EA-NGWCLC 2001

Foot & Mouth Disease Epidemic.

Disposal of culled stock by burial: Guidance and Reference Data for the protection of controlled waters

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Statement of use
This report is intended for use by Agency staff and Government bodies involved in the burial of livestock culled during the 2001 Foot and Mouth epidemic and as a longer term record of reference data. It is in draft and subject to revision as experience is gained during the epidemic.

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EXECUTIVE SUMMARY

The 2001 outbreak of Foot and Mouth Disease (FMD) was first noted in late February 2001, with over 400 outbreaks being confirmed within four weeks, principally in the western and northern parts of England and Wales.

Early in March 2001 the Environment Agency requested WRc to review, as a matter of urgency, information on the pollution potential arising from the burial of large numbers of animals slaughtered under the FMD eradication scheme. At the same time staff from the National Groundwater & Contaminated Land Centre undertook work on risk assessment for burial sites.

In the early stages of the epidemic the Agency adopted the following preferred hierarchy for cattle carcass disposal in particular:

- Rendering;
- Incineration in purpose designed facilities
- Landfill at suitably licensed sites;
- On-site burning;
- On-site burial.

Because of the risk of BSE transmission, initially the Agency and MAFF agreed that there should be no burial or landfilling of cattle. After further examination of the risks, this restriction was relaxed to cover cattle over 5 years old only.

This report provides guidance on the burial of carcasses arising from the Foot & Mouth epidemic that need disposal under an emergency, but controlled, situation that must avoid polluting the environment. Certain areas of knowledge have been learnt quickly during the process, others approaches have been based on modification of normal practices to the emergency response.

KEY WORDS

Foot and Mouth, epidemic, groundwater, burial, carcass disposal, pollution, BSE infectivity, prions, pollutants, risk assessment, risk management

1. INTRODUCTION & SUMMARY GUIDANCE TABLES

The 2001 outbreak of Foot and Mouth Disease (FMD) was first noted in late February 2001, with over 400 outbreaks being confirmed within four weeks and 1400 within eight weeks, principally in the western and northern parts of England and Wales.

On 16th March the Environment Agency requested WRc to review, as a matter of urgency, information on the pollution potential arising from the burial of large numbers of animals slaughtered under the FMD eradication scheme. At the same time staff from the National Groundwater & Contaminated Land Centre (NGWCLC) undertook work on risk assessment for burial sites in support of operational staff who were assessing individual sites in response to MAFF/Army requests.

It became clear that little reliable data existed on many aspects relating to previous disposals of carcasses, particularly on the scale of disposal that was necessary resulting from the epidemic. Early drafts of this document relied on desk study and sparse reference data. Subsequently, it has been possible to use data from the epidemic to inform and improve the guidance and reference material. As more data become available the document will be updated as necessary.

In the early stages of the epidemic the Agency adopted the following preferred hierarchy for carcass disposal :

- Rendering;
- Incineration in purpose designed facilities;
- Landfill at suitably licensed sites;
- On-site burning;
- On-site burial, including mass burial sites.

Because of the risk of BSE transmission, initially the Agency and MAFF agreed that there should be no burial or landfilling of cattle. After further examination of the risks, this restriction was relaxed to cover cattle over 5 years old only.

During the early stages of the epidemic the urgent need to remove slaughtered animals from farms to disposal facilities gave rise to a demand for on-site burial, as other routes for disposal presented difficulties at some locations. For small numbers of animals it has been feasible to follow existing guidance. However, as the epidemic progressed the need for mass burial sites increased, particularly in the epidemic hot spots. Initially, with little time for engineering of the disposal sites the emphasis was placed on rapid location of hydrogeologically secure and logistically suitable sites and disposal without the lining of disposal pits. As time and experience has progressed, lining of the larger sites has been feasible and has become essential due to the large volume of liquor produced.

As this document indicates, the choice between a dilute-and-disperse and a full or partial containment design for a burial facility is a site-specific one, dependent on factors such as the hydrogeological setting and size of the disposal.

The succeeding pages in this Introduction comprise tabulated summary guidance that distils the material within the rest of the report and highlights key issues; the tables are cross referenced to sections of the report so that further details may be referred to as required. The tables constitute the Agency's good practice guidance for burial, but should be adapted dependent on site-specific conditions and professional assessment by suitably qualified and experienced staff. They show the Agency's grading of risks for various disposal options and types of carcasses.

Chapters 2, 3, 4 & 5 provide background data and calculations relating to the source term for risk assessments (that is, the pollutant loading). Chapter 6 considers aspects of the burial pit design and is supported by the good practice guidance on engineering matters contained in Appendix B. Risk assessment techniques are discussed in Chapter 7 and this is in turn supported by descriptions of the risk assessment tools provided in Appendix C.

As this is essentially a working document, no conclusions or recommendations are included at this stage.

Environment Agency grading of risks to controlled waters for disposals

Disposal Option	Type of carcass		
	Non BSE risk animals (sheep, pigs etc)	Cattle <5 years	Cattle > 5years
Rendering	**1**	**1**	**1**
Incineration (off site)	**1**	**1**	**1**
Landfill	**2**	**3**	**5**
Burning (on-site)	**2**	**3***	**4**
Burial	**2**	**3***	**5**

Key

1 – Minimal risk, disposal acceptable.

2 – Option can be considered subject to site-specific risk assessment (extent dependent on size of disposal).

3 – Option can be considered **if** carcasses can be separated, subject to semi-quantitative site-specific risk assessment.

4 – Small/moderate (less than 1000 carcasses) disposals only, subject to semi-quantitative, site-specific risk assessment.

5 – Unacceptable risks – cannot be considered.

* smaller disposals may only need a qualitative assessment.

All options must be reviewed on a site-specific basis (desk study as a minimum) to ensure potential loadings and disposal environment do not present an unacceptable risk to controlled waters. All Grade 2, 3 & 4 sites must also be outside Source Protection Zone I of the Agency's Policy and Practice for the Protection of Groundwater and comply with COGAP set-off distances, as a minimum. Larger set-off distances may be required for larger disposals.

SUMMARY GUIDANCE ON BURIAL OF CARCASSES

ENVIRONMENTAL HAZARDS	REFERENCE
1. Carcasses release approximately 33% of their mass in fluid, around 50% of which is likely to be released within 1 week of deposition and the remainder within 2 months. Initial leachate collection and disposal is likely pose a problem in most burial sites.	Section 5.1 of this report
2. Assume that the average figures for burial volumes are 0.075 m^3/sheep and 1.05 m^3/cow and that the total volume of body fluids available for release (within the 2 months noted above) are 16 litres/adult sheep and 170 litres/adult cow (average weights and herd age distribution are provided in Table 4.2 of the guidance/reference data report).	5.1
3. The initial leachate from burials will be rich in ammonium (typically 500-2000 mg/l as N) and potassium (400-3000 mg/l), with a very high COD (75 000 – 100 000 mg/l). Initial pH is neutral to slightly acidic.	5.3
4. 95% of the carcasses are degradable and this mass will need to be removed from site as gas, extracted leachate or seepage from the site through time. The time for the majority of degradation to take place is likely to be 5-10 years, dependent on site conditions, though there may be a potential for release of contaminants for longer periods than this.	5.2
5. For hazard assessment purposes it should be assumed that the foot and mouth virus can survive in groundwater for several weeks. If the fluids from the carcasses can reach groundwater, and particularly if there is fissure flow beneath the burial site, the risk of FMD transmission through groundwater should be considered.	7.7
6. Other pathogenic organisms that may be present in leachate from decomposing carcasses include BSE/vCJD, *E.Coli O157*, *Campylobacter, Salmonella, Leptospira* and water borne protozoa including *Cryptosporidium* and *Giardia*. With the exception of the protozoa, movement through the unsaturated zone and a groundwater travel time of 50 days (Source Protection Zone I) should be sufficient to provide a high degree of protection.	7.7
7. As over 5 years cattle are excluded from burial sites, there is no significant risk from BSE infectivity.	
8. Methane, diphosphane and other gases may be released during decomposition.	
9. There is little evidence of sheep dip chemicals being present in leachate generated at mass disposal sites that have received sheep carcasses. As such there is unlikely to be a risk to groundwater from sheep dip chemicals.	7.7.5

SITE LOCATION | **REFERENCE**

1. Burial sites should not be located in areas subject to surface flooding.
2. All burial pits must be **at least** 250 metres away from any well, borehole or spring used for abstraction and, in addition, not in Source Protection Zone I for any supply. In high permeability (usually major) aquifers and also for mass burial sites, this set off distance should be increased to at least 500 metres, unless fully engineered containment is used. — COGAP, section 7 and Appendix C
3. Mass burial sites must not be located on Major aquifers, on Minor aquifers where there is less than 5 metres of unsaturated zone (minimum 1m below the base of the burial pit), in groundwater Source Protection Zones, or below the regional water table.
4. Burial pits must be at least 30m away from any watercourse and at least 10m from any field drain. Any identified drains should be removed or permanently sealed.
5. Burial pits should not be located directly on fissured and/or high permeability strata.
6. A detailed record of the burial pit location, numbers & types of carcasses disposed, and pit construction should be made and submitted to the Environment Agency.
7. Site Location must follow risk assessment that as a minimum should consist of an initial risk screening exercise (desk study and minimum good practice criteria as above).
8. The Agency will conduct initial risk screening to locate mass burial sites, which will then be passed to MAFF for further evaluation (for logistics etc.). Final location should follow any further risk assessment that is necessary; this risk assessment is to be undertaken by MAFF and reviewed by the Agency.

SITE ASSESSMENT & DESIGN	REF
1. Risk assessment for burial sites should follow the general tiered approach published by DETR/Agency/IEH, that is (in turn and as appropriate), initial risk screening, generic risk assessment and site-specific quantitative risk assessment. A record should be made of the data used during the assessment, together with the results.	7.2
2. Initial site assessment should be preceded by a prior investigation, which should consider the loading, hydrological/ hydrogeological setting, receiving capabilities of the subsurface (site-specific vulnerability and potential for attenuation), and potential changes in groundwater quality as a minimum. For smaller sites a desk-based study (risk screening) may be sufficient but for a mass burial site the design must be supported by intrusive site-specific data and quantitative risk assessment.	7.2
3. The risk assessment constitutes a 'prior investigation' required by the Groundwater Regulations 1998.	
4. Due to the hazards presented by large volumes of fluids released from carcasses, particularly in the first 2 months following burial, arrangements for leachate management (including disposal) should be considered for all sites. These will be essential for all larger and contained sites.	5.1
5. Dilute & disperse sites are only suitable for disposals where intergranular flow can be relied upon and the attenuating capabilities are sufficient to deal with the proposed pollutant loading, as determined by site-specific risk assessment. At most sites dilute & disperse will only be suitable for quite small disposals (32 tonnes or less). Larger sites will require generic quantitative risk assessment as a minimum. A significant unsaturated zone (>5m) is a prerequisite for a large dilute & disperse burial pit design.	6.1-6.3
6. Some dilute and disperse sites in lower permeability formations will need leachate collection and disposal facilities at least in the short term to deal with the initial release of fluids from the carcasses.	6.3
7. Minimum set-off criteria (in Site Location above) should be followed for dilute and disperse sites and are likely to be increased based upon site-specific risk assessment.	6.1-6.3
8. Contained sites (either natural or artificial) will require leachate collection and disposal arrangements from the outset, with a long-term commitment to leachate treatment/disposal. Such sites should still follow minimum good practice set-off criteria.	6.1-6.3
9. Large mass burial sites should be naturally or artificially contained. The containment measures should reflect the size of the disposal, the consequences of potential leakage and the likely duration of the pollution potential of the site.	6.1-6.3
10. Containment will require long term management of the site, including leachate treatment/disposal: if this is not feasible, the site should be rejected.	6.1-6.3

SITE ENGINEERING	REFERENCE
General	
1. All subsurface field drains in the vicinity of the burial pit should be intercepted and preferably removed to avoid short-circuiting of the natural subsurface flow system. If field drains are believed to exist (or suspected) hydraulically down-gradient of the site, the extent and outflow points should be thoroughly investigated to determine the risk to surface water or, if there are soakaways, to groundwater.	6.3
2. Capping should allow for subsidence of the buried carcasses, with an extended period for cap maintenance to ensure that a surface depression is not formed. Initial mounding will need to be replenished both in the short and long term.	6.4
3. Capping is likely to result in the squeezing of fluid from the mass of carcasses, increasing leachate production and, if not controlled, leachate levels.	6.3
Dilute and disperse sites	
4. The hydraulic conductivity of the base of the site should be greater than that of the capping layer.	6.3
5. Where the base of the burial pit has been smeared or occluded during construction it should be ripped and possibly replaced with a layer of crushed stone to facilitate even drainage.	
Contained sites	
6. Contained sites should not be regarded as fully contained landfills unless high standards of QA during construction and testing are feasible and are undertaken.	6.1 - 6.3
7. All contained sites should have basal leachate collection systems and leachate extraction facilities.	6.1 – 6.3
8. Leachate extraction facilities must be capable of operation as soon as disposal commences.	

SITE OPERATION & MANAGEMENT

1. A method statement (working plan) should be agreed for all sites and should be updated as necessary.
2. All burial sites over 8 tonnes should have a Groundwater Regulations authorisation which should be reviewed as soon as practicable to include monitoring arrangements for the site.

MONITORING

1. All monitoring suites should contain: 6.5

   COD, TOC, ammonium, chloride, potassium, Electrical Conductivity, TON, pH and phosphorus. 6.5

2. Leachate should include total solids and total dissolved solids, where the latter is feasible. Where significant numbers of sheep have been deposited chemical analysis of a representative range of sheep dip chemicals should be included to establish whether OP and SP chemicals are likely to be present.
3. Groundwater suites should comprise major ions in addition to the above.
4. Consideration should also be given to the inclusion of phenol and iodide, which may arise from the use of disinfectants and to undertaking a GCMS scan for disinfectants generally.

AFTERCARE AND DECOMMISSIONING

To be included in future versions.

2. BACKGROUND AND OBJECTIVES OF GUIDANCE

2.1 Background

The most common disposal route for slaughtered animals affected by Foot & Mouth disease during the early stages of the epidemic (FMD) has been burning. However, with the large number of animals already slaughtered, and the precautionary slaughter of many hundreds of thousands of unaffected animals, there is increasing pressure to bury the carcasses rather than burn, in order to dispose of the carcasses as quickly as possible.

Existing guidance (MAFF 1998, 2001) on the disposal of animal carcasses addresses the disposal of relatively small numbers on farms. This assumes a dilute-and-disperse approach that, with the relatively small volumes that were envisaged in this guidance, would be suitable in the majority of locations, subject to minimum good practice criteria (as noted in section 7.1 of this document).

There has been no previous detailed guidance on the disposal to land of large numbers of carcasses (many hundreds or thousands). As the result of the FMD epidemic, Environment Agency staff have been asked to consider mass burials at sites where there will be little time to arrange fully engineered containment of the products of degradation and where, during the initial phase of site selection, there may be limited knowledge of subsurface site conditions.

The size of mass burial sites may range from hundreds, to hundreds of thousands, of carcasses but, with progression of the disease, requirements have emerged for a smaller number of larger sites, mainly for logistical and long-term management reasons. This guidance is directed to support the disposal needs at all burial sites, but with an emphasis on the medium to large sites.

2.2 Scope of work

The Environment Agency requires an understanding of the decomposition and leachate and gas producing processes, which follow the slaughter and burial of animal carcasses (sheep, pigs, cattle), so that the risks associated with proposed mass burials of such carcasses may be determined with greater confidence.

Matters of particular concern are:

- the composition and volumes of leachate and gas which may be produced;
- the time-scales over which the processes may operate;
- needs for monitoring of burial sites.

At the start of the 2001 FMD epidemic there were little reliable data to support the risk assessment, design and construction of mass burial sites.

3. THE RELEASE OF POLLUTANTS FROM BURIALS

3.1 Degradation processes

The production, release and migration of pollutants from burials is governed by similar processes to those which control the stabilisation of degradable wastes in landfills, and which are summarised in Figure 3.1. However, burial sites can differ significantly from landfills and may not provide the extensive leachate and gas containment and control measures that are expected to be in place at licensed landfill sites. Consequently, whilst the processes which control degradation are similar, the ease with which the degradation products may enter the wider environment are likely to be different.

In the case of landfilled wastes, the initial aerobic phase (phase I) is completed rapidly and, because the input of wastes exceeds the rate at which oxygen may gain access to the degrading mass, the greater part of decomposition takes place under anaerobic conditions.

During phase II, free oxygen is absent, having been consumed by the initial aerobic bacterial activity, and heterotrophic forms begin the anaerobic process by sulphate and nitrate reduction, initiating the breakdown of long chain carbohydrates and lipids with the release of carbon dioxide and water and of proteins with the degradation pathway through amino acids to ammonium. Malodorous gases (hydrogen sulphide and sulphur containing terpenes) may be formed during this and the subsequent phase of decomposition.

Once alternative electron receptors (nitrate and sulphate) have been consumed, anaerobic populations continue the degradation process (phase III) with the end products being short chain fatty acids, which reduce the pH of the degrading mass and typically result in highly polluting dissolved organic loads in the leachate (expressed as BOD and COD). The principal gaseous product remains carbon dioxide, from microbial respiration, but specialised bacterial populations that produce hydrogen, and which convert hydrogen to methane, may be present to a limited extent.

During phase IV, the high loadings of dissolved, labile organic compounds are transformed to gaseous methane and carbon dioxide, with the result that the dissolved pollution load is significantly reduced. The bacterial suite that controls the methanogenic process are sensitive to pH conditions and are effectively inoperative at pH values below about 6.5. The transition from phase III to phase IV is only possible if sufficient buffering exists within the degrading mass to provide near neutral conditions. If the buffering capacity is absent, or inaccessible, the decomposition process is likely to remain locked into phase III, with a continued output of high strength leachate. This situation was commonly observed in landfills taking putrescible wastes during the early 1970s, before the development of cellular, containment landfilling.

The final phase, V, is characterised by a return to aerobic conditions and rapid reduction of ammonium. The pollution potential of the waste mass at this stage is minimal.

The progression from phase I to, ultimately, phase V for a single mass of material (for example the burial of a slaughtered herd) is reflected in an initial rapid increase in the rate at which pollutants are emitted (phases I – II), followed by a declining source term as the components are removed progressively by leaching or gaseous emission. If the system moves from phase II to phase IV the source term for dissolved pollutants declines rapidly, but if the system becomes 'locked' into phase III the rate of decline of dissolved components is less rapid, and approximates to the exponential decrease found in fully mixed leaching.

In the case of single burials, changes within the body tissues (especially a reduction in Eh) within the first day or so after death prevent the growth of aerobic bacteria, except on the surface of the body where it is exposed to the atmosphere. As a consequence, the principal agents of putrefaction of internal organs are anaerobic forms and the principal soluble and gaseous products of decay are essentially the same as those which result from the anaerobic phases of waste degradation (II and III on Figure 3.1). The buffering capacity of a typical mammalian body is low (the principal cation, calcium, provides less than 5% dry weight of the body mass (Forbes, 1987)) and it is unlikely that degradation enters phase IV, so that significant methane production would not be expected. For mass burials of slaughtered animals, the large volume of decaying matter make it probable that anaerobic, acetogenic processes (phase III) will persist within the grave for years after burial.

As the soluble and gaseous components move away from the burial site it is possible that the buffering capacity of the ground could encourage local methanogenesis, but it is considered they are more likely to encounter aerobic conditions within the ground and will be attenuated by oxidation. In the case of free draining soils, the volume of space through which anaerobic conditions extend as the result of the decomposition of the degrading corpses is likely to be restricted to the immediate vicinity of the burial site, and subsequent transformations of initial degradation products will be essentially aerobic. At sites with impeded drainage, rather more extensive anaerobic conditions may develop, but the extent will be a function of the mass of the burial and the initial oxygen content of the ground. A possible consequence of impeded drainage may be the generation of the gas diphosphane, which ignites spontaneously when it comes into contact with oxygen (Pentecost, 1997) to appear as 'Will 'o the Whisp' or 'corpse candles'.

The rate of decay depends upon a number of variables. The greatest effect on a body's decay rate is temperature and access to the body by carrion insects and vertebrates. Warm temperatures accelerate decomposition, freezing slows the process, primarily the difference is caused by effect of temperature on the activity of scavengers such as carnivorous insects, as well as the microbial fauna. In the case of human burials, these processes are retarded by enclosing the corpse in a coffin and, possibly, by embalming. In the case of slaughtered stock these inhibiting factors do not apply and it is not unlikely that at least some invertebrate scavengers will have established themselves on the corpses before burial is accomplished.

3.2 Burial conditions

Factors that influence the progression of the degradation processes noted above include:

- The method of slaughter and age of the carcasses before burial;
- The addition of disinfectants or materials such as lime;
- The size and degree of containment of the burial pit;
- The leachate level within the waste, including any facilities for leachate drainage and extraction within the burial pit.

If the carcasses are not punctured before burial, experience has shown that there is substantial retention of gases within them. This can result in both problems with the rising of carcasses within the waste mass and the delay of gas release. Therefore, it is considered good practice to puncture carcasses before disposal. However, puncturing will tend to encourage the release of both gas and body fluids. The rapid release of such fluids has lead to leachate problems at a number of sites and high leachate levels have resulted. These conditions will tend to inhibit gas release and affect the progression of degradation processes. It is essential that leachate collection and removal facilities are installed at all but the smaller disposal pits.

Disinfectants are applied variably to carcasses on farms and during transport to disposal sites. There are a large number of permitted disinfectants and their detailed impact on degradation and leachate quality is unclear at present. In years past, lime was added extensively to carcasses during burial. However, this was thought to inhibit degradation and this has not been routinely practised during the current epidemic, though there are reports that lime has been added to carcasses at some farms prior to removal for disposal, where it has taken several days to remove the carcasses from the place of slaughter.

Most licensed landfills are deep, extensive and are contained by natural or artificial low permeability lining and capping. This will tend to encourage the development of anaerobic conditions, particularly in the later stages of disposal/decomposition. In contrast, most of the carcass disposal pits are relatively shallow, small and tend to be in the form of trenches. Many are not naturally or artificially contained. In these circumstances, whilst the initial release of body fluids (with a high BOD, COD etc) will encourage anaerobic conditions within the waste, once the leachate level reduces, it may be possible to return to aerobic conditions more rapidly than within a landfill. A containment burial pit design will tend to create more anaerobic conditions than a dilute-and-disperse approach.

The leachate results from mass burial pits constructed early in the FMD epidemic suggest that there has been rapid progression to Phase III in Figure 3.1, with neutral to slightly acidic pH, low nitrogen, high COD and high ammonium.

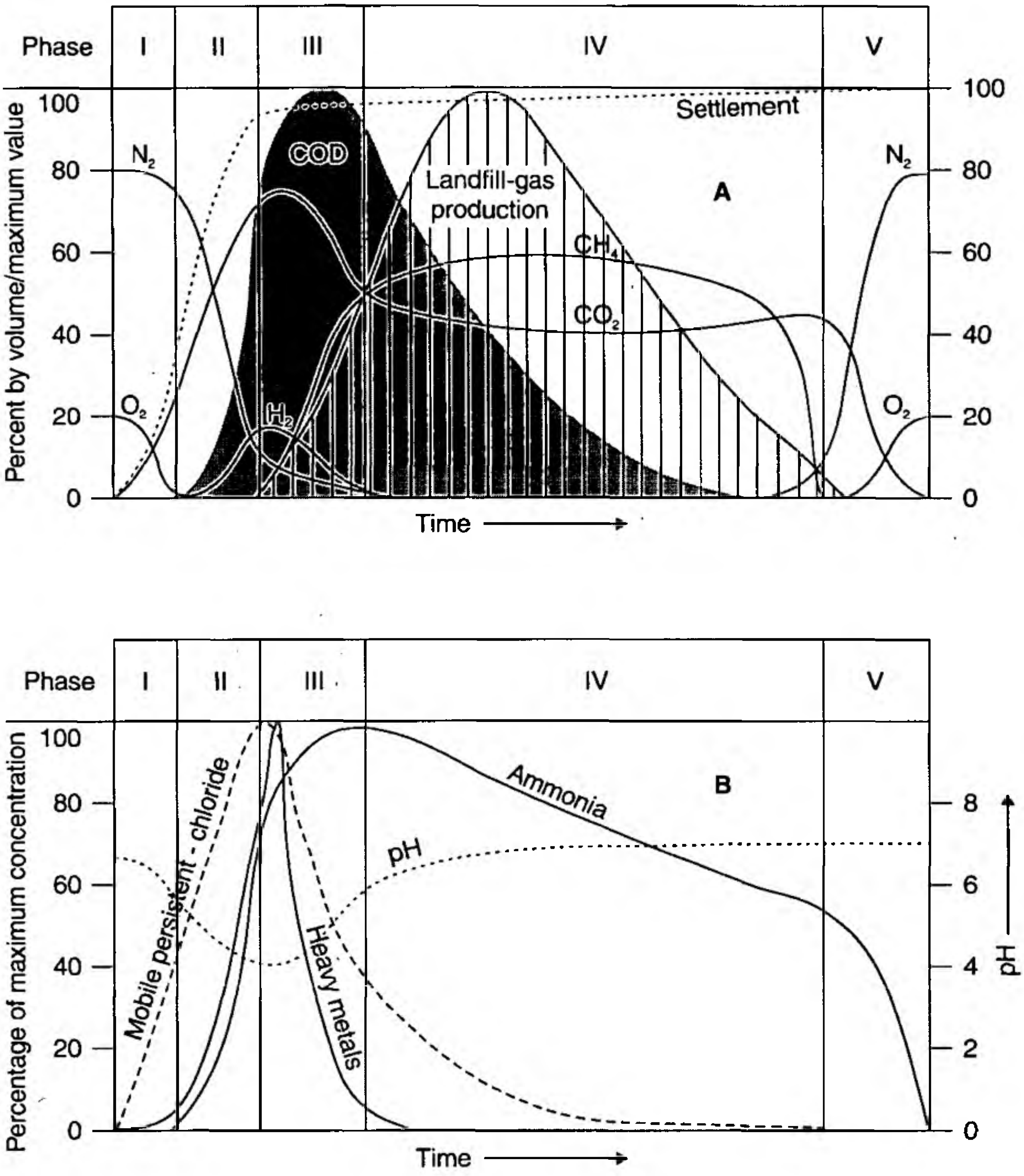


Figure 3.1 Schematic of the evolution of organic (A) and inorganic (B) components by degradation of putrescible materials in a typical domestic landfill.

4. SOURCES OF INFORMATION AND ASSUMPTIONS

4.1 Sources of information.

Initially, the principal source of information on the release of potential pollutants from burials was Environment Agency R&D Technical Report P223 (Young *et al*, 1999). Specific information on the probable age profile of herds and of typical body weights has been based on Young *et al* (1999), discussion with Agency officers and additional advice received from Alex Russell of MAFF Animal Health Office at Coley Park Reading.

Additional information related to the survival of the Foot and Mouth virus in the environment has been gained from the following website sources:-

www.thepigsite.com and www.thepoint.demon.co.uk/fmdnotes.htm

As the epidemic and experience with burial sites has progressed, additional empirical site data have been obtained.

4.2 Assumed age profile and body weights.

The estimates in the final column of Table 4.1 assume the young animals have been born, but not separated from their herds. In Chapter 5 these data are used to estimate typical slaughter weights of whole herds, assuming that the young animals are at the lower end of their weight range.

Table 4.1 : Estimate of make up of herds, age and weights.

Animal	Juvenile weight (kg)	Adult weight (kg)	Herd age distribution (by numbers)
Cattle	25 – 50 (dairy) 40 - 70 (beef)	450 – 650 (dairy) 500 (below 30 months beef)	Adult 66% Juvenile 34%
Sheep	8 at birth to 35 at 6 months	65 - 80	Adults 33% Juvenile 67%
Pigs	2 at birth – 18 (weaner)	150 breeding stock or 130 – 225 sow + piglets	Adult 15% Juvenile 85%

4.3 Estimation of size of burial pits.

The area and volume of burial pits for slaughtered animals were initially estimated from the data on animal weights and age distributions contained in Table 4.1, using the following assumptions:-

- The bulk density of the animals is 0.9 g/cm^3;
- The carcasses are placed randomly in the pit, with a packing factor of 1.4 (equivalent to 30% porosity), to arrive at typical burial volumes of about 0.6 m^3 for cattle and between 0.04 and 0.05 m^3 per sheep or pig.

However, practical experience at some of the mass burial sites suggests that in practice the volumes for sheep and cattle are greater than above and appropriately adjusted values are incorporated in Table 4.2, for herds of 100 cattle or 1000 sheep or pigs. The increase is attributed in part to carcass bloat, which effectively reduces the bulk density.

Table 4.2 : Estimated burial volumes (m^3), excluding two metres capping layer, for sample herds.

Herd size / type	Typical total weight (tonnes)	Burial volume (m^3)
100 cattle	37.3	105
1000 sheep	31.8	75
1000 pigs	27.6	65

Burial volumes for other numbers of animals are simply estimated on a *pro rata* basis.

If it is further assumed that:

- The pits are excavated to a maximum depth of 4 metres, with not less than 1 metre of unsaturated sub-soil beneath the base of the pit;
- The carcasses are covered by two metres of sub-soil/top soil (section 277 COGAP specifies one metre, but it is understood that at some sites 2 metres are now recommended).

5. ESTIMATION OF POLLUTION LOAD

5.1 Rate of release of principal pollutants.

In considering the potential pollutant loads released by human burials, Young *et al* (1999) assumed that 75% of the carbonaceous content of a human corpse is readily degradable, with half-life of one year. The annual release of organic carbon and ammonium from a single burial of 70 kg was also estimated, based on a declining source term. The estimated decline in releases was consistent with information on the time for reduction of a human corpse to a skeleton in a coffined burial. Although the corpses of slaughtered animals may be disinfected before removal from the places of slaughter to the mass burial sites (often with citric acid) and lime may occasionally be added to the carcasses at the slaughter locations before transport for burial, it is considered unlikely that those actions will delay the onset of putrefaction for any significant time. Un-coffined burial of human corpses, which are comparable in mass to those of sheep and pigs, are reduced to skeletal remains within about ten years, suggesting an effective half-life decay of about one year.

In order to provide comparable estimates for slaughtered stock, and to allow for the greater proportions moderately or slowly degradable horn and hair, annual releases have been based on the relative proportions of rapidly, moderately and slowly degradable material shown in Table 5.1, and on the following assumptions regarding the rate of decay of each class of material:-

- Rapidly degradable half life one (1) year
- Moderately degradable half life five (5) years
- Slowly degradable half life ten (10) years

Table 5.1 : Comparison of degradable content of mammalian corpse with household waste

Component	Readily degraded %	Moderate degradation %	Slow degradation %	Inert %
Mammalian corpse	60	15	20	5*
Fresh household waste	18	12	31	39

Note: * The 5% represents what is left after high-temperature cremation (not on-site burning on pyres). It consists principally of mineral salts. Very slow degradable components of bone (apatite) and slowly degradable hoof/horn/hair (keratin) may be close to inert for practical purposes. Data from van Haaran, (1951), Taylor, Woodgate and Atkinson (1995) and Polytechnic of East London, (1992).

Mammalian carcasses typically comprise a higher proportion of readily degraded material than does household waste. The ratios of carbon to nitrogen to phosphorus in fresh corpses (about 30 : 3 : 1 – Forbes, 1987) provides a better balance for microbial metabolism (both aerobic and anaerobic) than does household waste and more rapid degradation would be expected. Fresh corpses also contain 55-60% water and are capable of rapid lysis unless placed almost immediately in drying conditions. Even under cold conditions corpses of the sizes in question are likely to begin to show evidence of bloat within a period of a few weeks. In practice, from experience with the early burial sites during the 2001 FMD epidemic, this period has been in the order of days.

Note on body fluid releases:

The immediate release of body fluids has been a particular problem at carcass burial sites. The estimated quantity of liquid theoretically available for immediate release from the carcasses is 170 litres/cow and 16 litres/sheep. Approximately 50% of this is likely to be released within one week of deposition, with the majority of the remainder being released within 2 months. In total this represents approximately one-third of the mass of the carcass. On this basis leachate removal and disposal is likely to be the key issue at most burial sites, as management of this relatively rapid release is likely to deal with a significant proportion of the potential pollutant loading from the carcasses.

To provide overall load estimates from carcass degradation on an annual basis, it has been assumed that the declining source term follows an exponential function of the type:

$$C_t = C_0 e^{-kt}$$

where C_0 is the initial mass, C_t is the mass remaining after time t and k is the first-order degradation rate ($time^{-1}$).

It has also been assumed (based on Forbes (1987) that the total content of carbon, nitrogen, chloride and potassium in one tonne (1000 kg) of fresh animal carcasses is:

355 kg C	(i.e. 35.5% carbon by mass)
40 kg N	(i.e. 4% nitrogen by mass)
1.3 kg Cl	(i.e. 0.13% chlorine by mass)
3.0 kg K	(i.e. 0.30% potassium by mass)

and that the elements are distributed proportionally between the three classes of degradability (Table 5.1). However, it should be noted that experience of assessing the availability of elements in putrescible municipal solid wastes (MSW) (Belevi and Baccini, 1989) has shown that the proportion of total contents which may be mobilised are as in Table 5.2. Taking account of the relative moisture contents of carcasses and MSW, the results of the computations are provided in Table 5.3. It should be noted that in all cases these are theoretical calculations and that actual rates will be governed by site-specific conditions relating to both the slaughter of the animals and the environmental conditions within the burial pits.

Table 5.2 : Proportions of available elements in degradable matter (after Belevi and Baccini, 1989)

Parameter	Proportion of total weight available (range).
Organic C	0.047 – 0.158 *
N	0.105 – 0.163
P	0.012 – 0.081
Cl	0.139 – 0.208

Note : * *The method of estimation used by Belevi and Baccini may have under-estimated the proportion of available organic carbon by between two and four times.*

In Table 5.3 the maximum availability is assumed. Data specific to potassium are not available, but for the purpose of providing initial estimates an availability similar to that for the chloride ion is assumed.

Table 5.3 : Potential annual releases (kg) of pollutants from burial of one tonne of slaughtered stock.

Year	TOC	NH_4	Cl	K
1	24	2.9	0.12	0.28
2	10.1	1.2	0.05	0.12
3	4.8	0.6	0.03	0.07
4	2.7	0.3	0.015	0.035
5	1.8	0.2	0.008	0.018
6	1.3	0.2	0.006	0.014
7	1.1	0.1	0.006	0.014
8	1.0	0.1	0.004	0.009
9	0.8	0.1	0.004	0.009
10	0.8	0.08	0.004	0.009
20 (average per year	0.3	0.05	<0.002	<0.005
30 (average per year)	0.1	0.02	<0.002	<0.005
40 (average per year)	0.03	<0.008	<0.002	<0.005
50 (average per year)	0.02	<0.008	<0.002	<0.005
60 (average per year)	0.003	<0.008	<0.002	<0.005

The estimates assume that considerably more than the 5% of the mass of carcasses, which would form a residue after high temperature incineration, remains as solid, 'inert' material after decomposition. In practical terms, a higher proportion of bone, horn and dental material is likely to remain as long-term stable material in the ground and not to contribute to water contamination any more than would a soil fertilised with organic materials.

5.2 Potential loads associated with burial of slaughtered herds.

Information on the typical body weights of animals and the age distributions of herds (Chapter 4) may be manipulated to estimate typical slaughter weights for whole herds, with the results shown in Table 5.3. The estimates assume that:

- slaughter takes place during April 2001;
- calves, lambs and piglets have been born and form an integral part of each herd.

If slaughter is delayed, growth of juveniles will increase the mean total mass of each herd.

Although the numbers of burials on individual farms or groups of farms may not exceed a few thousand sheep or pigs, the establishment of very large burial sites to accept carcasses from a wide region indicates that some sites may have several hundred thousand carcasses. Because of other concerns, in particular the potential presence of BSE infectivity, the burial of cattle older than 5 years (born before August 1996) is not permitted. Cattle born after August 1996 may be buried (subject to a favourable outcome from an environmental risk assessment), providing a cattle passport (which were issued to all cattle born after August 1996) proves its age.

Table 5.4 : Estimated total slaughter weight of herds or carcasses taken to a regional disposal centre.

Type of animal	Number in herd or disposal to regional centre.	Total slaughter weight (kg)
Cattle	100	37300
Cattle	1000	373000
Sheep	1000	31800
Sheep	100000	3180000
Pigs	1000	27600
Pigs	100000	2760000

More than 70 percent of the total polluting load is likely to be released within the first five years following burial and Tables 5.5-10 provide estimates of the possible loads over that time for herds or regional collection centres, of the sizes considered above. Data from the initial burial sites, and in particular the release of body fluids support a rapid release of pollutant loading in the first year.

Table 5.6 : Potential pollution releases (kg/year), years 1 - 5, from 100 slaughtered cattle.

Year	TOC	NH4	Cl	K
1	895	108	4.5	10
2	377	45	1.9	4.5
3	179	22	1.1	2,6
4	101	11	0.6	1.3
5	67	7.5	0.3	0.7

Table 5.8 : Potential pollution releases (kg/yr), years 1 - 5, from 1000 slaughtered cattle.

Year	TOC	NH4	Cl	K
1	8952	1082	44.8	104
2	3767	448	18.7	44.8
3	1790	224	11.2	26.1
4	1007	112	5.6	13.1
5	671	74.6	3.0	6.7

Table 5.10 : Potential releases (kg/year), years 1-5, herd of 1000 sheep.

Year	TOC	NH_4	Cl	K
1	763	92	3.8	8.9
2	321	38	1.6	3.8
3	153	19	0.95	2.2
4	86	9.5	0.48	1.1
5	57	6.4	0.25	0.57

Table 5.12 : Potential releases (kg/yr), years 1 - 5, burial of 100000 sheep.

Year	TOC	NH_4	Cl	K
1	76320	9222	382	890
2	32118	3816	159	382
3	15264	1908	95	223
4	8586	954	48	111
5	5724	636	25	57

Table 5.14 : Potential releases (kg/year), years 1-5, herd of 1000 pigs.

Year	TOC	NH_4	Cl	K
1	662	80	3.3	7.7
2	279	33	1.4	3.3
3	132	16.6	0.8	1.9
4	75	8.3	0.4	1.0
5	50	5.5	0.2	0.5

Table 5.16 : Potential releases (kg/yr), years 1 - 5, from burial of 100000 pigs.

Year	TOC	NH_4	Cl	K
1	66240	8004	331	773
2	27876	3312	138	331
3	13248	1656	83	193
4	7452	828	41	97
5	4968	552	22	49.7

Estimates for smaller or larger herds may be made by *pro rata* proportioning. The caveats noted earlier with respect to slaughter and burial conditions again apply.

6. CONSIDERATIONS IN BURIAL SITE DESIGN.

6.1 Design principle

In order to provide realistic guidance it has been necessary to consider the potential impact of burials on a limited number of possible scenarios, which include different, but feasible, combinations of hydrological and operational conditions. The influence of hydrological conditions on the transport and fate of pollutants is considered particularly in section 7 of this guidance, but operational constraints will influence the ways in which the burials may impact on the environment and particularly on water resources.

The principal factor that determined the extent to which sites could be prepared (engineered) for the receipt of carcasses in the early stages of the epidemic was time. Even with some advance planning within the context of the later stages of the epidemic, it is unlikely that there will be sufficient time to plan and install containment and control systems of the types normally required for licensed non-inert landfills.

During the early stages of site selection an iteration is needed to assess whether the site and the volume of carcasses involved are in principle suitable for disposal on an uncontained, a naturally contained basis or an artificially contained (engineered) basis. The higher the degree of containment, the more sophisticated on-site leachate collection and extraction facilities will need to be prior to disposal. Even for some dilute and disperse sites it may be advisable to consider basic facilities for the removal of the initial flush of body fluids, as noted earlier. However, where long-term maintenance is required, this should form part of the requirements of the authorisation issued by the Agency to MAFF under the Groundwater Regulations 1998.

Contained solutions by their very nature involve a long-term commitment to site management and substantial expenditure on leachate treatment and disposal. Space on site for, and the long-term feasibility of, operating such facilities is a key consideration. To put this issue in context, if 95% of the carcasses deposited at a site are degradable, then this proportion of the deposited mass must be removed from the site through time, in the form of leachate extraction, seepage from the site or gas migration.

Dilute and disperse designs are only suitable where the attenuating capabilities of the local subsurface environment are adequate to deal with the proposed pollutant loading. Experience from the early stages of the epidemic has shown that it is essential to characterise and have confidence in the subsurface conditions, such that there is slow movement of the pollutant loading out of the burial pit and no receptors in the vicinity of the site. Dilute and disperse solutions can only work where there is no short-circuiting of the assumed groundwater flow conditions (for example, by artificial site drainage). Every effort should be made to ensure that the sites have been selected or remedial works instigated so as to ensure as far as possible the absence of these features.

In many respects the ideal criteria for a dilute and disperse burial site are analogous to those which were considered most desirable for a 'dilute and disperse' landfill (Department of the Environment, 1978), that is to say:-

- Not within the catchment of a significant water resource (groundwater or surface water);

- Site on soil/subsoil of moderate hydraulic conductivity, which would allow the release of leachate/gases to the environment at a steady, controlled rate;

- The dominance of intergranular flow systems, and the absence of flow systems dominated by coarse granular materials and/or fractures, weathered zones and karstic conditions;

- Soil and subsoil with a mixed mineralogy, offering attenuation by exchange and sorption processes, buffering of acid and alkaline solutions and sites for the colonisation of attenuating microbial populations.

At the two extremes, it is unlikely that contained solutions will be feasible for small disposals or that dilute and disperse will be an option for a large mass burial site. Given the trend towards larger and fewer burial sites during the epidemic, partly for logistical reasons, it is likely that most new sites coming forward will need to be considered on a containment basis. However, if long term management of the site is not feasible, including reliable and cost effective leachate treatment/disposal, it should be rejected.

6.2 Role of the unsaturated zone

An unsaturated zone has the potential to slow down the migration of any pollutants and to attenuate some contaminants. Providing that the flow is via the pores of the strata and not via fissures, a relatively thin (2-5m thick) unsaturated zone can give significant additional protection to groundwater. However, the pollution loading has a major influence on the extent of contamination and a large volume of carcasses within a small disposal area will, in principle, have a greater loading on the attenuating capabilities of the unsaturated zone than the same volume over a larger area. This matter is considered further in section 7. The absence of any unsaturated zone should be taken as a high risk factor in any situation where there is a groundwater resource, even for contained solutions.

Given that burials require a cover of 1-2m, in practice there will need to be an unsaturated zone of at least 4-5m below original ground level for there to be any unsaturated zone beneath the base of the burial pit. The insistence on an unsaturated zone will be a significant constraint in many lowland areas but is entirely justifiable where there is a groundwater resource (all major and minor aquifers and some weakly permeable non-aquifers that are used for small private water supplies in the locality). A significant unsaturated zone (at least 5m thick) is a prerequisite for a dilute and disperse burial pit design. In areas where the water table is high, consideration could be given to partial land raise solutions, though the implications of escape of leachate need to be carefully considered.

6.3 Engineering of burial pits.

6.3.1 General

Subject to satisfactory environmental performance, any site design that requires long-term maintenance other than regrading of the cover should be considered in principle less sustainable than a design where only passive controls are needed. Any design that results in dry entombment of the carcasses, resulting in a very slow rate of degradation, is also undesirable, from a sustainability viewpoint. On the other hand, it is necessary to ensure that the disposals do not create gross pollution. Very rapid degradation that results in a massive peak loading of contaminants is also undesirable, as this has a high probability of overwhelming either the natural attenuating capabilities of the subsurface environment, leading to pollution of water resources (in the case of a dilute and disperse burial pit) or leachate treatment and disposal facilities (in the case of a contained burial pit). In principle, a steady rate of degradation should be sought, probably over a period of a few years.

Disposal into standing water or sub-water table lined burial pits are not acceptable (see 6.2 above). In areas where the water table is uncertain, initial trial pits should be dug to check that there is likely to be no groundwater ingress to the burial pits.

When assessing possible engineering measures for mass burial sites, the possible presence of field drains and other drainage systems should be considered. Many clay sites are heavily drained (by field drains) in order to reduce water content and improve the horticultural properties of the soils. Similarly, many military sites, such as airfields, are heavily drained in order to prevent the collection of standing water, which would cause operational difficulties. There may be more than one drainage system on site representing different phases of site development. The presence of drainage systems could allow rapid migration of polluting fluids (leachate, blood etc) to surface water systems, by-passing the attenuating properties of the soil and geological strata.

On sites with low groundwater vulnerability, the movement of polluting fluids through unprotected / identified drainage systems probably poses the greatest threat to water quality. Every effort should be made to identify and remove, or permanently seal, drainage systems close to where burial pits are proposed.

6.3.2 Dilute and disperse sites

Conceptually, a design that invokes and encourages natural attenuation as a means of reducing the risk of pollution will be more appropriate to the majority of smaller sites. For reasons of passive hydrological control at such dilute and disperse sites, it is desirable that the hydraulic conductivity of the base of the site should be greater than that of the capping layers, to prevent accumulation of polluted liquids within the pit, with risk of overtopping and surface flows.

In the case of sites located on fine grade alluvial sediments, glacial deposits of a similar nature or fine granular geological formations, such as the silty deposits at the base of the Tertiary succession, parts of the Upper and Lower Greensand (excluding the Folkestone Beds and Hythe Beds), and weathered areas of mudstones and marls, ripping of the base of the excavation to a depth of one metre should be carried out before disposal commences, in order to release surface compaction or glazing which may have taken place during excavation.

Sites excavated into consolidated strata should have a layer of broken / crushed stone left in place across the base of the site, preferably to a depth of one metre, to provide an initial drainage and filtration blanket before liquids gain access to the underlying and adjacent consolidated materials.

It is extremely undesirable that any burial sites should be located on fracture flow or karstified formations, but if local conditions indicate a necessity for this type of site (the disposal mass is small, there is no other viable disposal option, and burial in this location under the circumstances of the epidemic is the 'best environmental option'), a crushed rock blanket of not less than one metre should entirely cover the base and extend at least two metres up the sides before disposals are started. Long-term monitoring of all significant burials on karst/fractured strata should be required. There should be no mass burials on such strata on a dilute and disperse basis.

6.3.3 Contained sites

It is impractical to engineer most sites to the specification that would normally be applied to licensed waste disposal facilities, in the time available. In principle, the sites should **not** be regarded as fully contained landfills, on the basis that in most cases it will not be feasible to construct, test and quality assure the lining (whether it be natural or artificial) to the degree normally expected. However, as the total pollutant loading and length of time that this will be significant are both significantly smaller than in most waste disposal sites, the engineering measures for containment do not necessarily need to be the same as for a licensed landfill, say with a 30 year operating life and a 30+ year aftercare period.

Burial sites proposed in low permeability sediments, for example in clay pits, should not present a significant threat to groundwater resources in the short to medium term, but may impact on surface waters, especially if the capping system allows more infiltration to the burial pit than can drain through the sides and base. The natural containment offered by such sites indicates that it will be necessary to install leachate drainage in the base of the site, with a means of recovering accumulated leachate for removal, treatment and environmentally sound disposal. Similarly, vents around the site periphery to release gases accumulating in the void may be needed, to prevent uncontrolled gas break-out.

The potential advantage of providing additional neutralising capacity (for example, lime or limestone rubble) to encourage the onset of methanogenesis and the reduction in dissolved organic pollutants has been described in section 3. If suitable limestone quarry wastes are available, they should be incorporated in the basal drainage layer, but it is recommended that lime should not be added to the mass of carcasses, since this will slow the rate of degradation (it will kill both harmful micro-organisms and those that are beneficial for degradation).

Note : For the reasons given above relating to the quality of construction etc., realistically achievable during the epidemic, **the provision of an engineered artificial lining at a burial site should not be seen as a means of enabling burial within an inherently vulnerable site** (with respect to groundwater, surface water etc). The provision of a lining should be regarded as a means of controlling leachate and gas migration to mitigate any residual risks that may arise at sites which have passed through risk screening (see section 7).

Detailed engineering measures for contained sites are provided in Appendix B.

6.4 Capping

During excavation of the burial pit, the soil, subsoil and underlying strata/sediments should be stacked separately, in order that the most suitable may be used for final capping. It is expected that individual pits will be filled rapidly and will need temporary cover prior to longer term capping. It is suggested that the initial covering should be made using the more permeable materials, with the least permeable being reserved for the final restoration. However, at some sites it may be necessary to restrict infiltration to the burials to reduce the short term production of leachate. In practice, there are various options for initial cover and their use may depend not only on water permeability considerations, but also taking into account odour and gas control. There are insufficient data at present to give firm recommendations on the suitability of initial cover options. Whatever covering is used, the long term implications for both final capping and processes within the waste mass must be considered.

Experience from the first mass burial sites suggests that a combination of rapid degradation of carcasses has resulted in significant gas and leachate production within a few days to weeks following burial. Failure to puncture some of the carcasses has resulted in movement within the waste mass as un-punctured carcasses bloat and rise through the surrounding waste mass (they effective float up through surrounding carcasses due to their relatively lower density).

In addition surcharging of the carcasses with a covering in the absence of leachate extraction is potentially dangerous, as this encourages the squeezing of fluid from the carcasses and exposure of pools of fluid (blood etc.) at the surface of the burial pit, leading to odour and potential health problems. Ideally, leachate extraction facilities should be in operation prior to covering.

The timing of any placement of capping over the initial cover is likely to be a site-specific decision. Rapid subsidence will follow disposal and removal of the initial flush of body fluids – the rate of this will depend both the burial pit conditions and the state of the carcasses on disposal. Initial experience suggests that subsidence of around 25% of the depth of carcasses takes place within a few weeks of disposal, providing leachate is extracted.

Due to the potential for longer term subsidence, mounding of the capping is desirable to prevent depressions forming that could collect surface runoff and enhance recharge within the disposal area. The extent of mounding should depend on the depth of initial cover and the depth of carcasses. It is suggested that an initial mounding of 5% of depth of the cover + 20% of the depth of carcasses. As an example, a 4m pit with 2m of carcasses and 2m of cover should be mounded by $\sim (0.05 \times 2) + (0.2 \times 2) = 0.1 + 0.4 = 0.5$ metres.

Irrespective of the depth of filling, caps should have slopes of 1 in 10 or more to encourage run-off. Given that 60% by volume of the carcasses will degrade rapidly and that eventually 95% will disintegrate, the mounding will need replenishment though time. It is recommended that the initial mounding should be inspected and replenished as necessary after 3 months, 6 months and then annually for at least five years after the time of burials.

It is preferable to use natural materials to cover the site, engineered to achieve a low (but not very low) permeability cap. The soils with the lowest permeability should be reserved for the final restoration, when settlement is essentially complete and only low drainage slopes are possible. These materials should not be wasted by incorporation in intermediate restoration levels, which subsequently become buried. At least 1m of cohesive soil should be used as cover. Artificial, very low permeability membranes etc. should only be used as a last resort when no low permeability material is available, as these run the risk of hindering the migration of gases and recharge to the extent that biodegradation could be inhibited. In addition, low permeability membranes will be disturbed by subsidence and will be difficult to maintain.

6.5 Monitoring

Monitoring can be divided into:

- Monitoring of the leachate;
- Monitoring of surface and groundwater;
- Monitoring of site facilities including settlement of the capping material, leachate treatment facilities etc.

For guidance on surface and groundwater monitoring, reference can be made to the Agency's existing guidance for monitoring of landfills and for the purposes of the Groundwater Regulations (Environment Agency, 2001a and b). Monitoring for such purposes should be included as a requirement on the Groundwater Regulations authorisation for the site.

For monitoring of leachate and groundwater near to the burial sites there will be need to be particular consideration of Health & Safety issues, specifically with respect to the transmission of the Foot & Mouth virus and other pathogens.

All monitoring suites should contain:

COD, TOC, ammonium, chloride, potassium, Electrical Conductivity, TON, pH and phosphorus.

Leachate should include total solids and total dissolved solids, where the latter is feasible.

Groundwater suites should comprise major ions in addition to the above.

Consideration should also be given to the inclusion of phenol and iodide, which may arise from the use of disinfectants and to undertaking a GCMS scan for disinfectants generally.

7. ASSESSMENT OF RISK

7.1 Existing guidance.

The burial of fallen stock on farms has been the subject of MAFF guidance for some considerable time (guidance documents on the protection of water 1985, 1991 and 1998 – (COGAP)), with the most recent addition (ABPO) dated January 2001. Under this latter guidance all burials over 8 tonnes per annum on an aquifer require a Groundwater Regulations authorisation from the Environment Agency. On non-aquifers, this need for an authorisation was at the discretion of the Agency (during the FMD epidemic all disposals over 8 tonnes have needed an authorisation). The existing guidance has been based on an assumption of the disposal at one time of a limited number of carcasses, and pragmatic criteria, based on long practical experience and observation, design to prevent damage to local water supplies (both surface water and groundwater). The criteria may be summarised as follows:-

No burial within:-

- 250 metres of any well, borehole or spring supplying water for human or dairy use.
- 30 metres of any other well, spring or watercourse
- 10 metres of a field drain.

Also the burial must:-

- have at least 1 metre of unsaturated ground below the base of the burial pit (the base of the pit must be dry at the time of digging);
- have at least 1 metre soil cover over the carcasses.

These criteria were examined by Young *et al* (1999) when reviewing the pollution potential of human burials and were found to be satisfactory. However, we should note that the COGAP guidance and the cemeteries work was aimed at relatively small numbers of burials over a period of time, not mass burials. In addition, the main risks considered by COGAP were to potable water supplies (for human drinking water). This guidance should be revisited for the purposes of the present work, where there is concern that there could also be short-term transmission of the Foot and Mouth virus to at-risk animals. Therefore, the good practice criteria noted above should be regarded as absolute minimum requirements.

In view of the potential for transmission via groundwater it is recommended that all water supplies that could be used for stock watering should also have the 250m set-off in this instance. Within the short timescale that is allowed for assessment during the FMD epidemic it will rarely be certain whether a particular watercourse or spring is in contact with groundwater from beneath a site. Therefore, it would be an appropriate precaution to ensure that all water features have a 250m buffer zone around them for the purposes of mass disposal of carcasses (for example, sheep, in the range of a few thousand) and that where burial of hundreds of thousands of carcasses is proposed the ideal stand-off distance will be no less than 500 metres. The exceptions to this should be where it can readily be demonstrated that the watercourse etc. is well up hydraulic gradient of, or not in hydraulic continuity with, groundwater or where a fully engineered containment solution has been constructed. In these situations the COGAP guidance should be followed, as minimum criteria.

As a pragmatic response to the emergency situation, which arose with the onset of the Foot and Mouth epidemic in February 2001, Agency officers prepared pragmatic guidance (Appendix A) based on a ranking of risks (high – low) associated with the vulnerability of aquifers and the mass of animals for burial. The guidance recommends that where less than 8 tonnes are involved, burials in areas of high risk, sensitive groundwater should not be allowed, but that in areas of lower risk burial in accordance with COGAP paragraph 276 would be acceptable without the necessity for further Agency authorisation. In the same areas, burials of up to 32 tonnes may be acceptable, but would require simple site investigation (trial pits) to confirm ground conditions.

The situation which exists in reality (as of mid-April 2001) is that burial sites are being constructed and filled, which are between two and four orders of magnitude larger than those envisaged in the interim guidance offered in Appendix A which is, therefore, superseded by the guidance in this document.

7.2 Approach to risk assessment

Under the terms of an authorisation under the Groundwater Regulations there should be no entry of List I substances into groundwater (the saturated zone) and no pollution of groundwater due to the entry of List II substances. The point of compliance would normally be below the authorised discharge. Pragmatically and particularly in the circumstances of the FMD epidemic, the point of compliance for pollution by List II substances can be set at a distance from the burial, to allow a mixing zone and also to allow for the location of monitoring facilities at which compliance can be assessed. A distance of around 50m would be reasonable under the circumstances but in many instances the site boundary may be a practical constraint.

Listed substances are chemicals noted in the groups and families contained within the Groundwater Directive and would include many of the breakdown products of the decay of carcasses. Micro-organisms do not constitute listed substances unless they are in the form of biocides. However, under the Water Resources Act, 1991 there would be an offence if the release of toxic, noxious or polluting matter resulted in the pollution of controlled waters.

From the Agency's viewpoint, predictive risk assessments have been made in terms of the potential impacts on water resources of dissolved pollutants and of certain pathogens. In the former case, the absence of potential List I compounds from the raw materials (dead animals) but the certain presence of List II substances, including ammonium (from the decomposition of the carcasses), makes it possible to assess the acceptability of disposals in terms of the impacts at compliance points within groundwater around the burial site.

The potential significance of contamination, in terms of whether pollution by List II substances has resulted, may be assessed by comparing the predicted pollutant concentrations against background water quality or a relevant use-related water quality standard. Where a burial pit is located over an aquifer that could be used for potable supply, comparison against drinking water standards may be most applicable. Where groundwater is likely to be a resource in terms of baseflow support to rivers or wetlands, comparison of predicted maximum concentrations with Environmental Quality Standards (EQS's) may be more relevant, though the point of compliance should be selected carefully and attenuation within the subsurface environment en route to the receptor will be a consideration.

Where there is a risk of discharge to surface water a direct comparison of the discharge quality with EQS's and other relevant surface water quality standards will be needed. It is unlikely that any discharge of leachate from a burial site to surface waters will be acceptable in the short term.

In the case of pathogens, a similar approach is possible, where adequate dose / response data are available for the specific pathogen and sensitive targets. Alternatively, the impact may be assessed from knowledge of the decay rate of the organism in the ground and estimates of the travel time from the source to the point of compliance.

Following the DETR/Agency/IEH guidance on risk assessment (DETR et al, 2000), risk assessment should proceed from simple risk screening, through generic risk assessment to site-specific quantitative risk assessment. This is to make most effective use of investigatory effort and is an entirely appropriate model for the FMD epidemic. Assessments may be made using increasingly complex tools, as below:

1. Screening assessments

   Initially, existing maps and data sources (some of which, such as maps indicating groundwater vulnerability, aquifer types or source protection zones, inherently include a risk assessment in their compilation) are consulted. A simple conceptual model of the site and the potential disposal operation is built up and tested against generic criteria of acceptability (location on a major aquifer, proximity to sources of supply, compliance with COGAP etc.) and an initial assessment is made.

2. Generic quantitative assessment

   Initial calculations may be used to determine, for a given size of burial and a few, generally non-site specific criteria, at what distance from the burial should the nearest point of compliance lie in order that there should be no unacceptable change in water quality. Sites at which the criteria are fulfilled could then be used without further extensive investigation or assessment.

   The use of basic equations, of the type employed in Tier 2 assessments for land contamination work (for example, as in Table 4.5 of Agency R& D Publication 20) would come under this category. The successful use of this method relies on the availability of reliable values for certain hydrological and hydrogeological parameters, including the services of an experienced hydrogeologist who can assign realistic values from a range of defaults.

3. Site-specific quantitative risk assessment

   Initially, site-specific data arising from a prior investigation can be employed in the basic equations noted above and using a variety of spreadsheets and generic packages. As the situation becomes more complex and more detailed analysis is necessary, the use of mathematical modelling packages, such as LandSim 2.0, which is able to account for the changes with time of the source term, interactions between the pollutants and the aquifer materials and the uncertainty inherent in the variability of many of the input parameters (stochastic processes), can be considered. Finally, a detailed tailored mathematical contaminant transport model could be used, using extensive site data obtained specifically for the purposes of the assessment. In practice, this will not be possible during the FMD epidemic, but may be necessary for retrospective and more detailed assessments of the long term impacts of the larger mass burial sites.

Appendix C provides details of the screening and spreadsheet assessments used by the Agency for the purposes of the FMD epidemic.

7.3 Generic risk assessment of the impact of burial sites on surrounding water resources.

7.3.1 Simple calculations based on measured or assumed hydraulic characteristics,

Simple estimates of the potential concentration at a down-gradient point in groundwater flowing beneath a burial pit may be made using the types of basic equations contained in Tier 3 of the Environment Agency R&D Publication 20 and from a basic manipulation of the Darcy flow equation:

$Q = k \cdot i \cdot a$, where

Q = flow rate (m/day)

k = hydraulic conductivity (m/d)

i = hydraulic gradient and

a = area of aquifer through which flow takes place.

Assume a burial of 100 000 sheep, which will occupy a volume of 7500 m^3, which will be taken to be in the form of a trench 4 metres deep (allowing a 1 metre cap above a 3 metre layer of carcasses), 10 metres wide and 250 metres in length.

Assume also that the long axis of the trench is arranged normal to groundwater flow, that the local hydraulic gradient is 0.01, the hydraulic conductivity 50 m/d, the depth to which leachate mixes with groundwater immediately below the site is 10 metres and that the full saturated depth of the aquifer is 50 metres.

Assume that the initial leachate generated in the burial pit contains 2000 mg/l of ammonium and that the annual effective rainfall is 300mm (0.3 m), making allowance for the effects of the cap.

Then, the annual volume of leachate will be

$$250 \times 10 \times 0.3 = 750 \text{ m}^3$$

and the annual volume of groundwater flowing beneath the site (within the mixing depth) will be :

> $50 \times 0.01 \times 10 \times 250 \times 365 = 456\ 250 \text{ m}^3$, with an 'instantaneous dilution of 456250/750 = 608-fold, to give an initial groundwater concentration of 3.3 mg/l of ammonium.

The effect of hydrodynamic dispersion is to 'spread' a plume of contaminant in the direction of flow, so that the plume thickness and width increase with distance from the source. Assuming that dispersion is proportional to flow distance, and that the lateral dispersivity is $0.01 \times$ flow length and vertical dispersivity is taken as $0.001 \times$ flow length, then at 250 metres from the source, the width of the plume will be 255m (compared to 250m at source) and its thickness 10.25m (compared to 10m at source). The additional dilution increase in the cross section of flow indicates that the concentration of ammonium at 250 metres from the source would be reduced to about 2 mg/l. A further four-fold reduction would be required to bring the concentration to below the Drinking Water standard, assuming that the groundwater passing beneath the site had a low initial ammonium content.

In the case examined, no account has been taken of attenuation by any process other than dilution and dispersion and it is possible that local experience would indicate that a greater reduction in concentration would be expected. Nonetheless, the example tends to support the conclusion of the simple screening estimates, that for large burial sites operated under the dilute and disperse principle with intergranular flow in the subsurface, several hundred metres should intervene between the burial pit and any receptors for a site to be acceptable.

7.3.2 Modelling releases and impacts using LandSim, Release 2.

LandSim Release 2.0 has been used to simulate the potential environmental impact of the burial of large numbers of carcasses slaughtered to control Foot and Mouth Disease. The modelling has focussed on the potential impacts on groundwater quality at distances of 50 and 250 metres from a burial site and has assumed hydraulic conductivities typical of aquifer materials (10^{-4} to 10^{-6} m/s, 10^{1} to 10^{-1} m/d) and of less permeable systems (10^{-6} to 10^{-8} m/s, 10^{-1} to 10^{-3} m/d).

The model has assumed that:

- the source term declines to a low value at between 10 and 15 years;
- the source is the burial of 6000 sheep, occupying a surface area of 10 by 10m (100m^2);
- the source term pollution strength is 2000mg/l ammonium; 4000mg/l chloride;
- degradation of ammonium by oxidation is a first order reaction with a half-life of 10^4 years;
- chloride is conservative and is neither retarded nor attenuated;
- infiltration rates appropriate to north-west England;
- unsaturated zone between 1 and 2 metres depth;

- movement of ammonium is retarded in both unsaturated and saturated zones. A Kd of 5 l/kg is assumed for the soil zone, where clay and organic matter content is higher and 1 l/kg in the aquifer. These values are considered realistic on the basis of work presented in R&D Technical Report P340 (Agency, 2000).

The results of the simulations for ammonium and chloride are summarised in Table 7.1, for the two hydrogeological regimes (active aquifer, restricted drainage system – aquitard or minor local aquifer). In each case the predicted concentrations at the 50 and 250m points of compliance are given at the 50percentile and the 90percentile (that is to say, there is a 50% or 90% likelihood that the maximum observed concentration at the compliance point will be less than the predicted value).

Table 7.1 : Results of generic assessment using LandSim 2.

Compliance point	Hydrogeological setting	Probability limit (percentile)	Predicted chloride (mg/l above background)	Predicted ammonium (mg/l above background)
50 m	Aquifer	50%	50	3
	Aquifer	90%	230	16
	Aquitard	50%	70	1
	Aquitard	90%	185	0.11
250 m	Aquifer	50%	5	0.2
	Aquifer	90%	37	2
	Aquitard	50%	0.2	0.02
	Aquitard	90%	11	0.36

The current Drinking Water Standard for chloride is 400 mg/l (reducing to 250 mg/l under the Water Supply (Water Quality) Regulations, 2000) and the standard for ammonium is 0.5 mg/l. The additional concentrations predicted would appear to be unlikely to cause the groundwater at the points of compliance to exceed the standards, particularly at the 250 metres point. The values should be viewed in light of the assumptions and the resultant uncertainty. If there were a discharge to surface water at this point the EQS of 0.015 mg/l ammonium would be appropriate and this standard would be failed.

The predictions are strongly influenced by the assumption of a declining source term. If a constant source term were to be assumed, the predicted maximum contaminant concentrations would be significantly greater than those presented above. However, the burial of carcasses will not create a constant source term, because the interment will provide an effectively instantaneous, discrete deposit that must inevitably provide a declining source of pollution.

7.4 Separation distance and cordon sanitaire.

Providing there are no water supplies/sensitive receptors immediately down hydraulic gradient there seems to be little benefit in insisting on large (>50m) separation distances between burial pits. To prevent excessive point loading the pits should be orientated across groundwater flow lines, where possible.

A 250m radius long term cordon sanitaire will be needed around the disposal sites within which there should be no drilling of wells and boreholes for water abstraction purposes (a basic pollution prevention measure, consistent with ABPO guidance and COGAP). It would be sensible to maintain this as a set-off distance for any intrusive activity with respect to the subsurface, other than the installation of monitoring facilities by statutory authorities, which would nevertheless have to be subject to stringent Health & Safety measures.

7.5 Record-keeping

It is essential that accurate records of the locations of the burial pits are kept for future reference. A field plan should be submitted after completion of disposal, together with records of the depth of the burial, number and type of carcasses etc.. MAFF / the Agency should record this info on a GIS system, compatible with existing databases.

7.6 Subsequent follow-up monitoring

The groundwater risk assessments that have been conducted for both carcass disposal and incineration are based on best available data, but by necessity include a significant number of assumptions. These assumptions have been based largely on what are considered conservative conditions, but may not be supported by direct scientific measurement. The opportunity to provide supporting data by way of follow up monitoring down-gradient of disposal sites should not be missed. Strictly controlled monitoring by the Agency/MAFF including specifically constructed boreholes etc will need to be planned as soon as resources allow. Subsequent groundwater monitoring will effectively be the 'requisite surveillance of groundwater' required of authorisations under the Groundwater Regulations (1998).

7.7 Survival and dispersion of the Foot and Mouth virus and other pathogens

A range of pathogenic organisms may be present in leachate from decomposing carcasses including:

- Foot and Mouth virus;
- BSE/vCJD;
- *E.Coli O157*;
- *Campylobacter;*
- *Salmonella;*
- *Leptospira;* and
- water borne protozoa including *Cryptosporidium* and *Giardia*.

7.7.1 Viruses

In addition to the chemical (organic and inorganic) pollution load that may be released from the buried carcasses, Foot and Mouth virus and other pathogens may be present on or in the carcasses. No information specific to the survival of the Foot and Mouth virus under burial conditions has been found, but the fate of viruses in soil and groundwater is controlled by attachment and release from geological substrates and by inactivation. The three variables found to govern transport and attenuation are pH, ionic strength and organic carbon content of the soil or aquifer material.

Attachment is enhanced and so transport hindered by low pH, high ionic strength and high organic loading. Even small amounts of organic material (>0.01%) will delay viral movement. It appears that polioviruses and other enteroviruses (of which the F&M apthovirus is a member) are most easily adsorbed with echoviruses> rotaviruses>caliciviruses. Infectivity can be retained by adsorbed viruses for considerable periods of time, but if transport of the virus is halted by the effects of adsorption, its potential for onwards transmission is effectively zero.

The survival potential of the Foot and Mouth virus in the general environment is indicated by information contained in the sources noted in section 4.1 of this guidance. The virus is disrupted by exposure to the air and ultraviolet radiation, with the result that it can survive on the soil surface for 28 days in the autumn, but for only 3 days during the summer. Viruses present on the skin of animals do not survive rigor mortis, but infection present in the lymph nodes and marrow of infected carcasses may remain viable for weeks and for 14 days within dry faecal matter. The virus is able to survive for longer periods in dark, damp, neutral pH conditions and has been found to remain viable for up to 6 months in farm slurry during the winter. The virus is tolerant of a range of pH conditions, from >6.0 to <8.5.

Overall, these data indicate that although the virus can tolerate cold conditions it is deactivated by even moderate temperatures, and is stable only within a relatively narrow pH range, close to neutral. If the virus does not survive rigor mortis (which typically lasts between 1 and a few days after death), then cull carcasses do not pose a threat of F&M infection. If culled animals are buried before rigor mortis subsides, or the statement regarding inactivation is not wholly true, then a potential infection risk may remain. The burial of significant numbers of slaughtered animals would be expected to encourage conditions with the pit (elevated temperature, acidity) antagonistic to the survival of the virus. If, however, viruses escape the burial pit and are able to move rapidly to groundwater, then the aqueous medium, with typical pH values of 5.5 – 8 and a relatively stable temperature of around 11 degrees Celsius, would appear to be one in which relatively prolonged survival (months rather than weeks, by analogy with slurry) is possible.

The most probable situation in which such an invasion of groundwater by the virus would be possible is that of a burial site on a heavily fractured or karstic aquifer, without an effective filter/adsorption zone between the burial level and the rock head. In these circumstances the virus could migrate both as discrete entities and attached to other suspended solids. For this reason proposed sites on coarse gravel containing shallow groundwater, karstic limestones, and fractured (including heavily weathered) strata should be rejected.

An example of maximum reported migration distances of viruses in groundwater are 1000-1600m in chanelled limestone and 250-500m in glacial silt-sand aquifers. In addition to the retardation of viruses and other pathogens in soils and aquifer materials by attachment to organic and inorganic particles, they may also be trapped within porous media by the effects of filtration. Filtration takes place when a liquid carrying particles passes through a porous media. The process represents the sum total of a number of factors:

- A straining (trapping) action which takes place initially at the surface of the filter medium, but which may be repeated as the liquid and remaining particles pass through successive layers with different porosities and pore size characteristics.
- The sedimentation of particle within the body of the filter medium, especially if 'dead end' pores are present.
- Attachment to particles by surface charge processes (adsorption as above).

If pore throat diameters or fissure apertures are greater than the suspended particles, then it would be expected that the particles would pass through the pores. However, if the differences in size are modest (a factor of two or three times) and a number of particles approach the a pore or fissure at the same time, the particles may become lodged across the pore ('bridging') leading to the build-up of a filter cake, which is then capable of retaining smaller particles.

Table 7.2 : Pathogen diameters compared with typical aquifer apertures (♦ indicates approximate size of *Cryptosporidium* oocyst).

Diameter	1 mm	0.1 mm	0.01 mm	1 μm	0.1 μm	0.01 μm
Pores	Gravel	Sandstone		Chalk		
Fissures	Sandstone Karstic limestone		Chalk			
Pathogens		Protozoa	◇	Bacteria	Viruses	

Table 7.2 compares the range of sizes of pathogens with the pores and fractures associated with the principal aquifer materials. Viruses are the smallest pathogenic forms and the table indicates that they capable of passing through most porous media, with the possible exception of very fine pores and microfissures characteristic of the Chalk aquifer.

The virus may also spread by wind and transfer distances of up to 300 km over water and 60 km over land have been quoted (www.thepigsite.com). It would, therefore, seem essential to remove the corpses from the surface as soon as possible, by incineration, rendering, landfilling or earth burial, and to minimise the distances over which the corpses must be transported from the places of slaughter to the final disposal point.

These data suggest that it would be prudent to assume for risk assessment purposes that there is a potential for transmission in groundwater with a residence time of several weeks. This would be consistent with many other micro-organisms and the with reason why the Agency and its predecessors derived the Zone I Source Protection Zone for all major potable supplies of water on the basis of a 50 day travel time in the saturated zone. On this basis there should be no burials whatsoever within SPZ Zone I. As these zones are relatively small this should not present an unreasonable constraint. Mapped source protection zones for major sources in England & Wales are noted on the Agency's website.

Recent studies in the Netherlands (Schijven, 2001) have suggested that although pathogenic bacteria may be inactivated to the extent than no health risk remains by groundwater travel times of 50 to 60 days, this time may be insufficient for the inactivation of viruses and pathogenic protozoa (*Cryptosporidium and Giardia*). In order to achieve the current Dutch maximum acceptable infection risk of one per 10 000 persons per year, the Maximum Admissible Concentration for drinking water would be 1.8 x 10-7 viruses per litre, implying a 5 to 8 log reduction in concentration compared with contaminated surface waters. In the least inactivated scenarios (persistent viral surrogate indicators, aquifer materials with mineralogies providing limited active attachment sites) model studies indicated that travel/retention times of between 180 and 420 days would be advised to ensure a 9 log (10 million-fold) removal of viruses.

7.7.2 Cryptosporidium parvum

The coccidian parasite, *Cryptosporidium parvum*, which may cause cryptosporidiosis in humans, is characteristically present in faeces excreted by young cattle and sheep and is likely to be present on and within carcasses, especially if a high proportion of young animals are included in the slaughter. The parasite is transmitted as spherical oocysts, about 5 μm in diameter, and is resistant to environmental conditions. It can survive for long periods (weeks or months) in dark, moist conditions in soil or water. The number of oocysts required to initiate infection in animals and humans is low, although there are phenotypes, which are specific to species and there appear to be inter species infection barriers. The size of the oocyst suggests that it is unlikely to be significantly mobile in the Chalk matrix and fine-grained sandstone, but would be capable of movement through coarser and fractured rocks.

7.7.3 BSE infectivity

Because of uncertainties regarding the environmental durability of BSE infectivity and the remote possibility that the infective agent could be dispersed by water, the burial of bovine carcasses born before August 1996 is not acceptable. The date of August 1996 relates to the date after which cattle feed composed of other mammalian material was banned, and incidence of BSE in newborn cattle has greatly reduced. However, the residues which remain at incineration sites (pyres) may be leached by rainfall and could act as pathways for the transmission of surviving BSE infectivity and an estimate of the risks through exposure to humans is presented below. In addition, the possible consequences of the direct burial of carcasses, should that become necessary, is examined.

The assessments are based on the following assumptions:

1. The incidence of BSE in the national herd is 0.72% (dairy herd) and 0.17% (beef herd), (DNV, 1997, 2001).

2. A 575 kg cow with clinical symptoms provides 700 human oral ID_{50} doses of the BSE infective agent. A typical cow contains 700 grams of brain and spinal cord, and it is assumed that 1g of this material contains 1 human oral ID_{50} dose.

3. All infected cattle contain the maximum amount of BSE infectivity.

4. The effect of burning on a pyre on the BSE infectivity is to reduce the remaining infectivity to 9% of its original load. This is assumed to be due to a 90% destruction during burning and a further 10% loss of the infective agent in the smoke, (DNV, 2001).

5. Once in the ground, the infectivity of the BSE agent decreases at the rate indicated in work by Brown and Gajdusek (1991), that is, a half-life of about 6 months.

6. The burial or incineration is of a herd consisting of 1000 animals (young and adult distributed as Table 4.1, slaughter weight as Table 5.3)

Based on the above, the infectivity as human oral ID_{50} (that is to say the BSE infectivity dose which would be expected to infect 50% of an exposed human population with vCJD) in one tonne of cattle will be:

Number of ID_{50} in one animal × number of animals per tonne × proportion of infection;

$700 \times (1000/575) \times 0.0072 = 8.77$ human oral ID_{50} units per tonne dairy cattle

The estimated weight of a slaughtered herd of 1000 animals is 373 tonnes (Table 5.3), which could contain a total of:

$373 \times 8.77 = 3270$ human oral ID_{50} units per 1000 dairy cattle (mixed herd)

It could further be estimated that an average adult dairy cow contains $700 \times 0.0072 = 5.04$ human oral ID_{50} units, and that an average cow taken from a whole herd of mixed ages contains 3.27 human oral ID_{50} units.

Estimates of potential dilution effects and transport times are made in the same way as in sections 7.4.2 and 7.4.2.

Note that the BSE infective agent is estimated to be one thousand (1000) times more infective to cattle than humans, so that if a water supply to stock is at risk a higher level of security must be applied.

Burial

For the first estimate a circular burial pit of 9.6 m radius (290 m^2 area) sited at a groundwater divide is assumed, with no groundwater underflow to provide initial dilution. If all the potential infectivity were to be released within the first year after burial and the mean annual infiltration at the site is 300mm, which is further combined with an assumed 1m of liquid arising from the decomposition of the carcasses, then the mean concentration in water percolating from the base of the burial would be:

$$3270 / (290 \times (0.3 + 1.0) \times 1000) = 8.67 \times 10^{-3} \text{ human oral } ID_{50} \text{ units / l.}$$

Leaching from incineration trench.

The potential for survival of BSE infectivity under incineration is uncertain, but it is extremely unlikely to be better than that exhibited to rendering. DNV (2001) estimate 90% destruction of the BSE infectivity during burning, and a further 10% loss in smoke arising from the pyre. Other work by Taylor et al (1995) estimates a 50-fold ($10^{1.7}$) reduction in infectivity. If the more conservative estimate is taken, the BSE infectivity in the pyre residues, which remain in the trench after burning is completed, may be estimated as:

$$3270 \times 0.9 \times 0.1 = 294 \text{ human oral } ID_{50} \text{ units from 1000 animal mixed herd}$$

If this load of BSE infectivity is released over a year, with infiltration of 300mm through the site, and groundwater flow is as described previously, then the concentration of infective units in the groundwater directly beneath the site may be estimated as:

$$294 / (0.3 \times 1000 \times 100) = 9.8 \times 10^{-3} \text{ human oral } ID_{50} \text{ units / litre}$$

where the pyre is assumed to have a footprint area of $100m^2$.

Using the modified Remedial Targets worksheet, the fate and transport of the infectivity can be simulated in the subsurface. Mathematical and conceptual assumptions are included within this assessment, so conservative parameter values have been used in the assessment:

Half-life : 700 days

Koc: 1100 kg/l

Using this approach, further reduction in the concentrations of human oral ID_{50} units in groundwater in a typical aquifer system are predicted as follows:

Distance from disposal site (m)	Attenuation Factor, AF
10	2
50	25
100	310
250	2.1×10^5
500	2.6×10^9

The results of this simple assessment indicate that at 250 metres from a disposal pit, the concentration of human oral ID_{50} units in groundwater will be reduced by a factor of about 200,000, and by about 3×10^9 at 500 metres.

The consequence is that BSE infectivity concentrations arising from a burial and pyre site (using conservative parameter values) are reduced to 4×10^{-8} and 5×10^{-8} human oral ID_{50} units / litre groundwater, respectively, at 250 metres from the disposal site.

If it is assumed that an individual ingests 5 litres of affected groundwater each day for a year, through drinking, food preparation, tooth brushing etc., then the maximum concentration of human oral ID_{50} units in water that would result in an annual risk of vCJD infection in an individual of 1×10^{-6} is: 1.1×10^{-9} human oral ID_{50} units / litre groundwater.

Other factors which may influence the concentration of BSE infectivity in water.

The low infection potentials indicated by these estimates take no account of three other processes that may be expected to reduce the potential for infection;

1. The attenuation of encephalopathy agents in the soil, as demonstrated by Brown and Gajdusek (1991) who, in a three-year soil burial trial, found a half-life decay of slightly over six months. The time for flow through the ground is depended on the local hydrogeological conditions but for the types of soils and subsoils which are considered suitable for mass burials the lapse time between migration from the burial pit and arrival at a point 250 or 2500 metres distant is likely to be measured in years. The additional reduction in infectivity by this route for up to 10 years (20 half-lives) is summarised below.

Years since burial (No. half-lives)	Attenuation factor, assuming half-life 0.5 yr.
1 (2)	0.14
2 (4)	0.018
6 (12)	0.000006
8 (16)	0.0000001
10 (20)	2×10^{-9}

2. Prions, which are widely believed to be the form of the BSE infective agent are amphipatic, that is to say both hydrophobic (water hating) and hydrophilic (water loving) groups exist on the same molecule (Gale *et al*, 1998). Because of their hydrophobic groups, such molecules cannot exist free in water. As a result of hydrophobic interactions, amphipatic molecules attach with great tenacity to other molecules and solid particles. This property hindered early attempts by scientists to purify the BSE infective agent, which is often described as 'sticky'. It is therefore believed that any BSE agent in the ground will bind to solids and particles. In buried animal carcasses the solids and particles to which the prions attach will be proteinaceous and carbohydrate in nature. Through decay of those components the bound prions will be dispersed (molecular dispersion), immediately attaching to other solid particles, with the result that the prions will not be dispersed from the burial site in the same way as dissolved substances. However, there is a

possibility that prions could be moved attached to fine particles in groundwater flows and there is an imperative to ensure that cattle burials should be sited only on soils and sub-soils with the minimum potential for rapid, by pass flows and the maximum filtering potential (essentially fine grained, non-fissured formations).

3. Release of the prions from the carcasses may not all take place within the first year after burial, but could follow an exponential curve with about 40% is released in the first year, 18% in the second, 11% in the third year and so on, comparable with the release pattern for chemical pollutants (Table 5.2). The effect is to reduce the peak concentrations that may be expected, but to increase the time over which the pollutant is discharge from the burial site.

7.7.4 *E. coli* 0157

Approximately 10% of the national herd carry *E coli* 0157. The bacterium would not survive incineration, but could be present in buried carcasses.

(ESTIMATES OF NUMBERS/ENVIRONMENTAL PERSISTENCE/INFECTIOUS DOSE TO HUMANS TO BE ADDED. BUT NOTE THAT CHLORINATION OF PUBLIC SUPPLIES WOULD KILL E. COLI – BUT THAT THIS LEAVES PRIVATE SUPPLIES AS MAIN RISK. IS E COLI 0157 ALSO PRESENT IN SHEEP AND PIGS?).

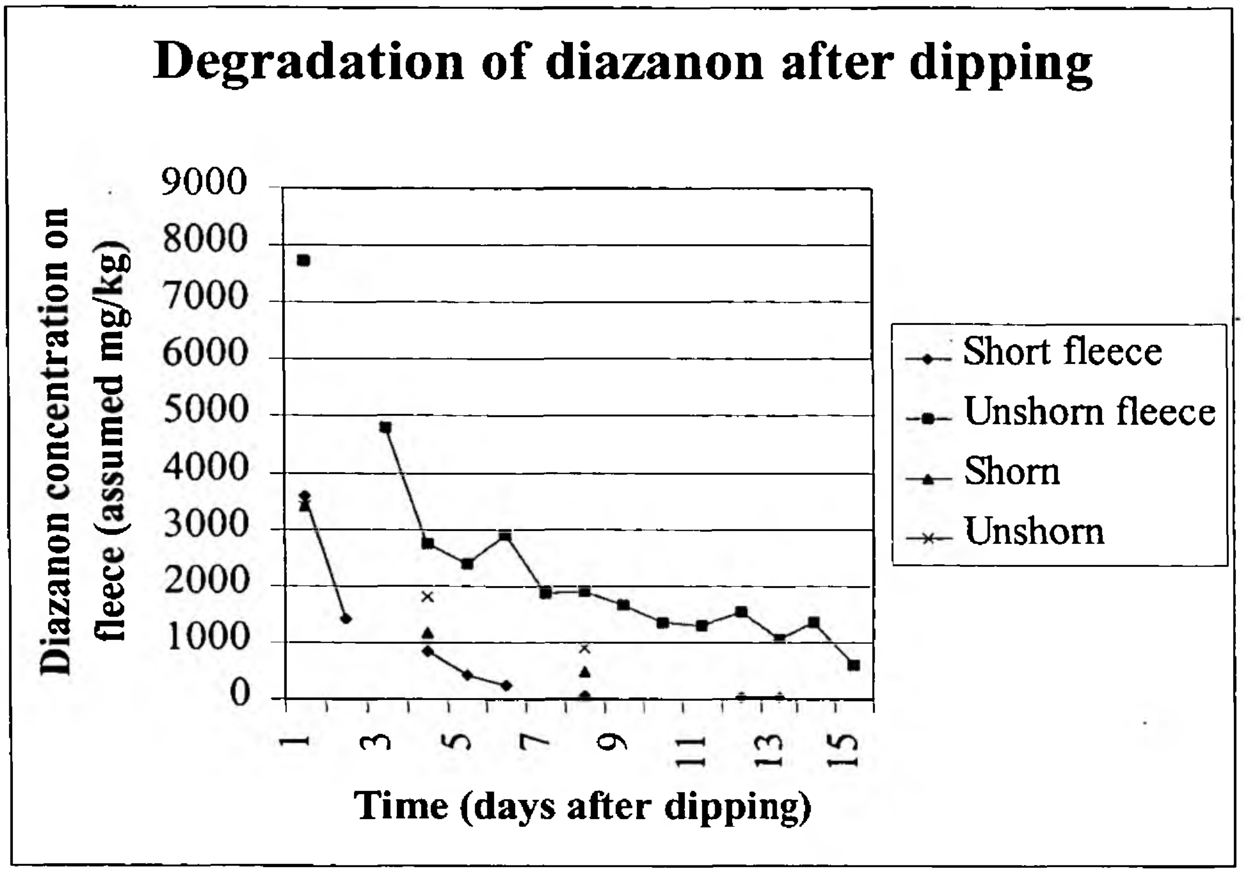
7.7.5 *Sheep dip chemicals*

Sheep dip chemicals comprising organophosphates (OPs) and synthetic pyrethroids (SPs) may be present on the carcasses (particularly fleeces) of culled sheep buried as a result of the foot & mouth epidemic. Both OP and SP chemicals are defined as List I Substances under the Groundwater Regulations 1998, and must therefore be prevented from entering groundwater. Any authorisation granted for the disposal of materials containing list I substances may only be issued if, following prior investigation, it can be shown that List I substances will not enter groundwater (the water table). Concern has been raised that disposal of sheep carcasses may result in entry of List I substances to groundwater beneath the site.

Dipping of sheep normally takes place twice annually, during autumn and spring. Review of data provided by MAFF on the persistence of diazanon on fleece (plotted below) indicates that once applied to fleece the dip chemicals degrade rapidly, typically with a degradation half-life of around 1 - 7 days. It appears that the concentration of diazanon typically decreases to non-detect levels within a few weeks of application.

The current foot & mouth epidemic broke in February 2001. It is likely that flocks were dipped in autumn 2000 as normal, but that the normal spring dip was postponed as a result of the foot & mouth outbreak and the resultant ban on livestock movement and restricted access to the countryside and farm land. It is likely therefore, that in the majority of cases culled sheep deposited from February through to May 2001 were not dipped during the spring and were last dipped in autumn 2000. This being the case, it is unlikely that there will be significant residual concentrations of sheep dip chemicals 6 months after dipping, when a degradation half-life of something less than 1 week is assumed.

There is, however, potential for sheep culled after a spring dip to contain significant concentrations of dip chemicals. It is likely that this is only likely to be a significant problem in areas of the country that were thought to be clear of FMD, restrictions lifted, and later outbreaks subsequently identified.



Information from MAFF suggests that the mass of fleece may vary quite widely with species and age of sheep as well as the time of year (i.e. proximity to shearing). It appears from MAFF information that the presence of a high proportion of lambs during the spring season would greatly reduce the average mass of fleece per animal buried, since the lambs have little fleece. This would further reduce the mass of sheep dip chemicals associated with burials, compared with a comparable cull in the autumn.

With regard to the fate of any sheep dip chemicals in the sub-surface after burial, it is difficult to make any robust assessment without site-specific data on soil and rock properties, however, the following points may be relevant:

- In typical contaminated land assessments equilibrium partitioning of the pollutant between soil and water is modelled, and this allows an assessment of the mobility of the pollutant to be made. In the case of a mass burial pit, however, the focus is essentially on partitioning of an organic compound between fleece and a leachate with a very high organic matter content. In this context equilibrium partitioning between soil and water does not adequately represent our conceptual model of how the system behaves. It may be reasonable assumption to make is that sheep dip chemicals are distributed evenly between the fleece and the organic leachate in proportions equal to the relative organic matter content of each. Since very large volumes of leachate have been generated at mass burial sites in the first few days to weeks, it is considered likely that the sheep dip chemicals will be largely present in the leachate rather than remain sorbed to fleece.

- Once the leachate percolates into underlying strata there is potential for some sorption of organic compounds from the leachate onto organic matter within the soil. However, the volumes of leachate generated and the high organic strength of that leachate might suggest that competition for those sorption sites will rapidly exhaust the sorption potential if the unsaturated zone is thin.

- Some information of degradation rates of sheep dip chemicals in soil and aquifers is presented in R&D Project Record P2/142/01. The data, collected from a number of sources suggests a half-life of 3 – 30 days for diazanon in soils and a half-life of around 50 days for cypermethrin. Both are reported as being aerobic degradation. The majority of available data from field trials of insecticide persistence is to evaluate its optimum application rate and frequency. It therefore relates to aerobic systems. Nevertheless, it has been reported that cypermethrin has been observed to degrade under anaerobic conditions similar to those that might be anticipated beneath a burial pit. The World Health Organisation (1989) further report that degradation of cypermethrin becomes increasingly rapid with an increase in pH (i.e. more alkaline systems).

On balance, it is considered likely that if sheep were not dipped during the spring because of the FMD outbreak (as the authors anticipate being the case), then it is unlikely that the concentration of sheep dip chemicals in the mass burial pit leachate will be significant. It is unlikely to be a threat to groundwater in the hydrogeological regimes in which the mass burial sites are located. However, if the spring dips have taken place – and this is most likely where movement restriction were temporarily lifted – then the potential for significant concentrations of sheep dip chemicals in the burial sites exists.

Chemical analysis of leachate from a number of mass burial sites indicates that, to date, concentrations of sheep dip chemicals are below detection levels.

7.8 Vulnerability of private supplies

In practice the most difficult risk to deal with is that for small potable supplies (private supplies). In cases where major burials (100 000's of sheep) are proposed a minimum set off distance of **1000m** should be followed for potable supplies and at least **500m** for all other supplies of water. In practice, however, it may be preferable to provide alternative (mains) water supplies to these isolated locations, if the site is otherwise hydrogeologically ideal.

7.9 Gaseous emissions

For reasons discussed in preceding sections, it is considered probable that although significant volumes of carbon dioxide and, possibly, malodorous gases may be produced during the initial stage of intense decomposition, the amount of methane is likely to be limited, unless the surrounding ground has a significant buffering capacity.

A one, or two metre thick soil cap may be expected to provide a reasonably effective barrier to odour emission, particularly if the top layer contains well degraded organic residues. If concerns remain over possible lateral migration of gas from the site, for example through fracture zones, then a venting trench could be constructed around the outer limit of the burial, possibly filled with rubble and furnished with vent pipes. Although such installations could help limit the migration of gas, they could also give rise to localised odour problems.

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For up to 120 sheep or 12 cattle (equates to 8 tonnes)

Risk	Comments	Disposal	Authorisation
High	• Very high water table in any aquifer. Risk of pollution of drinking water supplies Risk of pollution due to rapid flow within fissured strata such as limestone or chalk.	• **Only burning acceptable.** • The Agency/MAFF should look for locations elsewhere on the farm with a lower risk; this may require MAFF to confirm the site conditions by digging trial pits.	Required but will not be given for carcass burial
Lower	Groundwaters are at risk but in a less sensitive setting	Burial in accordance with COGAP para 276.	Not necessary on non-aquifer, but recommended

For disposals > 8 tonnes

Risk	Comments	Disposal	Authorisation
High	• Very high water table in any aquifer. Risk of pollution of drinking water supplies Risk of pollution due to rapid flow within fissured strata such as limestone or chalk.	• Burial of carcasses unacceptable. Burning may reduce risk to acceptable levels, dependant upon number of carcasses. • The Agency/MAFF should look for locations elsewhere on the farm with a lower risk; this may require MAFF to confirm the site conditions by digging trial pits.	Required but will not be given for carcass burial
Lower	Groundwaters are at risk but in a less sensitive setting	Burning is preferred. Consider relocation with MAFF. Burial may be considered depending on numbers in relation to the risk to groundwater subject to an overall maximum of 32 tonnes; however, MAFF would need to confirm the site conditions by digging trial pits. May require site visit from Agency staff to validate that site conditions comply (or exceed) COGAP para 276.	Required

APPENDIX A INTERIM GUIDANCE – GROUNDWATER CONSIDERATIONS FOR BURIAL OR BURNING.

Initial guidance issued by the Agency in February 2001, prior to the results of generic risk assessment, relevant to relatively small disposals.

Low	Situations such as non-aquifer where no water supplies, thick impermeable drift etc.	Burial may be considered depending on numbers subject to an overall maximum of 64 tonnes, however, MAFF may need to confirm the site conditions by digging trial pits.	Required, except for non-aquifers where optional

Digging trial pits - The Agency would prefer to see all trial pits dug below the planned base of the pit to confirm the presence of at least 1m of dry subsoil beneath burial depth.

Refusals of disposals: The Agency does not have to issue authorisation if the Agency believes the risk of the location or method of disposal is too great. MAFF should be informed of the Agency's decision and the reasons. That doesn't mean MAFF can't go ahead, but it would be technically illegal and the risk would be on MAFF and it might be necessary to go back and do a clean up operation.

COGAP: It is assumed that all carcass burials will be in accordance with the guidance in COGAP, and Authorisation will not be given where this is not met. There is no advice in that document with regard to incineration residues, but the same advice on pit location and construction can be taken as best practice.

APPENDIX B : ENGINEERING MEASURES FOR CONTAINED MASS BURIAL SITES

DRAFT GENERIC FRAMEWORK FOR ENGINEERING OF MASS BURIAL SITES

1.0 : Introduction

This document has been developed by the Environment Agency and its consultants to provide guidance and advice for assessing and developing containment burial sites for the disposal of animal carcasses. This note has been developed in recognition of the emergency conditions that prevail at the moment; it is necessarily brief and is not applicable to other waste management activities. Although they may use many common elements of design and construction materials, these sites are not licensed landfills and must be considered within the context of the materials being deposited and the conditions prevailing during the epidemic.

More detailed Agency guidance concerning earthworks, liner types/installation etc. is available to underpin this framework.

All mass burial sites are authorised under the Groundwater Regulations, which require precautions to be taken to prevent List I and limit List II substances entering the groundwater; however, it should be noted that only List II substances should be involved in carcass burial (assuming no sheep dip chemicals are identified in leachate). The basic principle used to develop the various levels of engineering for mass burial sites is one of containment with liquor extraction and treatment, although sites based on the attenuation principle may be acceptable in certain circumstances.

2.0 Objectives

The objective of this document is to present a generic framework for the engineering of mass burial and FMD ash sites to meet the following requirements:

- Compliance with the Groundwater Regulations 1998;
- Quickest practicable design and installation on cell basis to reduce impact on environment;
- Effective pollution prevention and control in the short and long term;
- Improve communications & clear "ownership" of guidance;
- Documentation (eg. As-built design & completion report) to assist with long-term management of each site.

The framework is generic in terms of selection of containment and drainage materials, as availability of material will be a key factor in expediting the works. **It must therefore be recognised that this is not a replacement for site specific engineering design.**

Frequent discussions between all parties must take place to ensure that the best system is designed and built on site and any issues encountered should be learnt from in developing subsequent cells.

3.0 Assumptions

- It is assumed that the site has been selected on the basis of tiered risk assessment, that is, an initial risk screening, (normally undertaken by the Agency) and a generic/site-specific quantitative risk assessment (normally undertaken by MAFF and its consultants). The assessments will be based initially upon a desk study and any available site investigation data, addressing geology/hydrogeology, all potential pathways to identified receptors and available engineering materials.
- It is also assumed that MAFF have undertaken or provided a minimum of preliminary ground investigation to establish the actual ground conditions that prevail at the site.
- Cell dimensions are derived from the hydrology of the site and predicted liquor generation, daily disposal rates and the limits of the engineering materials used. Consideration should be given as to whether the site will be operated aerobically or anaerobically.
- It is assumed that liquor disposal/treatment has been established, with contingencies, to ensure that levels can be effectively managed.

  THIS HAS BEEN FOUND TO BE CRITICAL AND IS AS IMPORTANT AS ANY OTHER ENGINEERING MEASURES. SUCH FACILITIES SHOULD BE IN PLACE PRIOR TO DISPOSAL OF CARCASSES IN THE BURIAL PITS.
- It is also assumed that infrastructure requirements, such as access, roads and space to develop associated plant and buildings have also been confirmed.

  STORAGE AND DISPOSAL ROUTES FOR LIQUOR (INCLUDING CONTINGENCIES) MUST BE ESTABLISHED AND PROVIDED, PRIOR TO DISPOSAL.
- Design and construction times must be kept to a minimum, although design and construction methodologies should be drawn up and agreed with the Agency prior to works commencing. Appropriately experienced staff need to be in place to design and oversee the works.

4.0 Engineering Principles

Site design should be on the basis of engineered containment, with exceptions permitted where controlled and monitored natural attenuation can be fully justified. The Environment Agency must be consulted at the earliest opportunity to facilitate early construction.

The priority is to expedite the construction of disposal sites in the first instance, with formal reporting, including QC results, taking place when practicable, in some instances after disposal operations commence. It is considered essential that an experienced geotechnical engineer is involved in designing and supervising the construction of each containment site.

Within the design, consideration needs to be given to the fact that very large quantities of liquor are produced within hours/days and there is no absorption capacity within the waste mass as is usual in landfill sites.

The design of the containment cells/trenches should consider the following points:

- The likely input rates of carcasses and the matching of prepared engineered area to input rate, to ensure effective contaminated/clean water management (similar to water balance in a landfill cell)

- Consideration should be given to the method of placing carcasses including access across a cell and/or the reach of excavators to trench width. Many geosynthetic materials will easily be damaged by uncontrolled tipping on side slopes.

It is recommended that carcasses are punctured prior to disposal to avoid buoyancy and aid compaction under load. The combination of early high liquor levels, buoyant carcasses and the need for cover can cause unstable waste masses.

5.0 Site Characterisation

Each site proposed as a burial site must be characterised with regard to geology, hydrogeology and nature & location of receptors. Site-specific information is paramount and must be collected via desk study and on site intrusive investigation.

Data should be collected from trial pits and cable percussion borings so that ground conditions to a depth of no less than 5 metres below ground level can be adequately characterised.

Bearing in mind the need for groundwater monitoring boreholes it may prove cost-effective to commence installing these at the investigation stage and obtain appropriate samples for; geotechnical testing, groundwater and/or surface water background quality. These data can then provide information on the true hydraulic gradients across the site. It is fundamental that the hydrogeology of the site is understood to an appropriate level before a site is developed. Infrastructure should be installed in each borehole to allow for sampling as works proceed.

Sample descriptions should be carried out to BS5930:1999, and reported along with field measurements and test results to justify the proposed engineering design. To expedite, professional judgement should be made on the containment properties of the strata sampled from the field descriptions & measurements and the results from classification tests (Plasticity indices, grading, moisture content, dry density). Samples will be taken for permeability testing but, due to time constraints, may need to be reported following construction.

Macro properties of the soil and rock mass, such as stratigraphic variation in 3-dimensions, discontinuities, artificial features and water seepages should also be recorded and used to develop the design.

A full understanding, via investigation, of the surface water and field drain layout must be undertaken. Utilising the knowledge of the local Environment Agency officers and site owners/operators can assist greatly in this process.

6.0 Site Preparation

Site preparation may require specific remedial measures, such as excavation of a sand lenses or installing drainage to minimise infiltration of surface water run-off. Such requirements should be addressed at the design stage and the measures actually taken recorded and described in the engineering completion report.

In particular overall site surface water drainage should be addressed along with the local effects of land drains. In many situations a surface water cut-off ditch with regular sumps may be appropriate.

In the case of trenches, trial pits at each end or at intervals along the length of each may be appropriate for investigation of minor problems and agreeing trench depth. The siting of trial pits should consider potential later interference with the construction of the burial pits.

Site preparation must be in accordance with an Agency agreed method statement (produced by MAFF or their consultants) and conducted under appropriately experienced supervision.

7.0 : Engineering of low permeability containment cells

All sites should be located in areas of low vulnerability with regard to groundwater, and where adequate protection of surface water quality can be designed and maintained. The lining system may be single or composite, and should be determined having regard to risk assessment and time constraints.

Due to time constraints, the most likely engineering methods will be; natural or enhanced in-situ containment, engineered clay liner, geosynthetic clay liner (GCL), or a combination to form a composite lining system. Other lining systems including welded polymeric flexible membrane liners (FML) can be considered on a site-by-site basis so long as they are practicable and available within the time constraints.

All cells should be prepared with a design gradient to promote flow of liquor to a collection point for extraction. Consideration should be given to design of the sump area to minimise leachate heads on the base of the cell.

All works must be prepared in accordance with an engineering proposal, method statement and quantitative risk assessment agreed with the Agency in advance. The Agency will provide assistance and ensure speed of response to ensure works can be commenced as soon as possible.

7.1 Natural or enhanced in-situ containment

In order to design a cell on the basis of natural in-situ containment the following should be carried out using data from trial pits or boreholes around the proposed site to confirm whether appropriate:

Hydrogeological risk assessment using method & input parameters agreed with the Agency (see other guidance for generic parameters, e.g. leachate source term),

Characterisation of in-situ low permeability strata from sample descriptions (BS5930:1999), field tests and classification tests. Continuing investigations are inevitable and data obtained can be used at a later stage for back analysis and refining the quantitative risk assessment and engineering design. Undisturbed and/or bulk samples can be taken for laboratory permeability tests and probable retrospective reporting.

Confirm that water table (active flow) is >1 metre below the base of the proposed cell; identify high permeability bands/lenses, water seepages and the potential for basal heave; and provide details of remedial measures required.

Enhancement may be required to remedy some problems, e.g. digging out a sand lens and replacement with clay, or to prepare the cell for disposal, e.g. compacting the base using a smooth roller.

7.2 Engineered clay liner

The main objective will be to achieve a permeability contrast between the containment system and drainage layer. A contrast of 5-6 orders of magnitude in permeability should be a target. However, liquor head needs to be well controlled.

An engineered clay liner should be constructed using appropriate plant and equipment to a thickness in the order of 0.5 to 1.0m on the base and sides of the cell. The clay should be from a well-characterised source, be compacted wet of optimum moisture content, be in a plastic state and strong enough to be trafficked over (e.g. ∃40KPa).

Compaction plant and lift thickness should be suitable to achieve the target permeability and samples should be taken to confirm that the target is met, although this is likely to be reported after burial has commenced. Guidance upon compaction can be taken from the Agency's Earthworks on Landfill Sites guidance and the Department of Transport Specification for Highway Works.

Side wall slopes may be at any angle from vertical to 1:3 dependant on height, strength of the ground and the length of time it will be open. For instance, trenches 4-5m deep in competent ground have proven to be stable for at least 2-3 days which was adequate for inspection and filling.

7.3 : Geosynthetic clay liner (GCL)

A GCL is quick and easy to install, making it an ideal material to use where time is constrained.

Manufacturing quality assurance (MQC) details need to be provided by the manufacturer at the time of delivery onto site.

The GCL should be installed on a well-prepared firm dry surface of low permeability material (smooth rolled if possible). Adjacent GCL sheets should overlap by 300mm, in accordance with the manufacturers installation standards. Overlaps should be in a roof tile arrangement downslope (toward the sump). The GCL sheets should be secured at the top of each cell slope and there should be adequate protection from major penetration, if necessary by using a geotextile protector.

Where crushed stone or secondary aggregate (sub-angular to angular) is to be used as the drainage layer the GCL will need to be protected (geotextile or blinding sand layer) to minimise the risk of puncture.

Due to uncertainty regarding hydration with a strong organic liquor, the GCL must be hydrated with clean water after installation of the drainage layer and before carcasses or pyre ash are deposited (unless the GCL is a pre-hydrated product).

For construction quality assurance purposes the manufacturers data sheets must be provided.

7.4 : Flexible Membrane Liner (FML) or Geomembrane

Any FML products that are commonly used at landfill sites will be applicable to the lining of mass burial sites. If welded on site each weld should be tested both destructively and non-destructively at the site. For construction quality assurance purposes the manufacturers data sheets must be provided.

In addition it may be appropriate to consider factory welded thinner more flexible products, so long as they are adequately protected from puncture, to speed lining works.

Further guidance can be sought from the Agency guidance underpinning this document.

8.0 Engineering Requirements for Liquor Collection

The effective collection of liquor is a key aspect of the design, and should provide a significant permeability contrast (around 5-6 orders of magnitude) between the containment system and drainage layer. Clogging will be the major issue regarding the efficacy of the liquor collection system & both short and long term design criteria will need to be met.

Immediate/Short term
Rapid generation (within 48 hours) of high organic strength liquor dominated by fluid release from the carcasses. The estimated quantity of liquid theoretically available for immediate release is 170 litres per cow and 16 litres per sheep. Approximately 50% of this is likely to be released within 1 week. The majority of the remainder will be released within 2 months. The rate of liquor release will be impeded in those carcasses that were not vented prior to disposal.

It is expected that there will be a high potential for biological, chemical and physical clogging. Due to this it is recommended that a full basal drainage blanket is installed in general with perforated pipe within the blanket and consideration given to side slope drainage.

Long term
In the long term the liquor release rate will be more closely related to the infiltration rate through the capping plus the decomposition products of the carcass tissues. Based on the assumption that the carcasses decompose over a period of 10 years, the estimated fluid release from the decomposition of carcass tissue is unlikely to exceed 2.5 litres per year for sheep and 40 litres per year for cattle. In most situations the rate of decomposition may be slower and the above figures are therefore conservative upper estimates.

Infiltration of incident rain and surface water will be dependant on the climate, the profile of the site, the design of the capping and whether or not it will be actively managed. As the liquor will be a mixture of the two, the chemical strength will be significantly higher in the early stages.

The types of materials that may be considered for constructing basal and side-wall drainage layers will be selected on the basis of suitability and availability.

8.1 Design criteria for drainage layers

Mandatory: all basal drainage layers should be installed across the entire base of the cell and include a pipe collection system and sump for pumping and monitoring.

Good practice design criteria (unless an alternative is justified using conservative site-specific design):

- Stone drainage layer – a minimum of 300mm and preferably a 500mm thick blanket using competent stone of minimum diameter of 16mm with sufficient strength to withstand loading;
- Pipe collection system – should be designed to ensure that the material is chemically resistant, has sufficient strength to withstand loading, and can cope with predicted flow rates;
- Pipe layout should be designed to optimise leachate drainage;
- The collection system must be installed under supervision and sufficient information collected, including as-built drawings for long-term management purposes;
- Side-wall drainage should be considered to manage excess leachate due to rapid production & settlement and to reduce risk of overtopping;
- If the site is constructed using geosynthetic based systems (GCL and FML) then heavy plant should not traffic over the liner without a sensible thickness of protective material (eg. 300mm for low ground pressure tracked plant).

9.0 Capping

Capping is required as early as possible to prevent infestation by flies and pests, control odour and reduce the increase in volume of liquor from incident rain. Capping also provides the overburden stress to induce settlement of the carcasses and therefore as much mass as possible is desirable, providing leachate extraction can keep pace with the squeezing effect of the overburden (leachate levels must not be allowed to rise up through the overburden). Settlement is very high during the first few weeks and any early capping will suffer settlement, distortion, shearing and change of gradient. Surface water may need to be actively pumped from the cap to reduce infiltration.

Consideration should be given to initial temporary capping, perhaps using geosynthetics followed by a permanent cap after the majority of settlement has taken place.

The main capping may be phased, perhaps laid in metre lifts, should be shaped to allow surface water run-off (and integrated into a surface water system) and consideration of reinforcement such as geogrid may reduce stress on the capping and avoid excessive erosion.

Gas will be produced initially at high levels but should fall away over time. However, some may still be produced over the longer term. Management systems should be considered dependent upon whether the waste mass is aerobic or anaerobic and odour control may be incorporated into a similar/same system.

Degradation of carcasses may be advantageously speeded by allowing in some moisture and an injection system or "leaky" cap may be considered. This should be balanced by such issues as odour control and liquor production. When all these factors are taken into consideration, the nature (permeability) of the capping may need to be varied through time.

The final capping can be in line with normal landfill practise and include compacted clay, geosynthetics or combinations and should consider long term use of the site, as well as environmental protection. Geosynthetics may require protection.

10 Quality Assurance/Quality Control (QA/QC)

The need for speed will not mean that QA/QC is abandoned. It will be limited in extent and documentation and may not be produced before burial starts. However, the design and a brief method statement should be produced and agreed prior to construction.

11 Reporting

Documentation for each cell engineered will be needed for the purpose of long-term management, but the priority is to expedite construction. Greater reliance on professional judgement and good communication links with the supervising engineers is required to reduce the need for subsequent mitigation due to poor quality construction and/or design targets not being met.

12 Further Guidance

The Agency has produced a number of guidance documents relating to specific areas of landfill engineering at licensed waste management facilities. They are necessarily too detailed to be used specifically for Foot & Mouth mass burial sites although they should be used as a guide to the methods of construction used, materials utilised and reporting required (pre and post construction). Variance from these documents on a site specific basis will need to be agreed by suitably experienced staff. The relevant documents are:

- Earthworks on Landfill Sites;
- Guidance on the use of Geosynthetic Clay Liners in Landfill Engineering (version 2 – 29/11/00);
- Guidance on the use of Geomembranes in Landfill Engineering (version 2 – 19/2/01);
- Guidance on Non-woven Protector Geotextiles for Landfill Engineering (February 1999).

APPENDIX C : RISK ASSESSMENT TOOLS

C1 : Initial Screening Assessment

The initial screening process should focus on the environmental sensitivity of the groundwater at the site and the proximity to surface water. Where the hydraulic permeability of the underlying strata is low and there is a significant thickness of unsaturated zone above the water table, the potential impacts on water quality are likely to be significantly less than for a site with permeable strata and a thin unsaturated zone.

When carcass disposal is proposed, a desk based qualitative risk assessment will be undertaken by the Environment Agency to determine whether the proposed disposal method is (in principle) appropriate from a water quality perspective. The assessment will form the basis of the minimum level of "prior investigation" that is required under the Groundwater Regulations 1998. Furthermore, the data collection will provide useful information for any future monitoring or remediation needs. The framework presented below refers only to disposals over 8 tonnes (disposals under 8 tonnes/annum should be undertaken according to MAFF ABPO guidance).

The assessment undertaken should be based on the source-pathway-target framework. It is considered the following information should be collected, in order to make the assessment.

Source

- Number and type of animals (tonnage equivalents);
- Any other waste disposed of (types and tonnages);
- Disinfectant.

Pathways and Targets

Information requirement	Detail/interpretation	Information source
Physical features	Topographic features Slopes Shake holes, swallow holes etc.	OS maps
Water features	Surface water Groundwater discharges Wetlands	OS maps
Aquifer status	Major, Minor, Non-aquifer	Groundwater Vulnerability Maps
Geology	Solid & drift Likely hydrogeological relationship Flow type (intergranular / fissure flow)	BGS Geology Maps BGS FMD team
*Soil properties	Leachability Attenuation capacity	*Groundwater Vulnerability Maps *Soil Survey Maps

*Groundwater Vulnerability	Sensitivity	*Groundwater Vulnerability Maps
Groundwater / Source Protection zones	Zone I, II, III & special zones	SPZ maps
Licensed groundwater & surface water abstractions	Use of the abstraction e.g. drinking water, irrigation etc	NALD (National Abstraction Licensing Database)
Water quality	Sensitivity	Surface Water Quality classification Groundwater Monitoring Network
Private water supplies	Location Type	Local Authority EHOs
Conservation issues	Water dependent SSSIs	EA Conservation staff

*Care should be taken in interpreting the information on vulnerability and soil maps as most disposals involve the removal of the soil layer on which the vulnerability assessment is based. Unless other site-specific information is available it should be assumed that all carcass burials have pits with a base 4 metres below ground level and all pyres have bases 1 metre below ground level.

A specimen form outlining the minimum data requirements for the purposes of an initial screening assessment is given in Table C1.

Screening out of unacceptable sites

Burial of over 8 tonnes of carcasses is considered unacceptable in principle in the following locations:

- In a Source Protection Zone I ; or
- Within 250 metres of a licensed or exempt surface or groundwater abstraction (in high permeability formations this should be increased to 500m unless fully engineered containment is proposed); or
- Within 30m of any other watercourse or 10m from any field drain; or
- Within an area subject to surface flooding; or
- In Major and Minor aquifers where the water table is within 5 metres of natural ground surface.

  Note: It is assumed that burial pits are 4m deep, thus this limit will ensure that there is **at least one metre of unsaturated ground** beneath the base of the pit. If the water table is high it is recommended that the pit is shallower (and therefore more extensive) or that burning should be considered as the preferred method of disposal.

Mass burial sites must not be located on major aquifers.

Table C1: Foot & Mouth outbreak: On-site disposal record of culled stock

Please complete this proforma to record details of sites where stock has been buried, burnt or otherwise disposed of to land as a result of the Foot & Mouth disease cull. The information will subsequently be used to ensure environmental monitoring of disposal sites.

Region		**Area**		
Site address				
Site owner / operator				
NGR (8 figure) of disposal site				
Reason for disposal (circle as applicable)	Confirmed FMD	Suspected FMD	Dangerous contact	3 km firewall
MAFF contact				

Animal type(s)	**Number of animals**	**Disposal method (burial, burning etc..)**
Cattle		
Sheep		
Pigs		
Goats		
Horses		
Deer		
Other (specify)		

Disposal activity details (e.g. depth of burial; use of additional substances and their volumes e.g. diesel for burning, liming of pits). ***Attach map of burial / pyre location if possible.***

Environmental setting		**Aquifer type/SPZ (circle as applicable)**				
Drift (if >4m)		Major	Minor	Non-aquif/ permeable	Non-aquif/ impermeable	
Solid geology (upper)		Major	Minor	Non-aquif/ permeable	Non-aquif/ impermeable	
Solid geology (lower, if applicable)		Major	Minor	Non-aquif/ permeable	Non-aquif/ impermeable	
Source Protection Zone?		SPZ I	SPZ II	SPZ III	Special zone	No SPZ
Proximity to licensed / exempt abstractions						
Proximity to surface watercourses						
Proximity to SSSI /site of conservation importance						

C2 : Generic Quantitative risk assessment

Screening of sites where a prior quantitative groundwater risk assessment is not necessary.

In the unusual circumstances of the Foot and Mouth epidemic there is a need to rapidly identify sites where burial of carcasses can be permitted with a minimum of prior investigation and risk assessment. The method described below attempts to facilitate this process.

The total tonnage of carcasses to be deposited in the burial pit should be determined from Table 4.1 or other site-specific data, where these are available.

Bulk permeability (hydraulic conductivity) and unsaturated zone depth should be determined from the qualitative assessment (desk study) that is required on all sites, including from sources such as BGS, aquifer properties manuals, local Agency records etc.. In all cases site-specific data should be used if these are available (see note below).

Table C2 can then be used to identify those sites and sizes of burial which by virtue of the inherent site properties, burial can be permitted without the need for a prior quantitative risk assessment. In all cases a qualitative (desk study) assessment must be conducted.

The results in this table have been checked by applying typical source terms to the range of hydrogeological circumstances indicated in the table and, assuming burial takes place according to good practice, as identified in this report, there should be no pollution of groundwater at the set-off distances indicated.

Notes:

1. The figures quoted in Table C2 are bulk hydraulic conductivity values. Where minor fissuring is suspected in the underlying strata, a reasonable maximum value should be chosen and, depending on the nature of the strata it may be necessary to discount the effect of the unsaturated zone. The tonnage values for the 2-5m interval should then be used in the screening assessment. If major fissuring is suspected or observed during burial, there should be no disposal at the site.
2. There should be a minimum of 5 metres of material of the assumed permeability, below the base of the burial pit. In cases of doubt, it must be assumed that the layer is not present or site investigation should be conducted to prove the character and depth of the strata.
3. Where there has been no previous investigation at or adjacent to a site and there is doubt about the characteristics of the shallow strata, including depth to the water table, it is essential that trial pitting is undertaken to determine site-specific geological and hydrogeological conditions. Mass disposals of over 8 tonnes should always be accompanied by trial pitting adjacent to, but not on the line of, the burial trench.
4. For low permeability sites (bulk permeability < 0.001 m/d), and with adherence to the good practice noted in Appendix 1, the risks to groundwater will be low, even for larger disposals. However, there will be a potential for build-up of leachate within the burial pit if the base of the pit is less permeable than the capping. The risk of surface run-off of pollutants following escape of leachate from the burial pit in the longer term should be considered, for these low permeability sites. Provisions will have to be made for leachate interception and removal at mass burial sites.
5. If a relatively impermeable cap is created to minimise infiltration, the rate of degradation

may be slowed down. The site may then have the potential to cause pollution for a long time (decades rather than years), which implies that the cordon sanitaire noted above may have to stay in place for a similar period.

Use of spreadsheets and modelling packages

The use of these is described below under site-specific risk assessment. However, these tools can be used in a generic way by undertaking a series of calculations/model runs with idealised hydrogeological circumstances and generic data. Usually these would be reasonable "worst case" runs. Specific sites may then be compared against these idealised conditions and, providing the site circumstances are relatively simple and comply with the general conceptual model behind the generic assessment, the generic results can be used, without the need for site-specific quantitative assessment. Clearly, this approach has to be used with care and it is important that site data are collected and examined to determine that the assumptions behind the generic assessment are valid. As with initial screening, generic assessment assumes that a certain level of good practice is adhered to.

C3 : Site-specific quantitative risk assessment

Where sites have passed through the initial screening assessment but have failed the generic risk assessment stage, a site-specific quantitative risk assessment should be undertaken prior to authorisation and commencement of disposal. A standard form of assessment has been prepared by the Agency's National Groundwater & Contaminated Land Centre based on the R&D Publication P20 spreadsheet approach. The spreadsheet and supporting notes are available from the NGWCLC.

In the case of large mass disposal sites with complex site hydrogeology, a more detailed approach may be required, employing tools such as LandSim 2 or other proprietary packages specifically developed to model complex systems. Detailed tailored contaminant transport models may also be used. However, the data collection for and the examination of the results of, these more complex tools will be time consuming and it is extremely unlikely that complex tools can be used in site selection. The emphasis must be in selecting an inherently secure site, particularly for the larger mass disposals, or in providing containment where there is a substantial uncertainty over the likely impact.

Complex modelling tools may be used retrospectively to examine and predict in detail the impact on the water environment in the medium and long term and may assist in the interpretation of the results of monitoring. The examination of the results of such models should be undertaken according to the guidance set out in the following Agency R&D Reports, which are available from the NGWCLC:

Environment Agency 2001 : Guide to Good Practice for the Development of Conceptual Models and the Selection and Application of Mathematical Models of Contaminant Transport Processes in the Subsurface. Draft Report.

Environment Agency, 2001 : Guidance on the Assessment and Interrogation of Subsurface Analytical Contaminant Fate and Transport Models. Final Report NC/99/38/1.

Environment Agency, 2001 : Guidance on Assigning Values to Uncertain Parameters in Subsurface Analytical Contaminant Fate and Transport Models. Draft Report.

Table C2 : Limit of carcass tonnages for burial, above which a site-specific semi-quantitative groundwater risk assessment is needed

Hydraulic conductivity(m/s) (m/d)	$>1.2 \times 10^{-5}$ > 1	1.2×10^{-6} - 1.2×10^{-5} 0.1 – 0.99	1.2×10^{-7} - 1.2×10^{-6} 0.01 – 0.099	1.2×10^{-8} - 1×10^{-7} 0.001 – 0.009	1.2×10^{-9} - 1×10^{-8} 0.0001 – 0.0009	$<1 \times 10^{-9}$ <0.0001
Unsaturated zone thickness below excavation base (m)	Values in metric tonnes					
2-5	8	8	32	200		
5 – 10	8	16	50	1000		
10 – 15	8	32	100	1000		
15 – 20	8	32	100	2000		
20 – 25	8	64	200	2000		
25 – 30	16	64	200	4000		
>30m	16	100	200	4000		

Need for prior quantitative risk assessment not driven by risk to groundwater. Assessment of risks to surface water needed, in conjunction with consideration of the potential for burial pit to fill with leachate.

The table assumes that there is at least five metres of proven material of the specified permeability below the base of the burial pit.

Disposal of less than eight (8) tonnes of carcasses acceptable subject to minimum requirements of MAFF ABPO and COGAP