of the population there are two main choices for disposal of human remains, to wit, burial or cremation. Nowadays cremation is considerably more common than burial with almost 75% of funerals resulting in cremation in 2002 (Cremation Society of Great Britain, 2003). An indication of the changes in fashion for cremation is that by contrast in 1885 there were precisely 3 recorded cremations. Though more exotic options such as burial at sea, launch of ashes into space or even conversion of ashes to a diamond are available; such disposal would seem to pose little direct risk to groundwater from the remains. Even more exotic options such as lyophilisation ("freeze-drying") followed by crushing, or alkaline hydrolysis in concentrated hydroxide followed by disposal to foul sewer, have been proposed but are not commonly available in England and Wales. To be clear, this report focuses solely on the impacts from burials and the potential for groundwater pollution, cremations are not considered further as there is a range of regulation and legislation specific to crematorium emissions.

As with any industry new techniques and procedures arise and customer demands can change both in response to changing demographics and also in response to changing environmental perceptions. Moreover, the ever increasing demand for development land, public perceptions particularly from site neighbours and the fact that in some areas of the country our cemetery capacity is fast filling up (London Planning Advisory Committee) provide pressures for and against new cemetery developments. With a current annual burial rate of 140,000 and an area of approximately $5m^3$ per burial (see below) we need approximately 70 hectares of land per year for this purpose.

The Home Office has recently published a consultation (Home Office, 2004) on the regulation and provision of cemeteries, which is intended as a first step to the reform of some of the rather aged burial law. In particular, the consultation considered the desirability of requiring local authorities to ensure that adequate cemetery space exists (currently this is discretionary), as well as the issue of reuse of burial grounds. Note that there are approximately 25,000 burial grounds across England and Wales (Home Office, 2004). The consultation is largely silent on the potential environmental pollution aspects of any such new policies.

2.1.2 Green burials

In recent years that has been increasing interest in the uptake of "green" burials and this was a focus in our earlier report. The term "green burial" can have many meanings ranging from carrying out the funeral and burial as a close family (rather than using the services of a funeral director) through some degree of environmental consideration (e.g.

use of a shroud or cardboard coffin in preference to a wooden coffin) to all the above plus the use of a “natural” burial ground. These latter are often meadow or woodland sites and are intended to be managed in a way that is environmentally or ecologically responsible. The previous Agency report noted that in 1997 there were more than 50 “green” burial grounds operating in Great Britain, with 40 more potential sites making applications for planning permission. More recently in 2003 the Natural Death Centre has published a list of more than 180 natural burial grounds (Wienrich and Speyer, 2003) and suggest that 200 exist (Personal communication). For the purposes of this report the most important features of such sites are that:

- they may present a higher proportion of new development proposals than might be supposed from the total number of such sites;
- such sites may be more likely to prohibit the use of preservatives (either in embalming of the corpse or in coffin construction) than more traditional sites;
- the sites may allow a larger grave area and thus have a lower frequency of corpses per hectare;
- development proposals may come from individuals or small companies who are not familiar with the Planning regime and unaware of groundwater considerations;
- such sites commonly plant native tree or shrub species around or on top of the grave thus providing different biological and recharge conditions through the grave.

However, despite the rapid increase in the numbers of these sites the total numbers of such burials is currently only a small proportion of the total with a report of 1,270 occurring in 2002 out of a total burial and cremation tally of approximately 600,000 per annum.

2.1.3 Burial depth

The depth to which coffins are buried depends in part on the nature of the site and the anticipated use. A normal minimum of 1.4m may be deeper particularly where the grave is expected to accommodate 2 or more burials. A table of grave depths for the Danescourt cemetery was published and is repeated here.

Table 2.1 Depths of burial

Number of coffins in grave	Depth (m bgl)
1	1.40
2	1.83
4	2.74

2.1.4 Burial numbers per unit area and volumes

As the settings and usage of cemeteries can vary widely so too can the numbers and proximity of bodies buried in a given area. In particular, the distribution of bodies within natural burial grounds may be more variable than traditional municipal sites. Users of this report may well have in mind a particular site and circumstance and should then refer to the individual case rather than rely on approximations provided here.

For those who require some guidance, the numbers presented in the previous Agency report remain valid. That is, traditional cemeteries may contain approximately 2,000 burials per hectare. Green burials would normally be expected to contain somewhat

fewer graves, at approximately 1,600 per hectare. However we note that perhaps the earliest and most famous example of the latter at Carlisle was planned with only 440 graves per hectare (Wienrich and Speyer, 2003) so the green number may normally be substantially less than that given above. Conversely, as the demand for green burials appears to be growing it may be prudent to reflect that these sites may be very likely to increase in size and perhaps density in years to come.

Using these numbers each grave would entail an area of approximately 5 m^2 for traditional cemeteries and from 6.3 to 23 m^2 for the green sites.

It was noted above that the similarities between cemeteries and landfills are limited. Certainly for most waste operations which we might consider landfills, the waste material would normally be much more closely packed together with perhaps a shallow cover of soil. For cemeteries this is clearly different; the bodies represent a very small proportion of the total site volume and are distributed approximately evenly with significant quantities of soil between them.

For example for a cemetery with 2,000 burials per hectare:

Interred mass =	2,000 x (body mass 70kg + coffin mass 15kg) 170 tonnes
Interred volume =	2,000 x (coffin volume 2.1m(l) x 0.75m(w) x 0.4m(h)) 1,260 cubic metres

(note this is quite a wide coffin, many may be significantly smaller)

By contrast:

Soil volume =	(10,000m^2 x 1.8m) – 1,260m^3 16,740 cubic metres
Soil mass =	23,436 tonnes (assuming soil density of 1.4$t.m^{-3}$)

That is, the graves represent less than 1% of the site mass and about 7% of the site volume down to 1.8m depth.

2.1.5 Embalming

The use of embalming in England and Wales is normally restricted to work intended to provide cosmetic enhancement until burial or cremation and to inhibit decay until after burial. Some also suggest that the process provides a disinfection of the body and certainly there is some evidence of a decrease in numbers of cultivable bacteria in formaldehyde treated bodies (Burke and Sheffner, 1976).

In essence, the process involves the injection of embalming fluid which is a solution of formaldehyde into the blood vessels and abdomen. Other components of the fluid may include surfactants to improve replacement of the original body fluid, antioxidants, buffers, and pinkish dyes such as eosin or erythrosine (Mayer, 2000). However, these components are normally in low concentration. The overall effect generates an improved appearance by filling out the face and tissues and giving a more lifelike colour to the skin.

The frequency of embalming is unclear, in the previous report it was noted that embalming may be practiced on approximately 50% of bodies though others suggest 75% of bodies (Personal communication). The decision to embalm is often at the discretion of the individual funeral director and may be more common where bodies are to be viewed before burial or cremation. Indeed, it may be that in some instances the decision of whether or not to embalm is tacit within the question of whether the body is to be viewed.

2.1.6 Coffins and other non-body contents of the grave

The options for containing the body at burial range vary widely from simple shrouds or even army surplus body bags to grand caskets of pine or hardwoods. Coffins and shrouds may therefore be composed of less rapidly degraded materials than the corpses which they enclose. Nevertheless, in modern burial practice most burials probably involve chipboard and medium density fibreboard (MDF) coffins which may begin to disintegrate rapidly in the ground compared with solid wooden boxes. Decay and collapse of chipboard coffins is reported to be evident within one month of burial, compared with 15 to 20 years in the case of pine or over 60 years for elm boxes, whilst cardboard coffins are reported to collapse onto the cadaver almost immediately on infilling the grave.

The use of MDF and chipboard as construction materials brings with it another source of formaldehyde into the grave since these materials are themselves produced from sawdust and wood fragments bonded with urea-formaldehyde resin or occasionally the more expensive phenol-formaldehyde resin. Urea-formaldehyde resins are prepared as colloids with a solids content of 65% and common usage levels may approximate to 8% resin to wood fibre (Groom *et al* 1999). The environmental concerns around formaldehyde in MDF are normally centred on off-gassing and inhalation in indoor air. Hence environmental reports mostly consider air quality above a board, however, free formaldehyde in MDF sawdust has been observed at approximately 350 micrograms per gram (Leungprasert and Otten). Thus for a 15kg coffin this would imply 5.25g of free formaldehyde. Note that the assumption of a 15kg coffin is an increase from the previous Agency report. This comes from consideration of the properties (Wood Panel Industries Federation, 2003) of the wood products used (Wood Panel Industries Federation, 2002) and assumptions on the size and shape of coffins. Clearly this figure will vary depending on the precise details of individual burials.

There is also the potential for metal and other objects to be interred in the grave; either as worn jewellery or even grave goods. Moreover, a proportion of the population may be expected to be interred with medical items such as orthopaedic implants or structures.

2.2 Overview of body decay

Previous environmental reports have often tended to consider the buried human corpse as a largely elemental mass of potentially polluting substances. Inclusion of the elemental composition (Table 2.2) (Forbes, 1987) in the previous Agency report further emphasised this with the omission of the Oxygen data in the first edition of that report.

Table 2.2 Elemental composition of a human body based on a standard or reference man of 70kg body weight

Element	Mass (g)
Oxygen	43000
Carbon	16000
Hydrogen	7000
Nitrogen	1800
Calcium	1100
Phosphorus	500
Sulfur	140
Potassium	140
Sodium	100
Chlorine	95
Magnesium	19
Iron	4.2
Copper	0.07
Lead	0.12
Cadmium	0.05
Nickel	0.01
Uranium	0.00009
Total body mass	70000

However, this is plainly a simplification of the nature and state of these elements as they are largely incorporated into organic compounds such as proteins, fats, bone etc. which in turn will have a major influence on their degradation and decay. Table 2.3 shows a summary of the structural aspects of a human body.

Table 2.3 Structural composition of a human body based on a standard or reference man of 70kg body weight.

Tissue	Mass (g)
Total body mass	70000
Skeletal muscle	28000
Adipose tissue	15000
Bone	5000
Cartilage	1100
Periarticular tissue	900
Marrow	3000
Skin	4900
Liver	1800
Brain	1400

The processes involved in decomposition of human remains have been extensively studied is in the field of forensic anthropology. However, the focus is often on techniques for dating the burial, for example in investigation of crime, rather than in elucidation of mass transfer of potential pollutants (Mann *et al*, 1990). Very recently though, the decomposition processes have been reviewed from the point of view of cemetery pollution (Dent *et al* 2004). For our purposes the key to appreciating the potential for

pollution from cemeteries is an understanding of the release and transport of body constituents into the wider environment. For example, doubtless during decomposition some of the body will be degraded to gases (Iserson, 1994) which may then escape to atmosphere, whereas other components may remain as long chain aliphatic compounds which may be detected in the soil after more than a century (Spongberg and Becks, 2000).

2.2.1 Macrofaunal Influence on Decomposition.

In this report we shall concentrate on the microbial degradation of a buried corpse. Certainly, where present, macrofauna can produce remarkably rapid decomposition as evidenced by the 5 month skeletonisation of a body found in a heated house living room (Schroeder *et al,* 2002). Alas, there is apparently little information available on the non-microbial soil fauna that might be present at traditional cemetery grave depth, or the effect they might have on the buried cadaver. This is probably because this is considered to be well below the normal depth at which plant roots, soil macrofauna, and mycorhizzal fungi function (Forbes *et al,* 2003). A study (Rodriguez and Bass,1985) on unembalmed corpses buried at varying depths demonstrated that the decomposition rate of the cadavers is highly dependent on the burial depth, environmental temperatures and level of insect activity. Carrion insect activity including *Calliphoridae* (blow flies) and *Scarcophagidae* (flesh flies) were noted in association with cadavers buried at 30cm depth, with flies present on the grave surface, and observed burrowing down to the cadaver through cracks in the soil. Eggs laid by adult flies on the grave surface hatched to produce immature larvae, which were also observed migrating down to the cadaver to feed. Beetle activity, principally of *Scarabaeidae* beetles, appeared to be limited to above ground cadaver decomposition. However, digging and carrion insect activities were limited to bodies buried at 30cm depth or above, with no insect activity found at 60cm. A body buried at 120cm was noted to have remained 'very well preserved' throughout the 12 months of the experiment.

Where cadaver macrofauna have been observed in shallow burials they are mainly of necrophagous arthropods, which are insects with sense organs stimulated by organic putrefaction gases that feed on decaying tissue. Approximately 10 insect families have been identified as belonging to this group, among which the orders of *Diptera* (flies) and *Coleoptera* (beetles) stand out particularly due to their activity and frequency on human remains (Campobasso *et al*, 2001). The blowflies *Calliphoridae* and *Muscidae* are able to colonise a corpse as quickly as 2-3 hours after exposure, with *Sarcophagidae* following on, and are principle vectors of degradation because their short life cycle allows a rapid elevation in numbers shortly after colonisation.

For the remainder of this report we have assumed that the traditional burial depths examples in Table 2.1 above will be used and therefore that insect activity within the grave need not concern us further.

2.2.2 Decay of the soft tissues

The processes effecting the degradation and ultimate disintegration of a corpse occur in a series of stages often described as autolysis, putrefaction, liquefaction and skeletonisation (Dent et al, 2004). These are indicative only though and should best be considered as a series of overlapping processes.

Autolysis begins almost immediately after death and includes all manner of processes that are natural 'self destruct' mechanisms (Fiedler and Graw, 2003) within individual

cells or within the wider body. These rely on the action of liberated enzymes or normal body flora micro-organisms. Putrefaction normally begins between 48 and 72 hours after death, although this will vary depending on the prevailing environmental conditions. The body's primary soft tissue constituents of proteins, fats and carbohydrates are broken down by proteolysis, hydrolysis, and oxidation or more likely, fermentation. The decomposition process continues with liquefaction, in which the tissues, softened during putrefaction, degrade into a liquid mass. Skeletonisation is considered to be complete when all of the soft tissue has been removed from the bones, which remain articulated by ligament.

2.2.4 Decay of soft tissues – fats and the formation of adipocere

After death, most bodies undergo putrefaction, in which the neutral fats of the decomposing corpse undergo hydrolysis to fatty acids followed by either hydrogenation, to form saturated rather than unsaturated fatty acids, or oxidation, yielding hydroxy-fatty acids. Assuming sufficient water and enzymes are available this will continue until all of the neutral body fat has been turned into liquefied fatty acids, which may be leached from the coffin. Two notable alternatives to this are possible under the right conditions; the dry decomposition referred to as mummification, and conversion of the body fat to a waxy substance known as adipocere (Fiedler and Graw, 2003).

Adipocere is a grey-white soap like or waxy material known to form as a later post-mortem change, resulting from the bacterial conversion of body fat into a lipid mixture. The main constituents of adipocere are the saturated fatty acids (palmitic, stearic, and myristic acids), with minor components comprising the unsaturated fatty acids (oleic and palmitoleic acid depending on the extent of adipocere formation), triglycerides, hydroxy-fatty acids and the salts of fatty acids (Forbes *et al,* 2003 and Stuart *et al*, 2000). If the conditions under which the hydrolysis and hydrogenation of the fatty acids occurs are right, adipocere will form as a result of the decay process, although the exact nature of adipocere, and its mechanism of formation has yet to be elucidated. The formation of fatty acids salts results from the reaction of fatty acids from the putrefaction process with sodium and potassium present in tissue fluids at neutral or slightly alkaline intracellular pH. If the body is then interred in soil or water with a high mineral content, cation exchange process may result in the displacement of sodium and potassium by calcium and magnesium ions, resulting in the formation of water insoluble soaps of the fatty acids.

The formation of adipocere can occur in various soil types, and may begin as soon as 6 weeks post-mortem, although complete transformation will take many weeks or years dependent on the burial and environmental conditions present, including temperature, pH, clothing, and soil type.

2.2.5 Bone

Unsurprisingly, bone (including tooth enamel) is normally the most resilient and longest lasting component of the body. It is comprised of several types of cells set within an inorganic calcium and phosphorus matrix to give the bone strength (Van De Graaff and Kent, 1998). In addition there is collagen, a structural protein. The relative proportions of each vary within and between bones dependent on the position within the bone structure or indeed the body. Overall, the bone mass may be considered as made up as 60% – 65% calcium hydroxyapatite and 35% protein (mostly collagen). The empirical structure for hydroxyapatite is:

$$Ca_{10}(OH)_2(PO_4)_6.(H_3O)_2$$

Bone dissolution is a slow process and hence the “time to skeleton” is a term used to measure the degradation of all those other body components mentioned above. Nevertheless the components of bone will slowly decompose; the protein content, mainly collagen, is subject to proteolytic attack in the normal ways and loss of collagen would normally render the remaining bone more brittle. Dissolution of the hydroxyapatite will come primarily from acid attack of the structure and replacement of the calcium with hydrogen ions. As such the rate will be dependent on the acidity of the surroundings and skeletal material may be expected to show faster dissolution in acid soils than similar material in neutral soils.

2.2.6 Factors Affecting Rate of Decomposition

Decomposition in the end relies on the rate of activity of degrading organisms and on the rates of the (bio)chemical reactions involved. Hence intrinsic and empirical factors which are seen to influence degradation rate include:

- Age at death – decompositions occurs more slowly in newborn babies
- Body mass index – decomposition may occur more rapidly in obese corpses
- Cause of death – early and rapid onset of putrefaction tends to occur in people who suffered wasting diseases, those suffering septic infections, and those suffering death by asphyxia
- Integrity of the corpse – any unhealed wounds or abrasions provide additional access for soil bacteria
- Burial depth – where shallow enough to allow macrofaunal attack
- Preservatives

Principal among the site related factors are (Santarsiero *et al*, 2000):

- Geological and hydrogeological characteristics of the soil, including soil type, permeability and porosity.
- Microbiological characteristics of the soil
- Mechanical, structural, and resistance parameters of the soil,
- Coffin or other container construction used
- Land cover - land cover and topography will affect infiltration and water-logging will retard decomposition.
- Climate
- Depth of the unsaturated zone – as well as acting as a barrier to contamination of an underlying aquifer, this can also present a means for infiltration of oxygen that may aid the decomposition process.

The interaction of these various factors can be complex, and is the subject of much study in forensics in the determination of post-mortem interval. In general it is therefore difficult to give a precise estimate of the length of time decomposition of the body would be expected to take. However, unless interred in preservative environments, such as those that would promote mummification (Polson *et al*,1985 and Janaway, 1997) skeletonisation of the body would usually be expected to be complete within an interval of approximately 10 years for burial in soil (Santarsiero *et al,* 2000) or 30 years for entombment and this would normally be expected to apply to at least 80% of cemetery burials.

2.3 Environmental change in the vicinity of the grave

The decay processes are noted to bring temporary increases in temperature above the ambient ground temperature, though this increase is more pronounced where macrofaunal decay is seen. Nevertheless, a corpse showing only microbial decay exhibited a mean temperature increase of 3.4^{o}C over the surrounding soil for a period of about 5 weeks and beginning about 4 weeks after burial (Rodriguez and Bass, 1985). This may well reflect the complete consumption of the readily available electron acceptors such as oxygen and nitrate and hence a time period after which the decay process proceeds at a slower rate.

The decay also appears to effect an increase in soil pH around or below the body (Rodriguez and Bass,1985 and Reed,1958) with an increase of 2.1 units recorded. Though the magnitude of this effect will depend in part on the buffering capacity of the soil, from a pollution prevention view it may retard the movement of metals out of the grave.

3. Potential groundwater pollutants from human burials

3.1 Potential pollutants

In the following pages we review the potential components of human bodies that may bring a pollutant risk to groundwater and derive likely loadings in the grave. We have also considered the processes that can contribute to their attenuation in the subsequent chapter. For some substances, such as ammonia, readers should also note that additional Environment Agency guidance on subsurface attenuation already exists (Buss *et al*, 2003).

3.2 Mass transfer out of the grave

Mass transfer of the end products of body degradation will occur in 2 main directions; up and down. Volatile gaseous products such as carbon dioxide, methane, ammonia, putrescine etc. will migrate towards the surface both by diffusion and advection. Soluble and suspended components such as ammonium and micro-organisms will migrate down through the subsurface entrained with recharge. Some lateral diffusion and dispersion may also occur. Under normal circumstances the convection of soil gases may be expected to provide relatively little gas exchange compared to diffusive transport (Jury *et al,* 1991) although if the body temperature is elevated above that of the surrounding soil this may change.

Unfortunately we have found no reports that quantify the extent to which gaseous and soluble or colloidal products are formed from a human body.

3.3 Ammoniacal nitrogen

The previous Agency report focussed heavily on the potential of ammoniacal nitrogen to move into the groundwater. Though understandable, this focus did affect presentation of the data and led others to state incorrectly that Nitrogen is the second most abundant element in the body; compare this with Table 2.2. Note also that this Nitrogen will mainly be present as fixed Nitrogen in reduced -NH_2 substituents of biological molecules such as proteins and peptides.

3.3.1 Ammoniacal loading in the grave

Table 2.2 shows that the example human body of 70kg contains 1.8kg of Nitrogen. One can also see from the section on coffins above that urea-formaldehyde resin might also contribute fixed nitrogen and that approximately 500g could come from this source (based on the molecular structure and mass of urea).

However, this ammoniacal content is not present as free ammonia nor as ammonium ions in solution; rather, and for both the biological and resin derived terms, it is present as a substituent of complex macromolecules which must degrade or be degraded in order for ammonium ions to be released. Furthermore, some of the proteins such as

collagen and keratin will be present in structures noted for their resilience including bone, cartilage, ligaments etc. Collagen, for example, is estimated to account for 35% of bone dry mass and perhaps 50% for cartillage. Such proteins then will likely be amongst the last degraded in the body both by virtue of their intrinsic secondary and tertiary structure, and their shielded position deep within the body and bone. Based on the body compositions above in Table 2.2 and the empirical structure of collagen ($C_{244}H_{385}N_{77}O_{72}$) (Kramer *et al*, 1999)) this suggests about 470g of nitrogen will remain when the process of skeletonisation is complete (with about 1250g of Carbon). Also, for the more degradable proteins present in the major organs and skeletal muscle their bioaccessibility to saprophytic micro-organisms may be less than ideal. For such organisms ingress into, and progress through, the body may be slow and as such the degradation rate may more likely be related to the accessible surface or volume rather than the “lump” concentration of protein or body in the ground.

The degradation of proteins and peptides, when it occurs, is likely to result in the release of amino-acids which may then enter anabolism for the degradative organism or more likely undergo deamination and fermentation. The characteristic death odour compounds of putrescine ($NH_2(CH_2)_5NH_2$ 1,4-diaminobutane or butanediamine) and cadaverine ($NH_2(CH_2)_5NH_2$) arise from the decarboxylation of amino-acids containing an amine side group. These compounds undoubtedly account for a proportion of the Nitrogen released from a body but that may be a small proportion and, in any event, we have not found any reports that provide quantification.

3.4 Formaldehyde

3.4.1 Chemistry and action

Formaldehyde (HCHO, CAS: 50-00-0) is the simplest aldehyde and has a profound biological effect in alkylating the amino or sulfhydryl side chains of amino acids. It may thus destroy the nature, shape and activity of a wide range of proteins and inhibit amino acid and protein biosynthesis. It can similarly alkylate the ring Nitrogen atoms of purine and pyrimidine bases, constituents of nucleic acids.

Formaldehyde is highly soluble (solubility limit @550 g l^{-1}) and reactive. It has a distinct odour and the Henry's Law constant of 3.27x10-7 atm.m^3 mol^{-1} and formaldehyde vapour released to the atmosphere will photodegrade in sunlight in a few hours (Public Health Service, U.S. Department of Health and Human Services, 1999).

Formaldehyde is an important industrial chemical with a wide range of uses in particular as a feed stock to make other chemicals including resin glues. Hence it has been found in wastewater from manufacturing and petrochemical plants (for example see: Sharma *et al* 1994 and International Agency for Research on Cancer, 1982). In general, formaldehyde has been considered an environmental risk to humans via inhalation since the opportunities for environmental exposure through direct ingestion are rare.

3.4.2 Formaldehyde loading in the grave

As noted above there are two potential sources of formaldehyde in the grave, embalming fluid and coffin manufacture. The loading from embalming was discussed in our earlier report and can be summarised thus: 9 litres of 2% formalin solution provide 180g of formaldehyde per body.

Urea formaldehyde resin used in pressed wood product manufacture is itself the product of condensation reactions of methyloureas and, as such, is susceptible to the reverse hydrolysis reactions (Conner, 1996) such as might be anticipated over the period of disintegration of the coffin. Resins are typically made using molar ratio of 1:1.1:urea:formaldehyde; the resin is transported as a 65% (w/v) colloid and used in the MDF and particleboard process at 10%(w/w) (Conner, 1996). Biological degradation of the urea-formaldehyde resin will also tend to be via hydrolysis to yield the biologically useful components urea and formaldehyde (see Glancer-Soljan *et al,* 2001 for example).

It is assumed that both abiotic and biotic degradation of the resin will therefore yield formaldehyde. For a 15kg coffin then:

15kg coffin of which 1,500g resin
Mass ratio urea:formaldehyde::60:30
Hence 500g formaldehyde per coffin

The release period for this formaldehyde is uncertain and we have assumed that in general it will be released by degradation of the coffin in the same time as decay of the body soft tissues.

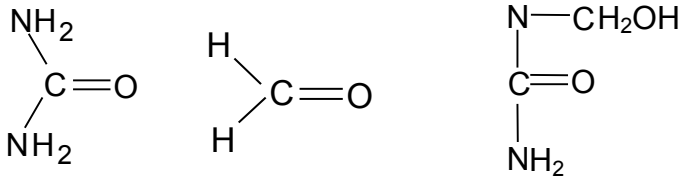
3.4.3 Degradation of formaldehyde

Formaldehyde is readily degraded by biological systems as long as the concentration is not so high as to be completely toxic to the degrading organism. Indeed, it is a component of central metabolism, particularly for organisms growing on C1 compounds. In the environment plants (Schaeffner *et al* 2002), animals, fungi and bacteria (Adroer *et al,* 1990) all exhibit formaldehyde degradation mechanisms. Recent isolation (Iwahara *et al*, 2002) has shown that some soil fungi are able to degrade formaldehyde at concentrations similar to that used in embalming fluid (i.e. 2% v/v) though it is unclear how geographically widespread this ability may be. It is also clear that, whilst aerobic conditions may provide the potential for more rapid bacterial degradation of formaldehyde, anaerobic degradation can occur (Omil *et al*, 1999).

There is little literature on observed rates of formaldehyde degradation in cemetery soil or groundwater. However, high efficiencies of formaldehyde removal (>>99%) from wastewaters have been reported under both aerobic and anaerobic conditions (Garrido *et al*, 2000). This would suggest that under grave conditions, where the availability of other macro- and micro- nutrients is likely to be good, high efficiencies and rates of formaldehyde degradation may also be expected.

3.4.4 Urea formaldehyde resins

Urea formaldehyde resins are formed in a two step process involving addition of formaldehyde and urea to form methyloureas followed by condensation of these into low molecular weight polymers.



Urea Formaldehyde Monomethylol urea

Interestingly, similar condensation products are used as slow release fertilisers for a variety of applications, not least in bioremediation of hydrocarbon spills. They provide a longer lasting source of fixed nitrogen and are known to be accessible to soil bacteria. Enzymatic mechanisms for the reactions involved have recently been described (Jahns *et al,* 2003). Equally, the condensation reaction used in manufacture is assisted by acid catalysts which become trapped with the resin in the wood product. Rewetting of the material causes reactivation of the catalyst and promotes the reverse hydrolytic reaction to produce formaldehyde and urea (Conner,1996).

3.5 Mercury

Mercury is considered here for completeness and in view of the likely increase in burial content of this metal in the coming years. The main potential source for Mercury in burials will be as amalgam in dental fillings.

The potential for atmospheric pollution with Mercury following cremation has long been considered and was recently the subject of a consultation by Defra (Defra (2003)) based on the need to abate release of dangerous substances under the OSPAR agreement.

Mercury is a metal which, in some forms, can be highly toxic to all orders of life. Awareness of the human health impacts of mercury have led many countries to ever increasing controls on its use and disposal. Moreover, the toxicology of Mercury and its compounds has been recently reviewed (Environment Agency 2002).

The pollution and health risks from dissolution of mercury amalgams in dental fillings has been a source of some controversy in recent years. Of particular interest has been the control of wastewaters from dental practices (see for example Kunkel *et al* 1996) and there are many reports of the slow release of mercury to intra-oral vapour and a few of release into saliva solution (Leistevuo *et al*, 2002). The breakdown of dental amalgam during life is caused by mechanical abrasion and (bio)chemical processes. These contribute to a low level of mercury present in the body beyond the teeth and which is normally excreted during life in the normal way. After death the mechanical abrasion from mastication processes cease and thereafter there will be slow (electro)chemical decomposition of the amalgam and dissolution into any surrounding aqueous phase.

3.5.1 Mercury loading in the grave

The composition of dental mercury amalgam fillings has varied over time and it is not possible here to consider all recipes. A standard for the powder mix was published in 1978 (International Standards Organisation) and it is assumed that liquid mercury is added to the solids mix in the ration of 1:1. Defra have estimated an average mercury loading of 3g per body (Defra, 2003) though clearly this will vary between individuals. Defra also noted that the amount of mercury released from crematoria is predicted to increase by about two-thirds from 2000 to 2020 based on dental records and actuarial data followed by a decrease back to 2000 emission levels around 2055.

There are no data on the release of mercury from dental fillings post mortem. However, recently the release of mercury from dental amalgams into a flowing stream has been studied (Okabe *et al,* 2003) which may be the closest approximation available to a conservative approach for amalgam dissolution in the grave. The work observed that dissolution is related to amalgam composition and solution pH. Over the 30 day leaching

experiments high initial leach rates fell rapidly and reached a steady state after a few days. Mercury leaching was enhanced by low pH and was also dependent on the formulation of amalgam used. Rates of mercury dissolution were approximately 0.03 micrograms per cm^2 surface per hour. This allows some calculation of the Mercury loss to the environment if a number of conservative assumptions about conditions and filling sizes are made.

Mass of mercury per body = 3g (from above)
Density of mercury = 13.5g.ml^{-1} (O'Neil *et al,* 2001).
Hence equivalent volume of Mercury = 0.2ml at s.t.p

Assume amalgam Mercury content = 50% v/v
Assume filling per body = 5 equal size
Hence volume per filling = (0.2ml x 2) / 5 = 0.08ml

Assume filling shape is spherical then volume of a sphere is given by

$$v = \frac{4}{3}.\pi.r^3$$

Hence rearranging and solving for sphere radius = $\sqrt[3]{\frac{3\times 0.08}{4\pi}}$ = 0.26cm

And sphere surface area = 4 x π x $(0.26)^2$ = 0.85 cm^2

Mercury dissolution rate = 0.03 micrograms per cm^2 surface per hour

Mercury grave dissolution rate = 0.03 x 0.85 x 5 x 8760 = 1.12 milligrams $body^{-1}$ $year^{-1}$.

3.6 Other metals

Depending on personal circumstance bodies at death may contain a variety of other metals mostly of medical or jewellery origin. Apart from those present as biological material (for example in the active site of many enzymes) the most obvious may be gold in tooth fillings; however, a great many orthopaedic and other items contain high quality, non-ferrous metals such as silver, platinum, palladium, cobalt etc. One estimate suggests that UK cremations involve approximately 1,350 kg non-ferrous metals and 22,500 kg of orthopaedic residues each year (De Wit, 2002). Simple extrapolation would suggest that burials therefore account for approximately 340 kg and 5,600 kg of each, respectively. Thus a cemetery containing 1,000 burials may contain about 4kg of such metals, on average.

Metal contamination around cemeteries is little studied, one case in the United States (Spongberg and Becks, 2000) showed little elevation of soil metal concentrations except for Arsenic which reached 8mg kg^{-1} presumably from 19th century embalming practices.

3.7 Pathogens

The issue of release of pathogens or potential pathogens from decomposing bodies is often raised in consideration of cemetery developments. This concern most frequently has centred around the possible transport of faecal organisms into nearby water bodies including groundwater and indeed this was the principal burden of the Cemetery Clauses Act 1847. In principle then it is possible to conceive of three scenarios for pathogen escape from a buried corpse:

- release of normal body flora, for example faecal organisms from the gut or skin or mucosal membranes, which may then become opportunistic pathogens
- release of existing pathogens from infections present at the time of death
- release of pathogens which invade the body after burial.

Potential pathogens would include:

- multicellular eukaryotic organisms e.g. worms
- unicellular eukaryotic organisms and their resting stages e.g. *Giardia*, *Cryptosporidium* oocysts
- bacteria, fungi and their spores
- viruses

In 1998 the Agency completed a review of microbial contaminants in groundwater (Environment Agency, 1998) which highlighted the lack of basic data on this topic and there remain few studies on the microbial and pathogen circumstances around cemeteries.

For those organisms or agents which are explicit pathogens present as infections at the time of death it is likely that after death the body becomes a relatively hostile environment. The loss of body processes such as circulation and thermoregulation will have profound effects on a pathogens own life and it seems likely that for most organisms as a minimum the generation of new pathogens will cease shortly thereafter. Certainly this will be the case for viruses which of course are incapable of replication without a living host cell. There will also be the potential injection of toxic formaldehyde, the bodies own cellular autolysis and attack from degradative organisms to contend with. However, some organisms may potentially enter more hardy life cycle phases such are spores or cysts. In summary it seems likely that the potential loading of explicit pathogens will be limited to no more than the maximal loading at the time of death.

For organisms present as normal body flora the situation may be more complex. Many organisms which inhabit the human body without harm may also become pathogens if circumstances permit. Such opportunistic pathogens would include many species in the gut, on the mucosa and skin. Such normal bacterial flora does flourish for a short period after death as the control mechanisms maintained during life are lost and increases in cultivable cell numbers of a few tenfold have been reported (Rose and Hackett, 1971).

In contrast, the practice of embalming may decrease the numbers of organisms present; formaldehyde or formalin products are used in other countries to sanitise sewage sludge before spreading (Godfree *et al,* 1983) but the comparison to embalmed bodies is unknown.

The movement of pathogens once in the groundwater may be rapid and in borehole tracing experiments viruses for example are commonly observed to travel well in advance of conservative tracers such as fluoroscein and rhodamine.

3.7.1 Pathogen loading in the grave

For organisms which are unable to replicate without a host the numbers at death therefore represent a maximum grave loading. This would include human viruses and most, if not all, eukaryotes. Hence only bacteria present a realistic threat of increasing numbers post interment.

To date most concern about pathogen transport from burial sites has centred on the traditional water quality parameters of enteric bacterial pathogens. For such enteric organisms it is possible to consider the likely initial loading present in individuals for whom the cause of death was something other than an enteric infection. The populations of many bacteria and viruses in human faeces are around 10^6 per gram (Dahi,1990). However, the dominant gut flora organisms such as *Escherichia coli* may be anticipated at several log-fold more than this perhaps 10^9 per gram or more. These concentrations may be multiplied by a few hundreds of grams of faecal material and gut contents that may be anticipated in the body suggesting between 10^{11} and 10^{12} organisms.

Protozoan enteric pathogens such as *Cryptosporidium* and *Giardia* may also be present in faeces though typically at lower concentrations perhaps 10^4 or 10^5 per gram. Similarly, any multicellular parasites such as roundworms or flukes would be present at even lower concentrations of perhaps 10^2 or 10^3 per gram faeces giving possible total loadings of 10^4 or 10^5. These larger, more complex organisms may also present less of a risk than the bacteria since their size may make transport through the subsurface more difficult. Figure 3.1 shows a comparison of organism size and pore or fracture size in geological formations.

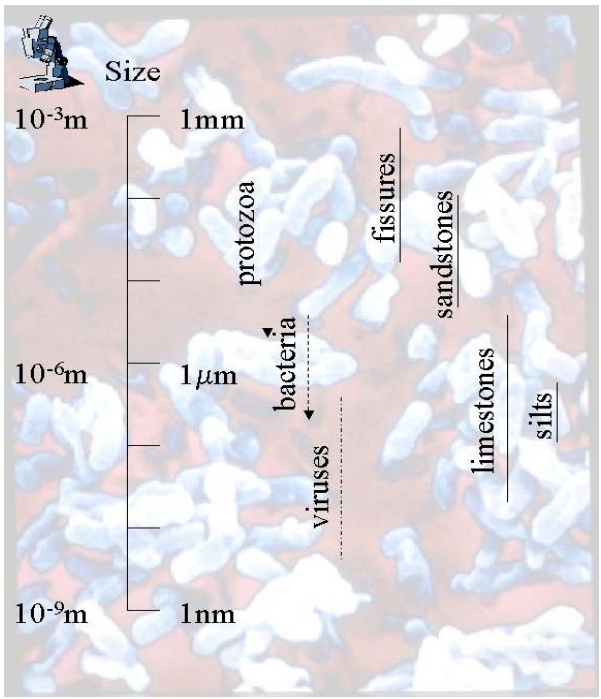


Figure 3.1 Comparison of sizes of organisms and subsurface pores

For pathogens which invade the body after death or indeed for indigenous organisms which actively degrade the body after death and which may then become opportunistic pathogens the situation is even less clear. There is some evidence of the increase of skin and mucosal flora post mortem (Burke and Sheffner, 1976) and this certainly seems reasonable. The investigation of a cemetery in Wolverhampton showed an interesting detection of *Staphylococcus aureus* in boreholes for which it is difficult to conceive of any other environmental source (Trick *et al,* 2002). Initial loadings of such organisms may be relatively modest by comparison with *Escherichia coli* for example, but if indeed they contribute to decomposition then increases in cell numbers may be rapid and substantial. With a distribution across the nasal and external surfaces of the body and the capacity for aerobic, anaerobic and fermentative metabolism such organisms are well placed to exploit the body.

Many soil bacteria which may play a part in decomposition are opportunistic pathogens, *Clostridium* and *Bacillus* spp. in particular also provide the ability to enter a non-vegetative phase which may both enhance longevity and transport characteristics. However, there are no reports that quantify the concentrations of such organisms in the grave.

3.8 Phosphorus and Calcium

3.8.1 Loading in the grave

The loading of these elements is given above in the section on body and bone composition and it is clear that the bone accounts for the vast majority of both Calcium (approximately 1100g) and Phosphorus (approximately 500g) in the body. Clearly there are other physiological uses for these elements: Phosphorus in energy metabolism for example and Calcium in signalling. Nevertheless the amounts used are insignificant for our purposes in comparison with the bone mass.

The previous Agency (Environment Agency,1999) report assumed that Phosphorus release from the body would occur in parallel with the release of soft tissue components. However this would imply that the bone dissolution would be complete at the end of the 10 year period which is otherwise given as the “time to skeleton” period, which is clearly inconsistent. This time to skeleton is a reasonable approximation in line with current estimates (Iserson, 1994), however the time taken for the decomposition of the skeleton itself will vary greatly depending in particular on the recharge conditions (i.e. how much water flows over the remains) and on the pH of the grave.

4. Natural attenuation processes for potential grave pollutants

4.1 Biodegradative routes and the availability of terminal electron acceptors in the grave

The initial in-grave decomposition conditions are usually aerobic as a consequence of the burial process. However, it is obvious that with the presence of a relatively large degradable organic mass such as a body the available oxygen will be rapidly depleted within the corpse itself. Moreover, the resupply of oxygen will be relatively slow due to diffusion of soil gas from the atmosphere above or the soil surrounding the body or carried by recharge. The grave model described by Dent *et al* (2004), suggests that approximately 5 moles of gaseous molecular oxygen is initially available for aerobic processes. In contrast the body carbon content of Table 2.2 above (16kg) implies that perhaps 1,300 to 1,500 moles of molecular oxygen would be needed for complete aerobic mineralisation of the organic carbon to carbon dioxide. Clearly then the oxygen that is immediately available is insufficient and the body will rapidly become anaerobic.

Subsequent supply of oxygen will then depend on the availability of dissolved oxygen in recharge, on diffusion of gaseous oxygen from the surface and laterally from the surrounding soil. These processes will be subject to many, often competing, site-specific factors. The amount of oxygen in recharge may be calculated assuming that the body receives infiltration only from directly above and that oxygen is present at the normal saturation level of 8 mg l^{-1}. Hence even for an area with high recharge of 500mm,

for a grave area of 2.1m x 0.75m = 1.58 m^2

with recharge of 500mm.yr^{-1}

this implies a volume of 790 litres containing 8 mg l^{-1} Oxygen

that is, 6.3 g of Oxygen per year, only about one-fifth of a mole.

The diffusion of Oxygen from the surface or surrounding soil will be subject to Fick's Law (Domenico and Schwartz, 1990) and may be highly site specific depending on both the geological setting of the grave and the construction, compaction and cover of the grave and surrounding soil. However, it is worth note that the diffusion rate will be affected greatly by the water content of the soil and for high water content and indeed below the water table the rate of oxygen supply will be greatly decreased.

Many of the commonly utilised alternative electron acceptors are likely to be present only in very low initial concentrations in the grave. As discussed above, most of the nitrogen present in the tissues will already be reduced as NH_2 substituents. Similarly, though sufur is a common component of organic molecules such as proteins this is normally as sulfhydryl -SH side groups. For metals such as iron and manganese, these are present in significantly lower quantities and again are likely to be present as already reduced

species. As soluble species likely to be present to some concentration in the overlying soil both nitrate and sulfate may be expected to be carried to the body with recharge. Site specific soil data may be available to assess the extent to which these electron acceptors are present. However, for nitrate at least it seems unlikely that quantities capable of promoting the anaerobic degradation of more than a few moles of carbon would be present.

As a consequence of this model, two issues are apparent:

- the body itself rapidly reaches an anaerobic state
- the (re)supply of these common terminal electron acceptors may then occur at a constant rate through diffusion and recharge
    - this implies a constant rate of electron transport dependent degradation rather than first-order kinetics with rate dependent on organic concentration.

The remaining biodegradation possibilities rest on fermentation and methanogenesis. Fermentation is the substrate level energy metabolism of organic substances and typically results in the production of organic acids such as acetate, lactate and butyrate. Fermentation of proteins and peptides will also produce amino acids which may then be incorporated into cell carbon or deaminated to produce more organic acids (and ammonia). Methane and carbon dioxide gases are produced as the end products from methanogenesis and as gases may be quite mobile in the subsurface.

4.2 Decay and dissolution model

The previous Agency (Environment Agency, 1999) report proposed a first order “half-life” approach to estimation of the pollutant flow for most of the components of the human body. It was assumed that for the carbon content of the body approximately 25% of this was not degraded within the time to skeleton but that all other components show a first order decay based on the total amount present in the body.

We propose a number of changes to this model based on the discussions above of contents and degradation paths whilst retaining other features such as decay timings, hence we suggest:

- skeletonisation of a buried corpse is assumed to take 10 years to complete.
- though embalming with formaldehyde may retard the decay to some degree, quantifiable effects data are not available and in view of the long timescales involved (10 years) rates of decay for embalmed and unembalmed bodies are assumed to be the same.
- the previous Agency report suggested that “green” burials may provide relatively rapid aerobic decay based on an assumed burial depth of 1.3m. However, this is still below the maximum observed depth for macrofauna-mediated decomposition and we suggest that decay rates for “green” and conventional burial sites should be assumed to be the same.
- temperature increase in the body is short duration and there is therefore no thermal convection driver for soil gas mass transfer.
- not all components will be readily degraded or solubilised during the skeletonisation process. In particular,
    - phosphorus (phosphate) will be present overwhelmingly as hydroxyapatite in bone and will mainly become accessible after the skeletonisation. Hence

phosphate dissolution will begin after 10 years of interment and will proceed with bone dissolution.
  - calcium - as for phosphate
  - collagen content of the bones will also be unavailable until skeletonisation has occurred. This will bring a further late phase of carbon and nitrogen loss amounting to about 400g of the body nitrogen.
- Mercury dissolution rates were calculated above and these should be used rather than assume a half-life. This is an approximation with many uncertainties such as surface access since as dissolution proceeds the contact surface area is likely to shrink thus altering the dissolution rate.
- The time for complete disappearance of the body including skeleton is unclear and rather variable. Some cemeteries place time limits on the ownership of grave sites and may reuse or move graves thereafter. For simplicity we have assumed below that this "time to dust or removal" is 100 years but this is a somewhat arbitrary choice and readers may wish to choose a different value.

- Degradation of tissues based on aerobic respiration will be limited by oxygen availability. This will be controlled by supply via dissolved oxygen in recharge or gaseous diffusion. Both of these may be expected to be constant rates related to depth, grave oxygen partial pressure, or recharge rate once the initial grave oxygen content has been exhausted.
- Degradation of tissues based on anaerobic respiration will be limited by availability of electron acceptors. This will be controlled by dissolved supply via recharge and may

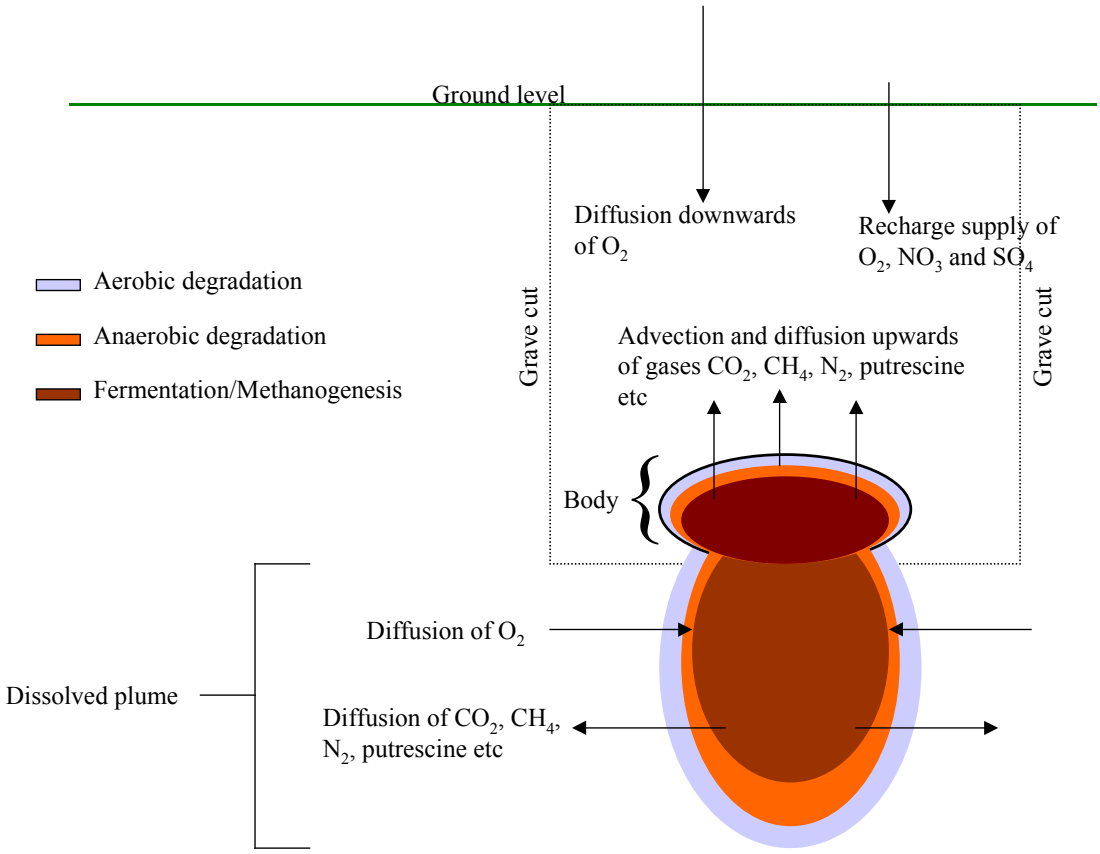


Figure 4.1 Transport of electron acceptors and degradation products into and out of the grave

be expected to be provided at a constant rate.

- Degradation of tissues based on fermentation will be limited by microbial access to tissue surfaces and ability to force entry into compact or protected tissues such as dense muscle, marrow etc. A suitable rate profile for such a complex problem is unclear however, it is clear that the above factors are not related to the simple "lump" concentration of organic material. We therefore propose a linear degradation rate for this process.
- Overall we therefore propose a constant linear rate for degradation of the body with delays for those components that are known to be resistant or shielded in some way.

These considerations are summarised in a decay rate and timings table (Table 4.1 below).

Table 4.1 Contaminant decay rates and timings

Contaminant	Mass per burial (g)	Available mass for release (g)	Release start year	Release end year	Kinetic release model	Release rate per burial (g y^{-1})
Calcium	1100	1100	10	100	Zero-order	12.22
Carbon	16000 + 10000[a]	14800[b] + 10000[a]	0	10	Zero-order	2480
Carbon	1200[b]	1200[b]	10	20	Zero-order	120
Nitrogen	1800 + 500[a,d]	1400[c] + 500[a,d]	0	10	Zero-order	190
Nitrogen	400	400	10	20	Zero-order	40
Mercury	3	3	0	2600	Zero-order	1.12×10^{-3}
Phosphorus	500	500	10	100	Zero-order	5.55
Formaldehyde	180	180	0	0.25	As a single event	NA
Formaldehyde	500[d]	500[d]	0	10	Zero-order[d]	50

Notes

[a] assumed from coffin of mass 15kg

[b] assumes that of the 16,000g body total then 1,200g are present in collagen in bone etc and so degraded after skeletonisation and completely lost over the subsequent decade

[c] assumes that of the 1,800g body total then 400g are present in collagen in bone etc and so degraded after skeletonisation and completely lost over the subsequent decade

[d] relies on catalytic hydrolysis of resin *in situ*

5. Risk assessment

The Agency has published widely on the assessment of pollution risks to groundwater. A variety of tools and techniques are therefore available to assist in the understanding and management of cemetery developments. The philosophy followed is one of using a tiered approach common to much environmental risk assessment (DETR (2000)). This is set out in more relevant detailed fashion in guidance on protection of groundwater (Environment Agency 1999) and assessment of natural attenuation (Environment Agency, 2000). We have not repeated the work here and readers should use this document simply to assist their conceptual model construction and risk assessment.

6. Discussion

Despite the fact that we have been burying the dead for most, if not all, of our history and beyond, our knowledge of the post-mortem processes and in particular the gross distribution, transport and fate of body elements from the grave remains very limited. This is increasingly important at a time when our existing cemeteries are fast filling up and applications for new developments may be expected to become frequent. At a burial rate of approximately 140,000 per year and with 2,000 graves per hectare we need 70 hectares of land every year for burials: about 100 football pitches.

In the absence of contrary quantifiable evidence much of our assessment was forced to assume that the products of decay remain in the solid or dissolved phases and are not transformed to gaseous products such as methane or molecular Nitrogen which may diffuse into the atmosphere. This is undoubtedly a conservative assumption, there are many processes which will act to bring about mass loss to the atmosphere, for example:

- aerobic and anaerobic respiration to liberate carbon dioxide
- methanogenesis
- evolution of reduced nitrogen compounds such as putrescine
- reduction of ammonium under alkaline conditions to ammonia and subsequent volatilisation
- nitrification of ammonia to nitrate and then denitrification to nitrogen gas

Unfortunately, a good understanding of the extent and importance of each of these processes and the rates at which they occur under a range of subsurface conditions is currently lacking.

6.1 Suggested further work

If we are to improve our understanding of the risks that cemetery developments may pose then there is a need for solid experimental science to quantify the processes involved. Though much could be achieved with laboratory and lysimeter studies and animal models eventually we would doubtless require some field scale evaluation. Moreover, as the key decay and attenuation processes occur within, close to, or beneath the body these are the areas that need to be investigated. Clearly this is a sensitive issue which has meant that very few investigations have been carried out in the past or the focus has been on crime investigation and forensic pathology rather than basic understanding of the fate and transport of body elements in bulk.

Certainly it is possible to conceive laboratory and lysimeter experiments that could be undertaken as PhD or post-doctoral studies in a standard academic frame. Alternatively the Agency could seek partner organisations who already carry out research in these areas to establish animal and or human burial research sites.

References & Bibliography

Adroer N., Casas C., de Mas C., Solà C. (1990) Mechanisms of formaldehyde biodegradation by *Pseudomonas putida*. Appl. Microbiol. Biotechnol. 33, 217–220.

Agency for Toxic Substances and Disease Registry. Toxicological profile for formaldehyde. Public Health Service, U.S. Department of Health and Human Services (1999).

Anon. (2001). Review of emissions from crematoria in the UK. Resurgam, 44 p81 - 127

Burke, P and Sheffner, A. (1976). The antimicrobial activity of embalming chemicals and topical disinfectants on the microbial flora of human remains. Health Lab Sci. 13, p267 – 270.

Buss, S, Herbert, A, Morgan, P and Thornton, S. (2003) Review of ammonium attenuation in soil and groundwater. Environment Agency ISBN 1 84432 110 1

Campobasso, C.P.; Di Vella, G.; Introna, F. (2001). Factors affecting decomposition and Diptera colonisation. *Forensic Science International* **120** 18-27

Conner, A. (1996) Urea-formaldehyde adhesive resins. In "Polymeric materials encyclopedia" Vol 11. Ed. Joseph C. Salamone.CRC Press ISBN 0-8493-2470-X

Cremation Society of Great Britain (2003). Progress of cremation in the UK 1885 – 2002. Cremation Society of Great Britain, Maidstone, Kent.

Dahi, E. (1990) Environmental Engineering in Developing Countries, 416 pp. Polyteknisk Forlag, Denmark

De Wit, F. (2002). Reclamation of Orthopaedic Implants and Non-ferrous Metals. Presentation to Institute of Cemetery and Crematorium Management ICCM National Office, City of London Cemetery, London.

Defra (2003) "Mercury emissions from crematoria: consultation on an assessment by the Environment Agency's Local Authority Unit". Defra UK.

Dent, B and Knight, M. (1998). Cemeteries: a special kind of landfill. Int Assoc Hydrogeol. Groundwater: Sustainable solutions. Melbourne February 1998.

Dent, B, Forbes, S and Stuart, B. (2004). Review of human decomposition processes in soil. Environmental Geology, 45, 576 – 585.

DETR (2000). Guidelines for environmental risk assessment and management. ISBN 0 11 753551 6. The Stationery Office, London.

Domenico, P and Schwartz, S. (1990). Physical and chemical hydrogeology. John Wiley. ISBN 0-471-50744-X

Environment Agency. (2002). Contaminants in soil: collation of toxicological data and intake values for humans. Mercury. Environment Agency R&D TOX 7 ISBN 1 857 05746 5

Environment Agency, (2000). Guidance on the assessment and monitring of natural attenuation of contaminants in groundwater. ISBN 1 85705 263 2

Environment Agency, (1999). Methodology for the derivation of remedial targets for soil and groundwater to protect water resources. ISBN 1 85705 196 3

Environment Agency. (1999). Pollution potential of cemeteries: draft guidance. R&D Report P223. ISBN 1 85705 021 5.

Environment Agency. (1998) A review of microbiological contaminants in groundwater. Environment Agency R&D P139

Fiedler, S.; Graw, M. (2003). Decomposition of buried corpses, with special reference to the formation of adipocere. *Naturwissenschaften* **90** 291-300.

Forbes, G. (1987). Human body composition: growth, aging, nutrition and activity. Springer-Verlag, New York.
Forbes, S.L.; Keegan, J.; Stuart, B.H.; Dent, B.B. (2003). A gas chromatography-mass spectrometry method for the detection of adipocere in grave soils. *European Journal of Lipid Science Technology* **105** 761-768.
Garrido J.M.*, Méndez R. and Lema J.M. (2000) Treatment of wastewaters from a formaldehyde-urea adhesives factory. Water Science and Technology Vol 42 Nos 5–6 pp 293–300
Glancer-Soljan, M, Soljan, V, Dragicevic, T, and Cecic, L. (2001) Aerobic Degradation of Formaldehyde in Wastewater, Food technol. biotechnol. 39 (3) 197–202
Godfree, A, Bevins, R and Jones, F. (1983). The destruction of pathogens and parasites in sewage sludge by chemical means. Water Poll Control, 1983 471-478.
Groom, L, Mott, L and Shaler, S. (1999). Relationship between fiber furnish properties and structural strength of MDF. Proc 33rd International Particleboard/Composite Materials Symposium. April 1999 Washington State University.
Home Office 2004. Burial law and policy in the 21st century: the need for a sensitive and sustainable approach. Home Office Communications Directorate 01/04
International Agency for Research on Cancer. Some industrial chemicals and dyestuffs. IARC Monogr. Eval. Carcinog. Risk Chem. Hum., 29: 345-389 (1982).
International Standards Organisation. Alloy for dental amalgam. ISO 1559. First edition 1978-11-15
Iserson, K. (1994). Death to Dust: What Happens to Dead Bodies. Galen Press, Tucson AZ ISBN 1 883620 07 4
Iwahara, M; Fukuda, R; Nakahara, K; Suzuki, K; Tanaka, T; Nomura. (2002) Isolation and Properties of Paecilomyces sp. No. 5 Capable of Degrading High Concentrations of Formaldehyde Biocontrol Science Vol. 7, no. 2, pp. 107-110.
Jahns, T, Ewen, H and Kaltwasser, H. (2003) Biodegradability of Urea-Aldehyde Condensation Products Journal of Polymers and the Environment, Vol. 11, No. 4, p155 – 159.
Janaway, R.C. (1997). The decay of buried human remains and their associated materials. In: Studies in crime: an introduction to forensic archaeology. Edited: Hunter, J., Roberts, C., Martin, A. Routledge, London.
Jury, W, Gardner, W and Gardner, W. (1991) Soil physics ISBN 0 471 83108 5 John Wiley and Sons.
Kramer, R, Bella, J, Mayville, P, Brodsky,B and Berman,H. (1999) Sequence dependant conformational variations of collagen triple helical structure. Nat.Struct.Biol. 6 p454 ASTM US ISSN 1072-8368
Kunkel, P, Cook, K, Mueller, P and York, R. (1996) The fate of mercury in dental amalgam. Water Environment and Technology. December 1996 p49 - 53
Leistevuo, J, Leistevuo, T, Helenius, H, Pyy, L, Huovinen, P, and Tenovuo, J. (2002). Arch Env Health, 57, 366 – 370.
Leungprasert S and Otten L. Fate of Formaldehyde in MDF Sawdust during MSW Composting School of Engineering, University of Guelph, Guelph, Ontario. NIG2W1
London Planning Advisory Committee, 'Planning for Burial Space in London: Policies for Sustainable Cemeteries in the New Millennium', available from the London Planning Advisory Committee (telephone as above, quoting ref. no. CON56) £28.
Mann, R, Bass, W, and Meadows, L. (1990). Time since death and decomposition of the human body. J Forensic sciences 35, 103 -111.
Mayer, G. (2000). Embalming. History, theory and practice. Mcgraw-Hill, New York. ISBN 0-8385-2187-8 p. 103 – 125.

Okabe, T, Elvebak, B, Carasco, L, Ferracane, R, Keanini, R and Nakajima, H. (2003). Mercury release from dental amalgams. Dental materials 19, 38 – 45.
Omil F., Méndez D., Vidal G., Méndez R., Lema J.M. (1999) Biodegradation of formaldehyde under anaerobic conditions. Enz. Microbial Technol., 24, 255–262.
O'Neil, M, Heckelman, P, Budavari, S. (2001). The Merck Index John Wiley and Sons ISBN: 0911910131
Personal communication. Natural Death Centre.
Polson, C.J.; Gee, D.J.; Knight, B. (1985). *The essentials of forensic medicine.* 4th Edn. Pergamon Press, Oxford.
Reed, H. (1958 A study of dog carcass communities in Tennessee, with special reference to insects. American Midland Naturalist 59, 213-245.
Rodriguez, W.C.; Bass, W.M. (1985). Decomposition of buried bodies and methods that may aid in their location. *Journal of Forensic Sciences* **30(3)** 836-852
Rose, G and Hackett, R. (1971). The microbiological evaluation and enumeration of postmortem specimens from human remains. Health Lab Sci. 8, 971.
Rugg, J. (2000) 'Defining the place of burial: what makes a cemetery a cemetery?', *Mortality*, 5, 3, pp259-75.
Santarsiero, A.; Cutilli, D.; Cappiello, G.; Minelli, L. (2000) Environmental and legislative aspects concerning existing and new cemetery planning. *Microchemical Journal* **67** 141-145.
Santarsiero, A.; Minelli, L.; Cutilli, D.; Cappiello, G. (2000) Hygienic aspects related to burial. *Microchemical Journal* **67** 135-139.
Schaeffner, A; Messner, B; Langebartels, C; Sandermann, H (2002) Genes and Enzymes for In-Planta Phytoremediation of Air, Water and Soil. Acta Biotechnologica Vol. 22, no. 1-2, pp.141-152.
Schroeder, H, Klotzbach, H, Oesterhelweg, L and Puschel, K. (2002). Larder beetles as an accelerating factor for decomposition of a human corpse. Forensic Science International 127, p231-236.
Sharma, S., Ramakrisshna, C., Desai, J.D. and Bhatt, N.M. *Microbiol. Biotechnol.* 1994, 40: 768-771.
Spongberg, A and Becks, P. (2000). Inorganic soil contamination from cemetery leachate. Water, Air and Soil Pollution. 117, p313-327.
Spongberg, A and Becks, P. (2000). Organic contamination in soils associated with cemeteries. J Soil Contam. 9(2), p.87 – 97.
Stuart, B.H.; Forbes, S.; Dent, B.B.; Hodgson, G. (2000). Studies of adipocere using diffuse reflectance infrared spectroscopy. *Vibrational Spectroscopy* **24** 233-242.
Trick, J, Klinck, B, Coombs, P, Chambers, J, Noy, D, West, J and Williams, G. (2002) Groundwater impact of Danescourt Cemetery, Wolverhampton. Environment Agency ISBN: 1 857 05983 2
Van De Graaff, Kent M. (1998). Human Anatomy 5th Edition. WEB McGraw-Hill. Boston, MA.
Wienrich, S and Speyer, J. (2003) The Natural Death Handbook, 4th Edition. Rider, London. ISBN 1 8441 3226 9
Wood Panel Industries Federation (2003) Panelguide. Wood Panel Industries Federation Grantham Lincs.
Wood Panel Industries Federation . (2002) INDUSTRY STANDARD IS (WPIF)1/2002 WOOD-BASED PANELS Wood Panel Industries Federation Grantham Lincs.

List of abbreviations

CAS Chemical Abstracts Service. Maintain a standard reference index of chemicals

Defra Department of Environment, Food and Rural Affairs

DMF Dimethylformamide

FMD Foot and Mouth Disease

MDF Medium density fibreboard, used in coffin construction

pH negative log of the hydrogen ion concentration, a measure of acidity

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