

Report To

Dumfries and Galloway Council

Air Monitoring of Carcass Pyre

At Whithorn

Part 1

Sampling and Analysis

Dr C McDonald
Glasgow Scientific Services
3 October 2001

INDEX

<u>Title</u>	<u>Page</u>
<u>Part 1</u>	
Introduction	01
Sampling Strategy	02
Pyre Construction	05
Sampling Sites	06
Samples Taken	09
Analysis	11
Results and Discussion	14
Table 1: PM ₁₀	22
Table 2: Dioxins and Furans	36
Table 3: Polyaromatic Hydrocarbons	50
Table 4: Polychlorobiphenyls	60
Table 5: Metals	74
Table 6: Sulphur Dioxide	87
Table 7: Carbon Dioxide and Carbon Monoxide	97
Table 8: Volatile Organic Carbon	105
Table 9: Aldehydes and Ketones	107
Table 10: Solvent Type Compounds	112
Table 11: Volatile Organic Compounds (Full Profile)	118
Table 12: Volatile Organic Compounds (Representative Profile)

Executive Summary

This report forms one part of a three organisation study.

Glasgow Scientific Services carried out sampling and analysis of the smoke plume raised as a result of the pyre of animal carcasses at High Bishopton Farm, Whithorn. The sampling was conducted over a 72-hour period from 15 April to 18 April 2001 inclusive.

Analysis was carried out for the size range within the particulate matter and the particulate matter then analysed for metals, dioxins, furans, polyaromatic hydrocarbons and polychlorobiphenyls.

The levels of the inorganic gasses oxygen, carbon monoxide, carbon dioxide, sulphur dioxide and nitrogen dioxide were measured, as was the composition of the organic gasses present in the plume.

The samples were analysed by Glasgow Scientific Services and AEA Technology Environmental.

All parameters were elevated in the plume compared to background levels apart from nitrogen dioxide, carbon dioxide and carbon monoxide. The burning had no effect on atmospheric oxygen levels or on explosive gas levels. There was evidence of plume dispersion reducing the levels of the measured parameters as the plume moved away from the fire ground.

No relevant parameter would fail the objective levels set in the Air Quality (Scotland) Regulations 2000, defined as they are in terms of annual averages. Similarly most parameters were within industrial exposure limits and are not considered to pose long term health effects. However levels of some parameters require closer study for possible short term health effects such as PM₁₀ particulate, polyaromatic hydrocarbons and sulphur dioxide levels. No attempt has been made to quantify the effect of the dioxins/ furans in this report.

Introduction

As part of the Government policy for containing the foot and mouth outbreak in cattle, infected animal carcasses are being destroyed by incineration on open pyres. This has led to smoke plumes being created and at the request of Dumfries and Galloway Council, Glasgow Scientific Services carried out air monitoring around such a pyre as part of a project to study possible health effects due to plume inhalation.

The project involved three agencies contributing different aspects :-

- Part 1: Glasgow Scientific Services would sample the plume during an event, analysing the samples taken and give a brief interpretation of the results.
- Part 2: The Environment Protection Agency would carry out plume dispersion modelling to study the effects of weather on the levels measured close to the fireground.
- Part 3: The Scottish Centre for Infection and Environmental health would carry out a detailed study of the health effects of the various parameters measured during the exercise.

This report forms Part 1 of the study.

Sampling Strategy

There were three possible approaches to sampling the plume :-

- i) Set up equipment in situations which would reflect actual human exposures to the plume during the episode eg at (in) houses and other areas of occupation.
- ii) Set up sampling equipment close to the pyre in order to measure all plume constituents and weather conditions, monitor how these change during the lifetime of the pyre, and then use models to estimate people exposure at various distances down wind.
- iii) Both of the above simultaneously.

Equipment and time constraints precluded approach (iii). Approach (i) would answer the question of exposure levels but only in the specific conditions pertaining at the time of this one event. Option (ii) should allow a determination of all components before dispersion for future reference and through dispersion modelling allow an estimate of human exposure at various locations to be made.

Option (ii) was used in this study.

The four aspects which were considered to be of interest in studying the plume consisted of three components of the plume - particulate matter, inorganic gasses and organic gasses as well as the weather conditions at the time.

i) Particulate Matter

This was considered to be the main (visible) constituent of the smoke as with any incomplete combustion fire. The size of interest is that below 10 micrometers diameter as this is the size which is drawn into the lungs. Also of interest is the actual composition of the particulate matter. Therefore, compounds such as dioxins and polyaromatic hydrocarbons were measured using suitable capturing media.

ii) Inorganic Gasses

Due to the presence of wood, coal and diesel as fuels and animal carcasses, gasses such as carbon dioxide, carbon monoxide, sulphur dioxide and nitrogen dioxide might be expected to be released during the burning period.

iii) Organic Gasses

All of the material being burned is of an organic nature and will result in a range of organic volatile compounds such as aldehydes, ketones and aromatic components

such as benzene. The exact composition will depend on the burning conditions at any one time.

iv) Weather Conditions

The weather will have an impact on the rate at which constituents of the plume will disperse and rise into the atmosphere. In particular the wind direction will carry the plume in a particular direction, while the wind speed will dilute or concentrate the components depending on its rate of flow.

These aspects were investigated by the following approaches:-

Particulate Matter

- i) High volume sampler
 - Total suspended matter
 - Metals
 - Dioxins
 - Furans
 - Polyaromatic Hydrocarbons
 - Polychlorobiphenyles

- ii) PM₁₀ Monitor
 - PM₁₀ particulates

- iii) Cyclone Filter
 - Respirable dust

Inorganic Gasses

- i) Neotox – XL Monitor
 - Nitrogen dioxide

- ii) Minigas –XL Monitor
 - Carbon monoxide
 - Sulphur dioxide
 - Oxygen
 - Explosive gases (organic)

iii) Solomat Surveyor Probe

Carbon dioxide
Carbon monoxide

iv) Gradko Diffusion tubes

Nitrogen Dioxide

Organic Gasses

i) A MiniRAE 2000 Monitor

Total volatile organic carbon compounds

ii) Tenax tubes

Trace Organic Solvents

iii) Charcoal tubes

Higher levels of organic solvents in case the tenax tubes were saturated due high levels of compounds.

iv) Composite tubes

More volatile organic components than above.

v) Silica tubes

Aldehydes and Ketones.

Weather Conditions

i) Ultimeter 2000 Weather Station

This is a continuous measuring system with records:-

Time and date
Wind direction
Wind Speed
Temperature
Wind Chill

Rainfall

Pyre Construction

The site had two separate pyres constructed in a line running north east to south west. Both pyres were 50 metres long and 1.5 metres wide with a 50 metre gap between them. This dual line construction was due to the presence of underground rock preventing the extension of the original trench inward from the boundary wall.

The pyre was located in a field at High Bishopton farm at grid reference 4320 4150 and was constructed in the standard format:-

Top	Diesel (more was added 26 hours later)
	Carcasses
	Coal
	Kindling
	Straw
	Heavy Timbers (raw untreated trees)
Bottom	Trenches

On the third day of the pyre (50 hours after commencement) cattle mats were added. This is not standard practice for these pyres.

Carcass material consisted of 511 cattle
 90 sheep
 3 pigs

Sampling Sites

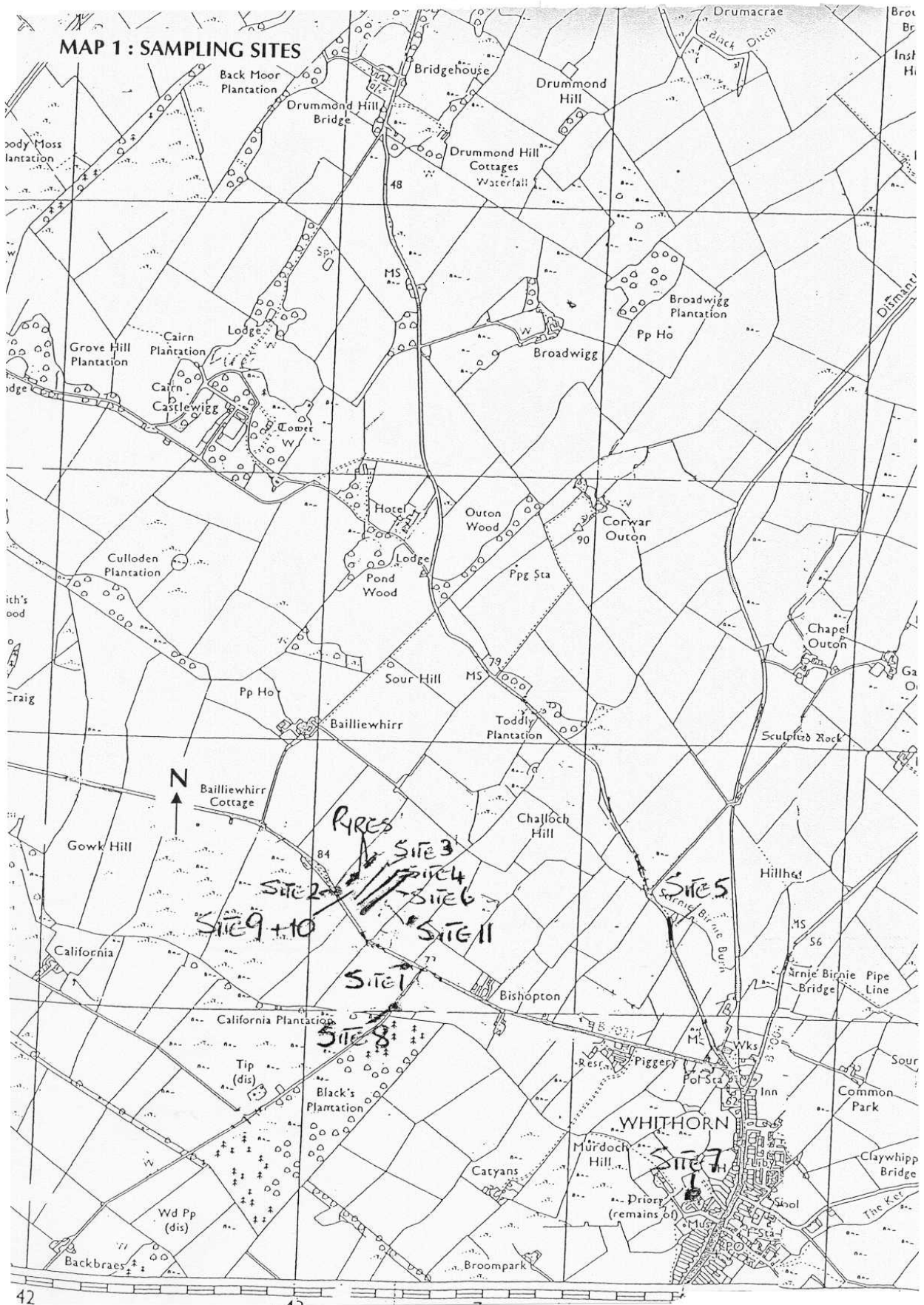
The site chosen was the pyre at High Bishopton Farm, Whithorn with sampling taking place from 13 April to 18 April 2001 inclusive. The site was selected for its sampling potential from all sides.

The Castlewigg Hotel was used for the background readings prior to the pyre being lit. In the event, due to ground softness, only two main sampling sites (Sites 1 and 2) could be utilised, both being on the road surface. During daylight hours the monitoring equipment was moved when practicable between these sites to keep the monitoring equipment in the plume. This was not possible during the hours of darkness. However monitoring was continued whether or not the equipment was in the plume. Other sampling sites utilised portable equipment and were all taken within the plume.

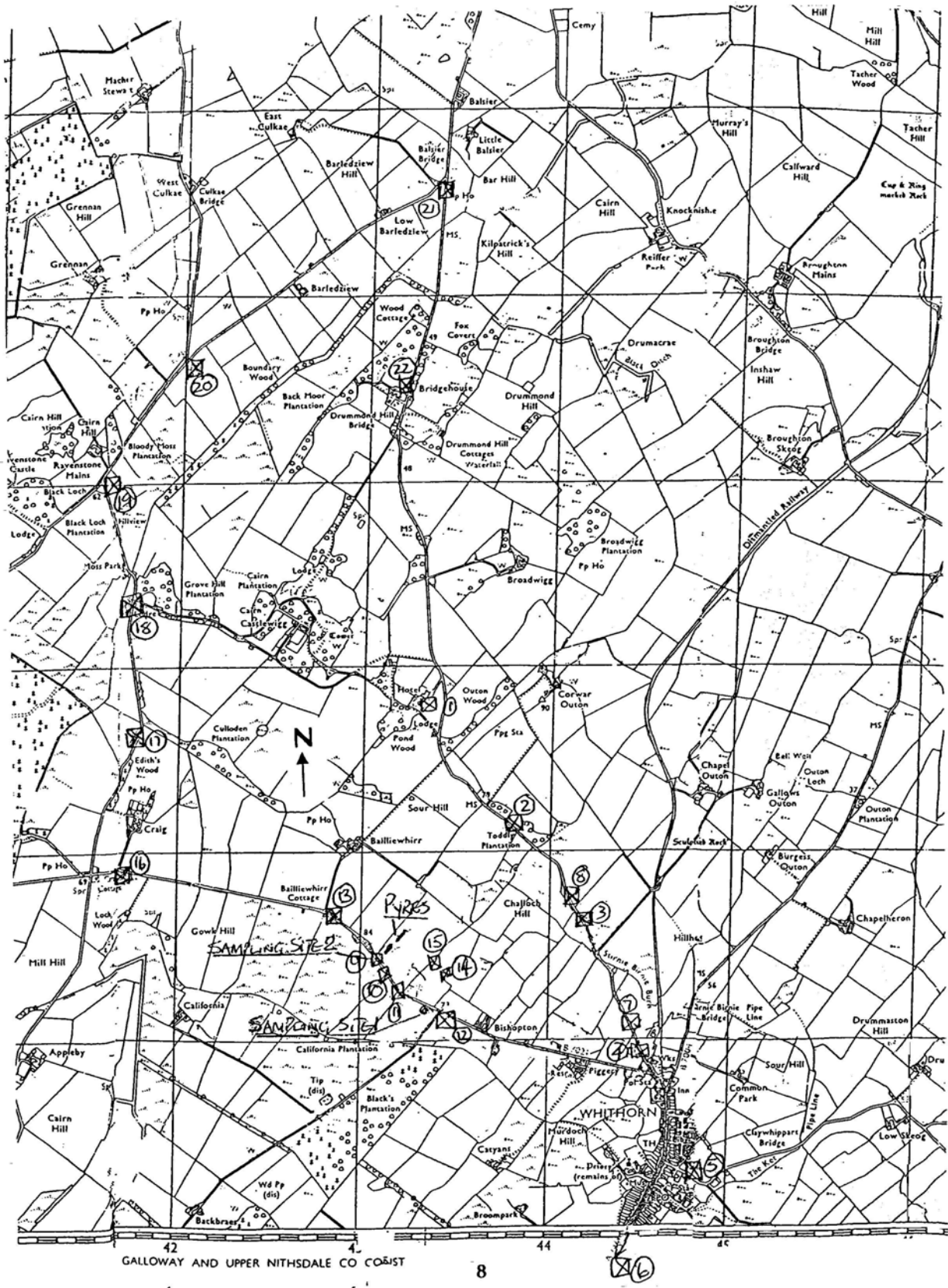
The following sites are illustrated in Map 1:-

Background	Castlewigg Hotel (grid reference 4337 4284)
Site 1	410 metres south east of the pyres (grid reference 4338 4118)
Site 2	50 metres south west of the pyres (grid reference 4320 4155)
Site 3	45 metres from pyre in field (in plume)
Site 4	70 metres from pyre in field (in plume)
Site 5	1250 metres from pyre at roadside (in plume)
Site 6	100 metres from pyre in field (in plume)
Site 7	1.7 kilometres from pyre at St Ninian's church, Whithorn (plume swirling)
Site 8 plume)	500 metres from pyre at roadside of California Plantation (in plume)
Site 9	40 metres from pyre in field before cattle mats added (in plume)
Site 10	40 metres from pyre in field after cattle mats added (in plume)
Site 11	250 metres from pyre in field before cattle mats added (in plume)

Nitrogen dioxide tube sites are illustrated in Map 2.



MAP 2 : DIFFUSION TUBE SITES



Samples Taken

i) High volume sampler

Six samples were taken over the three day period, one background, four at site 1 and one at site 2.

ii) PM₁₀ Monitor

The monitor was run continuously apart from breakdowns and when moving location between sites 1 and 2. Readings were taken over 5 minute averages and recorded.

Seven filter samples were taken, one background, five at site 1 and one at site 2.

iii) Cyclone Filter

Four samples were taken, three at site 1 and one at site 2. A fifth sample was lost due to equipment failure.

iv) Neotox – XL Monitor

The monitor ran continuously over the whole sampling period giving readings at five minute intervals.

v) Minigas –XL Monitor

The monitor was set to read every five minutes, being switched off when changing sites. The data was grouped into seven sampling sessions, one background, three at site 1, two at site 2, and one at site 4.

vi) Solomat Surveyor Probe

The instrument was set up to run continuously over the whole sampling period giving readings every ten minutes. In the event, technical difficulties with electricity generators reduced the data available. The data was structured into seven sampling periods, six at site 1 and one at site 2. The background reading was part of the lost data set.

vii) A MiniRAE 2000 Monitor

The instrument was set up to run continuously over the whole sampling period giving readings every ten minutes. However the instrument did not operate properly and the only information retrievable was twenty four spot manual readings. Twenty two of these were taken at site 1, one at site 2 and one at site 4.

viii) Gradko Diffusion tubes

Twenty two tubes were sited around the fire ground prior to the fire starting and exposed for the whole sampling period.

ix) Tenax tubes

Twenty three tubes samples were taken over the 72 hours. One background, eight at site 1, three at site 2, two at site 3, two at site 4, one site 5, one at site 6, one at site 7, one at site 8, one at site 9, one at site 10 and one at site 11.

x) Charcoal tubes

Thirteen samples were taken. Seven at site 1, two at site 2, and one each at sites 3, 4, 5 and 6.

xi) Composite tubes

Nine tube samples were taken. Three at site 1, one at site 3, one at site 4, one at site 5, one at site 6, one at site 9 and one at site 10.

xii) Silica tubes

Eleven samples were taken. Six at site 1, one at site 2, two at site 2, and two at site 4.

Analysis

High Volume Sampler Particulates

The equipment is designed to trap particulates suspended in the atmosphere by dragging air through a glass fibre filter. The size range collected lies between 0.1 micrometres and 100 micrometres. Filters were weighed before and after exposure to give the total weight of particulate matter collected over the time period. The air volume was also measured allowing results to be calculated as weight per volume.

The filters were divided into two portions and each portion analysed for:-

i) Metals

The filter paper portion was digested in aqua regia and made to volume. The solution was analysed by inductively coupled plasma emission spectroscopy for a range of 17 metals. Arsenic was determined by hydride generation followed by fluorescence detection.

ii) Dioxins/ Furans/ Polychlorobiphenyls/ Polyaromatic Hydrocarbons

These were analysed by AEA Technology Environmental. The filter portion was solvent extracted and the extract cleaned up by a multi phase column technique to remove interfering compounds. The cleaned extract was fractionated by liquid chromatography which separates the dioxins, furans, Polychlorobiphenyls and polyaromatic hydrocarbons into different fractions for analysis. The first three classes of compounds were then measured by separate runs through high resolution gas chromatography/ high resolution mass spectrometry. The latter was measured by the same technique but using low resolution.

PM₁₀ Monitor

The Casella APM 950 PM₁₀ Monitor is an instrument designed to monitor the mass concentration of airborne particulates of size less than ten micrometers in diameter in real time. An integral data logger records readings averaged over five minute intervals. The instrument was used continuously through out the sampling period apart from periods when the equipment was moved. The equipment also allows the collection of the particulate matter on filters. By the pre and post weighing of these filters, further readings for cross checking were obtained.

Cyclone Filter

The instrument operates by centrifugal force separating the particles into light and heavy fractions. The light fraction is trapped on a pre weighed filter. Post exposure weighing and reference to the volume drawn into the instruments allows a weight per cubic metre to be calculated. The instrument is designed for carrying out COSSH assessments where exposure to dust is an issue and respirable dust is being measured.

Neotox – XL Monitor

The equipment is designed to react to nitrogen dioxide gas diffusing through an electro-chemical sensor.

Minigas –XL Monitor

The equipment is designed to react independently to carbon monoxide, sulphur dioxide and oxygen gasses diffusing through electrochemical sensors. The equipment also detects explosive gases by the same technique being calibrated on methane gas.

Solomat Surveyor Probe

The instrument has an external probe. Carbon dioxide gas diffusing across the probe reacts with an NDIR optical bench sensor to produce a reading. Similarly carbon monoxide reacts with an electrochemical micro sensor to produce a reading.

MiniRAE 2000 Monitor

The instrument operates by reacting to volatile organic compounds through a photo ionisation detector. The instrument is designed to give a measure of the volatile organic compounds presence without any information on their characterisation. The instrument was calibrated against isobutylene.

Gradko Diffusion tubes

Nitrogen dioxide diffuses into the opening at the end of the tube and reacts with triethanolamine absorbent. The absorbent/ nitrogen dioxide is reacted with sulphanilimide and couples with NEDA to produce a purple/ red azo dye complex. The intensity of the colour is measured in a spectrophotometer.

Tenax tubes / Composite tubes

Air is drawn through tubes containing a specific packing material for periods of 20 minutes. Volatile organic compounds are absorbed onto the material. The volatile

organic compounds are desorbed directly by heat onto the column of a gas chromatograph mass spectrometer.

Charcoal tubes

Air is drawn through tubes containing coconut charcoal for periods of 30 minutes. The charcoal is eluted with carbon disulphide and injected onto a gas chromatographic column for detection with a flame ionisation detector.

Silica tubes

The tubes contain DNPH absorbent designed to trap aldehyde and ketone based compounds in air drawn through it for 60 minutes. The aldehydes and ketones are eluted with acetonitrile and determined by HPLC with an UV detector.

Results and Discussion

Particulates

i) PM₁₀

The particulate matter was collected through three different sets of sampling equipment - the high volume sampler, the PM₁₀ sampler and the cyclone filter.

The 5 minute average PM₁₀ results are given in Table 1 together with the associated weather data and sampling site. The computerised average particulate level over the whole sampling period was 214.2ug/m³. The average particulate level measured from weighing the trapped material on the filters was 215.5 ug/m³. The closeness of these two figures gives added confidence in the accuracy of the readings.

The range of results (ug/m³) from the three measuring devices were:-

High Volume Sampler	57 - 1884
Cyclone Filter	<5 - 1547
PM ₁₀ Monitor	23 - 1171

The particle sizes being trapped by the different pieces of equipment are not directly comparable and sampling times do not match exactly. The three sets of figures are however in the same ranges and corroborate each other.

The levels recorded follow two patterns. The first is a pattern of high levels being recorded when the sampling equipment is directly in the plume and reducing as the wind veers and fluctuates. The second pattern is that of reducing levels towards the end of the pyre life. Both of these patterns would be expected.

The patterns are evident in the twenty four hour average PM₁₀ levels calculated from the five minute readings. These are:-

Background	13/4	16.5 ug/m ³
Day 1	15/4 - 16/4	646.9 ug/m ³
Day 2	16/4 - 17/4	11.9 ug/m ³
Day 3	17/4 - 18/4	59.5 ug/m ³

Day one was at the start of the pyre life and nearly all of the readings were taken in the smoke plume. Day two readings were predominately taken out of the plume due to the wind direction and the inability to site the sampling equipment in the soft earthed field. The final day figures were mostly in the smoke, but during the final stages of the fire.

The Air Quality (Scotland) Regulations 2000 set objective levels of 50ug/m³ or less when expressed as a 24 hour mean, not to be exceeded more than 35 times a year and 40 ug/m³ or less, when expressed as an annual mean. The twenty four hour period is measured from midnight, but for the purposes of this comparison exercise the twenty four hour periods were measured from the start of the fire.

During the pyre episode, two of the readings exceeded the 50ug/m³ objective level but as the pyre had a finite life span, and the background level is well below this limit then it is extremely unlikely that the high readings would be repeated more than the 35 times limit. Furthermore the extrapolated annual mean at this site based on these figures would be 18.3 ug/m³, well below the annual set maximum.

Although the annual air quality objective level will not be breached, short-term exposure to particulate matter could occur during the lifetime of the pyre and will depend on plume dispersion characteristics.

ii) Dioxins/ Furans

The results for these classes of compounds are given in Table 2 together with the associated weather and sites data. Dioxins are based on a 6-carbon ring benzene structure while furans have an additional 5-carbon ring entity. The various isomers are identified by digits reflecting the number and position of the chlorine atoms in the chemical structure apart from two (OCDD and OCDF) for which only one structure is possible.

The pyre is contributing to atmospheric levels as reflected in a comparison of the results of plume related samples with the non-detection of these compounds in the background sample apart from Furan 2378. Site 1 at the start of the pyre contained more dioxins than furans while samples taken subsequently at this site contained more furans than dioxins. This may reflect the burning conditions at various stages of the fire. Both dioxins and furans were detected at Site 2 situated closer to the fire, with this filter containing the widest range of compounds.

Dioxin 2378 is the most toxic compound in this dioxin/furan class and all other dioxins and furans are compared to this compound when considering health effects. An international toxic equivalent (to dioxin 2378) is calculated and it is this figure which determines the extent of health effects.

iii) Polyaromatic Hydrocarbons

The results together with the site and weather and site data are given in Table 3. PAH's are formed due to incomplete combustion of organic matter and are usually associated with the burning of coal and other fossil fuels.

The pyre burning is contributing significantly the atmospheric PAH levels in the proximity of the fire when pyre exposed filters are compared to the

background filter. There is a pattern of higher levels at the beginning of the fire life, with levels tailing off towards the end, although filter time in the smoke will also be a factor. The levels at site 2 which is closer to the fire than site 1, were lower than the initial samples taken at site 1 in the case of PAH's. Other determinands have exhibited higher levels at this site 2. Again, the site 2 sample was taken after the fire was established and may reflect the more complete combustion at this stage, the coal supply becoming exhausted and the fire being maintained by the carcasses themselves.

i) Polychlorobiphenyls

The results together with the site and weather and site data are given in Table 4. In theory, there are 209 possible isomers of these compounds. These are identified by the numbers following the letters "PCB" in the table. The seven isomers of most toxicological interest in the UK are isomers 28, 52, 101, 118, 138, 153 and 180. Isomers 153 and 180 appeared on all five pyre based filters, while all of the others were present at some point over the 72 hour period.

The pattern of the PCB's is what might be expected, in that the highest level was found at site 2 closest to the fire, while levels on the other filters at site 1 varied with the amount of smoke trapped on the filter.

Atmospheric levels reported for elsewhere range from less than 1 ng/m³ to 50 ng/m³. The total levels measured during this exercise ranged from 0.005 ng/m³ to 0.2 ng/m³.

PCB's are of more importance in terms of food intake being soluble in fat and become deposited in adipose tissue. While the pyre is contributing to atmospheric levels as reflected in the non-detection of these compounds in the background sample therefore, they are not considered to be a health problem to the public.

ii) Metals

The results of metal analysis are given in Table 5 together with the site and weather data. The fire burning is not having a significant effect on atmospheric metal levels. The higher levels recorded at site 2 are due to this site being much closer to the fire. Site 2 was 50 metres from the fire while site 1 from where all the other samples were taken was 150 metres from the fire. This illustrates the effect of dispersion on levels as the plume moves further away from the site of the fire.

The apparently high sodium, calcium, magnesium and potassium levels will be caused by the proximity of the site to the sea.

Lead is the only metal to have a set air quality objective level in the Air Quality Monitoring (Scotland) Regulations 2000 (500 ng/m³ as an annual average) and this was never exceeded during the monitoring period.

Inorganic Gases

i) Nitrogen Dioxide

Nitrogen dioxide might be expected to be present in the plume due to the large amount of nitrogen containing protein in the animal carcasses.

The results for the nitrogen dioxide levels recorded over the whole sampling period by the Neotox instrument were all below its detection limit (1ppm).

The results of levels obtained from the diffusion tube samples were also all below the detection limit of the technique (1ppb) apart from samples at sites 12 and 14 where levels of 2ppb were detected.

The Neotox instrument was intended to detect and measure higher levels of nitrogen dioxide which might have been expected from the pyres. The diffusion tube method is a much more sensitive technique and the results from the two techniques are consistent.

The Air Quality (Scotland) Regulations 2000 set a nitrogen dioxide objective level of 105ppb for the level of nitrogen dioxide as an hourly mean and 21ppb as an annual mean. Neither of these levels were reached at any time during the sampling period.

On the basis of these figures, the pyres are not contributing to atmospheric levels of nitrogen dioxide and pose no health hazard in this respect. The nitrogen may be remaining as part of the particulate matter due to incomplete combustion.

ii) Oxygen

The oxygen level in the plume varied from 20.1% to 20.6% against a background reading of 20.4%. All of these are in the typical range for atmospheric oxygen and the pyres are not contributing to a detectable diminution of atmospheric oxygen levels.

iii) Sulphur Dioxide

Sulphur Dioxide was expected to be present due to the burning of coal and diesel in the pyre. The results are given in Table 6 together with the site and weather data.

The levels rose gradually from a background level of 0.1ppm although this is at the detection limit of the instrument, to range between 1ppm and 3.6ppm before settling down below 1ppm again, nine hours after the pyre was lit. The level rose again when the sampler was moved closer to the fire at site 2 with levels ranging from 1ppm to 6.3ppm being recorded. Back at site 1, towards the end of the fire life, the levels did not vary much above background levels.

High levels ranging from 2ppm to 10.5ppm were recorded when the sampler was positioned at site 4 in the plume much nearer the pyre.

The most lenient standard objective level in the Air Quality (Scotland) Regulations 2000 is 0.1ppm. Clearly most readings in the plume exceeded this level. Also, the EH/40 8-hour time weighted average is 2ppm.

There is evidence of levels reducing as would be expected as the plume moves away from the pyre.

iv) Carbon Dioxide and Carbon Monoxide

The results for these two gases together with the associated site and weather data are given in Table 7. There was instrument failure during the taking of the background sample. No direct background level is available therefore for comparison. However, normal atmospheric levels of carbon dioxide are in the range 300 to 700ppm and those for carbon monoxide in the range 0.01ppm to 0.2ppm with urban mean concentrations of 17ppm.

The carbon dioxide levels measured during the monitoring were well within this range with a measured range of 360ppm to 411ppm. Furthermore, the WHO indoor air quality guide level is 1000ppm, ie continuous breathing and the EH/40 8-hour time weighted average for occupational exposure, 5000ppm.

On the basis of these standards, the carbon dioxide levels will not pose a health hazard in the plume.

In the case of carbon monoxide the recorded levels ranged from 0.1ppm to 8.6ppm, with the higher levels being recorded while the detector was in the smoke plume. This would be consistent with incomplete combustion of the organic matter in the plume.

The EH/40 8-hour time weighted average for carbon monoxide is 30ppm with extended periods of exposure to levels of 200ppm being cause for concern. Also 70ppm is the lowest level at which medical symptoms are described. Finally, the Air Quality (Scotland) Regulations 2000 objective level is a maximum of 10ppm as a running 8-hour mean.

On the basis of these standards, the carbon monoxide levels will not pose a health hazard.

Organic Gases

i) Total Volatile Carbon

The results are given in Table 8 together with the site and weather data. No background reading was available. However, rural background levels of up to

0.03ppm TVC have been recorded by the laboratory in the past. The levels measured are significantly higher than this and are to be expected in a fire plume setting. TVC is not a discrete chemical but is a measure of the total accumulative effect of all the organic components of the smoke which are in the gaseous form. The two highest readings were recorded at sites 2 and 4. Both of these sites were closer to the fire than site 1 from where all the other readings were taken. This is a further indication of the effects of plume dispersion.

ii) Aldehydes/Ketones (silica tubes)

The results together with the site and weather data are given in Table 9. No background sample was taken. The higher readings are recorded at those sites closest to the fire. All the compounds found in these samples have been reported as being present in smoke from other types of fires and are not peculiar to carcass burning. The individual concentrations of these compounds in the smoke will be dependent on burning conditions at any one time and variability in concentrations do not signify a particular event.

Various guideline standards exist for some of these compounds. WHO quote a tolerable concentration of 2000 $\mu\text{g}/\text{m}^3$ for acetaldehyde and guideline values of 500 $\mu\text{g}/\text{m}^3$ for acrolein and 100 $\mu\text{g}/\text{m}^3$ for formaldehyde.

All recorded values were below these figures.

iii) Solvent Type Compounds (charcoal tubes)

The results together with the site and weather data are given in Table 10. None of the chemicals listed in the table were detected in samples taken at site 1, apart from a minor xylene concentration in two samples taken from within the smoke plume. Site 1 was situated 150 metres from the fire. Again none of these chemicals were detected in the samples taken at sites 5 and 6, while in the smoke plume. These sites were situated, 100 metres and 1250 metres respectively, from the fire. At site 2, one sample gave no readings while the other gave measurements ranging from 0.1 mg/m^3 to 0.5 mg/m^3 . There is no obvious reason evident for this. The other two samples where detectable levels were measured were at sites 3 and 4, both of which were close to the fire in the field.

WHO guidelines quote ambient air concentrations for benzene of between 0.005 mg/m^3 and 0.02 mg/m^3 ; toluene between 0.005 mg/m^3 and 0.12 mg/m^3 and xylenes between 0.001 mg/m^3 and 0.1 mg/m^3 . When detected, the concentrations of these compounds were above the maxima quoted, but this would be expected in a smoke situation.

WHO figures for lowest observed effect levels are 0.3 mg/m^3 for toluene and 0.9 mg/m^3 for xylenes. The former is based on a week exposure and the latter on a yearly exposure time. The EH/40 exposure maximum for benzene is 9.6 mg/m^3 over an 8 hour time weighted average.

Finally, the Air Quality (Scotland) Regulations 2000 objective level is 0.0165 mg/m^3 based on a running annual mean. While the recorded levels in the plume are above this figure, the non detectable levels in other samples indicate that the objective level will not be breached over a yearly cycle.

Based on these figures and the absence of detectable levels away from the fireground indicate that there are no health effects to the general public from these substances in the smoke plume.

iv) Volatile Organic Compounds (tenax and composite tubes)

The results together with the site and weather data are given in Tables 11 and 12. The two sampling regimes were intended to compliment each other and the figures given in the table correspond to the combined information delivered from each type of tube. The compounds have been reported in separate classes for ease of interpretation. Where no entry appears against a particular compound then that compound was not detected. Where a ">" sign appears in the second column, this indicates that the reported levels on that line are minimum figures, the filters having been overloaded or solvent breakthrough occurring during the sampling process. The presence of an "=" sign in these lines indicates that these are true readings and not minimum levels. However due to the sampling process, it is still possible to compare these "greater than" values against the results for other samples in the series. "t.i." in the tables indicates a tentative identification.

Five general profiles were observed in the chromatograms which were richer in volatile organic compounds. Five representative chromatograms were subjected to a full spectral determination of compounds present. These results are presented in Table 11. The remainder were analysed in a manner which identified those compounds representative of the overall profile. These results are presented in Table 12. For completeness, the relevant results from the five profile samples are included again in this table.

The burning of organic matter will produce a range of compounds due to the incomplete combustion process which produces the smoke. The range of compounds identified in the pyre output, due to the nature of the material being burned will be similar to that produced in any process which involves the cooking of meat or burning of fossil fuels. The levels of individual components will however vary.

The highest individual levels were generally recorded in sample "profile 4". This sample was taken close to the fire in the plume. Across the samples taken at site 1, (tubes 1,2,3,4,5,6 and 14) during the lifetime of the fire there is a general trend of falling levels as the source of material reduced. The other general trend is that of reducing levels with distance from the fire base. In particular, the two most distant sites (5 and 7) exhibited levels comparable to background and demonstrate the effects of plume dispersion on levels.

1,3 Butadiene is the only compound (other than benzene which has already been discussed) to have an objective level in the Air Quality (Scotland) Regulations 2000 and which is 0.00225 mg/m³ based on an annual average. This compound was not detected in the background sample but was detected in the plume at levels ranging from greater than 0.001 mg/m³ to greater than 0.044 mg/m³. Taking this latter concentration as a worst case and lasting for a whole day, then the annual exposure would be below this figure. The lack of detection of this compound at sampling sites 5 and 7 however indicates that exposure away from the fire ground is nil.

The benzene levels measured by this technique agreed with those discussed above under solvent type compounds.

The effects of the addition of the cattle mats on day three can be seen by the higher levels of most compounds in tube 16 at site 10 compared to the results for site 9 (tube 15) and site 11 (tube 18).

i) Explosive Gases

The background reading was zero, while all readings over the whole sampling period were 1% of the lower explosive limit. These readings are insignificant and are likely to be smoke interferences rather than true readings. Clearly, had there been an explosive gas problem then this would have been evident physically.