The Public Health Impact of the Buncefield Oil Depot Fire

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Report prepared by

the Chief Executive's Office,
Health Protection Agency
in collaboration with the
Dacorum and Watford and
Three Rivers Primary Care Trusts.

Prof. Pat Troop
Chief Executive, Health Protection Agency

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and
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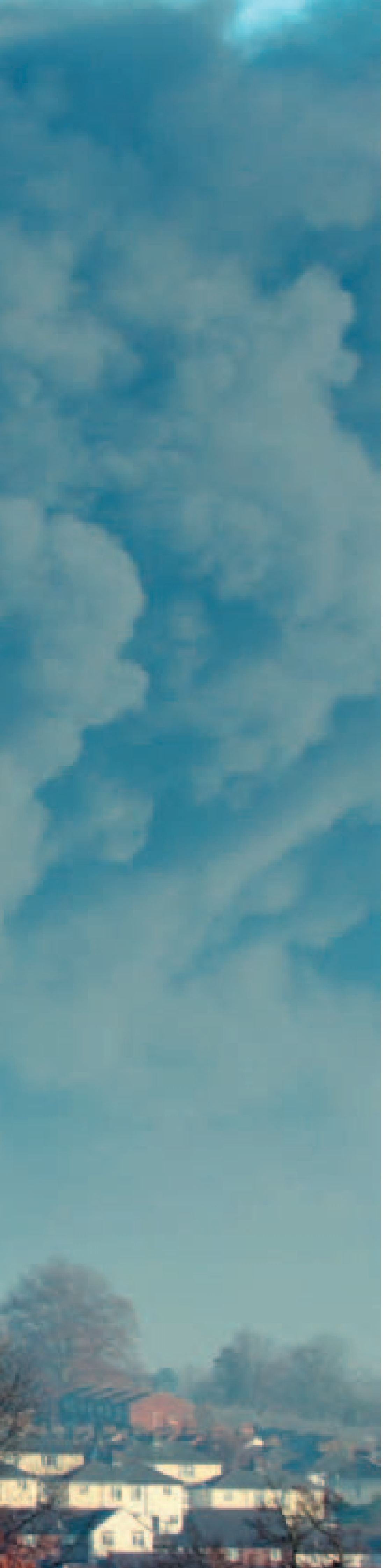

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Chief Executive's Foreword

This report is important as it is the first time this type of public health follow-up study has been undertaken and reported following a major environmental incident in the UK. It was lucky that due to exceptional circumstances such as time of day and the weather conditions no-one was seriously injured following the fire at the Buncefield oil depot.

Understandably at the time of the fire there were serious concerns about the short, medium and long-term health risks which is why we agreed to carry out a number of studies to look at what actually happened; both information gathering and the advice provided, and to assess the public health effects of this incident.

The findings reported here indicate there were no serious public health effects from exposure to the fire. However, useful information has been gathered through these studies and this will help us, and many others, respond better to future incidents which threaten the health of the public.

Undertaking this work has proved an excellent example of working across many organisations and partners in particular the Dacorum and Watford and Three Rivers Primary Care Trusts and other members of the steering group.

Pat Troop

Professor Pat Troop
Chief Executive
Health Protection Agency

Executive Summary

On Sunday 11 December 2005, the Buncefield oil depot in Hemel Hempstead exploded into flames starting the largest fire in Europe since WWII. It took four days to bring the fire under control, by which time 22 tanks of diesel, kerosene and aviation fuel had been destroyed. Fumes from the fire caused a black plume of smoke that could be seen on satellite images, heading southeast over London and ultimately towards France and Portugal. Hundreds of people living locally were forced to leave their homes and sections of the M1 motorway were closed. This report details the work to assess the public health impact from the fire and following it. This incident has been widely reported elsewhere and is not covered in detail here nor are the reasons why this incident occurred.

The initial view, based on previous knowledge, experience and expert advice, was that the plume of smoke posed a minimal risk to health. In the very high temperatures of the fire, it was predicted that all organic chemicals in the fuel would be completely destroyed, leaving few pollutants. The public were informed that the risk to health was low and should not be associated with increased illness. However, caution was still recommended and residents in the Hemel Hempstead area and where they directly experienced smoke were advised to "stay in doors, keep windows closed and tune into local media for further updates."

In the event of any large chemical or environmental incident, it is essential for the agencies involved in health protection to rapidly assess any potential health impacts. The immediate concern was to assess the risk to health and provide advice on how to reduce any threat to people in the vicinity or those fighting the fire. The air quality was monitored during the incident and this indicated that the plume was not significantly adding to existing levels of air pollution, with particulate levels no worse than that found near a busy main road.

Although the evidence suggested it was highly unlikely that there were any health problems as a result of the smoke plume, it was recognised that given the unprecedented scale of the explosion and fire, there was understandable public concern about any possible health effects and it was important to address this anxiety. These concerns included the risk to health from smoke, contamination of the general environment (including soil, and exposure to debris) and other fallout from the smoke plume, as well as living or working under the smoke plume.

The work was carried out under the guidance of a multi-agency Steering Group chaired by the Health Protection Agency (HPA). This Group agreed to assess whether the advice provided at the time was correct; and review and monitor any direct and possible longer-term health impacts on the health of the local population and frontline workers at Buncefield. These follow-up studies aimed to establish whether any long-term effects; physical, psychological or toxic were experienced and to identify any public concerns. This work was carried out by the HPA working closely with the Dacorum and Watford and Three Rivers Primary Care Trusts.

Five studies were undertaken.

- The risk assessment evaluation was carried out to assess whether the information at the time of the incident was accurate and if the public health advice provided based on this was correct. The first risk assessment, made at the peak of the crisis concluded that there was negligible risk from the plume and that there was no significant exposure to hazardous chemicals to the public living near the site or under the smoke plume.
- A case note review of accident and emergency attendances looked at records from Watford and Hemel Hempstead Accident and Emergency (A&E) departments. These were reviewed to identify individuals who had health issues related to the fire. A questionnaire was completed for each selected A&E case record using the information contained in the A&E record.
- An occupational health survey was undertaken for those who responded to the fire, including fire and rescue services, ambulance services, local authority staff, police departments and those involved in caring for casualties, construction and engineering work and environmental sampling. Due to the complicated nature of this work and the number of organisations involved the results from this study are not yet available.
- Understandably due to the scale and location of the incident there were concerns amongst the public that this incident may have a health impact. In order to assess this concern, a survey was carried out involving over 5,000 local people answering a questionnaire.

  The survey looked at peoples' concerns about any health effect for them or their families at the time of the incident, if there were any on-going health concerns and their response to the public health advice.

- The air quality assessment carried out during and after the incident, and how this was used for exposure assessment and toxicological risk assessment was reviewed. A detailed analysis of all exposure data was also carried out to help organisations conduct similar assessments in the future. The findings from this report are being looked at to develop frameworks for improved sampling and testing between all the agencies involved in this field.

The main findings from these studies show that there was:

- no evidence of a public health risk from the plume either as deposits or air quality;
- a relatively small number of people attended A&E. Of the 244 patients who attended three quarters were from the emergency services and of all those attending 90% were sent home without needing follow up; most of the others had minor injuries;
- differences in people's view of exposure depending on location; with people under the plume more likely to be worried about exposure than those not;
- a drop in the level of anxiety amongst the public from approximately 50% at the time of the incident to 13% about 7 weeks after the event.

The public questionnaire identified that the main source of public health advice was through national and local television and local radio, with little use made of NHS Direct, GPs or the internet. However, not all the public received the advice and so ways of improving how health advice to the public is disseminated need to be investigated.

The incident demonstrated the value of an integrated health protection service, able to work across different sectors and provide comprehensive advice and support. This was the first major environmental incident faced by the HPA and although the response was effective, valuable lessons were learned about how to improve the future public health response, both within the HPA and across the range of other organisations involved.

Photo: Hertfordshire Fire and Rescue Service

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

Summary of the Buncefield Oil Depot Fire

At 0600 on the morning of Sunday 11th December 2005 the first of a series of explosions occurred at the Buncefield oil depot, resulting in a huge fire producing a massive smoke plume that could clearly be seen over London and the South East of England. The explosions were felt in the local area, causing widespread structural damage to both commercial and residential buildings, and were reported to have been heard as far away as the Netherlands. A major incident was declared and a command centre (Strategic Co-ordinating Group) set up which took the decision to evacuate those with damaged homes and workplaces, and to tell everyone under the plume to shelter, 'go in, stay in, tune in'. This command centre called on many organisations and government agencies to help the Emergency Services in the response to this incident. During the following 48 hours or so further explosions occurred and the fire continued until it was finally under control by the evening of Wednesday 14th.

At the time of the fire the Met Office provided details of the plume direction and spread through visual observations, satellite images, and computer modelling. The weather conditions were stable which allowed the smoke to rise to the higher levels of the atmosphere and be trapped there. Information on air quality both around the site and throughout southern England was collected by a number of agencies, including the Fire Brigade, local authorities and the Health and Safety Laboratory. Soil and grass samples were also collected and analysed to support the air quality data by identifying whether any chemicals from the smoke had fallen onto the ground. Fortunately due to the heat generated by the fire and the favourable local wind and weather conditions, the potential impact of the fire on the local population was minimised.

The Health Protection Agency provided local and regional staff to support the incident and national experts in chemical hazards and emergency response. This team worked very closely with the Dacorum and Watford and Three Rivers Primary Care Trusts to provide advice and help on any potential health impact of the incident and to monitor this. The immediate concern was to assess the risk to health and provide advice on how to reduce any threat to people in the vicinity or those fighting the fire. Information was provided to the police, fire and other emergency services on toxic substances that could be released by the fire and the possible health effects of breathing in smoke particulates. The health impact during the incident was monitored by using reports from hospital Accident and Emergency departments (A&E), General Practice (GP) and NHS Direct to identify anyone who was suffering from breathing problems or any other symptoms associated with the fire.

The initial view, based on previous knowledge, experience and expert advice, was that the plume of smoke posed a minimal risk to health. In the very high temperatures of the fire, it was predicted that all organic chemicals in the fuel would be completely destroyed, leaving few pollutants.

The public were informed that the risk to health was low and should not be associated with increased illness. However, caution was still recommended and residents in the Hemel Hempstead area and where they directly experienced smoke were advised to "stay in doors, keep windows closed and tune into local media for further updates."

Many organisations and agencies were involved, including:

Emergency Services:

Fire and Rescue Services from 33 areas
Police co-ordinated by Hertfordshire police
Metropolitan police
Hertfordshire Ambulance crews

and the following bodies:

Hertfordshire County Council
Dacorum Borough Council
London Fire Brigade Scientific Advisors
Dacorum Primary Care Trust
Watford and Three Rivers Primary Care Trust
Environment Agency
Health Protection Agency
Health and Safety Laboratory
Thames Water
Defence, Science and Technology Laboratory
Ministry of Defence
Health and Safety Executive
Food Standards Agency
Met Office

Air quality was monitored during the incident and this indicated that the plume was not significantly adding to existing levels of air pollution, with particulate levels no worse than that found near a busy main road.
Air monitoring and environmental sampling continued throughout the incident and did not identify any pollutants at levels outside the normal range. Therefore it was concluded that there was minimal exposure to hazardous chemicals of the public living near the site or under the area of the plume as a result of the fire. A report published in May: 'Interim Review of Air Quality Aspects of the Buncefield Oil Deport Explosion', written for Defra by consultants Netcen, the Met Office and the Health Protection Agency summarised the air pollution and quality during and after the fire in more detail.

Due to the scale of the incident there was extensive media news coverage locally, nationally and internationally. The local and national media played an important role in providing advice to the public about the risks to their health from the fire and were kept informed of relevant information. This was done through appearances on national television, press releases, and a regularly updated list of frequently asked questions and answers.

Although the plume was not known to have grounded and all the initial findings indicated there was at most a minimal public health impact with no widespread public exposure to the plume, there was concern that such a large incident could cause adverse health effects.
In order to assess this a number of studies were carried out after the incident to assess any longer term environment and health impacts. These studies are described in the next section.

Photo: Hertfordshire Fire and Rescue Service

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

Photo: Hertfordshire Fire and Rescue Service

Assessing the Public Health Impact

In the event of any large chemical or environmental incident, it is essential for the agencies involved in health protection to rapidly assess any potential health impacts. This is done by using a variety of approaches based on the experience of previous incidents. When information about the hazards posed during the incident becomes clearer, a decision needs to be taken on the need to carry out any follow up investigations. This decision considers the concerns of the public and how best to address these. This was important in this case given the scale and location of the incident. Experience from major incidents in New York, Madrid and the Netherlands as well as the UK has demonstrated the value of assessing the health impact on the population in directly addressing public anxieties.

Following the incident a multi agency Steering Group, led by the Health Protection Agency was set up to assess the need for follow up studies and agree what these should be. The Steering Group has representatives from many of the organisations involved in assessing and providing health advice directly following the fire including the Dacorum and Watford and Three Rivers Primary Care Trusts.

Steering Group members
Health Protection Agency
Regional Director of Public Health
Met Office
Strategic Health Authority
Public Health Observatory
Health and Safety Laboratory
Food Standards Agency
Environment Agency
Defra
Institute of Psychiatry
Dacorum Primary Care Trust

This Group agreed to assess whether the advice provided at the time was correct; and review and monitor any direct and possible longer-term health impacts on the health of the local population and frontline workers at Buncefield.

Although the evidence suggested it was highly unlikely that there were any health problems as a result of the smoke plume, it was recognised that the public might have concerns about any possible effects and it was important to address this anxiety. These concerns included the risk to health from smoke, contamination of the general environment (including soil, and exposure to debris) and other fallout from the smoke plume, as well as living or working under the smoke plume.

Five studies were set up:

1. Risk assessment evaluation

This study was carried out to assess whether the information at the time of the incident was accurate and if the public health advice provided based on this was correct. The first major risk assessment was undertaken when the fire occurred and concluded that there was negligible environmental risk from the plume and that the public health advice was correct. Further environmental data, such as soil and grass samples, were analysed to review this assessment. This investigation also searched for any evidence of significant plume grounding and to determine if there was a need for further sampling.

2. Case note review

Most of those who had health effects or were injured by the blast would have made contact with the health service, through the local A&E departments, their GPs or NHS Direct. The contacts with these services were all reviewed, finding there were very few reports from either GPs or NHS Direct. It was therefore agreed that the greatest impact was on the A&E departments and that this would be the focus of this study. Approximately 1600 records from Watford and Hemel Hempstead A&E departments were reviewed to identify individuals who presented with health issues related to the fire.

3. Occupational health register

There were approximately 2100 personnel from fifty one organisations involved in responding to the incident. These services included thirty three fire and rescue services, local ambulance services, police forces, local authority staff, and those involved in caring for casualties, construction and engineering work and environmental sampling. The Occupational Health Departments of the Emergency Services wanted a record of those exposed, their use of protective equipment, health complaints and contact with health services. A questionnaire was developed in collaboration with the Occupational Health Departments who then made this available to all those employed to deal with the fire in any way.

4. Concerns among the public

Understandably due to the scale and location of the incident there were concerns amongst the public that this incident may have a health impact. Some of these concerns are addressed through the other reviews but previous experience has highlighted the importance of assessing the public's concerns directly. In order to establish any ongoing public concerns for their health, including stress, a postal questionnaire was sent out at the end of January.

The questionnaires were sent to:

- those 500 within 1k of the site who were evacuated
- a random sample of
  - 1000 residents north of the fire in Dacorum PCT
  - 2000 residents south of the fire in Dacorum PCT
  - 1500 residents in Watford and Three Rivers PCT

These questionnaires were analysed to identify the public's concerns resulting from both physical and perceived exposure at the time of the incident and if these concerns had changed by the time they received the questionnaire. These findings will be used to improve how the concerns of the public are addressed in the future and public health messages communicated.

5. Air quality assessment

A detailed review of the air pollution data collected and analysed by the various organisations involved was carried out, together with an evaluation of how this was used to identify any potential health risks resulting from any possible exposure to the plume. This information will be used to help and improve how organisations collect samples and conduct similar assessments in the future.

Photo: Hertfordshire Fire and Rescue Service

Photo: Rob Holder

Key Findings

The main conclusion from the studies reported here is that there is no evidence of a significant public health risk from exposure to the fire and thick smoke resulting from the explosion and fire at the Buncefield oil depot. These findings are published in more detail in appendices 1-4.

The key findings from these investigations show that there was:

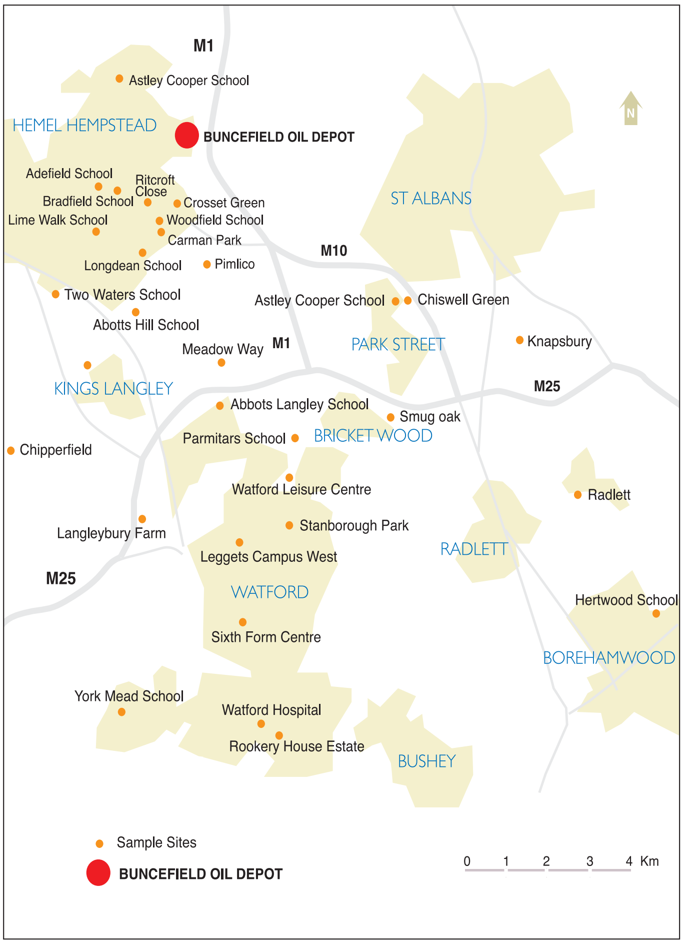
- no evidence of a public health risk from the plume either as ground deposits or air quality;
- a relatively small number of people attended A&E. Of the 244 people who attended three quarters were from the emergency services and of all those attending 90% were sent home without needing follow up; most of the others had minor injuries;
- differences in people's view of exposure depended on location; with people under the plume more likely to be worried about exposure than those not;
- a drop in the level of anxiety amongst the public who responded to the questionnaire from approximately 50% at the time of the incident to 13% about 7 weeks after the event.

1. Risk assessment evaluation

The environmental impact was assessed to confirm that the public health advice given during the incident was correct and that there was no significant exposure to hazardous chemicals to the public living near the site or under the smoke plume. The air quality data at the time showed that it was unlikely that there would be any impact at ground level from the plume. To confirm this, seventy two samples from thirty three locations were taken from soils and grass downwind of the fire and compared with control locations and available information on background levels of pollutants. Locations are shown at Figure 1. Several wipe samples of dust and soot were also collected and analysed. All samples were collected before substantial rainfall in the area thereby avoiding the possibility of rain washing away any pollution attached to soil, vegetation or property.

Samples were analysed at two laboratories for a combination of chemicals including dioxins, furans, heavy metals (including nickel and vanadium which are considered appropriate markers for oil combustion) and fluorides.

Figure 1: Location of environmental sampling points following Buncefield Oil Depot Fire.



When compared with the control site and available data on the background levels of these pollutants in typical UK soils and grasses, the vast majority of samples analysed were unexceptional and did not show any evidence of contamination due to the fire. There was no clear association with distance from the fire or with the probable dispersion of the plume. There were, however, several results that required further explanation. When investigated further it was concluded that, on the balance of evidence, these results were not due to the fire. Historical contamination is considered a more probable cause and at one of these sites there is a plausible source of contaminated land (a nearby former power station).

Pollutant levels in the vast majority of surface soil and grasses are unexceptional and do not present a risk to human health.

While localised plume grounding cannot be discounted, this investigation is consistent with the view that prolonged plume grounding downwind of the fire did not occur.

These findings mean that there is no credible evidence of a public health risk resulting from deposits from the fire.

Full report at appendix 1

2. Case note review

The records were reviewed of those people who sought medical attention at Hemel Hempstead and Watford A&E departments between the 11th and 14th December. No other A&E departments in the South East of England reported seeing anyone as a result of the fire. A questionnaire was completed for each selected A&E case record using the information contained in this.

In total 244 people attended A&E of which 117 had symptoms attributable to the fire, the rest attended for a check up but were well. Most attended Hemel Hempstead A&E on Sunday 11th December. Three quarters of these were members of the emergency services of which two thirds just attended for a check up and had no symptoms. The majority, 90% of attendees, were sent home without the need for any follow up. Three people were admitted to hospital, fifteen were sent to their GP for follow up, three were referred to an orthopaedic surgeon, and one to a cardiologist.

Of the 117 attending A&E with symptoms, members of the public accounted for 38. They presented mainly with injuries such as cuts and sprains or with respiratory symptoms including shortness of breath, cough and asthma. Those working at or near the depot largely attended with injuries and respiratory symptoms such as shortness of breath and sore throat. The 63 emergency workers mainly presented with respiratory complaints of which half were sore throats.

Approximately half of those presenting with symptoms had respiratory complaints, including three people presenting with asthma attacks. The two members of the public who had respiratory complaints both had a previous history of respiratory problems.

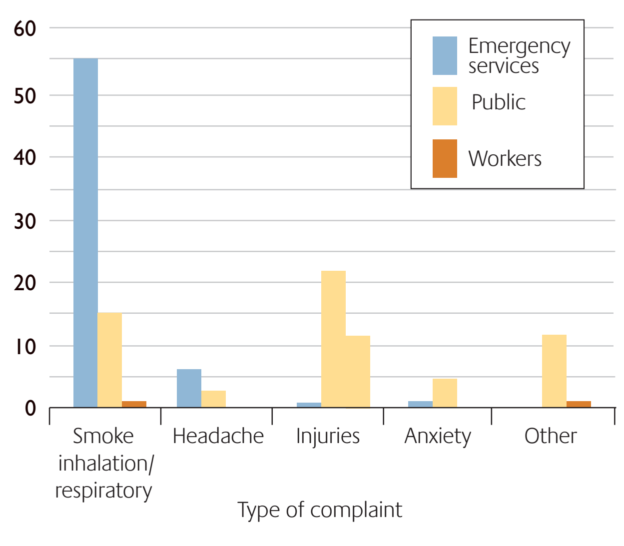
Photo: Hertfordshire Fire and Rescue Service

Photo: Rob Holder

Key Findings

The second most common presentation was injuries, followed by headache and anxiety. Two people suffered from cardiac complaints. Figure 2 below shows the main types of symptoms presented to A&E by patient grouping: emergency services, public and oil depot workers.

Figure 2: Distribution of main presenting complaint to accident and emergency



The potential exposure to members of the public was assessed by looking at their location at the time of injury or other complaint. The majority of the public who were injured were within a mile of the oil depot with three being more than three miles away. Of those who had respiratory complaints eight were living under the plume but four were not.

Despite the extensive and protracted fire, the public health impact as measured by A&E attendance was relatively small, indicating that exposure to hazardous substances was minimal.

Full report at appendix 2

3. Occupational health survey

A questionnaire has been distributed by the emergency services occupational health departments. Due to the complicated nature of this work and the number of organisations involved the results from this study are not yet available. When finalised the findings will be posted on the websites of the participating organisations.

4. Concerns among the public

The follow-up survey was carried out to get a full understanding of the health concerns, including stress, which local people may have experienced. A letter and questionnaire were sent to a random sample of 5000 local people at the end of January to identify any concerns about the risk to their health from the smoke, contamination of the general environment (including soil, and exposure to debris) and other fallout from the smoke plume. The sample covered both the north half of Dacorum PCT, which had little exposure to the incident, the south half which was largely under the plume and Watford and Three Rivers PCT which was also under the plume.

The survey looked at peoples' concerns about any health effect for them or their families at the time of the incident, if there were any on-going health concerns and their response to the public health advice. The survey had a response rate of 40%. A telephone survey was carried out to see why people had not responded; the main reason given was lack of concern about the health effects.

The findings showed that the level of perceived exposure varied depending on location, and that those who were under the plume being more likely to be worried about exposure than those not. Comments showed that the level of anxiety amongst the public that responded had dropped from approximately 50% at the time of the incident to 13% when the questionnaire was distributed (7 weeks after the event). With the main reason for concern at the time being breathing in toxic smoke, changing to concerns about long term health effects when the questionnaire was distributed.

The main findings were:

1. Levels of perceived exposure varied between areas.
2. Sources of public health advice did not vary between areas.
3. People were more likely to be stressed or report symptoms relating to wider health issues than to perceived exposure to the incident.
4. There was a major reduction in the number of respondents with health worries at the time of the survey compared with the number who had concerns at the time of the incident, as seen in figures 3 and 4.
5. There was a very low rate of psychological distress throughout the study area.

Figure 3: Invited comments on health worries at the time of the incident

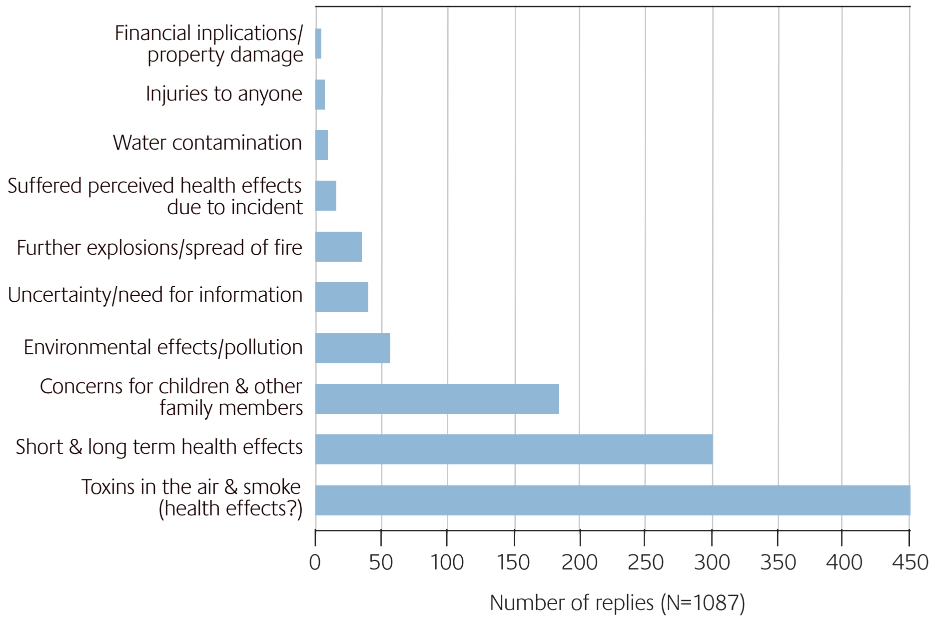
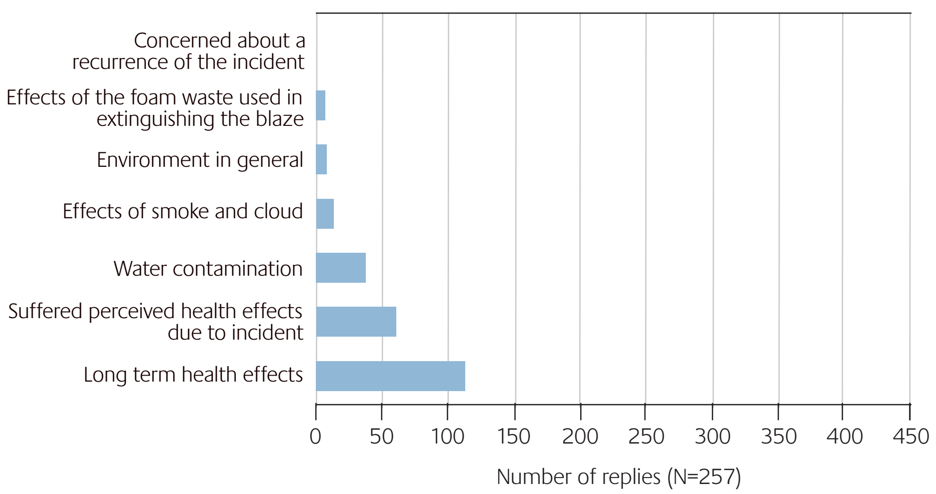


Figure 4: Invited comments on health worries at the time of completing the questionnaire



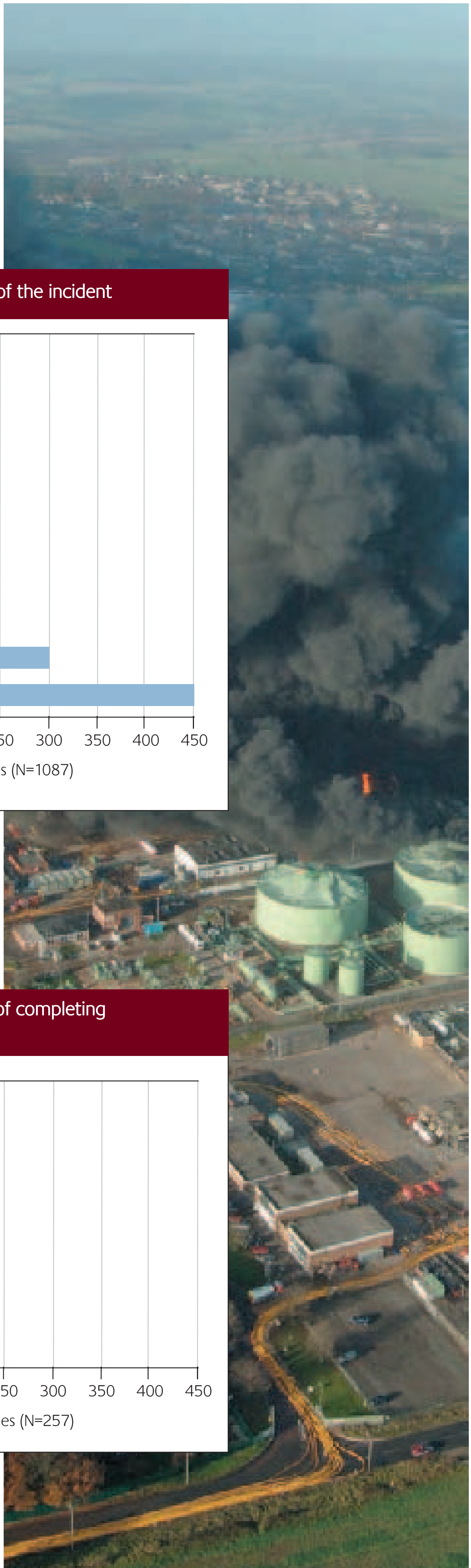


Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

Key Findings

The incident at Buncefield resulted in a high physical impact, with 88% of respondents in south Dacorum claiming to have heard the explosions, and 84% considered the smoke cloud to be near their homes. Despite this, low levels of psychological distress were recorded and symptom reporting was also low. The area with the highest level of reported psychological distress was south Dacorum. It is normal that individuals involved in an incident of this type experience psychological reactions, however most of these resolve with time.

The main source of public health advice was national and local television and local radio. In north Dacorum and Watford and Three Rivers PCT areas only around half of those surveyed heard the public health advice, this increased to around three quarters in south Dacorum PCT. Little use was made of NHS Direct, GPs or the internet. There is a need to identify ways of improving how health advice to the public is disseminated.

Full report at appendix 3

5. Air quality assessment

This review summarises the atmospheric modelling and monitoring that was carried out during and after the incident, and how this was used for exposure assessment and toxicological risk assessment. It explains how this data was used to provide advice during the first four days of the incident. In addition, it details how the HPA has taken forward further actions since the acute response stage of the incident.

Despite the unprecedented scale of the Buncefield explosion and fire, the findings of both monitoring and modelling suggest that the fire did not result in any significant ground-level concentrations of atmospheric pollutants. This was due to high plume buoyancy caused by the high temperatures of the fire and favourable weather conditions that resulted in the plume being trapped at a high level in the atmosphere with minimal mixing to the ground.

The findings from this report are being looked at to develop frameworks for improved sampling and testing between all the agencies involved in this field.

The report published in May 'Interim Review of Air Quality Aspects of the Buncefield Oil Deport Explosion', authored for Defra by consultants Netcen, the Met Office and the Health Protection Agency summarised the air pollution monitoring during and after the fires and assessed the impact on air quality in more detail.
This is available at :www.defra.gov.uk/environment/airquality/buncefield/index.htm

Full report at appendix 4.

Photo: Hertfordshire Fire and Rescue Service

Appendix 1

Environmental Impacts of the Buncefield Oil Depot Explosion

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Contents

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Executive Summary

In response to the Buncefield Fuel Depot fire of the 11th December 2005, the Health Protection Agency undertook an initial screening investigation of surface soils and grasses downwind of the fire in order to determine whether there was a) any evidence of significant plume grounding and b) a need for more detailed sampling. During the 14th and 15th December, teams from the HPA's Centre for Radiation, Chemicals and Environmental Hazards collected a total of 72 samples from 33 locations including a control site, a site located upwind of the fire. Several wipe samples of dust and soot were also collected and analysed. All samples were collected before substantial rainfall in the area thereby avoiding the possibility of rain washing away any pollution attached to soil, vegetation or property.

Samples were analysed at two laboratories for a combination of polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans), heavy metals (including nickel and vanadium which are considered appropriate markers for oil combustion), fluorides and perfluorooctane sulphonate (PFOS).

When compared with the control site and also available data on the background levels of these pollutants in typical UK soils and grasses, the vast majority of samples analysed were unexceptional and did not show any evidence of contamination due to the fire. There was no clear association with distance from the fire or with the probable dispersion of the plume. There were, however, a small number of results which require further explanation, notably high total PAH concentrations in soil and grass samples collected in South Watford.

Samples collected in South Watford (approximately 10 kilometres to the south of the depot) showed evidence of elevated PAH. However, it is concluded that, on the balance of evidence, this contamination was not a result of the fire. It is not considered credible that the high concentrations in soil and grass could have been caused by grounding of the plume. There was no evidence of plume grounding, neither visually or from nearby air monitoring stations in this area and no evidence of contamination by other pollutants that could be associated with the fire, such as nickel and vanadium. Historical contamination is considered a more probable cause and at one of these sites there is a plausible source of contaminated land (a nearby former power station).

In conclusion, this investigation has not found any credible evidence of contamination of soil and grasses due to the fire at the Buncefield Oil Depot. Pollutant levels in the vast majority of surface soil and grasses are unexceptional and do not present a risk to human health. While localised plume grounding cannot be discounted, this investigation supports the view that prolonged plume grounding downwind of the fire did not occur.

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

GLOSSARY

AFFFs	Aqueous Film Forming Foams
CHaPD	Chemical Hazards and Poisons Division
COT	Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment
CRCE	Centre for Radiation, Chemicals and Environmental Hazards
Defra	Department of the Environment, Food and Rural Affairs
EA	Environment Agency
EPA	Environmental Protection Agency
FSA	Food Standards Agency
HPA	Health Protection Agency
NHS	National Health Service
NATO	North Atlantic Treaty Organisation
OS	Ordnance Survey
PAHs	Polycyclic Aromatic Hydrocarbons
PFOS	Perfluorooctane Sulphonate
RPD	Radiation Protection Division
SGV	Soil Guideline Value
TEF	Toxic Equivalency Factors
US	United States
UKAS	United Kingdom Accreditation Service
WHO	World Health Organisation

1 Introduction

The Health Protection Agency's (HPA) Centre for Radiation, Chemical and Environmental Hazards (CRCE) comprises the Radiation Protection Division (RPD) (formerly the National Radiological Protection Board) and the Chemical Hazards and Poisons Division (CHaPD). The latter provides scientific and medical advice to government, the National Health Service and other bodies on the known health effects of chemicals, poisons and related environmental hazards. This advice covers clinical issues such as antidotes and medical treatment, protective equipment, decontamination and evacuation; also, toxicological and epidemiological advice on the likely impact on public health.

On Sunday 11th December 2005, there was a major explosion at the Buncefield Oil Depot, Hemel Hempstead, Hertfordshire. Large scale fires involving a range of petroleum products burnt until Thursday 15th December and an extensive plume of black smoke was released. This plume was visible for many miles and also on satellite imagery and generated considerable concern about the potential impacts on public health both in the immediate vicinity of the depot and across much of southern England. The fire was the largest of its kind in the UK, since the second World War.

Uncontrolled fires can generate a plume which contains gaseous pollutants, smoke (which effectively disperses as a gas), and large particles. Large pieces of debris carried by the heat of the plume (macro deposition) can be deposited a few kilometres downwind of the fire. Material from the plume can deposit on land and water surfaces by wet and dry deposition. Dry deposition occurs continuously, even when it rains, and depends on a range of parameters (including wind speed, atmospheric stability, surface roughness, size of depositing particles) and is important for gaseous pollutants. Wet deposition of material can occur up to hundreds of kilometres from the point source.

In response to this fire CHaPD, together with environmental sampling teams from RPD, decided to undertake monitoring of soils and grasses around the depot. Sampling was undertaken at a number of locations on Wednesday 14th and Thursday 15th December 2005 while the fire was still being extinguished and before prolonged rainfall in the area. Samples were collected and transported to the laboratories for analysis by Friday 16th December. Sampling points were selected based on visible observations made during the fire and the predicted dispersion of the plume.

There were two clear aims of this investigation:

a) To determine whether there was any evidence of significant plume grounding; and

b) To determine whether there was a need for more detailed sampling.

This investigation was not intended to directly assess human health effects via the food chain or any other route and no samples were taken from crops or allotments. Assessment of the risk to health through the food chain is the responsibility of the Food Standards Agency (FSA) and not the HPA. During the fire the FSA stated that there were no immediate concerns from the fire with regard to food (Cabinet Office Top Level Briefing No 3, 14 December 2005). The effects of this plume on air quality are not considered in this report. This report will present and summarise the environmental sampling undertaken and discuss the significance of the results.

2 Sampling Protocol

2.1 Introduction

The decision to sample was taken by CRCE on Tuesday 13th December 2005 and sampling teams were mobilised 24 hours later. The sampling strategy developed concentrated on collecting environmental samples thought most likely to reflect recent deposition of airborne pollutants. As a result, grass and surface soil (to a maximum depth of 10 cm) were collected together with wipe samples from upturned surfaces.

Three teams of between two and three people were mobilised into the area around Hemel Hempstead during the 14th and 15th December. Over this period these teams sampled at 33 locations and collected 72 samples for analysis. Sample collection and storage broadly followed the guidance recommended for a "fast" response by Department of the Environment, Food and Rural Affairs (Defra) (Defra, 1999) together with methodologies for sampling of soil and herbage developed by the RPD.
As recommended by Defra, a single soil and grass sample was collected at each sample location with *ad hoc* wipe and debris samples as required. One background and one upwind sample sites were also included in the sample strategy.

2.2 Sample locations

Over the first 48 hours (11th and 12th December 2005) the plume from the fire was extremely buoyant, extended hundreds of metres upwards and became trapped above a temperature inversion. This resulted in the plume being dispersed considerable distances downwind and data from a number of ambient air monitoring stations downwind of the fire indicated that prolonged grounding of the plume had not occurred. However, as the fire cooled and was extinguished the plume became less buoyant and the probability of localised grounding increased. During this period (13th-14th December 2005), areas of possible ground level deposition were predicted by a number of dispersion models, including AERMOD and ADMS models run by the Environment Agency (EA). These models indicated that points of maximum ground level concentration fluctuated with the temperature of the plume, source strength and prevailing meteorological conditions. The sampling strategy concentrated on this period when plume grounding was more likely and sample locations were identified using the predictions from plume dispersion models together with observations from the field (*i.e.* reports of visible plume at ground-level, the presence of soot and debris). The investigation focused on priority 'sensitive' sites, including: schools, hospitals, housing estates, parks, nurseries, *etc*. Access to the oil depot was restricted and the nearest samples could be located was approximately 2 km from the site boundary.

The sampling teams focused on two main sources of information:

a) The predicted point of maximum ground-level deposition using available plume dispersion models, particularly AERMOD/ADMS models developed by the EA, NAME models produced by the Meteorological Office and CHEMETs requested by the Emergency Services during the fire (see Appendix A);

b) Areas with documented visible plume at ground level or where there was possible fall-out from the fire (soot, debris *etc*).

Since traditional plume dispersion models may have little application to releases due to fires, considerable emphasis was placed on visual observations on the behaviour of the plume.

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Samples locations are shown in Maps 1 and 2 in Section 8 of the report and also in detail in Appendix B. Based on data from the plume dispersion models, two distinct sample areas were chosen:

a) A downwind transect of the fire running approximately 15 km in a SSE direction from the point source to the south of Watford; and

b) An arc running from west to east to capture the change in plume direction from the 11th December to the 14th December. This was situated approximately 6 km from the point source, running from the west of Watford to the west of St Albans.

Within these areas, a total of 16 sample locations were identified, focusing on sensitive sites within possible plume grounding areas. It was originally thought that these locations would represent the majority of the sampling locations. However, a further 15 sample locations were identified *ad hoc* by the sample teams following visual observations and reports from the field. A background control site in Aylesbury some 25 km west of the fire and an upwind site 2 km from the fire were also chosen.

A total of 72 samples were collected from 33 locations. These included four wipe samples of dust and soot, collected downwind of the fire. A single sample of soil and grass was collected at each sample location.

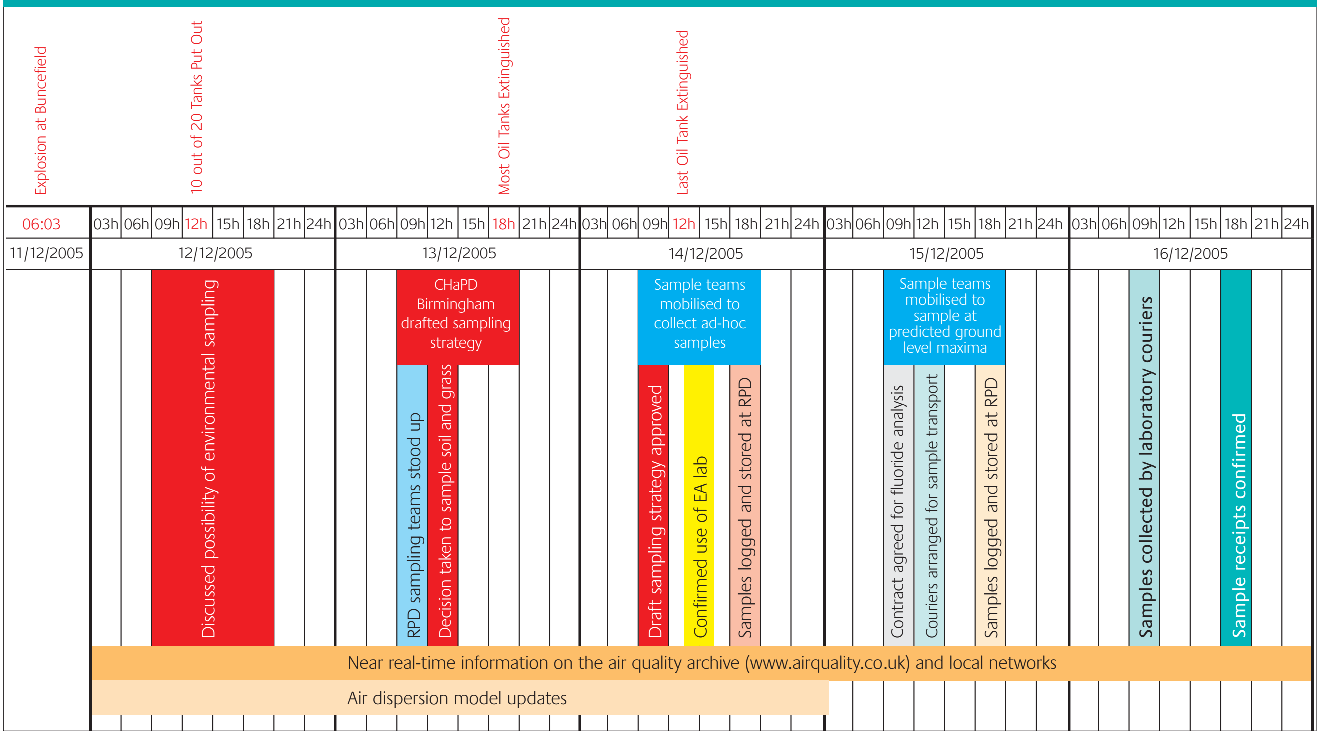
2.3 Sample collection

Sample collection and storage broadly followed the guidance in the Defra manual together with methodologies developed by the RPD for sampling of soil and herbage. A timeline for the sampling strategy is given in Figure 1. Where possible sample locations avoided areas in the shelter of large objects such as buildings, tress etc which may affect deposition. Samples were also collected away from main roads (typically at least 70-100 metres away from the kerbside). However, due to the time available it was not possible to consider other potential sources of pollution such as contaminated land and local industry.

2.3.1 Grass Sampling

An area one metre by one metre was marked out and grass cut with shears to a length of about 1-2 cm. All grass was collected in a sample bag, the excess air squeezed out and the bag sealed, double bagged and labelled.

Figure 1. Soil sampling timeline



2.3.2 *Soil Sampling*

Each soil sample was collected using a 3.5 cm diameter corer tube to a depth of 10 centimetres. The tube was then capped, double bagged and labelled.

2.3.3 *Wipe Sampling*

Wipe samples for soot and dust were collected by wiping a piece of moistened sterilised paper over a representative hard upturned surface such as a car roof or letter box. The wipes were then doubled bagged and labelled. Blank wipes were also bagged and sent for analysis.

2.3.4 *Collection and storage*

All samples were taken on Wednesday 14th and Thursday 15th December 2005 before substantial rainfall in the area washed away any pollution attached to soil, grass or property. Samples were refrigerated to approximately $4^{o}C$ when returned to base. Samples were submitted to the laboratories for analysis within 24 to 48 hours of collection.

2.3.5 *Field and trip blanks*

Ideally field and trip blanks should have been collected but appropriate media similar to the sample matrix (*e.g.* acid washed sand for soil, analytical grade cellulose for the vegetation) were not available during the investigation and field and trip blanks were not performed. Blank wipes were bagged and sent for analysis.

2.3.6 *Archiving*

A small number of samples were archived and the laboratory also retained a portion of each sample for re-analyses if required.

2.3.7 *Laboratories*

Samples were sent to two UKAS[1] accredited laboratories for analysis, the Environment Agency's National Laboratory Service (Leeds) and the commercial laboratory, TES Bretby (Burton on Trent).

2.3.8 *Document control*

All samples were subject to appropriate document control with all samples and relevant sample history logged and recorded. All samples were clearly labelled and the background samples kept separate from the potentially contaminated samples. Each sample was subjected to a detailed chain of custody from the sample team to the laboratory for analysis.

For each sample, the following details were recorded:

- relevant label
- type of sample
- date and time of collection
- approximate location with reference to a landmark, town and/or road on the Ordnance Survey (OS) Road Atlas
- easting's and northing's recorded by a handheld satellite navigation system
- description of ground
- description of weather

To summarise, a total of 72 samples were collected from 33 locations. One sample was a control (located in an urban area outside the affected region), one was located 2 km upwind of Buncefield and the other 31 located between 2 and 13 km downwind.

2.4. Pollutants

CHaPD selected five groups of pollutants for environmental monitoring. The selection criteria were based upon both scientific concerns (atmospheric sampling at the scene, knowledge of the materials involved, potential for formation within the plume and potential health impacts) and political/public concerns. These classes were:

a) Polycyclic aromatic hydrocarbons (PAHs);

b) Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans);

c) Heavy metals (particularly nickel and vanadium);

d) Fluorides (total); and

e) Perfluorooctane sulphonate (PFOS).

[1] United Kingdom Accreditation Service

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There are a number of uncertainties associated with these pollutants. In particular, it is accepted that in very high temperatures of the fire all organic chemicals would have been completely destroyed. However, there is the possibility that in the cooler margins of the fire and during the relatively short period at the end of the fire, some products of incomplete combustion may have been emitted at these lower temperatures. Despite these concerns at the time of sampling these substances represent our best estimate of potential emissions.

Photo: Rob Holder

2.4.1 PAHs

The United States (US) Environmental Protection Agency's (EPA) method 610 suite of 16 parent PAHs was chosen as an indicative measure of general environmental contamination. It is acknowledged that the EPA suite is not appropriate for food safety assessment but as crops and the food chain were not considered in this investigation, the US EPA suite was considered a suitable indicator of PAH contamination, particularly as most published literature cited these 16 PAHs.

2.4.2 Dioxins and furans

The uncontrolled oil fire had the potential to produce dioxins and furans and the decision to analyse was taken after consideration of their toxicity and environmental persistence.

2.4.3 Heavy Metals

The heavy metals nickel and vanadium were chosen as likely markers of oil combustion. As there were some concerns about the variety of materials involved in the fire, a number of other heavy metals were also analysed (i.e. cadmium, chromium, nickel, lead and zinc). Scientific advisors at the scene also monitored for the presence of these metals in the atmosphere. Furthermore these other heavy metals would also give some indication of background anthropogenic contamination.

2.4.4 Perfluorooctane sulphonate (PFOS)

Aqueous film forming foams (AFFFs) were used to control this fuel fire and some older stock contained PFOS and related perfluorinated acids; a component of many old AFFFs. The issue of environmental pollution by perfluorinated compounds including perfluorinated carboxylates and sulfonates has received much attention because of their environmental persistence.

2.4.5 Fluorides (total)

During the fire it became apparent that much of the flame suppressant foams used could produce hydrogen fluoride due to thermal degradation. Total fluoride was used a proxy measure of gaseous and particulate hydrogen fluoride that may have been released during the fire.

Where the sample size permitted, samples were subdivided providing 93 analyses of a variety of pollutants (see Table 1). All samples were analysed for either PAHs or heavy metals (specifically nickel and vanadium) or both where sample size allowed. A small subsection (approximately 15%) were analysed for dioxins and furans. Soils and grass close to the scene were also analysed for fluorides and PFOS.

Heavy metals, PAHs, dioxins and furans and PFOS were analysed at the EA's laboratory in Leeds and fluorides at TES Bretby in Burton on Trent. It is worth noting that the EA's laboratory also handled their own samples collected from Buncefield, specifically water samples collected for PFOS analysis. This meant that the EA's samples were prioritised ahead of the HPA's samples.

Table 1: Summary of samples collected

Number of samples	Type	Samples interpreted by HPA (included in this report)
32	Soil (3 archived)	8 fluoride 10 heavy metals 14 PAHs 6 dioxins/furans 3 PFOS
32	Grass	17 heavy metals 17 PAHs 6 dioxins/furans 2 PFOS
4	Wipe	2 heavy metals 2 PAHs
2	Blank (wipe)	2 PAHs 2 heavy metals 2 dioxins/furans
1	Debris	1 PAHs
1	Insulation	1 PAHs
72	TOTAL	8 fluoride 31 heavy metals 37 PAHs 14 dioxins/furans 5 PFOS

3 Results

3.1 Background data

This investigation followed the guidelines recommended by Defra for a fast response (Defra, 1999) and originally planned to sample at 16 locations only. As a result only one control site, together with an upwind site, was selected. While this is a conventional approach, the use of one control site meant the investigation contained a limited amount of data on background levels of pollution in the area around the oil depot. As a result this report has had to rely heavily on data reported in the scientific literature for comparison purposes. Typical UK urban background PAH and dioxin data were particularly limited, especially in grasses. In order to address this problem, the EA provided a sub-section of unpublished data from an on-going national survey of metals, PAHs and dioxins in soils and grasses (see Appendix C).

3.2 Heavy metals

3.2.1 Vanadium and nickel

Of the heavy metals analysed vanadium and nickel were considered the most appropriate markers of oil combustion. The mean vanadium concentration in soils was comparable to that reported in the control site and reported levels were also well within typical UK ranges for urban soils (see Table 2). The highest recorded concentration of vanadium in soil (59 mg kg^{-1}) was actually reported at upwind of the fire. Map 4 illustrates the distribution of vanadium in soils around the site.

The distribution of vanadium in grasses downwind of the site were also unexceptional (see Map 3) with the highest concentrations found at a distance of approximately 8 - 12 km. Many samples were collected from locations close to modelled points of maximum ground level pollutant concentrations. However, of the six highest concentrations in grasses no sample was within close proximity (i.e. within 0.5 km) any of these predicted points of plume grounding. Only one sample was within 1 km and the remaining five samples, including the highest concentration, were in excess of 2 km of these predicted areas of grounding. Therefore it is not considered that vanadium concentrations in grass are evidence of potential grounding of the plume.

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Nickel concentrations in soils around Buncefield (8 - 41mg kg^{-1}) were also unexceptional and within typical urban background levels (15 - 47 mg kg^{-1}) (Fordyce et al, 2005) (see Table 2) and comparable with that reported at the control site (29 mg kg^{-1}). Reported concentrations were well below the appropriate Soil Guideline Value (SGV) (50 mg kg^{-1}). Map 6 illustrates the distribution of nickel in soils around the site.

Comparison was also made with unpublished data on nickel in soils and herbage, collected as part of the EA's Soil and Herbage Survey[2] (Barraclough, personal communication, 2006). The median soil concentration for nickel around Buncefield is within typical distributions for both urban and rural locations (see unpublished data in Appendix C).

The distribution of nickel in grasses downwind of the site was also unexceptional (see map 5 and Table 2). Median concentrations for nickel did not exceed the upper 95th percentile concentrations in urban herbage as reported by the EA's Soil and Herbage Survey (Barraclough, personal communication, 2006)

There was also no association in terms of proximity to modelled points of ground level pollutant maxima. Of the six highest grass nickel concentrations only one sample was located within 500 m of a predicted area of grounding while three samples, including the highest reported concentration, were in excess of 1 kilometre of the predicted points of maximum deposition. Again this suggests that grounding as predicted by the dispersion models did not occur.

Finally, there was no relationship between nickel and vanadium concentrations in grass and distance from the site.

3.2.2. Other heavy metals

As discussed earlier, several other heavy metals were analysed although they are not considered markers for combustion of refined oil. Reported levels in both soils and grasses were not elevated when compared with levels reported in UK environments (Lark *et al*, 2006; Fordyce *et al*, 2005; Bowen, 1985; and Adriano, 1986) (see Table 2).

Furthermore, soil levels are not above the relevant SGVs for the appropriate land use. No pattern in concentration was observed with distance from depot or from other sample locations (data not shown).

The median soil concentrations for metals in soils are within the typical distributions for both urban and rural locations as reported by the EA's Soil and Herbage Survey (Barraclough, personal communication, 2006). The median concentrations for chromium, lead, nickel and zinc exceed the upper 95th percentile concentrations in rural herbage, but not the upper 95th percentile in urban herbage, whilst copper also exceeds the upper 95th percentile in rural herbage (see unpublished data in Appendix C).

Reported concentrations of cadmium in soil at two locations were above 1 mg kg^{-1} (the SGV for allotments and residential gardens with plant uptake) but considerably lower than the more the relevant SGV for residential developments without plant uptake (30 mg kg^{-1}).
As cadmium is not considered a marker for combustion of refined oil, this pollution is not considered to the due to fallout from the fire.

3.2.3. Wipe samples

Two wipe samples were taken, one from a plastic picnic table at Two Waters School 4 km south west of the fire and the other from a painted letter box lid at Bradfield School 2 km south-west of the fire. One wipe sample had an elevated zinc concentration, although neither had elevated levels of nickel and vanadium (which are recognised oil combustion markers). It is likely that the elevated zinc in the wipe sample is due to sources other than plume grounding, particularly as zinc is not considered a marker for the combustion of refined oil. Other potential sources of pollution include background urban contamination and/or contamination from the surface itself (*i.e.* from the painted galvanised letterbox lid).

[2] This survey did not look for Vanadium

Table 2: Summary of heavy metals data. All values are mg kg^{-1} (dry weight).

Heavy metal	SGV1[1]	UK soil Median range	Soil samples *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium	---	34.7- 83.0[2]	28.0	59.0	43.0	40.0	44.0
Nickel	50	15 - 47[3]	8.0	40.8	21.9	16.7	29.0
Cadmium	1	0.3 - 2.0[3]	0.1	2.9	0.8	0.4	1.0
Chromium	130	43 - 108[3]	23.9	43.9	30.8	27.0	29.2
Copper	---	2 - 250[4]	8.2	41.2	24.7	21.4	38.5
Lead	450	45 - 225[3]	43.6	103.0	69.3	60.2	44.4
Zinc	---	5 - 816[5]	44.0	257.0	156.1	138.0	146.0
Heavy metal	Maximum recommended concentration for production grass species		Grass samples *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium	---		1.0	22.2	8.8	9.3	5.9
Nickel	---		2.7	18.1	7.8	7.3	5.1
Cadmium	---		0.1	0.7	0.2	0.2	0.5
Chromium	---		1.1	29.4	11.6	10.8	7.2
Copper	250[6]		10.9	105.0	32.0	25.6	10.4
Lead	---		2.7	62.7	19.4	15.0	15.6
Zinc	1000[6]		26.3	90.5	53.7	50.7	54.5
Heavy metal			Wipe samples (mg wipe^{-1}) *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium			12.5	12.5	12.5	12.5	---
Nickel			17.2	25.8	21.5	21.5	---
Cadmium			4.1	17.9	11.0	11.0	---
Chromium			27.0	31.7	29.3	29.3	---
Copper			55.9	82.4	69.2	69.2	---
Lead			38.3	76.6	57.4	57.4	---
Zinc			525.0	3360.0	1942.5	1942.5	---

[1] residential with plant uptake
[2] both urban and rural sites Lark et al (2006)
[3] urban sites Fordyce et al (2005)
[4] both urban and rural sites Bowen (1985)
[5] both urban and rural Adriano (1986)
[6] DETR (1996)

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3.3 Polycyclic aromatic hydrocarbons (PAHs)

Typically, quantitative analysis and method calibration for PAHs are completed for the 16 parent PAH species specified in the priority list of the US EPA (Method 610). These species are the predominant ones and include a representative group of the carcinogenic PAHs; the sum of these 16 species has been utilised in this report and is referred to as "total PAH" (see Table 3). The data for one of these 16 species, benzo(a)pyrene, have been included in Table 4 as this is most studied PAH and is widely regarded as a potent carcinogen. Where concentrations were below limits of detection, half detection limits were used.

3.3.1 Soils

Total PAH concentrations in the majority of soils sampled downwind of the fire were within typical urban levels reported in the scientific literature and comparable with concentrations recorded at the control site (3.98 mg kg^{-1}) and the upwind site (8.45 mg kg^{-1}) (see Table 3).

Published data for the UK include mean values of 2.02 mg kg^{-1} and 4.42 mg kg^{-1} in Birmingham urban soil (Smith *et al*, 1995 and Butler *et al*, 1984), whilst Meharg *et al* (1998) observed a mean background value of 2.70 mg kg^{-1}. A mean urban value in Brisbane, Australia, was found to be 3.35 mg kg^{-1} (Yang et al, 1991), whilst a mean value of 3.00 mg kg^{-1} was observed in the United States (cited by Bakker *et al*, 2000). Map 8 illustrates the distribution of PAH in soils around the site.

In addition to published data, concentrations reported in soils around Buncefield were also comparable with data collected by the EA in their unpublished Soil and Herbage Survery. Reported data for the total of 16 PAHs when compared to the total of 22 PAHs cited in the EA's Soil and Herbage Survey indicates that median values are likely to be within the upper 95th percentiles for urban soils (Barraclough, personal communication, 2006) (see unpublished data in Appendix C).

While the majority of samples downwind were typical of urban locations, higher concentrations of PAHs in total and of all single compounds were observed in soils collected from a small geographical area approximately 10 to 13 km from the fire (see Map 8). These soil samples were

Table 3: Summary of total of 16 US EPA (Method 610) parent SPAH data. All values are mg kg^{-1} (dry weight)

Media PAH	UK urban (range)	Typical kerbside (range)	Buncefield samples				
			Minimum	*Maximum*	*Mean*	*Median*	*Control*
Soil[1] n=13	0.95 - 4.42	9.75 - 20.00	0.92	239	36.82	3.10	3.98
Grass[2] n=16	0.09 - 0.15	0.19	0.14	171	2.47	0.831	1.55

Table 4: Summary of benzo(a)pyrene data. All values are mg kg^{-1} (dry weight)

Media BaP	UK urban (range)	Typical kerbside (range)	Buncefield samples				
			Minimum	*Maximum*	*Mean*	*Median*	*Control*
Soil[1] n=13	0.07 - 0.15	0.97 - 2.00	0.082	19.4	3.37	0.37	0.46
Grass[2] n=16	0.006	0.080	0.006	1.99	0.247	0.084	0.16

[1] Smith *et al*, 1995; Butler *et al*, 1984
[2] Meharg *et al*, 1998; Crepineau and Rychen, 2003

collected in a triangle within South Watford near to two modelled positions of ground-level pollutant maxima (specifically relating to the outputs of two dispersion models dated 0900 GMT on the 13th December 2005; the AERMOD dispersion model with a plume rise of 200 m, and the ADMS dispersion model with a plume rise of 200 m) (see Appendix A for more details).

The concentration of total PAH recorded in sample CC008.2 (33.1 mg kg^{-1}) was elevated by one order of magnitude above typical background levels. This sample was taken on a school playing field at York Mead School, Croxley Green, South Watford (approximately 13 km from the fire). To put into context this value is of a similar magnitude to cited kerbside values. Smith *et al* (1995) observed PAHs in urban roadside dust to be 9.75 mg kg^{-1} while Butler *et al* (1984) observed motorway kerbside samples to be 20.0 mg kg^{-1}. Roadsides are known to have a major influence on PAH concentrations in soil with Harrison and Johnston (1985) reporting that while most PAHs were deposited within the first 4 m from the road, the influence of the road may extend to a distance of 70 m. However, a site visit after the fire revealed that this sampling location to be in excess of 100 m from the nearest main road.

Concentrations measured in two other samples were higher. Samples CA005.2 (239 mg kg^{-1}) from playing fields at West Hertfordshire College, Watford (approximately 10 km from the fire) and CC007.2 (171 mg kg^{-1}) from Rookery Housing Estate, Watford (approximately 13 km from the fire) were found to be extremely elevated (i.e. approximately two orders of magnitude above background levels). By way of comparison, these values far exceed those reported by Meharg *et al* (1998), who recorded data on total PAHs in soils under the plume of a large scale chemical fire (10,000 tonnes of polypropylene) to be between 12.0 to 18.0 mg kg^{-1}; values which were 17-fold to 366-fold above appropriate background levels (at a distance of 4.5 km from the fire). In this incident, Meharg reported that the majority of PAHs were considered to be from dry deposition of particulates.

Elevated PAH concentrations have been reported near to oil refineries with Bakker *et al* (2000) recording very high PAH concentrations in soils adjacent to an oil refinery in Belgium. Reported values (up to 300 mg kg^{-1}) are comparable with the two uppermost sample values collected at Buncefield. However, the highest concentrations reported in the Belgium study were only found in soils some 50 m from the refinery. Elevated concentrations due to the daily operations at the refinery were found up to 3 km from the site but levels had decreased significantly by 1.3 km from the installation (by one order of magnitude to approximately 10 mg kg^{-1}). By contrast soils with the highest PAH concentrations around Buncefield were approximately 10-13 km away from the installation; this distance would suggest that there has been either some localised plume grounding from the fire which did not occur elsewhere or, alternatively, the presence of some other, as yet, unidentified localised source (e.g. contaminated land or mobile source).

Recorded PAH profiles for all but one of the soil samples (including both the upwind and control samples) are comparable, suggesting a similar source type (see Figures 2 and 3 in Appendix D). The general profile is similar to that of vehicular emissions (i.e. markers include fluoranthene, pyrene and benzo(ghi)perylene and to some extent benzo(b)fluoranthene and phenanthrene) (Smith et al 1996), although it is possible that another source could produce such a profile. Of the three soil samples with the highest PAH concentrations, sample CA005.2 has an anomalously high relative value for phenanthrene. There is some evidence that phenanthrene is a marker for diesel engine emissions (Smith and Harrison, 1998), although it is feasible that this pollutant could have originated from a number of hydrocarbon sources.

By contrast, concentrations of a key oil combustion marker, fluorene, are relatively low, suggesting the absence of any underlying oil combustion source. However, it should be borne in mind that fluorene is distributed mostly in the vapour phase rather than the particulate phase in the urban environment and the resultant PAH profile appears to be the result of wet and dry particulate deposition.

3.3.2 Grasses

PAH levels in grasses, including both the control and upwind samples, were typically above published data (see Table 4). However, when compared to the total of 22 PAHs cited in the EA's Soil and Herbage Survey, median values are not exceptional and are expected to be within the upper 95th percentiles for urban herbage (Barraclough, personal communication, 2006) (see unpublished data in Appendix C). Map 7 illustrates the distribution of PAHs in grasses around the site.

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Reported concentrations in grass are consistent with those values reported in grasses adjacent to an oil refinery in Belgium, namely 2.0 mg kg^{-1} (Bakker *et al*, 2000), suggesting that normal day-to-day operations might result in increased PAH levels in grasses. This study observed that values decreased by more than one order of magnitude with a distance of 4 km from the refinery. No such decrease with distance from the source was observed around Buncefield although restricted access to the site meant that the nearest grass samples were around 2 km away from the source (see Map 7).

The time of year may also have influenced the reported concentrations. There are significant cycles in concentrations of many airborne pollutants in grass because of the growth dilution effect, which is much greater in warmer months of the year. Therefore, it is possible that reported concentrations during December would be somewhat higher than concentrations reported in the literature for samples collected at other times of the year. Furthermore much of the data is for food crops rather than grasses and data for differing types of vegetation are not directly comparable due to inter alia small differences in factors such as lipid content, specific leaf area of the plants (*i.e.* surface area), roughness of the leaf area, leaf orientation and leaf age.

The PAH profiles in all the grass samples, including the control and upwind sample, are similar, again suggesting a common source of pollution, which is most unlikely to be the fire (Appendix D).

The two highest PAH concentrations were recorded in grass and these correspond to the most elevated PAH levels in soils namely samples CA005.1 (16.5 mg kg^{-1}) and CC007.1 (11.1 mg kg^{-1}) (see Maps 7 and 8). Grass PAH concentrations at these locations are approximately one order of magnitude higher than both the Buncefield control and median values, and approximately two orders of magnitude above levels typically reported at other urban locations within the UK. The source of this contamination is not known but there are a number of explanations. Grass height at these two locations was, at 1 to 2 cm, the shortest of all the sampling locations (these were school/college playing fields). This would have increased the potential for cross contamination with soil and it is possible that soil contamination of grass samples through soil splash may partly explain these concentrations. Likewise root uptake of PAH from soil could have played a role. PAH concentrations in plants are typically due to gaseous deposition (*i.e.* vapour phase absorption) rather than wet and dry particulate deposition due to blow-off and wash off of contaminants from the leaves (Bakker *et al*, 2000). By contrast, root uptake to above-ground plant parts is not usually a major pathway. However, it is plausible that root uptake could, in theory, be a major contributor to PAH concentrations in grasses at these two locations because of the exceptional high PAH concentrations in soil. Using published shoot concentration factors (the dry weight concentration in the plant tissue divided by the dry weight concentration in the soil) (Gao and Zhu, 2004 and Weatherly-Watts *et al*, 2006), root uptake to above-ground parts could plausibly explain the two elevated concentrations found in grass at these locations.

3.3.3 Wipes and debris

Two wipe samples were taken for the analysis of PAHs. Both samples recorded low PAH concentrations (0.14 and 0.19 mg per wipe). One wipe sample was taken from the top of a plastic slide at Woodfield School (*i.e.* approximately 2.5 km south of the oil depot), the other from a solar panel on a car park machine at Watford General Hospital (near to sample number CC007.2, approximately 13 km south of the oil depot). The latter was collected near to the location of the high PAH concentrations in soil and grass. The relatively low concentrations recorded in the wipe samples are not consistent with elevated PAH levels found in soil and the PAH profile also differs, suggesting a different source, although it is not possible to determine whether the sampled material was associated with the fire.

One sample of large debris (collected 2.5 km south of the fire) was analysed for PAHs and concentrations were found to be extremely low. This sample was discarded as the origin of the debris was unknown and it may not have been associated with the fire.

3.4 Dioxins and furans

Dioxins are a large group of substances with similar structure. They exhibit similar types of toxic effect but vary widely in potency. One compound, 2,3,7,8–tetrachlorodibenzo-p-dioxin (TCDD) is the most toxic

and has been studied in detail. Since these compounds always occur as mixtures, a system of weighting the amount of the individual compounds on the basis of their potency has been devised based on Toxic Equivalents. This expresses the potency of the other compounds as a fraction of the potency of TCDD and the relative potency of compound are summed to obtain a toxicity-weighted mass quantity, known as dioxin-Toxic Equivalents (TEQ). This is the approach recommended by the World Health Organisation (WHO) and endorsed by the relevant independent expert advisory committee in the UK, namely the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT). The toxic equivalent values to use for the individual compounds are agreed internationally. Prior to this a number of different weighting systems were in existence, the principal one being that devised by the NATO[3] committee on Challenges to Modern Society. There are only minor differences in the Toxic Equivalency Factors (TEFs) between the two systems and any differences in I-TEQ will be small. Where concentrations were below limits of detection, half detection limits were used.

3.4.1 Soils

Reported concentrations around Buncefield are consistent with published background data for soils and comparable with concentrations reported at the control site (see Table 5). Both the mean and median values fall within the typical range reported in both UK urban soils (0.87 to 87 ng TEQ WHO kg^{-1} dry weight) and rural soils (0.78 to 20 ng TEQ WHO kg^{-1} dry weight). All data from Buncefield were similar to background levels in South Wales reported by Lovett *et al* (1998) (*i.e.* median value 6.3 ng TEQ NATO kg^{-1} dry weight), in Belfast reported by Eduljee and Gair (1996) (*i.e.* mean 4.3 ng TEQ NATO kg^{-1} dry weight) and in Lancaster reported by Wild *et al* (1994) (*i.e.* mean 2.27 ng TEQ NATO kg^{-1} dry weight).

Concentrations in soil are also well within the ranges for both urban and rural soil reported by the EA's Soil and Herbage Survey (Barraclough, personal communication, 2006) (see unpublished data in Appendix C).

3.4.2 Grasses

Reported concentrations around Buncefield are consistent with published background data for grasses and comparable with concentrations reported at the control site (see Table 5). Data on background levels in UK grasses are but a typical range in rural grass of 0.47 to 5.0 ng TEQ NATO kg^{-1} dry weight was cited by Edulejee and Gair (1996). While Kjeller *et al* (1991) reported a mean value of 0.86 ng TEQ NATO kg-1 dry weight at a semi-rural UK location. Both the mean and median values fall within the typical range reported in UK rural environments and are also within the ranges for both urban and rural herbage reported by the EA's Soil and Herbage Survey (Barraclough, personal communication) (see unpublished data in Appendix C).

3.5 PFOS and other perfluoroalkyl sulponate substances (PFAS)

With two exceptions, all samples analysed did not detect PFOS and other PFAS below the detection limit of 0.2 g kg^{-1}. Samples taken at one location did detect trace amounts of the perfluorooctylsulphonate anion only.

Table 5: Summary of dioxin and furan data (expressed as ng TEQ WHO kg^{-1} dry weight)

Media I-TEQ	Typical UK urban (range)	Typical UK rural (range)	Buncefield samples				
			Minimum	*Maximum*	*Mean*	*Median*	*Control*
Soil[1] n=5	0.87 - 87	0.78 - 20	2.46	7.92	4.94	4.71	3.01
Grass[2] n=5	-	0.47 - 5.00	0.52	2.14	1.57	1.87	1.57

[1] Roots *et al*, 2004
[2] Eduljee and Gair, 1996 (expressed as ng TEQ NATO kg^{-1} dry weight)
[3] North Atlantic Treaty Organization

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

3.6 Fluorides

Concentrations of fluorides in soil downwind from Buncefield ranged from 0.9 to 22.7 mg kg^{-1}, with a median value of 1.25 mg kg^{-1}. These levels are typical for reported urban levels and more than an order of magnitude below reported maximum soil concentration limits (500 mg kg^{-1}) and lower than the much stricter grass guideline (30 mg kg^{-1}) in agricultural land (DETR, 1996). The highest fluoride level was 22.7 mg kg^{-1} located in a rural setting and was probably elevated due to fertilizer usage. Fluoride levels in grass were not analysed (due to the difficulty in identifying a commercial laboratory that would undertake such an analysis).

4 Discussion

Data from the majority of soil and grass samples indicate that the fire did not result in significant contamination of the environment around the depot. Measured pollutant levels were unexceptional and typical of urban and suburban locations in the UK. However, PAH concentrations in soil at three locations in South Watford approximately 10 to 13 km from the fire were high. Grass concentrations at two of these locations were also higher than other samples. These results are worthy of further discussion, particularly as these levels are considerably higher than would be expected in a typical urban environment.

Two hypotheses are proposed which might explain these results.

4.1 Hypothesis 1

Elevated concentrations at locations in South Watford are, principally, a result of a plume grounding episode following the Buncefield Oil Depot fire.

4.1.1 Supporting data

- Sample points were located near to an area predicted to be a point of maximum ground-level deposition when the plume was modelled on the 13th December 2005 (0900 GMT) (although samples located near to other predicted points of maximum ground-level deposition do not show such contamination).
- There is both temporal (sampled two days after the chemical fire) and spatial (location downwind from the source) plausibility.
- The samples taken (particularly grass) could be indicative of recent atmospheric deposition.
- The scale of the increase in concentrations in this location when compared with other samples is consistent with reports following similar large scale fires where total PAH concentrations in soil were seen to increase by 17 to 366-fold over background levels.

4.2 Hypothesis 2

Elevated concentrations at locations in South Watford are, principally, a result of other pollution sources such as historical contamination, contaminated land, vehicle emissions etc.

4.2.1 Supporting data

- The high concentration of total PAHs in soils could have only been caused by a prolonged grounding event containing extremely high PAH concentrations. To date there is no evidence that the plume contained high levels of PAHs. Data collected from high altitude aerial samples by the Meteorological Office reported low PAH levels in the plume above the fire. It is also expected that in the very high temperatures of the fire the overwhelming majority of organic chemicals would have been completely destroyed.

- Wipes samples collected in the vicinity of these high soil and grass samples contained relatively little total PAH suggesting no PAH-enriched particulate deposition occurred in these locations.

- There is no evidence of a plume grounding episode from two local authority air quality monitoring stations (*i.e.* Watford and Three Rivers) located near to this area. Hourly PM_{10} data from these monitoring stations only identified a number of short term peaks in concentrations that could have been entirely traffic related.

- Data on other pollutants does not provide any supporting evidence of a plume grounding episode in this area. In particular levels of nickel and vanadium, key markers for oil combustion, were unexceptional (including a sample collected between the three elevated total PAH soil samples).

- No reports of visible plume grounding in this area have been received to date.

- Soil samples were taken in the top 10 cm. Ideally samples should have been taken within 0 to 5 cm and it is possible that PAH concentrations in soils at this depth may also reflect past pollution sources or events.

- The profiles of PAHs in both soils and grass from this area are similar not only to each other but also to the vast majority of the other samples (including the control and the upwind site). The profile is similar to the one associated with vehicular emissions and different to that expected from oil combustion (due to low relative ratios of fluorene:benzo(a)pyrene).

- It is entirely plausible that PAH concentrations could be due to contaminated land, roadside contamination or a number of localised pollution sources (*e.g.* spillage, bonfire, or mobile source such as train or vehicular). Further investigation by CHaPD, including a site visit to Buncefield in January 2006, discovered that soil and grass samples collected from one of these locations were less than 200 m from two historical pollution sources, namely a former gas-fired power station and a former sewage works. Both industries could have, in the past, caused PAH pollution. It is likely that both, particularly the former power station, would have had a considerable influence on pollution in the surrounding area.

- Grass at the two locations with elevated total PAH concentrations was very short compared with other samples, increasing the potential for cross-contamination with soil (*i.e.* by soil splash or by accidental collection of soil along with grass sample).

- Although root plant uptake is not considered a major pathway for PAH, because of the high soil concentrations plant uptake could, potentially, explain the recorded levels in corresponding grass samples.

After consideration of the evidence presented above, we concluded that the elevated PAH concentrations found in environmental samples in this area were not due to the fire at the Buncefield Oil Depot.

However, reported concentrations of PAH including benzo(a)pyrene are high, particularly in soil. The main route of concern at these locations would be direct soil ingestion by young children (< 6 years of age). However, the potential for young children to be exposed to PAH from these soils is low as the samples were taken from areas not likely to be frequented by very young children (parkland and open spaces) and any direct contact with surface soil will be reduced due to good coverage with grass. Therefore, the potential public health risk is considered low but further work is recommended to investigate the source and extent of this pollution.

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

5 Conclusion

Concentrations of PAHs and other pollutants were determined in soil and grasses around Buncefield following the oil depot fire. Data from the vast majority of soil and grass samples were unexceptional and were typical of urban and suburban locations in the UK. The highest concentrations were measured in the soil samples. This was to be expected, as soil may accumulate pollution for a long period of time, whereas exposure of grasses is dependent on their lifetime and is more reflective of recent deposition.

There was no relationship between pollutant concentrations and distance from the site or with the predicted areas of plume grounding. In the most part, pollutant concentrations in soils and grasses from samples more remote from the source of the fire were comparable with samples collected closer to the site. This is consistent with observations made during the fire. The plume was observed to reach a height of around 3000 m and remained aloft due to the presence of a temperature inversion. Air quality information obtained during and after the fire showed that there was no widespread increase in ground-level air pollution concentrations.

PAH concentrations in grass samples from all locations were higher than expected but consistent with unpublished data for other urban and suburban environments in the UK. Concentrations in the control and upwind samples were comparable to those reported in samples collected downwind. Therefore, it is concluded that reported concentrations in grass are not due to the fire.

Some elevated PAH levels were found in soils and grasses collected from a relatively small geographical area in South Watford approximately 10 to 13 km south of the fire. PAH concentrations in soils collected at these locations were considerably higher than other samples collected downwind and also the control and upwind sample. They were also higher than published data on urban soils and grasses. In addition, PAH concentrations in grasses collected at two of these three locations within this area were also found to have significant PAH. However, on the balance of evidence these concentrations were not due to the fire at the Buncefield Oil Depot. There is no direct evidence of plume grounding from two nearby air quality monitoring stations or from observations from the field. Concentrations of other pollutants, particularly nickel and vanadium, do not show such marked contamination. Furthermore even if a localised plume grounding event occurred in this region, it is considered unfeasible that deposition would have resulted in such high concentrations. Air monitoring data collected during the fire indicates that PAH concentrations in the plume were low and insufficient to result in such concentrations. Historical contamination is a more probable source and at one of these sites, there is a plausible source of land contamination (a former power station).

Overall, it can be concluded that the fire at the Buncefield Oil Depot did not result in substantial pollution of soil and grasses. A large number of measurements found that pollutant levels were, in general, unexceptional and typical of UK urban environments. While localised plume grounding cannot be discounted, this investigation supports the view that prolonged plume grounding downwind of the fire did not occur. Therefore it is unlikely that surface soils and grasses around the fuel depot present a widespread public health risk.

6 References

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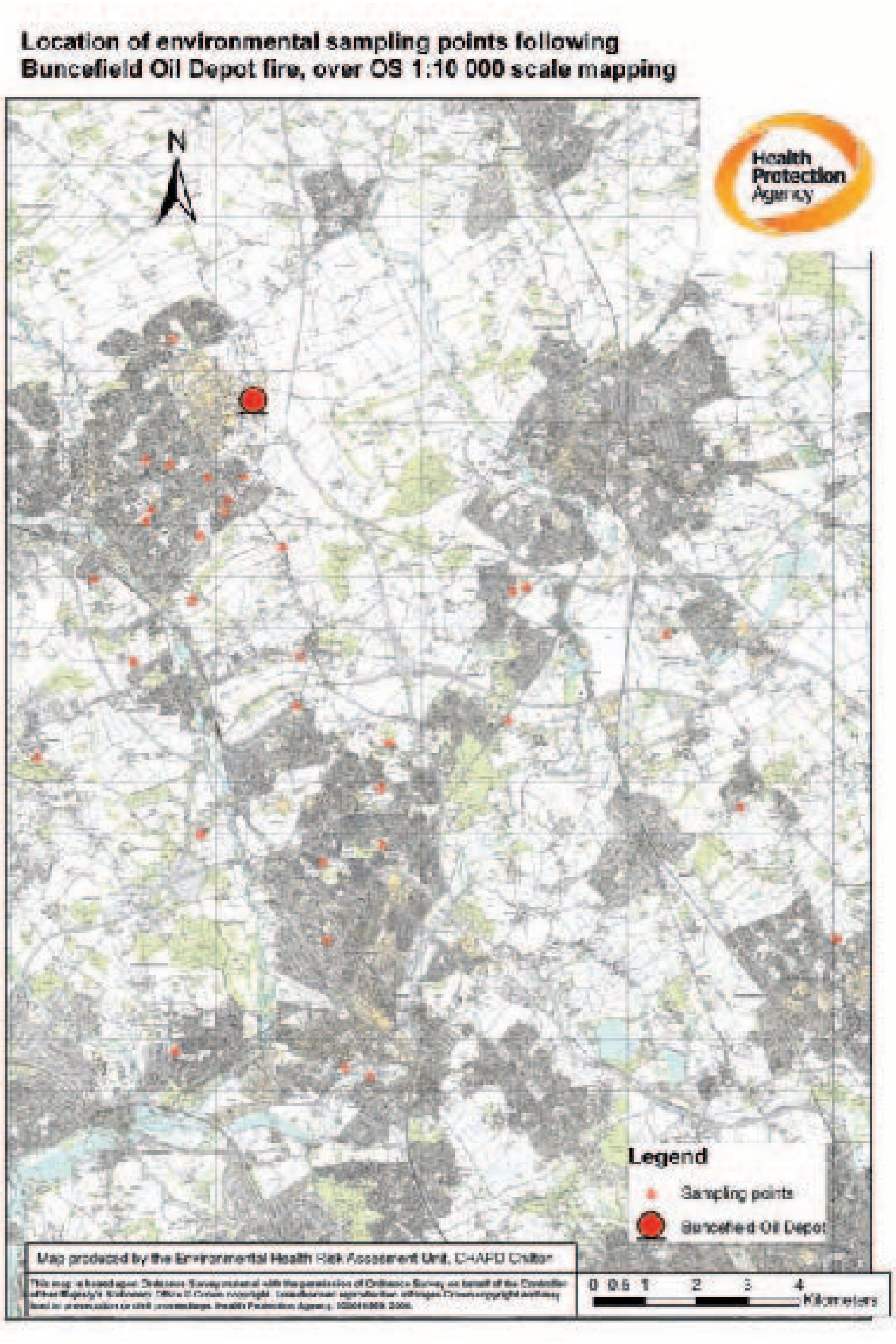
Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

7 Maps

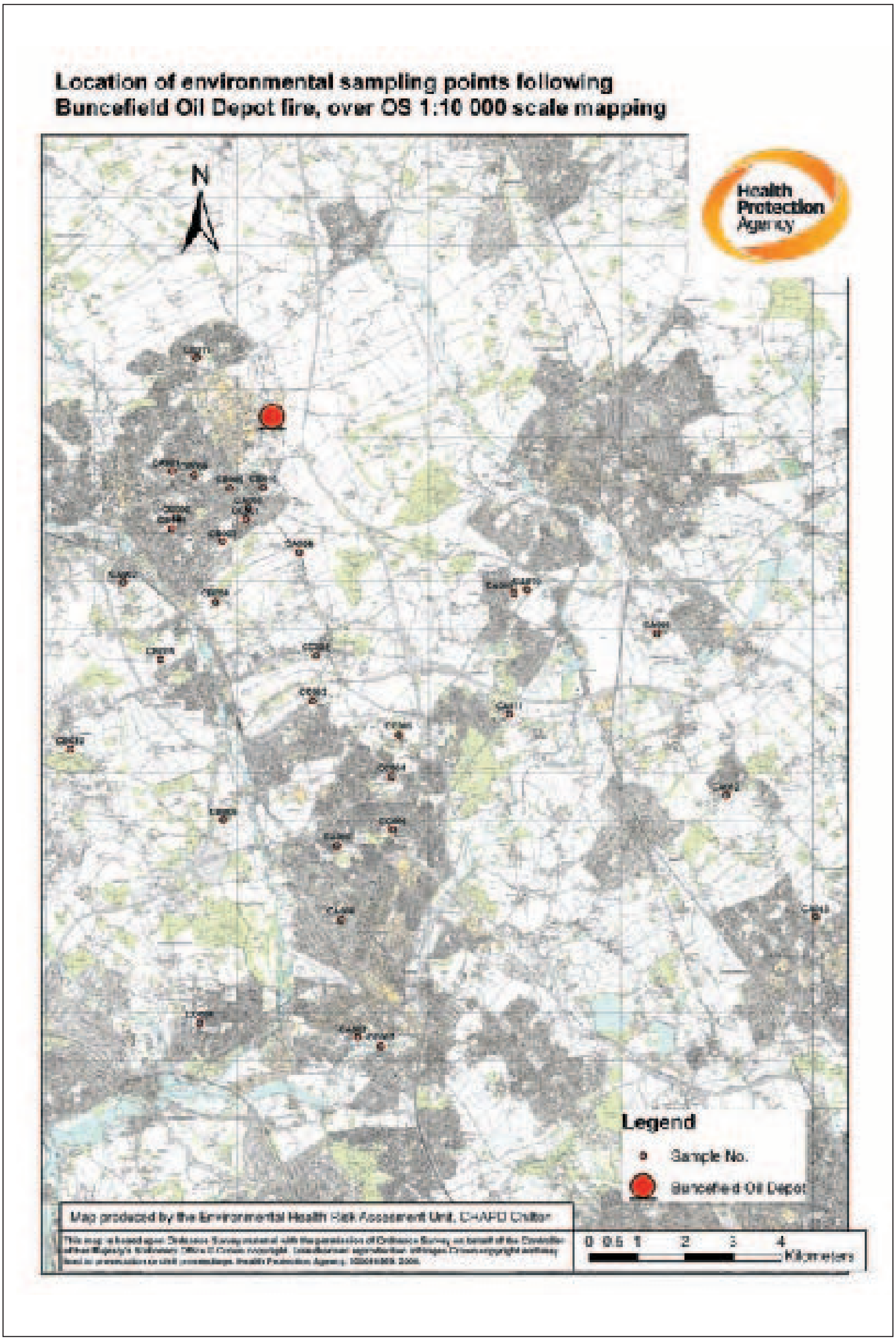
Map 1:

Sample locations (by location)



Map 2:

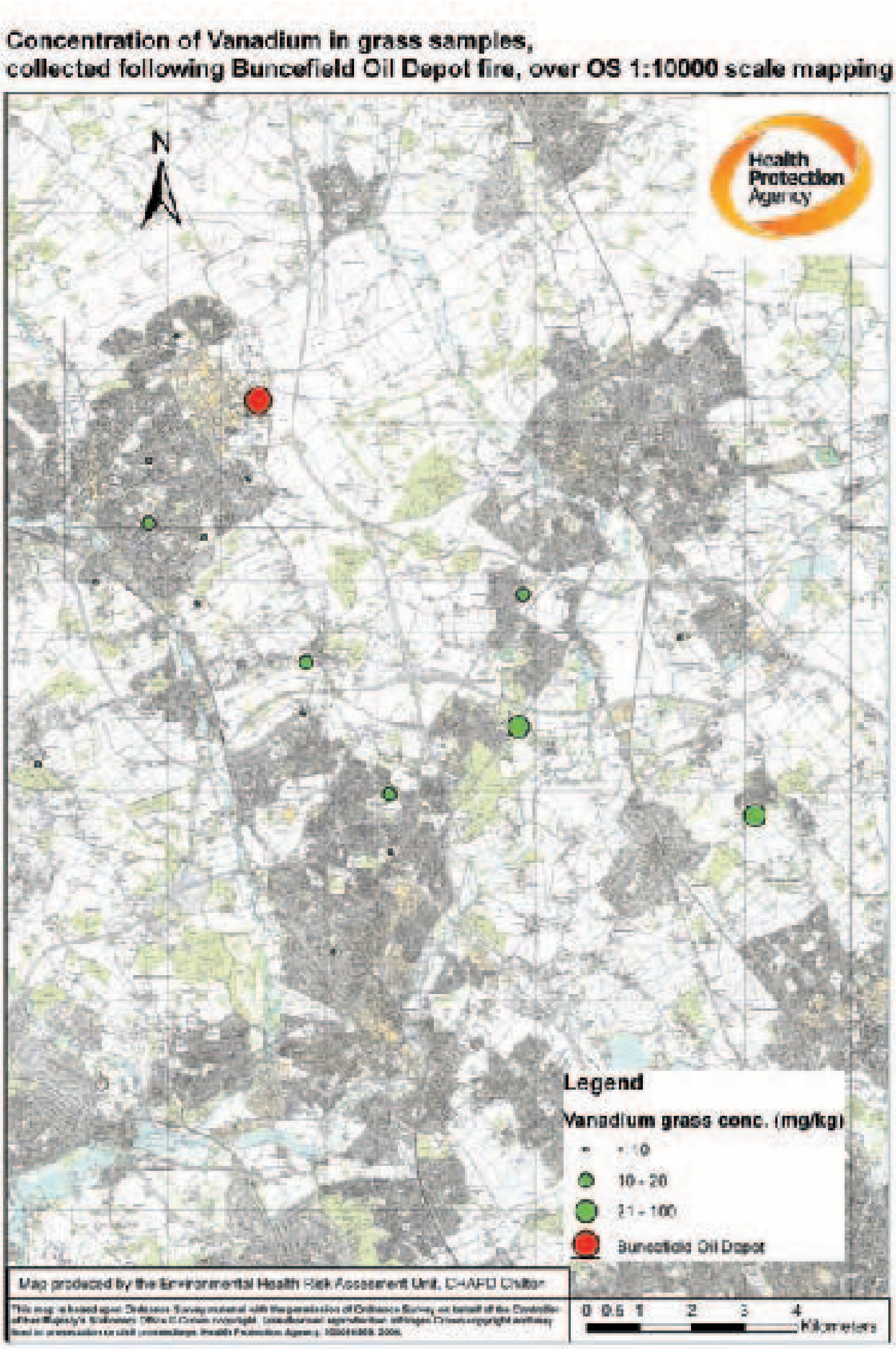
Sample locations (by sample number)



Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

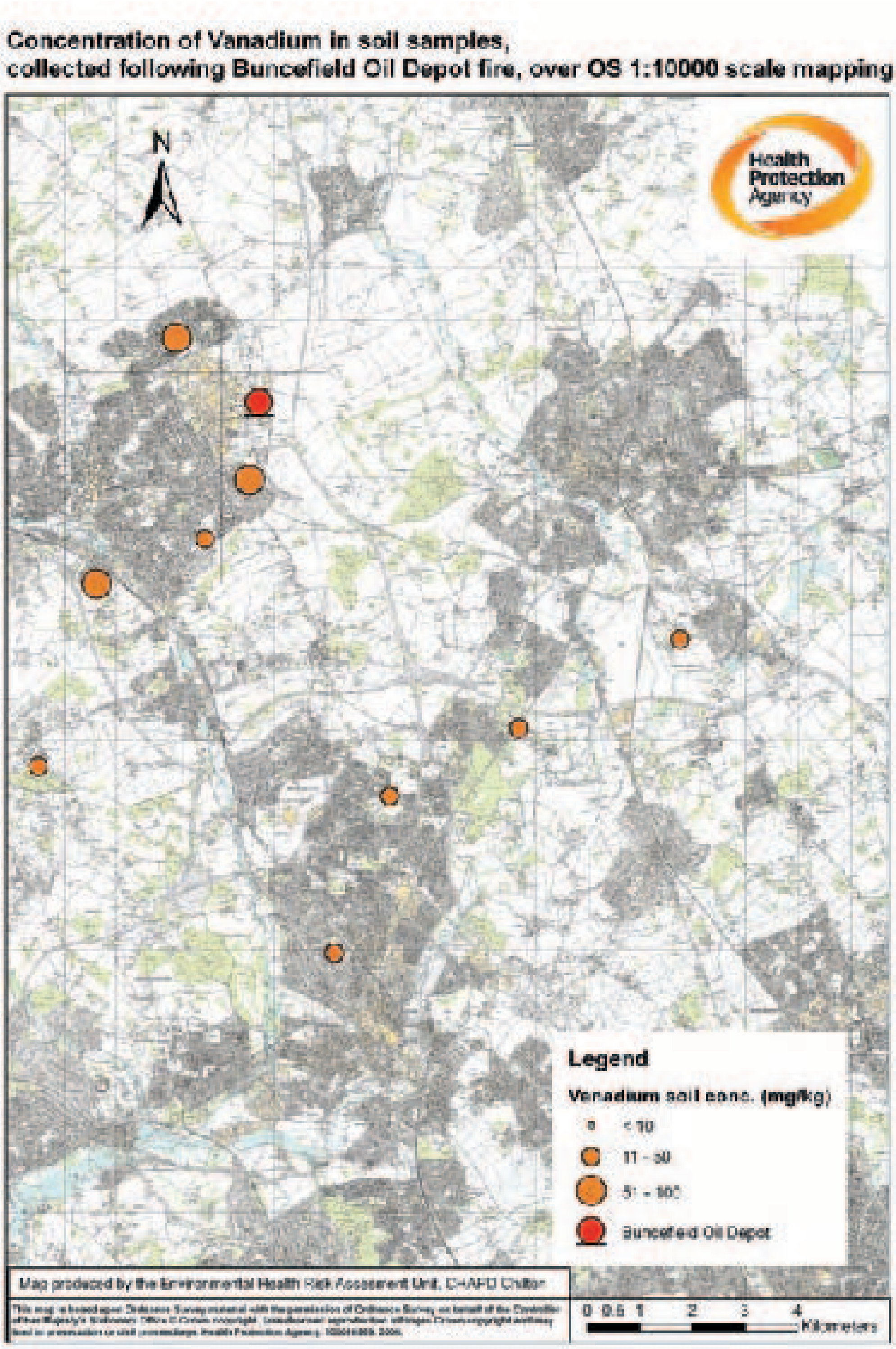
Map 3:

Vanadium concentrations in grass



Map 4:

Vanadium concentrations in soil



Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Map 5:

Nickel concentrations in grass

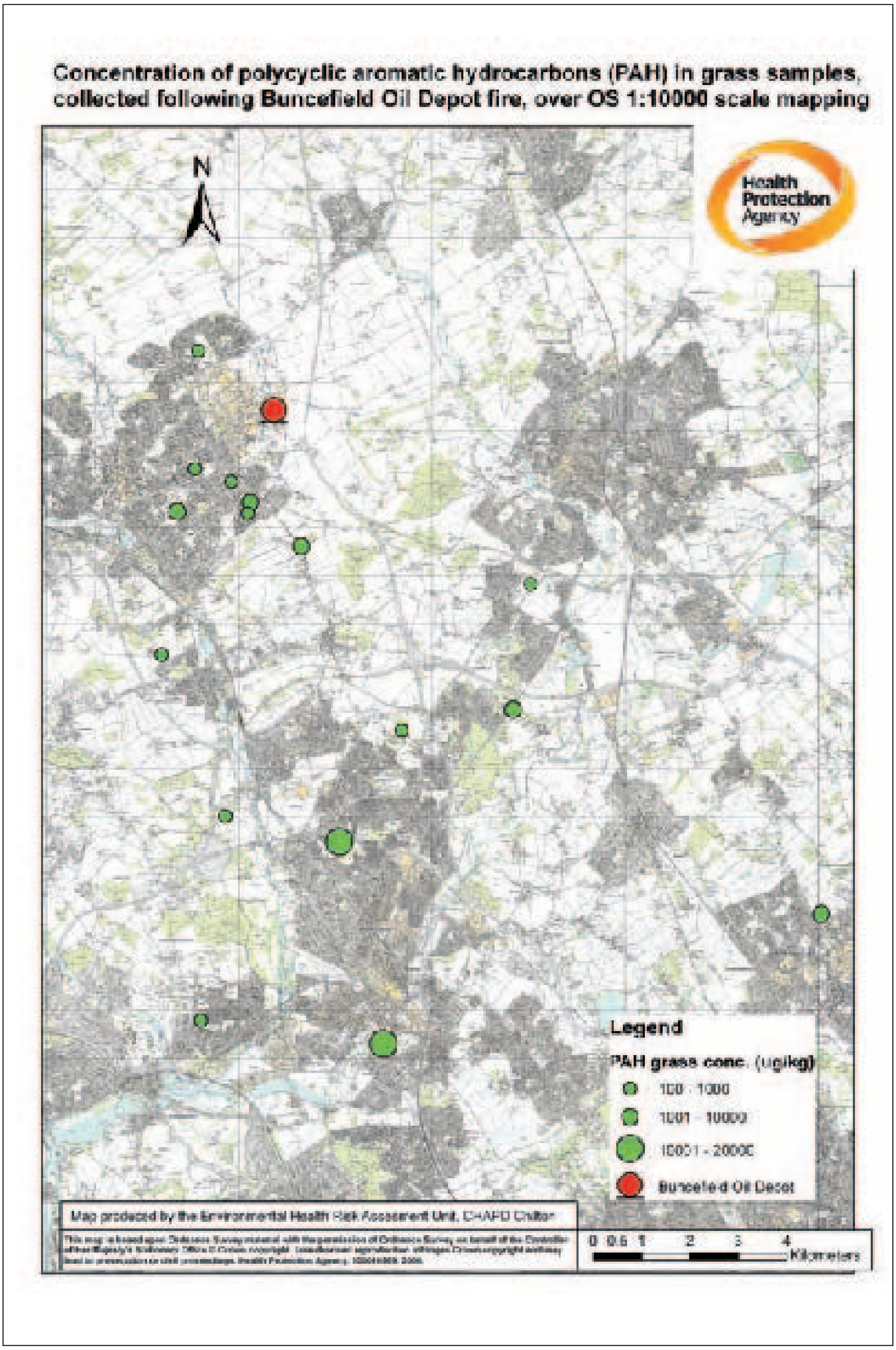
Map 6:

Nickel concentrations in soil

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Map 7:

PAH concentrations in grass



Map 8:

PAH concentrations in soil

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Appendix A: Dispersion models used to identify sample locations

AERMOD / AMDS dispersion models

AERMOD dispersion model with a plume rise of 100 metres, 09.00 13th December.

ADMS dispersion model with a plume rise of 100 metres, 09.00 13th December.

AERMOD dispersion model with a plume rise of 200 metres, 09.00 13th December.

ADMS dispersion model with a plume rise of 200 metres, 09.00 13th December.

AERMOD dispersion model with a plume rise of 100 metres, 15.00 13th December.

ADMS dispersion model with a plume rise of 200 metres, 15.00 13th December.

AERMOD dispersion model with a plume rise of 200 metres, 17.00 13th December.

ADMS dispersion model with a plume rise of 150 metres, 12.00 14th December 2005.

AERMOD dispersion model with a plume rise of 100 metres, 09.00 13th December.

ADMS dispersion model with a plume rise of 200 metres, 12.00 14th December.

NAME dispersion models

Run name: Fire_low_20051312;

Run time 1535 UTC 13/12/2005;

Time ending 12/13/2005 (6:00:00 PM to 11:00:00 PM).

CHEMETs

Date produced	Time period
11/12/15	08.12
11/12/15	08.34
11/12/15	11.44
11/12/15	17.30 – 21.00
11/12/15	21.00 – 01.00
12/12/05	05.00 – 11.00
12/12/05	13.00 – 16.00
12/12/05	16.00 – 19.00
12/12/05	19.00 – 22.00
12/12/05	22.00 – 06.00
13/12/05	06.00 – 12.00
13/12/05	09.00 – 12.00
13/12/05	11.20 – 14.00
13/12/05	12.00 – 13.00
13/12/05	13.00 – 14.00
13/12/05	14.00 – 15.00
13/12/05	15.00 – 16.00
13/12/05	16.00 – 17.00
13/12/05	17.00 – 18.00
13/12/05	18.00 – 19.00
13/12/05	19.00 – 20.00
13/12/05	20.00 – 21.00
13/12/05	21.00 – 22.00
13/12/05	22.00 – 23.00
13/12/05	23.00 – 00.00
14/12/05	00.00 – 03.00
14/12/05	03.00 – 06.00
14/12/05	06.00 – 09.00
14/12/05	09.00 – 12.00
14/12/05	16.18
15/12/05	06.30 – 09.30
15/12/05	10.30 – 18.30
15/12/05	18.00 – 06.00

Appendix B

Sample locations

Sample	Sample No.	Eastings	Northings	Sample Point Name	Distance from depot (m)	Distance from depot (km)	Distance from depot (miles)
1	CA001.1	506633	207294	Bradfield School	2345	2.34	1.47
1	CA001.2	506633	207294	Bradfield School	2345	2.34	1.47
1	CA001.3	506633	207294	Bradfield School	2345	2.34	1.47
2	CA002.1	505613	204968	Two Waters School	4605	4.61	2.88
2	CA002.2	505613	204968	Two Waters School	4605	4.61	2.88
2	CA002.3	505613	204968	Two Waters School	4605	4.61	2.88
3	CA003.1	508222	206522	Crosset Green	1914	1.91	1.20
3	CA003.2	508222	206522	Crosset Green	1914	1.91	1.20
4	CA004.1	509278	205608	Pimlico	2820	2.82	1.76
4	CA004.2	509278	205608	Pimlico	2820	2.82	1.76
5	CA005.1	510073	199490	Leggets Campus West	8984	8.98	5.62
5	CA005.2	510073	199490	Leggets Campus West	8984	8.98	5.62
6	CA006.1	510158	197940	Sixth Form Centre	10530	10.53	6.58
6	CA006.2	510158	197940	Sixth Form Centre	10530	10.53	6.58
7	CA007.1	510515	195478	Watford Hospital	13018	13.02	8.14
7	CA007.2	510515	195478	Watford Hospital	13018	13.02	8.14
7	CA007.3	510515	195478	Watford Hospital	13018	13.02	8.14
8	CB001.1	506626	206096	Jarman Park	3089	3.09	1.93
8	CB001.2	606626	206096	Jarman Park	3089	3.09	1.93
9	CB002.1	506711	206327	Lime Walk Primary School	2863	2.86	1.79
9	CB002.2	506711	206327	Lime Walk Primary School	2863	2.86	1.79
10	CB003.1	507688	205822	Longdean School	2748	2.75	1.72
10	CB003.2	507688	205822	Longdean School	2748	2.75	1.72
11	CB004.1	507530	204568	Abotts Hill School	3984	3.98	2.49
11	CB004.2	507530	204568	Abotts Hill School	3984	3.98	2.49
12	CB005.1	506390	203367	Kings Langley	5518	5.52	3.45
12	CB005.2	506390	203367	Kings Langley	5518	5.52	3.45
13	CB006.1	507708	200019	Langleybury Farm	8413	8.41	5.26
13	CB006.2	507708	200019	Langleybury Farm	8413	8.41	5.26
14	CB007.1	483552	214006	Oakfield Park (control)	25787	25.79	16.12
14	CB007.2	483552	214006	Oakfield Park (control)	25787	25.79	16.12
15	CC001.1	508171	206293	Woodfield School	2148	2.15	1.34
15	CC001.2	508171	206293	Woodfield School	2148	2.15	1.34
15	CC001.3	508171	206293	Woodfield School	2148	2.15	1.34
15	CC001.4	508171	206293	Woodfield School	2148	2.15	1.34
16	CC002.1	509628	203447	Meadow Way	5008	5.01	3.13

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Appendix B- *continued*

Sample locations

Sample	Sample No.	Eastings	Northings	Sample Point Name	Distance from depot (m)	Distance from depot (km)	Distance from depot (miles)
16	CC002.2	509628	203447	Meadow Way	5008	5.01	3.13
17	CC003.1	509576	202505	Parmiter's School	5929	5.93	3.71
17	CC003.2	509576	202505	Parmiter's School	5929	5.93	3.71
18	CC004.1	511211	200933	Watford Leisure Centre	7845	7.85	4.90
18	CC004.2	511211	200933	Watford Leisure Centre	7845	7.85	4.90
19	CC005.1	511363	201800	Abbots Langley School	7084	7.08	4.43
19	CC005.2	511363	201800	Abbots Langley School	7084	7.08	4.43
20	CC006.1	511241	199821	Stanborough Park	8915	8.92	5.57
20	CC006.2	511241	199821	Stanborough Park	8915	8.92	5.57
21	CC007.1	510987	195302	Rookery House Estate	13265	13.26	8.29
21	CC007.2	510987	195302	Rookery House Estate	13265	13.26	8.29
22	CC008.1	507203	195788	York Mead School	12674	12.67	7.92
22	CC008.2	507203	195788	York Mead School	12674	12.67	7.92
23	CB008.1	507080	207213	Adefield School	2004	2.00	1.25
23	CB008.2	507080	207213	Adefield School	2004	2.00	1.25
24	CB009.1	507835	206945	Ritcroft Close	1676	1.68	1.05
24	CB009.2	507835	206945	Ritcroft Close	1676	1.68	1.05
25	CB010.1	508537	206957	Leverstock Green	1425	1.43	0.89
25	CB010.2	508537	206957	Leverstock Green	1425	1.43	0.89
26	CB011.1	507147	209659	Astley Cooper School	2030	2.03	1.27
26	CB011.2	507147	209659	Astley Cooper School	2030	2.03	1.27
27	CB012.1	504507	201502	Chiperfield	8056	8.06	5.03
27	CB012.2	504507	201502	Chiperfield	8056	8.06	5.03
28	CA008.1	516751	203914	Knapsbury	9188	9.19	5.74
28	CA008.2	516751	203914	Knapsbury	9188	9.19	5.74
29	CA009.1	513768	204738	Chiswell Green	6223	6.22	3.89
29	CA009.2	513768	204738	Chiswell Green	6223	6.22	3.89
30	CA010.1	514045	204824	Chiswell Green	6402	6.40	4.00
30	CA010.2	514045	204824	Chiswell Green	6402	6.40	4.00
30	CA010.3	514045	204824	Chiswell Green	6402	6.40	4.00
31	CA011.1	513681	202225	Smug Oak	7901	7.90	4.94
31	CA011.2	513681	202225	Smug Oak	7901	7.90	4.94
32	CA012.1	518192	200534	Radlett	12297	12.30	7.69
32	CA012.2	518192	200534	Radlett	12297	12.30	7.69
33	CA013.1	520062	197994	Hertwood School	15376	15.38	9.61
33	CA013.2	520062	197994	Hertwood School	15376	15.38	9.61

Appendix C: Data from the EA Soil and Herbage Survey[4]

Heavy Metals

Table 1. Summary of heavy metals data. All values are mg kg^{-1} (dry weight).

Heavy metal	Soil samples				
	Buncefield (median)	*UK SHS rural median*	*UK SHS rural upper 95%ile*	*UK SHS urban median*	*UK SHS urban upper 95%ile*
Cadmium	0.39	0.29	1.15	0.29	1.22
Chromium	27.0	29.8	59.4	24.5	42.9
Copper	21.4	17.4	43.3	31.8	164.6
Lead	60.2	40.8	157.6	115.5	314.7
Nickel	16.7	16.6	34.2	17.75	52.0
Zinc	138.0	79.5	224.0	112.0	420.6
Heavy metal	**Grass samples**				
	Buncefield (median)	*UK SHS rural median*	*UK SHS rural upper 95%ile*	*UK SHS urban median*	*UK SHS urban upper 95%ile*
Cadmium	0.175	0.10	0.31	0.13	0.47
Chromium	10.8	1.0	4.58	1.16	11.85
Copper	25.6	7.03	11.5	9.8	22.7
Lead	15	1.00	5.4	4.4	35.2
Nickel	7.33	1.19	3.9	2.8	7.73
Zinc	50.7	32.0	53.5	50.0	104.4

Polycyclic aromatic hydrocarbons (PAHs)

Table 2. Summary of total of 16 US EPA (Method 610) parent PAH data. All values are mg kg^{-1} (dry weight)

Media SPAH	Samples				
	Buncefield (median)	*UK SHS rural median*	*UK SHS rural upper 95%ile*	*UK SHS urban median*	*UK SHS urban upper 95%ile*
Soil* n=13	3.10	0.936	7.98	10.5	42.7
Grass* n=16	0.831	0.102	0.499	0.305	3.44

* Note: UK SHS data for 22 PAHs

Dioxins and furans

Table 3. Summary of dioxin and furan data (expressed as ng TEQ WHO kg^{-1} dry weight)

Media SI-TEQ	Samples				
	Buncefield (median)	*UK SHS rural median*	*UK SHS rural upper 95%ile*	*UK SHS urban median*	*UK SHS urban upper 95%ile*
Soil n=6	4.71	2.53	14.41	11.11	34.0
Grass* n=6	1.87	1.02	6.87	0.90	6.50

* Note: urban herbage median is lower than rural

4 (Barraclough, personal communication, 2006).

Appendix 1 Environmental Impacts of the Buncefield Oil Depot Explosion

Appendix D: PAH profiles

Figure 2. Soil ratios of concentrations of individual parent PAHs to benzo(a)pyrene.

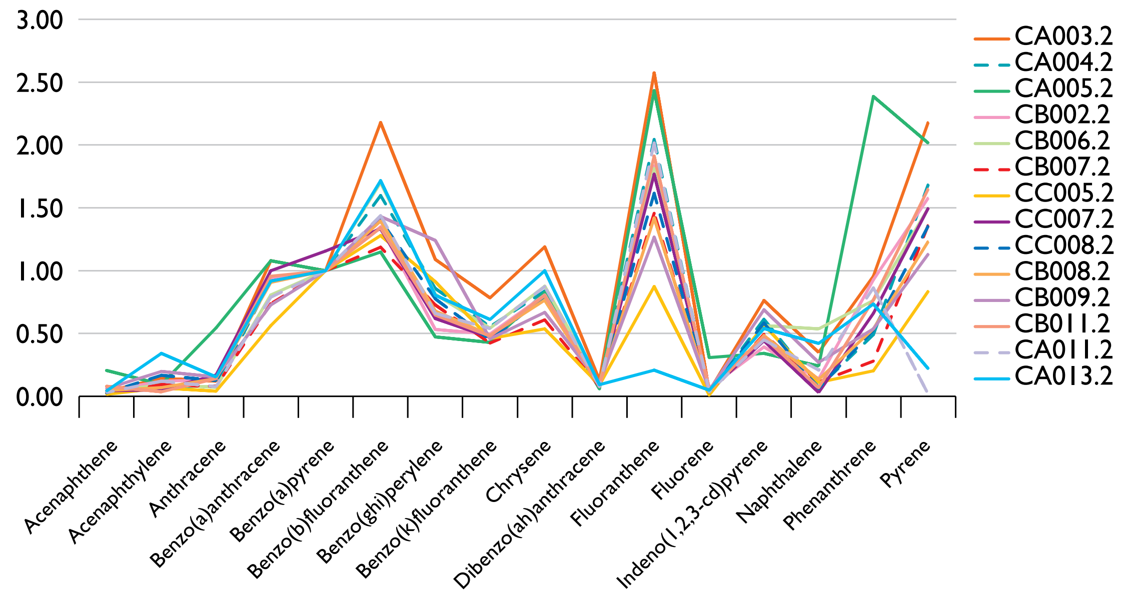
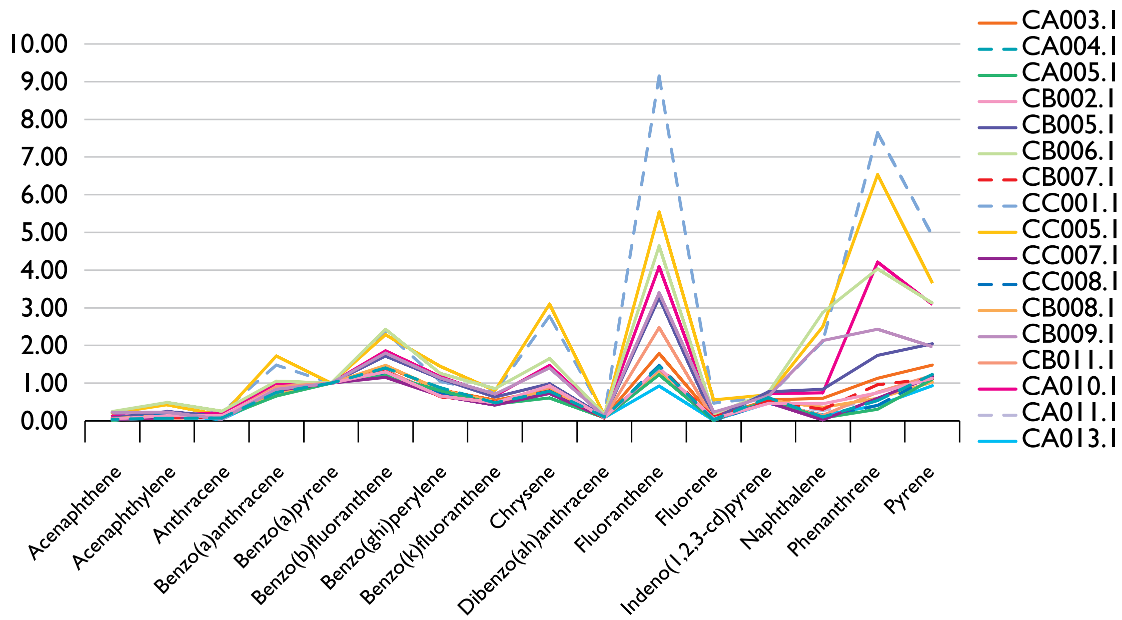


Figure 3. Grass ratios of concentrations of individual parent PAHs to benzo(a)pyrene.



Appendix 2

Study of Accident and Emergency Attendances in Hemel Hempstead and Watford

Photo: Hertfordshire Fire and Rescue Service

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Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

Executive Summary

Purpose

To describe the results of the study of A&E attendance in Watford and Hemel Hempstead, following the Buncefield oil depot explosion and consequent fire on 11/12/2005.

Objectives

- To describe the impact of the Buncefield fire on A&E services in Hemel Hempstead and Watford, for the period 06:00 Sunday 11/12/05 to 18:00 Wednesday 14/12/05.
- To describe the number of attendees with health conditions attributable to the fire and the type of presentation.
- To estimate the exposure of the population to the fire by assessing health effects by distance to the fire.

Study design

Retrospective descriptive study.

Methods

A&E case records were reviewed to identify all the people who attended with conditions resulting from the Buncefield oil depot fire. A questionnaire was completed for each selected A&E case record using the information contained in the A&E record.

Results

- In total 244 people sought medical attention from the A&E departments in Hemel Hempstead and Watford.
- The A&E department in Hemel Hempstead experienced a 65% increase of attendance during the first day of the fire.
- 117 people presented with symptoms that were attributed to the fire.
- Approximately half of those presenting with symptoms had respiratory complaints (N=66), including three people presenting with asthma attacks. The second most common presentation was injuries, followed by headache and anxiety. Two people suffered from cardiac complaints.
- Most patients (209, 90%) were discharged home without a need for further follow up. Three people were admitted to hospital, fifteen were sent to their GP for follow up, three were referred to an orthopedic surgeon, and one to a cardiologist.

Conclusions

Despite the extensive and protracted fire, the public health impact as measured by A&E attendance was relatively small, indicating that exposure to hazardous substances was minimal. The findings of this study need to be taken into account in the context of other investigations into the health effects of the Buncefield fire.

Photo: Rob Holder

Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

ACKNOWLEDGEMENTS

In alphabetical order:

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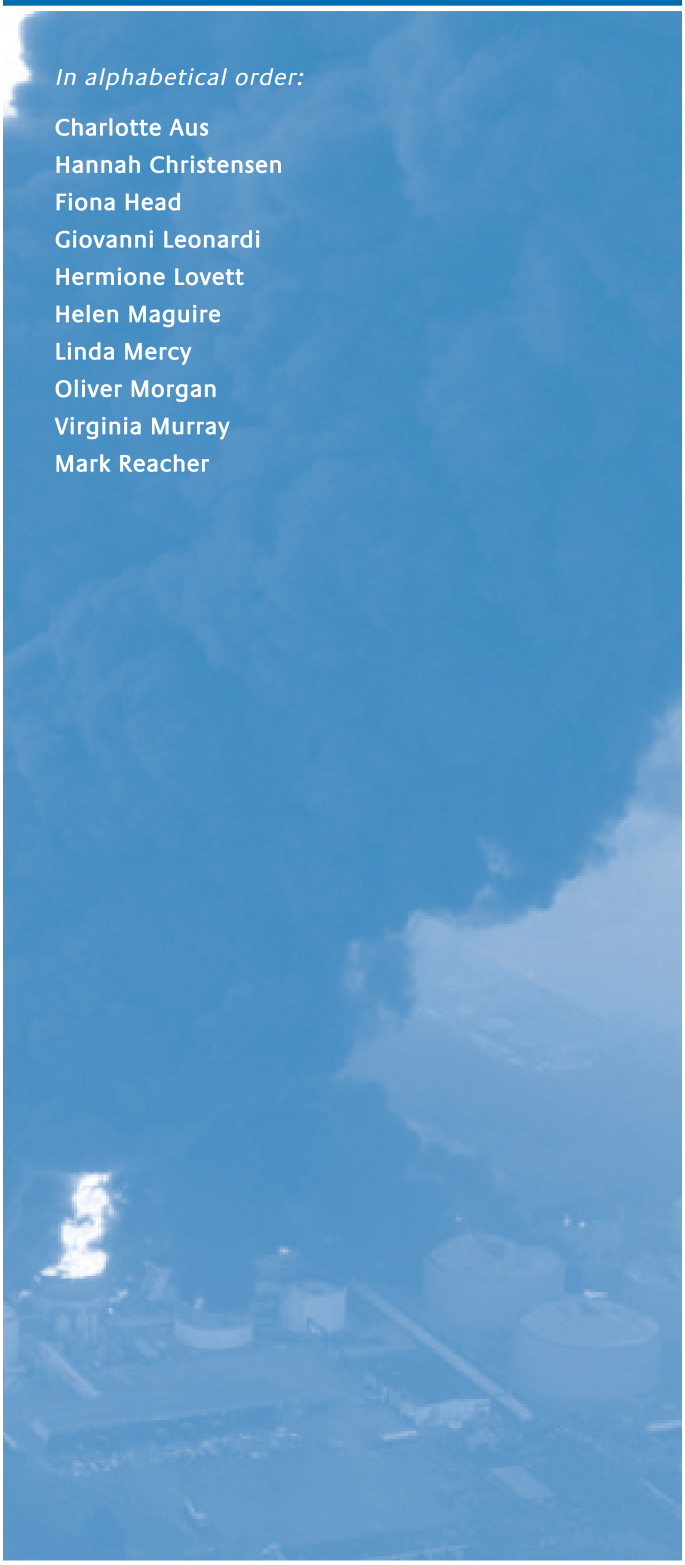


1 Purpose

The purpose of this paper is to describe the results of a study of Accident and Emergency (A&E), attendance in Watford and Hemel Hempstead, following the Buncefield oil depot explosion and consequent fire that took place on 11/12/2005.

2 Background

During the early hours of Sunday 11/12/05, there was an explosion at the Buncefield oil depot, near Hemel Hempstead, Hertfordshire. The blast resulted in a large fire, which blazed for several days. Local residents were advised to stay at home and close windows.

Exposure to combustion pollutants in the smoke such as: carbon dioxide, carbon monoxide, sulphur dioxide, hydrocarbons, particulates and volatile organic compounds, is known to have the potential to cause short or long term adverse health effects among those exposed[6]. Fortunately in this incident, the fire's high combustion efficiency and the favourable local wind and weather conditions[5], reduced the fire's potential health impact on local populations. The weather conditions were stable which allowed the smoke to rise to the higher layers of the atmosphere. In addition, most hazardous chemicals burnt and were reduced to carbon and water as a result of extreme high combustion temperatures[1].

The Health Protection Agency (HPA) has an important role in assessing the health impact of exposure to environmental hazards. In the acute phase of the incident a surveillance system was set up at the Hertfordshire A&E departments to determine the health impact of the event by identifying the number and type of presenting complaints. Reporting was incomplete in the acute phase, and therefore it was agreed that a retrospective study was needed to determine the acute health impact as a result of exposure to the fire.

3 Objectives

- To describe the impact of the Buncefield fire on A&E services of Hemel Hempstead and Watford, for the period 06:00 Sunday 11/12/05 to 18:00 Wednesday 14/12/05.
- To describe the number of attendees with health conditions attributable to the fire and type of presentation.
- To estimate the exposure of the population to the fire by assessing health effects by distance to the fire.

4 Methods

4.1 Study design

Retrospective descriptive study of Watford and Hempstead A&E case records.

4.2 Case definition

Any individual who attended Watford or Hemel Hempstead A&E department as a result of exposure to the Buncefield Oil Depot Fire.

4.3 Study population

- All individuals who attended Watford and Hempstead A&E departments from 06:00 Sunday 11/12/05 and 18:00 Wednesday 14/12/05.

4.4 Study period

The study covered the period between 11/12/05 06:00 – 14/12/05 18:00. This period was selected based on the following factors:

- Time of explosion: 06:00 on 11/12/05 (source: BBC).
- Time of main fire extinguish: 02:00 am on 14/12/05 (source: BBC).
- Time of smoke clearance: a few hours after 02:00 on Wednesday 14/12/05.
- 18:00 on 14/12/05 was selected as the end of the period of study to allow the inclusion of any delayed respiratory and cardiac illness related to the Buncefield oil fire.

4.5 Study characteristics

The study comprised the identification of all A&E case records within the period 06:00 Sunday 11/12/05 to 18:00 Wednesday 14/12/05 with a clear statement indicating that the attendance was a direct result of the Buncefield oil depot fire. Subsequently information on exposure, date and time of A&E attendance, presenting complaint, past medical history, diagnosis, and follow up was recorded onto a questionnaire (appendix 2).

4.6 Data collection

In January 2006 a list of A&E attendances in Watford and Hemel Hempstead, between 06:00 on 11/12/05 and 18:00 on 14/12/05 was obtained. All case records were carefully read and selected for relevance to the oil depot fire. Information was recorded using a standardised questionnaire. Data was entered onto an Access database and analysed using Excel.

5 Results

5.1 Impact on A&E services

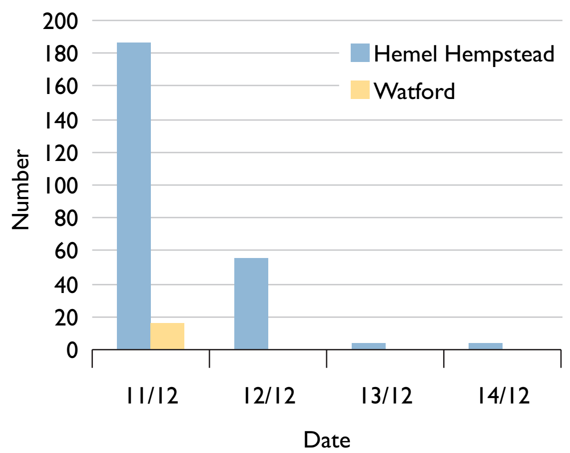
The search of A&E records identified 244 people who attended A&E in Hemel Hempstead or Watford as a result of the Buncefield oil depot fire.

Of all attendances resulting from the fire, 229 (94%) sought medical care in the Hemel Hempstead A&E department, and 15 (6%) sought medical care in Watford A&E.

On Sunday 11/12/05 the greater part of the workload in Hemel Hempstead A&E related to the Buncefield oil depot fire with 63% of all attendances due to this incident. The number of attendances resulting from the oil depot fire declined sharply during the second day after the explosion. The last related attendance was recorded between 10:00 and 12:00 on 14/12/05 (figure 1).

In total 15 people attended the A&E in Watford, 8 (53%) were members of the emergency services, and 7 (47%) were members of the public. All attendances to Watford A&E took place on the first day of the fire (11/12/05), (figure 1).

Figure 1: Distribution of A&E attendances by A&E department and date (N=244)



Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

Table 1. Impact on A&E department in Hemel Hempstead. (Absolute numbers of attendances related to the fire)

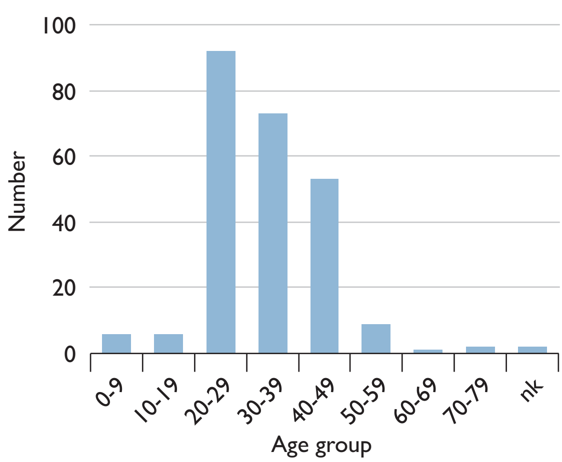
Date	Attendance related to Buncefield (N)	(%)	Attendance related to other causes (N)	(%)	Total (N)
11/12	170	(63%)	101	(37%)	271
12/12	54	(29%)	131	(71%)	185
13/12	2	(2%)	116	(98%)	118
14/12	2	(2%)	138	(98%)	140

The majority of people who attended A&E were male (195/244; 80%). Most people were aged between 20-49 years, (218/244; 89%) (figure 2).

The majority of attendees arrived by means of their own transport (220/244; 90%), 9 out of the 244 (4%) were transported by ambulance, and 2 (1%) were brought in by police car.

In total 25 (10%) of all persons who attended the A&E required further follow up. Three were admitted to hospital, fifteen were sent to their GP for follow up, and seven were either referred to the A&E, orthopaedic or cardiologist for further follow up, (table 3). All people needing further follow up, had attended Hemel Hempstead A&E.

Figure 2: Age distribution of all A&E attendees (N=244)



6 Attendances by population group

The attendees fell into three groups; workers at the depot at the time of the explosion (17/244; 7%), emergency services deployed at scene (mainly police officers and fire fighters), (187/244; 77%), and members of the public; mainly residents from Hemel Hempstead (40/244; 16%).

All oil depot workers and most members of the public (29/40; 66%) attended on the 1st day of the fire, 11/12/05. (figure 3). Members of the emergency services were advised by senior police officers to attend the A&E for a medical check up. This means that some members of the emergency services presented asymptomatic (table 2). It is not possible to estimate how many emergency service workers would have attended the A&E, if that advice had not been given. The advice was revoked during the course of 12/12/05, which was followed by a dramatic drop in attendance among members of the emergency services.

Table 2: Distribution of symptomatic and asymptomatic cases

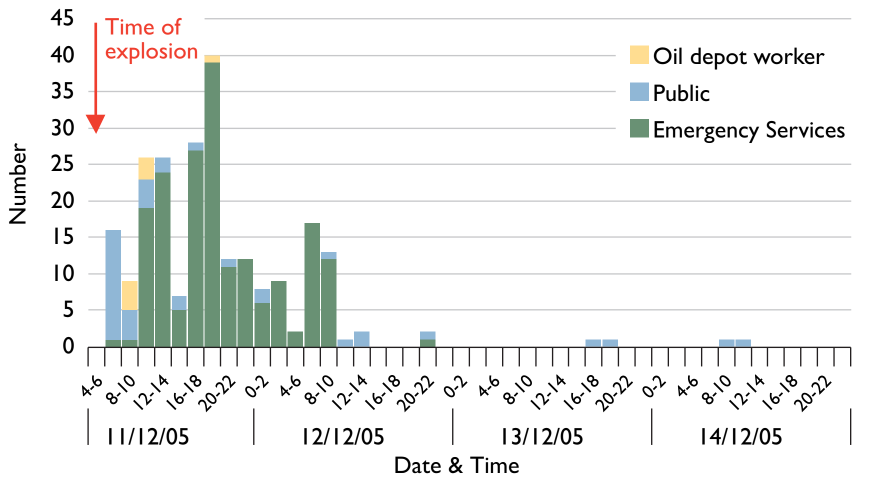
	Symptomatic	Asymptomatic	Total
Emergency Services	63 (34%)	124 (66%)	187 (77%)
Worker	16 (94%)	1 (6%)	17 (7%)
Public*	38 (95%)	0 (0%)	40 (16%)
Tot No:	117 (48%)	127 (52%)	244 (100%)

* Insufficient data was available for 2 members of the public.

6.1 Emergency services

Due to concerns about the potential health effects related to exposure to the smoke, emergency service workers, mostly police officers, were initially advised by their senior colleagues to attend A&E for a medical check-up. During the 12/12/05, once more information became available, this advice was withdrawn. In total 187 emergency service workers attended A&E. 179/187 (96%) emergency service workers attended Hemel Hempstead A&E, and 8/187 (4%) attended Watford A&E. 142/187 (76%), were aged between 20-39 years (figure 4). The majority were male (159/187; 85%).

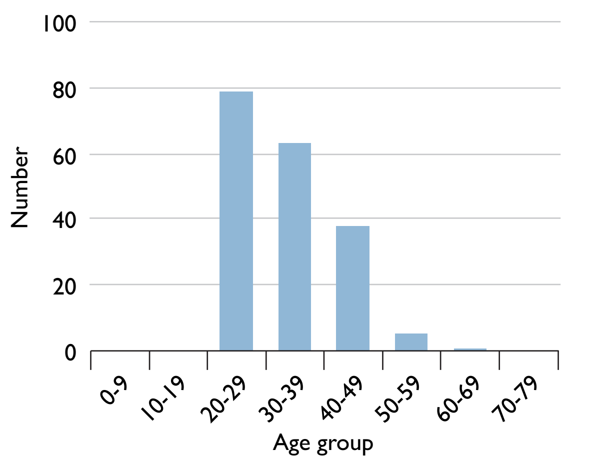
Figure 3. Distribution of A&E attendances by date and time (N=244)



Of those emergency service workers who attended A&E, 63 (34%) presented with symptoms, and some presented with multiple complaints.

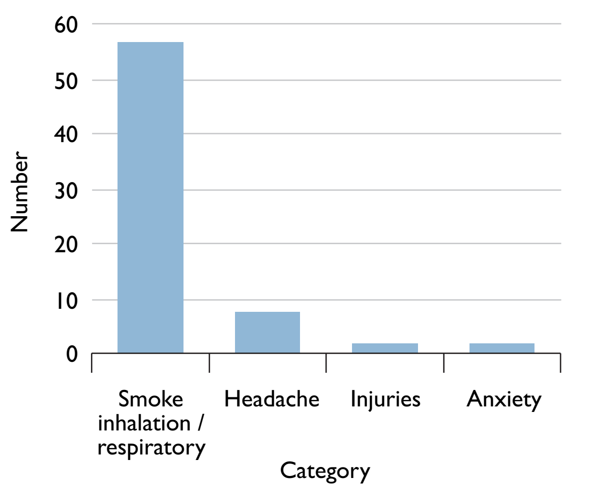
The majority of complaints were respiratory complaints 53/63 (84%), such as sore throat (30/63; 48%), cough (12/63; 19%), and shortness of breath (8/63; 13%). The second most commonly reported problem was headache (15/63; 24%) (figure 5).

Figure 4: Distribution of attendance of the emergency services by age group N=186*)



* Date of birth not available for 1 case

Figure 5: Distribution of emergency services staff by main presenting complaint (N=63)



Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

Table 3: Follow up by group (N=244)

	Follow up in A&E	Admitted to hospital (N)	Follow up by GP (N)	Cardiology referral (N)	Orthopaedic referral (N)	Not known (N)	No follow up (N)	Total (N)
Emergency services	0	0	3	0	0	2	182	187
Worker at depot	2	0	1	0	2	0	12	17
Public	1	3	11	1	1	8	15	40

In total, 3 out of 187 (2%) members of the emergency services needed medical follow up (table 3). All three were referred to their GP. One suffered from shortness of breath. Information on diagnosis was not available for the other two (table 3).

6.2 Members of the public

In total, forty members of the public sought medical care between the 11/12/05 and 14/12/05. Thirty-three (83%) attended Hemel Hempstead A&E, and 7 (17%), Watford. 23/40 (58%) attended the A&E within the first six hours after the blast.

Half the cases were female (20/40; 50%), and a relatively large proportion of cases were children aged between 0 and 19 years (10/40; 25%) (figure 6).

Thirty-eight members of the public (95%) presented with symptoms. Information on symptoms was not available for the other two. Some people presented with multiple complaints.

Injuries were the most common presentation (24/38; 63%) including lacerations (15/38; 39%), and sprains, (7/38; 18%). One person suffered a rib fracture. Eleven people (29%) had respiratory symptoms such as shortness of breath (5/38; 13%), cough, or asthma attack (both 3/38; 8%). Two people (5%) suffered from cardiac complaints. One person presented with palpitations and one with angina. Six people suffered from anxiety, (16%), five from ringing in the ears, (13%), and four presented with vomiting (11%) (figure 7).

Figure 6: Age distribution of members of the public who attended A&E (N=40)

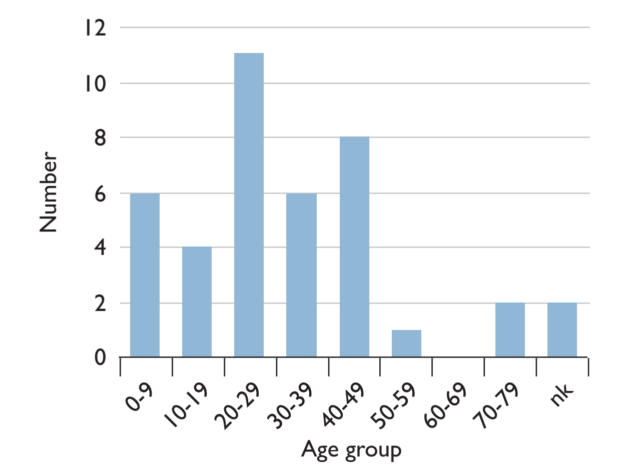
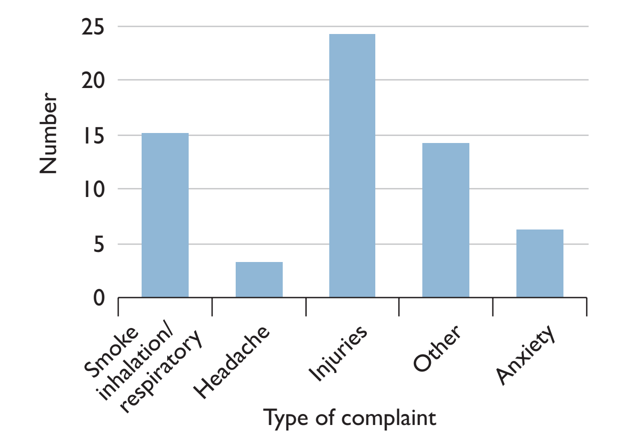


Figure 7: Distribution of members of the public by main presenting complaint (N=38)

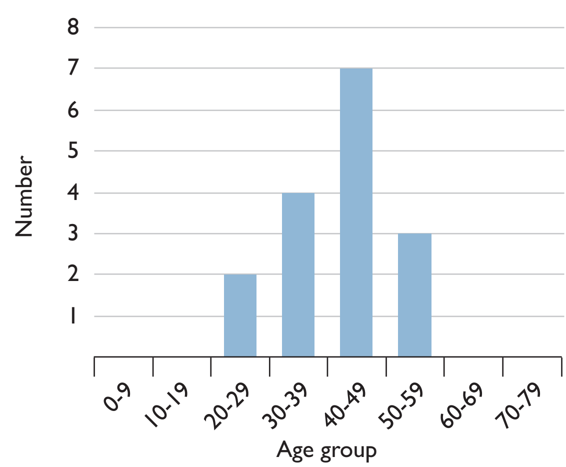


6.3 Oil depot workers

Seventeen people working at, or close to, the oil depot at the time of explosion attended A&E. All 17 attended at Hemel Hempstead. Sixteen (94%) attended within the first six hours after the initial explosion.

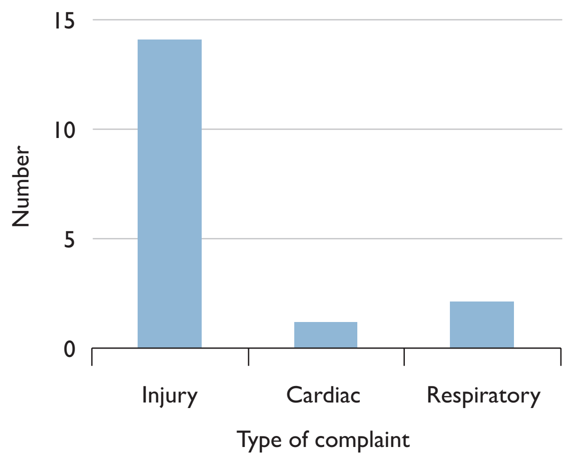
The majority of workers were aged between 40-49 years, (7/17; 41%), (figure 8). All but one were male.

Figure 8: Age distribution of oil depot workers attending the A&E (N=16)



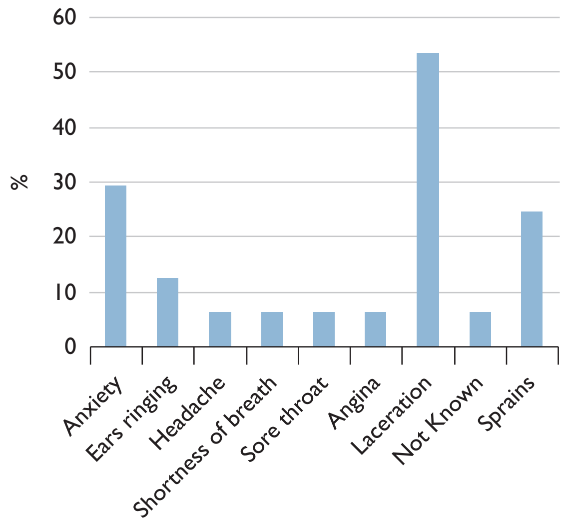
The most common type of presentation was injuries followed by respiratory irritation (figure 9).

Figure 9: Distribution of oil depot workers by main presenting complaint (N=16)



Fourteen out of the sixteen symptomatic workers, presented with injuries including lacerations and sprains. Two workers presented with respiratory complaints (shortness of breath and sore throat) and one person presented with angina pectoris. Some workers also presented with other additional complaints such as anxiety (n=5) and ringing in the ears (N=2), (figure 10).

Figure 10: Distribution of oil depot workers by presenting complaint (N=25 complaints in 17 people)



In total, 5 out of the 17 (29%) workers at the oil depot needed further medical follow up (table 3). Two were followed up in A&E for lacerations. Two had sprains and were referred to an orthopedic surgeon and one was referred to the GP for anxiety and lacerations.

Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

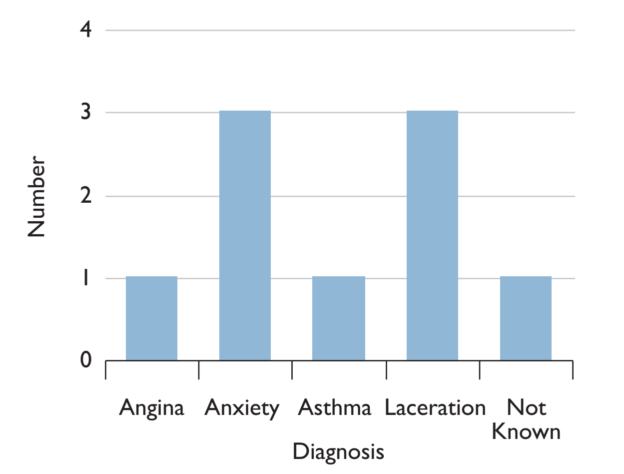
7 Mode of transport

Nine people were transported to A&E by ambulance. Two attendees were transported to A&E by police car. They were both police officers responding to the fire.

Of the nine attendees transported by ambulance, three were workers employed at the oil depot at the time of explosion, five were members of the public and one was a member of the emergency services.

The main diagnoses of the patients transported by ambulance are shown in figure 11. Some of these patients presented with multiple complaints.

Figure 11: Diagnosis of attendees arriving by ambulance (N=9)



8 Estimation of exposure

This study did not provide a direct estimation of exposure to hazardous substances. The main aim was to investigate the impact on A&E departments. However, we have used the information available to assess exposure among members of the public indirectly by mapping health effects by distance to the fire at time of exposure (table 4).

Table 4: Distance to the Buncefield oil depot of members of the public at the time of exposure grouped by presenting complaint (n = 53*)

Complaint	N	Minimum	Maximum	Average
Cardiac & Respiratory	13	0	4.67	1.8
Injuries	23	0	11.9	2.2
Other	17	0.4	2.5	1

* Insufficient data was available in 7 cases who were excluded from the calculations.

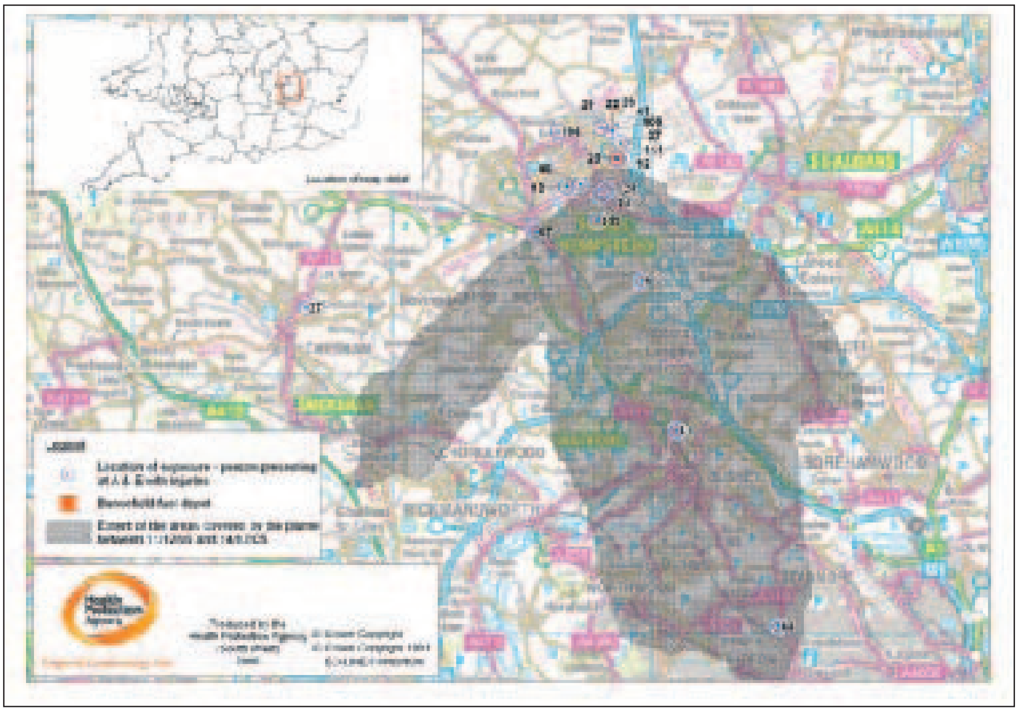
The average distance between the location at the time of injury and the oil depot was 2.2 miles. Map 1 shows the location of the members of the public at time of injury.

Four cases provided locations at the time of injury relatively far away from site (> 3 miles). When these cases are excluded the average distance is reduced to 0.92 miles.

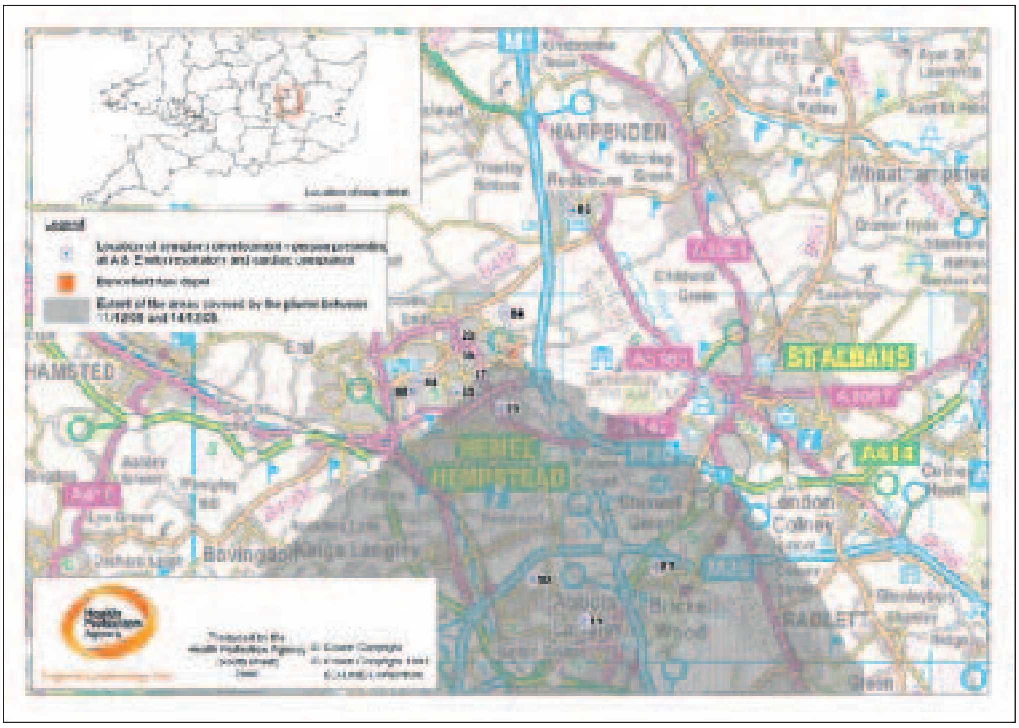
Of those members of the public who presented with respiratory or cardiac complaints, eight were living in an area covered by the plume at some point between 11/12/05 and 14/12/05. The average distance between location of residence and the oil depot among these cases was 1.9 miles. Four members of the public were not resident in an area covered by the smoke plume between 11/12/05 and 14/12/05. The average distance to the oil depot for this group was 1.7 miles (map 2).

Further work outside the scope of this study would need to be undertaken to determine if these people were under the plume at the actual time the symptoms developed.

Map 1: Location of members of the public who presented with injuries to A&E in Hemel Hempstead and Watford at the time of injury.



Map 2: Location at the time of exposure of members of the public who presented to A&E in Hemel Hempstead or Watford with respiratory or cardiac complaints.



Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

9 Discussion and Conclusions

This study describes the impact of the Buncefield oil depot fire and explosion on the acute trusts locally in the immediate period following the incident.

In total 244 people sought medical attention in an A&E department in Hemel Hempstead or Watford following the fire. Nearly 95% of attendances related to this event were recorded in Hemel Hempstead, and three quarters of those were members of the emergency services. Two thirds of the emergency service workers were asymptomatic and attended for a check up.

There were, however, 117 people who presented with symptoms that could be attributed to the fire. Of those 63 were members of the emergency services, 16 were oil depot workers and 38 were members of the public. Approximately half had symptoms of respiratory irritation such as asthma attacks, shortness of breath and sore throat or smoke inhalation. Of those only two were members of the public and they both had a previous history of respiratory complaints. The second most common presentation was injuries, followed by headache and anxiety. Three people suffered from cardiac complaints, two from angina pectoralis, and one from palpitations. Of all attendees three people were admitted to hospital, fifteen were sent to their GP for follow up, and most patients (90%) were discharged home without a need for further follow up.

This study has some limitations. We only identified cases attending to two A&E departments. People may have sought help from primary care services or from A&E departments further a field. Some records had incomplete or incorrect information. The analysis of the data on respiratory and other health effects among members of the public by distance to the fire site should be interpreted with caution because the total numbers of people public with complaints related to the fire was small and the data was incomplete. There is also some indication that data quality may be an issue. For example, some members of the public presenting with injuries reported a location at the time of exposure at significant distance from the site, which may be an error in data collection.

Despite the extensive fire and thick smoke development, the public health impact as detected by A&E attendance was relatively small. This may be due to the time of explosion; 06:00 on a sunday morning and the weather conditions. Nevertheless, the incident resulted in a significant workload for the acute trust at Hemel Hempstead where an increase in attendance of 168% was recorded on the first day of the incident.

The findings of this study need to be considered in the context of other investigations into the health effects of the Buncefield fire.

10 References

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4 J Hazard Mater. First lessons of the Toulouse ammonium nitrate disaster, 21st September 2001, AZF plant, France. 2004.

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Appendix A: Summary tables

Table 5. Impact on Accident and Emergency departments (absolute numbers of attendances related to the fire)

	Emergency Services (N)	Oil depot workers (N)	Members of public (N)	Total (N)
Hemel Hempstead(HH)	179	17	33	229
Watford	8	0	7	15
Total	187	17	40	244

Table 6. Impact on Accident and Emergency departments (absolute numbers of attendances related to the fire)

	Asymptomatic (N)	Symptomatic (N)	Total (N)
HH	122	107	229
Watford	5	10	15
Total	127	117	244

Table 7. Distribution of symptomatic and asymptomatic cases

	Asymptomatic (N)	Symptomatic (N)	Total (N)
Emergency Services	63 (26%)	124 (51%)	187 (77%)
Worker	16 (7%)	1 (0.5%)	17 (7%)
Public	38 (16%)	2 (1%)	40 (16%)
Total	117 (48%)	127 (52%)	244 (100%)

TABLE 8. Number and type of injuries

	Laceration (N)	Sprain (N)	Fracture (N)	Not (N)
HH	23	10	1	1
Watford	2	1	0	0
Total	25	11	1	1

Table 10. Number and type of presentations with cardiac and mental health complaints

	Mental Health	Cardiac complaints	
	Anxiety *(N)*	*Angina* *(N)*	*Palpitations* *(N)*
HH	12	2	1
Watford	0	0	0
Total	12	2	1

Photo: Hertfordshire Fire and Rescue Service

Table 9: Number and type of presentations with respiratory complaints

	Asthma (N)	Cough (N)	Sore throat (N)	Shortness of breath (N)	Smoke inhalation (N)	UTRI (N)	Total (N)
HH	1	15	30	11	3	2	62
Watford	2	0	2	3	2	0	9
Total	3	15	32	14	5	2	71

Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

Appendix B: Questionnaire used to collect data from A&E records

QUESTIONNAIRE (Final 17/01/06)

BUNCEFIELD OIL DEPOT FIRE
RECORD OF INDIVIDUAL'S CONTACT WITH
HEALTH SERVICES AS A RESULT OF THE FIRE
In strict medical confidence

This questionnaire aims to identify and collect basic data on people who presented to health services as a result of the Buncefield Oil Depot Fire.
Please complete this form for each presentation of an individual to a health service as a result of the Buncefield Oil Depot Fire.

SECTION 1 - Details of place and time of presentation

1.1 Where was this patient seen?

Watford General Accident and Emergency Department ☐

Hemel Hempstead Accident and Emergency Department ☐

***Occupational Health Service* (please specify where)** ☐

1.2 Form completed by *(name)*

1.3 Date of first contact with this health service *(dd/mm/yyyy)*

1.4 Time of first contact with this health service — **am/pm** *(Please circle)*

SECTION 2 - Patient details

2.1 Surname

2.2 Forename

2.3 *Sex* **(please tick)** *male* ☐ *female* ☐

2.4 NHS Number

2.5 Hospital Number

2.6 A&E Number

2.7 Occupational Health number

2.8 Other unique identifying number

2.9 Date of Birth *(dd/mm/yyyy)*

2.10
Home Address
1st line of address
Town
County
Postcode *(Required)*

2.11 Name of GP

2.12 Name of Surgery

2.13
Surgery Address
1st line of address
Town
County
Postcode *(Required)*

Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

SECTION 3 - Clinical Details

3.1 Did this person presenting to the health care provider have an illness and / or injury which either that person and / or the attending clinician believed to have been a result of the Buncefield Oil Depot Fire?

Yes ☐ ***No*** ☐

3.2

How did this person arrive at this health care provider? **(please tick one box)**

999 call ☐

Non-urgent ambulance ☐

Patient own transport (e.g. car, bus) ☐

Walk ☐

3.3

What was the route of referral ? **(please tick one box)**

GP referral ☐

Self-referral ☐

Advised to attend by occupational health physician ☐

Other ☐ ***Please specify*** ____________

3.4 *What was the presenting complaint?* **(please tick applicable boxes)**

Injury ☐ ***Please specify*** ____________

Cardiac Problems ☐ ***Please specify*** ____________

Respiratory problem	☐	***Please specify***	
Other	☐	***Please specify***	

3.5 **Does this patient have a past medical history of?** *(You may tick more than one box)*

Cardiovascular problems **(If yes , please specify)**	***Yes*** ☐	***No*** ☐	***Unsure*** ☐
Respiratory problems **(If yes , please specify)**	***Yes*** ☐	***No*** ☐	***Unsure*** ☐
Mental health problems **(If yes , please specify)**	***Yes*** ☐	***No*** ☐	***Unsure*** ☐

3.6 *What was the diagnosis on this attendance?*

A&E Code (if known)

3.7 *What was the outcome of this attendance?* **(Please tick boxes that apply)**

Discharged - no follow up	☐
Discharged - GP follow up	☐
Admission to hospital - general ward	☐
Admission to hospital - ITU	☐

Appendix 2 Study of Accident & Emergency Attendances in Hemel Hempstead and Watford

Admission to hospital for surgery/other **(please specify)** ☐

Death ☐

SECTION 4 - Exposure details

4.1

Was this person exposed to the fire because of their occupation? ***Yes*** ☐ ***No*** ☐

If yes, which occupational group do they belong to?

Police ☐

Fire ☐

Ambulance ☐

Health and Safety Executive ☐

Local authority ☐

Ministry of Defence ☐

Press ☐

Other **(please specify)** ☐

4.2 *Where was the person at the time of exposure?*

Home?	***Yes*** ☐	***No*** ☐	***Unsure*** ☐
At the scene of the fire?	***Yes*** ☐	***No*** ☐	***Unsure*** ☐
At the scene of the fire and deployed within the cordon?	***Yes*** ☐	***No*** ☐	***Unsure*** ☐

Comment (free text):

4.3 *Exposure Diary*
(Record of where person was in the week of the incident including postcode if possible)

Date	***0000 to 1200 hours***	***1200 to 2400 hours***
Sun 11 Dec		
Mon 12 Dec		
Tues 13 Dec		
Wed 14 Dec		

Please complete and return by post marked "CONFIDENTIAL" in a double enveloped package to:
BFR
Regional Epidemiology Unit
HPA East of England
Institute of Public health
Cambridge
CB2 2SR

Appendix 3

Buncefield Follow Up Population Survey

Photo: Rob Holder

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Contents

Appendix 3 Buncefield Follow-up Population Survey

Executive summary

Introduction

Following the explosions at the Buncefield oil refinery on December 11th 2005 the Health Protection Agency conducted a follow-up survey in an attempt to get a full understanding of the health concerns, including stress, which local people may have had as a result of the explosions.

Methods

Three areas were surveyed comprising the north half of Dacorum PCT, (an area not covered by the plume), the south half of Dacorum PCT (an area largely covered by the plume from the incident) and Watford and Three Rivers PCT (an area also covered by the plume). A total of 4,920 questionnaires were sent at random to residents.

Results

A 40% response rate of completed returned questionnaires was achieved.

The main findings were:

1. Levels of perceived exposure varied between areas.

2. Sources of public health advice did not vary between areas.

3. Predictors of psychological distress and symptom reporting were more strongly related to wider health issues than to perceived exposure to the incident.

4. The number of respondents reporting worries at the time of the survey compared with the number who said they had concerns at the time of the incident was much smaller.

5. There was a very low rate of psychological distress throughout the study area.

Conclusions

The incident at Buncefield resulted in a high physical impact, with 88% of respondents in South Dacorum claiming to have heard the explosions, and 84% considered the smoke cloud to be near their homes. Despite this low levels of psychological distress were recorded and physical symptom reporting was also low, although the area with the highest level of reported psychological distress was South Dacorum.

Photo: Hertfordshire Fire and Rescue Service

Appendix 3 Buncefield Follow-up Population Survey

Photo: Rob Holder

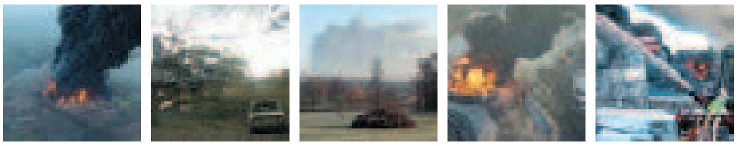
Introduction

The Buncefield depot is a major distribution terminal operated by Total and part-owned by Texaco, storing oil, petrol as well as kerosene which supplies airports across the region, including Heathrow and Luton. It is the country's fifth largest fuel distribution depot, and it is also used by BP, Shell and British Pipeline.

On Sunday 11th December 2006, at approximately 06:00hrs, the first of several explosions hit the Buncefield oil refinery in Hemel Hempstead injuring forty-two people. In addition to the explosions, the fire also produced a large plume of smoke rising above the town and dispersing over southern England.

In response to the incident, the NHS and the Health Protection Agency issued advice for people in the Hemel Hempstead area to 'stay in doors, keep windows closed and tune into local media for further updates' as a precautionary measure. People likely to be affected by the smoke plume, such as those with respiratory problems, for example asthma or chronic bronchitis; or those with cardiac problems were advised to be especially vigilant.

Following the Buncefield incident the Health Protection Agency, in support of the Dacorum and the Watford and Three Rivers Primary Care Trusts, conducted a follow-up survey in an attempt to gain a fuller understanding of the health concerns, including stress, which local people may have experienced as a result of the explosions. The follow-up was a questionnaire survey sent to a random sample of individuals living in the two Primary Care Trusts (PCTs).



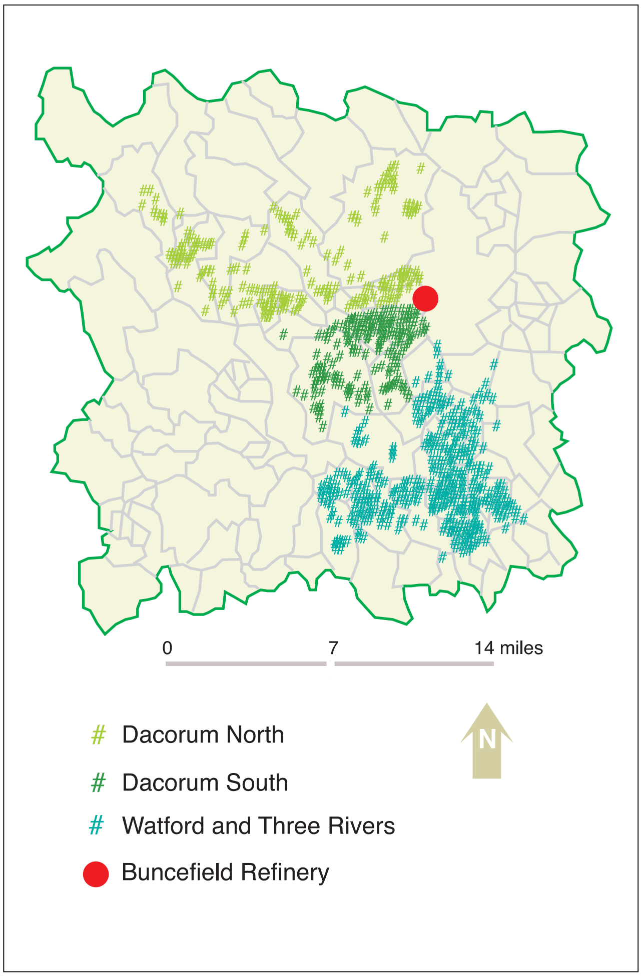
Methods

Population sample

A random sample of 4,920 patients registered with the PCTs was provided by the Strategic Health Authority (SHA). Dacorum PCT was divided into two areas according to plume coverage. North Dacorum was not covered by the Buncefield plume and was considered separately from South Dacorum as a comparison area which, together with Watford and Three Rivers PCT was covered by the plume.

One thousand participants were drawn from North Dacorum, 2,000 from South Dacorum and 1,920 from Watford and Three Rivers. The selected sample was 50.5% female.

Figure 1: Areas from which the study population was drawn



Questionnaire

A questionnaire was developed using expert consensus. Physical exposure was assessed in terms of distance of home from the incident and in terms of plume coverage. Perceived exposure was assessed by a range of items relating to the experience of the incident. The two primary outcomes were physical symptom reporting and psychological distress. Symptom reporting was assessed using a symptoms checklist that has been used in previous chemically related incidents. Psychological distress was assessed using the GHQ12; a standard and widely used instrument.

Survey methods

The questionnaire, along with a brief covering letter and a freepost return envelope was mailed to all participants within 7 weeks of the incident. Non responders were sent a reminder card two weeks later.

A random sample of 217 non-responders was selected and a phone survey was conducted in an effort to ascertain why people did not return their questionnaires.
A summary of this study is given in the appendix.

Statistical methods

Distance from the incident was treated as a continuous variable. Other exposure variables were treated as categorical variables.

The number of symptoms reported was summed to provide a symptom score. The distribution of symptom reporting was extremely skewed with most participants reporting no symptoms. For analytical purposes the sample was also divided into those reporting no symptoms and those reporting at least one symptom.

The GHQ12 was scored in the usual way with persons scoring '4' or more being considered to display psychological distress. One missing score was allowed for the GHQ with the missing value being imputed as the rounded average score for the 11 present items. Responses with more than one missing GHQ item were omitted from the analysis.

Appendix 3 Buncefield Follow-up Population Survey

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

Results

1. Response Rates

The total number of responses to the questionnaires and the follow-up reminder cards, which were sent approximately two weeks after the questionnaires, was 2,128 of which 2,001(41%)were completed to some extent. Table 1 shows South Dacorum provided the highest response rate (44%) followed by North Dacorum (41%) (x^2=2.4, df=1, p=0.123). Watford and Three Rivers had a significantly lower response rate (37%) (x^2= 24.3, df=2, p=<0.0005). Responders tended to live slightly closer to the incident (mean difference=0.65 km, t=4.5, p<0.0005) and to be female (59%).

Table 1: Survey response according to PCT

PCT	Response *Frequency (%)*
Dacorum North	413 (41%)
Dacorum South	886 (44%)
Watford and Three Rivers	702 (37%)
Total	**2,001 (41%)**

2. Descriptive statistics

There were no differences in average age or sex distribution between PCT areas (Table 2). Levels of self report exposure to the incident varied greatly according to the type of exposure (sound, sight, smell) but reported exposure was consistently higher in South Dacorum.

There were no differences between areas in self reported general heath, chest or heart problems. Although the prevalence of nervous problems was low in all areas it was higher in South Dacorum. South Dacorum also had a higher prevalence of other long term health problems and a higher proportion of people reporting a worsening of their problems since the fire.

Respondents were asked two questions to elicit their perceived personal health and local environmental risk for the future. The prevalence of raised perceived health risk was low at 7% for both North Dacorum and Watford, but was higher at 13% for South Dacorum. The prevalence of raised perceived environmental risk was higher than for perceived health risk in all areas but was highest in South Dacorum at 50%.

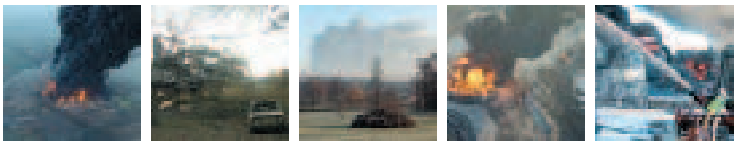


Table 2: Characteristics of sample according to PCT

Variable	PCT		
	Dacorum North	Dacorum South	Watford and Three Rivers
Demographics			
Age :Mean (SD)	53.5 (17.3)	53.9 (18.0)	51.8 (17.6)
Sex : count (%) female	55.5%	57.5%	62.1%
Exposure			
Heard explosion	71%	88%	85%***
Saw flames	47%	51%	27%***
Cloud near house	54%	84%	67%***
Smoke over house	8%	39%	23%***
Ash on house	6%	24%	14%***
Smell fire from house	47%	71%	59%***
The smell was offensive	49%	57%	50%*
Health Concerns			
Health worries at time	59%	73%	58%***
Health worries still	10%	18%	11%***
Health problems			
Long term health problems	28%	32%	27%
Long term chest problems	9%	13%	11%
Long term heart problems	6%	7%	6%
Long term nervous problems	1.5%	3.5%	1.9%*
Other long term health problems	12%	11%	9%
Problems have worsened since fire	8%	18%	11%*
Perceived risk			
Raised perceived health risk	7%	13%	7%***
Raised perceived environmental risk	45%	50%	41%**

Where: * $p<0.05$
** $p<0.01$
*** $p<0.001$

Appendix 3 Buncefield Follow-up Population Survey

3. The dissemination of public health advice

In South Dacorum 626 (73%) respondents reported receiving the public health advice to "go in, stay in and tune in" as compared to 214 (54%) in North Dacorum and 369 (54%) in Watford and Three Rivers (Table 3). There was no virtually difference in the source of the public health advice between areas. The main source of advice was national television (≈ 70%) with little use being made of NHS direct, internet or GP Surgeries.

The percentages are derived from the 1,209 participants who remember receiving public health advice rather than from all respondents. If all respondents were included, the proportion of the general population who remembered receiving the public health advice from specific sources was lower.

4. Public health impact

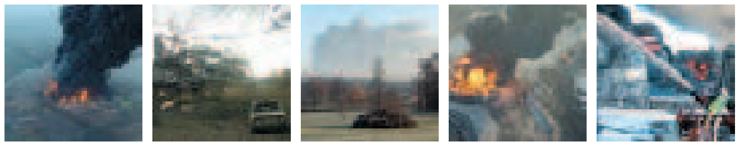
Public health impact was primarily assessed in terms of symptom reporting and levels of psychological distress. Figure 2 shows levels of symptom reporting were low with 1,115 (64%) respondents reporting no symptoms. Of these who did report symptoms 234 (13%) reported one or two symptoms and 169 (10%) reported three or four symptoms.

Dividing the sample into those reporting no symptoms and those reporting 1 or more symptoms clarified the difference between areas. In South Dacorum 314 (40%) reported 1 or more symptom as compared to 112 (31%) in North Dacorum and 207 (35%) in Watford (x^2=8.56, df=2, p=0.014).

Table 3: Obtaining public health advice to "Go in, stay in and Tune in" by PCT

Variable	PCT		
	Dacorum North	Dacorum South	Watford and Three Rivers
Advice was obtained	54%	73%	54%***
Source of advice if obtained			
Local paper	14%	17%	12%
National paper	12%	13%	15%
Local radio	41%	36%	37%
National radio	23%	26%	27%
Family and friends	14%	21%	21%
Neighbours	6%	8%	10%
Local TV news	39%	43%	39%
National TV news	72%	73%	70%
Satellite TV news	28%	22%	24%
NHS direct	0%	0.48%	1.63%*
GP Surgery	0%	1.44%	1.08%
Internet	6%	7%	10%

Where: * p<0.05
** p<0.01
*** p<0.001



In conclusion, symptom reporting differed slightly between areas with slightly more symptoms being reported in South Dacorum; the most exposed area.

Figure 3 shows levels of psychological distress were also low. Of the 1,571 people who provided useable GHQ data, only 142 (9%) would be considered as psychologically distressed. Levels of psychological distress were slightly higher in South Dacorum (11%) compared with the other areas (7%) (x^2=6.5, df=2, p=0.039) but all of these values are lower than would be anticipated in a general population sample.

Figure 2: Distribution of physical symptom reporting by PCT

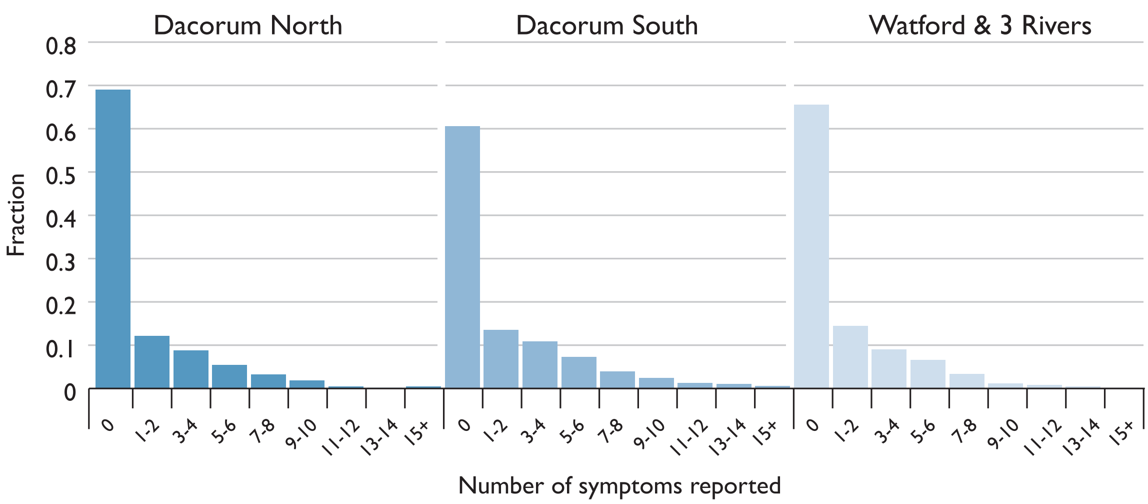
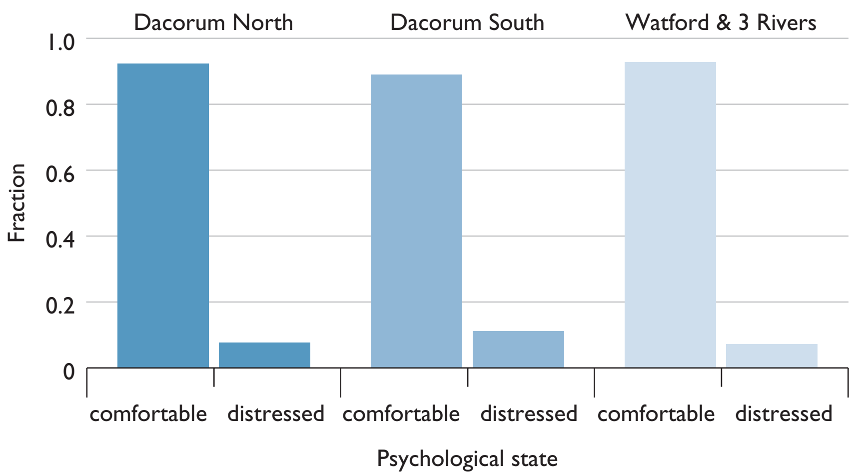


Figure 3: Levels of psychological distress by PCT

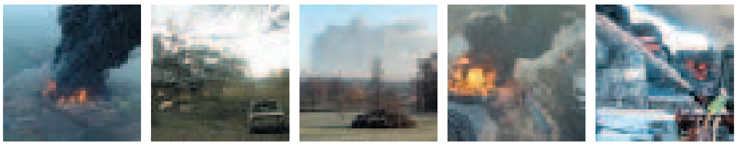


Appendix 3 Buncefield Follow-up Population Survey

5. Determinants of public health impact

Although the impact of the incident on public health was not large, it was related to perceived exposure. Tables 4-10 show that if the primary outcomes of psychological distress and symptom reporting, along with secondary outcomes of health worries and perceived risk, are related to indices of perceived exposure, strong associations are found. For all of these tables the proportion of people with psychological distress or who report symptoms, or who report health worries or raised perceived risk is higher in the group with greater perceived exposure.

Photo: Hertfordshire Fire and Rescue Service



Outcome		Did not hear explosion	Heard explosion	Statistical significance
Psychological distress	No	371 (26%)	1,050 (74%)	0.009
	Yes	23 (16%)	119 (84%)	
Symptoms	No	317 (29%)	794 (71%)	<0.0005
	Yes	127 (20%)	502 (80%)	
Health worries at time of incident	No	441 (28%)	1,117 (72%)	<0.0005
	Yes	48 (13%)	310 (87%)	
Health worries at time of questionnaire	No	438 (27%)	1,204 (73%)	0.008
	Yes	51 (19%)	217 (81%)	
Perceived future health risk	No	448 (27%)	1,231 (73%)	0.001
	Yes	27 (15%)	153 (85%)	
Perceived future environmental risk	No	270 (27%)	741 (73%)	0.229
	Yes	209 (24%)	652 (76%)	

Table 4: Associations of "hearing the first explosion" with health impact outcomes

Outcome		Could not see flames	Could see flames	Statistical significance
Psychological distress	No	839 (59%)	582 (41%)	<0.0005
	Yes	61 (43%)	81 (57%)	
Symptoms	No	798 (64%)	399 (36%)	<0.0005
	Yes	296 (47%)	333 (53%)	
Health worries at time of incident	No	970 (63%)	583 (37%)	<0.0005
	Yes	139 (39%)	221 (61%)	
Health worries at time of questionnaire	No	985 (60%)	654 (40%)	<0.0005
	Yes	123 (46%)	146 (54%)	
Perceived future health risk	No	1,001 (60%)	676 (40%)	0.001
	Yes	85 (47%)	96 (53%)	
Perceived future environmental risk	No	631 (62%)	380 (38%)	<0.0005
	Yes	461 (54%)	398 (46%)	

Table 5: Associations of "seeing the flames" with health impact outcomes

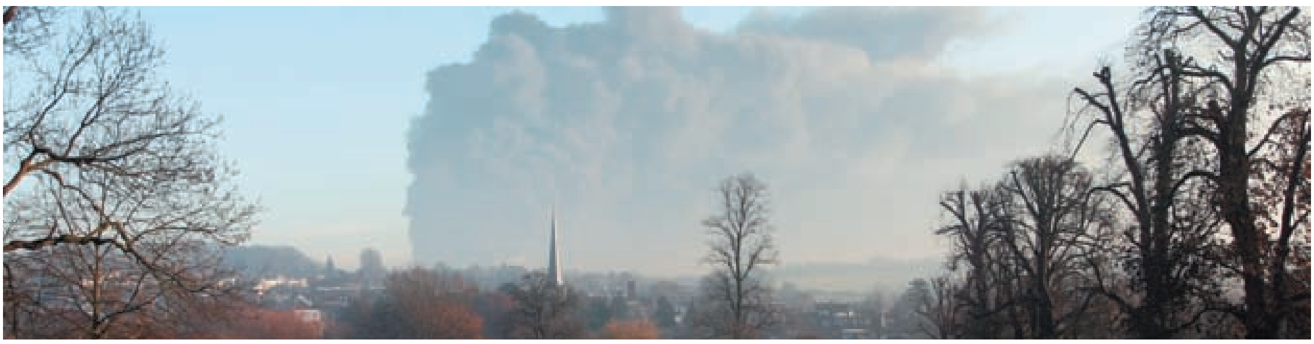


Photo: Rob Holder

Appendix 3 Buncefield Follow-up Population Survey

Table 6: Associations of "house being close to the cloud" with health impact outcomes

Outcome		House not close to smoke cloud	House close to smoke cloud	Statistical significance
Psychological distress	No	413 (29%)	1,004 (71%)	0.005
	Yes	25 (18%)	115 (82%)	
Symptoms	No	385 (35%)	717 (65%)	<0.0005
	Yes	107 (17%)	518 (83%)	
Health worries at time of incident	No	499 (32%)	1,048 (68%)	<0.0005
	Yes	33 (9%)	325 (91%)	
Health worries at time of questionnaire	No	504 (31%)	1,131 (69%)	<0.0005
	Yes	36 (14%)	230 (86%)	
Perceived future health risk	No	507 (30%)	1,164 (70%)	<0.0005
	Yes	21 (12%)	159 (88%)	
Perceived future environmental risk	No	339 (34%)	668 (66%)	<0.0005
	Yes	190 (22%)	668 (78%)	

Table 7: Associations of "cloud coming down over house" with health impact outcomes

Outcome		Cloud did not come down over house	Cloud did come down over house	Statistical significance
Psychological distress	No	1,065 (76%)	346 (24%)	<0.0005
	Yes	75 (54%)	65 (46%)	
Symptoms	No	884 (80%)	220 (20%)	<0.0005
	Yes	382 (62%)	239 (38%)	
Health worries at time of incident	No	1,222 (79%)	325 (21%)	<0.0005
	Yes	177 (50%)	179 (50%)	
Health worries at time of questionnaire	No	1,225 (77%)	381 (23%)	<0.0005
	Yes	146 (55%)	119 (45%)	
Perceived future health risk	No	1,274 (76%)	394 (24%)	<0.0005
	Yes	93 (52%)	86 (48%)	
Perceived future environmental risk	No	799 (80%)	206 (20%)	<0.0005
	Yes	574 (67%)	283 (33%)	

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

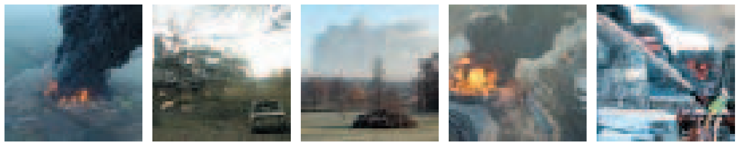


Table 8: Associations of "ash or debris coming down in garden" with health impact outcomes

Outcome		Ash did not fall on house	Ash did fall on house	Statistical significance
Psychological distress	No	1,195 (84%)	224 (16%)	<0.0005
	Yes	97 (70%)	42 (30%)	
Symptoms	No	988 (89%)	119 (11%)	<0.0005
	Yes	454 (73%)	170 (27%)	
Health worries at time of incident	No	1,350 (87%)	200 (13%)	<0.0005
	Yes	235 (66%)	121 (34%)	
Health worries at time of questionnaire	No	1,408 (86%)	229 (14%)	<0.0005
	Yes	179 (68%)	86 (32%)	
Perceived future health risk	No	1,430 (85%)	245 (15%)	<0.0005
	Yes	119 (66%)	61 (34%)	
Perceived future environmental risk	No	881 (87%)	129 (13%)	<0.0005
	Yes	675 (79%)	183 (21%)	

Table 9: Associations of "smelling the fire from house" with health impact outcomes

Outcome		Could not smell the fire strongly	Could smell the fire strongly	Statistical significance
Psychological distress	No	1,153 (81%)	270 (19%)	<0.0005
	Yes	84 (60%)	57 (40%)	
Symptoms	No	965 (87%)	144 (13%)	<0.0005
	Yes	414 (66%)	215 (34%)	
Health worries at time of incident	No	1,327 (85%)	233 (15%)	<0.0005
	Yes	194 (54%)	163 (46%)	
Health worries at time of questionnaire	No	1,363 (83%)	280 (17%)	<0.0005
	Yes	159 (59%)	109 (41%)	
Perceived future health risk	No	1,390 (83%)	289 (17%)	<0.0005
	Yes	99 (55%)	82 (45%)	
Perceived future environmental risk	No	864 (85%)	148 (15%)	<0.0005
	Yes	624 (72%)	238 (28%)	

Photo: Hertfordshire Fire and Rescue Service

Appendix 3 Buncefield Follow-up Population Survey

Table 10: Associations of "the smell being offensive" with health impact outcomes

Outcome		The smell not offensive	The smell was offensive	Statistical significance
Psychological distress	No	403 (47%)	447 (53%)	<0.0005
	Yes	25 (21%)	93 (79%)	
Symptoms	No	323 (57%)	244 (43%)	<0.0005
	Yes	149 (30%)	343 (70%)	
Health worries at time of incident	No	463 (53%)	407 (47%)	<0.0005
	Yes	59 (20%)	236 (80%)	
Health worries at time of questionnaire	No	476 (50%)	467 (50%)	<0.0005
	Yes	45 (45%)	169 (55%)	
Perceived future health risk	No	487 (50%)	481 (50%)	<0.0005
	Yes	25 (17%)	125 (83%)	
Perceived future environmental risk	No	313 (58%)	229 (42%)	<0.0005
	Yes	204 (34%)	399 (66%)	

6. Participants' comments

At four points in the questionnaire, participants were invited to comment on their worries concerning:

1. Their health at the time of the fire.
2. Their worries concerning their health at the time of completing the questionnaire.
3. Their perception of their future health as a result of the incident.
4. The public health advice they had received.

For each area comments were categorised according to the area of concern.

Comments on their health at the time of the fire were made by 1,087 (54%) respondents. Table 11 give the breakdown of theses comments by area concern. The vast majority of the concerns were in relation to health. The largest area of concern was for toxins in the air and smoke.

Table 12 shows the number of respondents with concerns that were current at the time of completing the questionnaire. Only 257 (13%) respondents reported concerns at the time of completing the questionnaire, and at this point in time health effects remained the central issue.

Table 11: Invited comments on health worries at the time of the incident

Area of concern	Frequency (%)
Toxins in the air and smoke (health effects?)	447 (41%)
Short and long term health effects	297 (27%)
Concerns for children & other family members	182 (17%)
Environmental effects/pollution	59 (5%)
Uncertainty/need for information	38 (4%)
Further explosions/spread of fire	33 (3%)
Suffered perceived health effects due to incident	12 (1%)
Water contamination	10 (1%)
Injuries to anyone	5 (0.5%)
Financial implications/property damage	4 (0.4%)
Total	1,087 (100%)

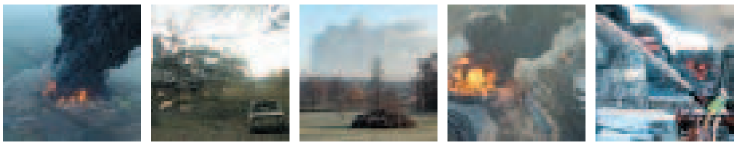


Table 12: Invited comments on health worries at the time of completing the questionnaire

Area of concern	Frequency (%)
Long term health effects	118 (46%)
Suffered perceived health effects due to incident	58 (23%)
Water contamination	41 (16%)
Effects of smoke and cloud	16 (6%)
Environment in general	11 (4%)
Effects of the Foam waste used in extinguishing the blaze	8 (3%)
Concerned about a recurrence of the incident	5 (2%)
Total	**257 (100%)**

Table 13: Invited comments on future health worries

Area of concern	Frequency (%)
Don't know/Not sure if my health will be affected	132 (45%)
Already suffered health effects	45 (15%0
Concerns about long term effects	32 (11%)
Hopefully (my) personal health will not be affected	31 (11%)
Statement that there was no personal effect of the incident	29 (10%)
Concern over environmental impact	24 (8%)
Total	**293 (100%)**

Table 13 shows the number of respondents who commented on whether they thought the explosions and the ensuing smoke plume might have an effect on their health in the long term. In total 293 (15%) people commented. Comments varied from people who did not know what the effects might be to those who were concerned that there would be long term effects.

Comments were also invited about the health advice of "Go in, stay in, tune in" with 219 (43%) expressing satisfaction with the advice that was given. Table 14 gives the range of suggestions for improving the advice available

Forty-nine people commented that they felt that the methods of dissemination could have been better. Suggestions included having public service officials making door to door calls providing advice, information leaflets through the door, a loudspeaker on a car making announcements or local information points being set up.

Table 14: Invited comments on improving health advice

Comment	Frequency (%)
Satisfied with advice	219 (43%)
Wanted more advice on procedures and more reassurance	98 (19%)
Wanted more information on road and school closures	68 (13%)
Wanted more information regarding the smoke cloud	56 (11%)
Wanted more health advice	51 (10%)
Wanted more advice on drinking water	9 (2%)
Wanted to know where to obtain fuel	5 (1%)
Total	**506 (100%)**

Appendix 3 Buncefield Follow-up Population Survey

7. Phone Survey of non-responders to the Buncefield follow-up survey

The response rate to the Buncefield follow-up survey was 41%. To assess the reasons for non-response a telephone survey of non-responders was conducted.

It was hoped that a stratified sample of non-responders could be contacted, as this would have reflected the stratification of the follow-up survey – unfortunately this was not possible, so a random sample was used instead. In addition the original database did not contain phone numbers, so directory enquiries and other resources were used to track down numbers where possible.

The flow chart (below) gives the pathway through the telephone survey. From 217 non responders who were identified, 68 phone numbers were traced and 41 contacts made.

217 non-responders identified

↓

68 numbers traced

↓

(after 3 phone calls)

↓

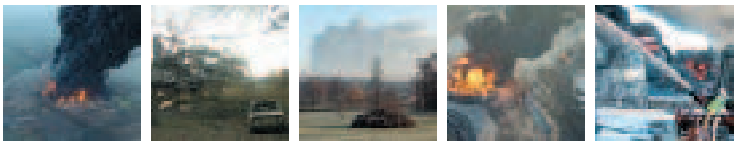
41 contacts made (1.4% of all non-responders)

The results of the telephone contacts are given in Table 15.

Table 15: Primary reason for non-response to the Buncefield follow-up survey

Reasons for non-response	
Not concerned about health effects	9
Insufficient time / not a priority	7
Don't live nearby / irrelevant to me	5
Sent questionnaire back (but not received by Cardiff)	5
Absent at time and / or subsequently	3
Did not receive questionnaire	3
Persons living in institutions	2
Thought study was waste of time / money	1
Received duplicate questionnaire (home & work)	1
Non-contributory contacts	
Wrong number	3
Refused to speak	2

Photo: Rob Holder



Discussion

The 40% response rate compares favourably with those of other studies of major incidents, with similar studies obtaining response rates of between 26% and 69%. A study examining the health effects among residents living near the World Trade Centre (WTC) site obtained a 26% response rate[1], while in a study examining the acute health effects of the Sea Empress oil spill obtained 69%[2].

Respondents were invited to comment on their concerns and express opinions at several points in the questionnaire. When considering the comments made with regard to health concerns, at the time of the fire, the main areas of concern was in relation to the toxins in the air and smoke and although not further specified it could be inferred that respondents were concerned not only about what toxins and chemicals were contained in the smoke plume but also about the possibility of health effects as a result of exposure to the smoke. 27% of respondents also expressed a concern for the short and long-term health effects of the incident, while 17% of respondents had concerns over the health of their children or other family members. There was a marked smaller the number of respondents expressing concerns at the time of completing the questionnaire compared to those who reported concerns at the time of the fire, with only 257 people reporting concerns at questionnaire completion. The lower numbers at the time of filling in the questionnaire is likely to reflect the passage of time since the sensory impact of the incident, as by the time the questionnaires were filled in the smoke plume would have dissipated and many people may have felt that any threat to their health had passed. Among those who did express concerns, these were primarily regarding the health effects of the incident, with 46% reporting they were concerned over long term effects and 23% reporting that they felt the had already suffered health effects as a result of the incident.

In all three areas the level of symptom reporting was low, with 64% of respondents reporting no symptoms at all. This is perhaps not unsurprising as the weather conditions as the time of the incident meant that the smoke plume remained high in the atmosphere and posed little risk to residents. In North Dacorum, the area least affected by the incident, only 112 respondents reported suffering one or and 207 in Watford & Three Rivers, which may indicate that the presence of the smoke plume played a role in symptom reporting resulting in slightly higher levels of reporting in the more exposed area. This possibility is strengthened by the finding that seeing and smelling the fire was associated with higher levels of both physical symptoms and psychological distress.

Given the 40% response rate of this study, it is difficult to compare the prevalence of psychological distress in this population with that found elsewhere. In the British Household Panel Survey, using a general population sample, the prevalence of psychological distress was reported as 24.6% [3]. Reasons for the low prevalence of psychological distress found here are unknown. It may be that levels of psychiatric morbidity are lower in this area of the country or that survey responders had lower distress than non-responders.

Conclusions

It may be concluded from this survey that although there was a physical impact following the explosions, the level of psychological distress reported here was low throughout the study area with only slightly higher levels in South Dacorum where the fire was most apparent. In relation to symptom reporting, although South Dacorum did show higher levels of symptom reporting, the difference between the areas was not great and it could therefore be concluded that there were little if any measurable health affects from the fire.

Recommendations

Major incidents such as the explosions and ensuing smoke plume at the Buncefield oil refinery have the potential to impact on public health, particularly when, as with Buncefield, they occur close to residential populations. Although this study showed low levels of psychological distress and symptom reporting, the 40% response rate, although adequate, is not optimal and therefore the primary recommendation for this study must be to look for ways to improve response rates in future surveys. The handling of the incident appears to have been efficient and effective and only a small number of respondents felt that they needed more information or that information should be provided in an alternative method. Despite the small numbers, it would be wise to pay heed to these concerns and perhaps look at implementing some of the suggestions in the case of future incidents.

[1] Lin et al. Am. J. Epidemiol. 2005;162:499-507
[2] Lyons et al. J. Epidemiol. Community Health 1999;53(5):306-310
[3] Weich et al. Br. J. Psychiat.2006;188:51-7

Appendix 4

Atmospheric Modelling and Monitoring

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Contents

Appendix 4 Atmospheric Modelling and Monitoring

Executive Summary

On Sunday 11th December 2005, there was a major explosion at the Buncefield oil depot near Hemel Hempstead. Following the explosion, large stocks of refined product including petrol, aviation turbine fuel, diesel and gas oil stored at the depot caught on fire. The plume of smoke from this fire was so large that it could be seen as far away as south London, and could also be clearly identified in satellite images.

This report summarises the atmospheric modelling and monitoring that was carried out during and after the incident, and how this was used by the Chemical Hazards and Poisons Division (CHaPD) of the Health Protection Agency (HPA) for exposure assessment and toxicological risk assessment. It explains how this data was used to provide HPA advice to the Strategic Co-ordinating Group (SCG) at Hertfordshire Police Headquarters during the first four days of the incident. In addition, it details how the HPA has taken forward further actions since the acute response stage of the incident.

Despite the unprecedented scale of the Buncefield explosion and fire, the results of both monitoring and modelling suggest that the fire did not result in any significant ground-level concentrations of atmospheric pollutants. This was due to high plume buoyancy caused by the high temperatures of the fire and favourable meteorological conditions that resulted in the plume being trapped at a high level in the atmosphere with minimal mixing to the ground.

Appendix 4 Atmospheric Modelling and Monitoring

GLOSSARY

AC	Acenaphthene
ACL	Acenaphthylene
ADMS	Atmospheric Dispersion Modelling System
AN	Anthracene
AURN	Automatic Rural and Urban Network
BAAN	Benzo(a)anthracene
BAP	Benzo(a)pyrene
BGHIP	Benzo(g,h,i)peryl
CHaPD	Chemical Hazards and Poisons Division
CHEMET	Chemical meteorological model
CHR	Chrysene and Benzo(k)fluoranthene mixture
CO2	Carbon dioxide
COMAH	Control of major accident hazards
CRCE	Centre for Radiation, Chemical and Environmental Hazards
DBAHA	Dibenzo(a,h)anthracene
Defra	Department of Environment, Food and Rural Affairs
EAL	Environmental Assessment Level
EMARC	Emergency Response and Monitoring Centre
ERG	Environmental Research Group
FA	Fluoranthene
FAAM	Facility for Airborne Atmospheric Measurements
FL	Fluorine
GFA	Glass Fibre Absorber
HAT	Health Advice Team
HSE	Health and Safety Executive
HPA	Health Protection Agency
HSL	Health and Safety Laboratory
IOM	Institute of Occupational Medicine
IP	Indeno (1,2,3-c,d) pyrene
LaRS	Local and Regional Services
NA	Naphthalene
NAME	Numerical Atmospheric-dispersion Modelling Environment (NAME)
ND	Not detected
Netcen	National Environmental Technology Centre
NHS	National Health Service
NO_x	Oxides of nitrogen
PAH	polycyclic aromatic hydrocarbon
PH	Phenanthrene
PM	Particulate matter
PM_{10}	particles with a diameter of less than 10µm
Py	Pyrene
RPD	Radiation Protection Division
SCG	Strategic Co-ordinating Group
UKAS	United Kingdom Accreditation Service
VOCs	volatile organic compounds

1 Introduction

On Sunday, 11th December at 06.00, a series of explosions started what was reputed to have been the largest fire in Europe for the past five decades. The fire continued over four days, causing a black plume of smoke that covered tens of kilometres, even visible on satellite images, heading south over England and ultimately towards mainland Europe.

This report summarises the atmospheric modelling and monitoring that was carried out during and after the incident and how this was used by the Chemical Hazards and Poisons Division (CHaPD) of the Health Protection Agency (HPA) for exposure assessment and toxicological risk assessment. It explains how this data was used to provide HPA advice to the Strategic Co-ordinating Group (SCG) at Hertfordshire Police Headquarters during the first four days of the incident.

2 CHaPD role in the Buncefield incident

On Day 1 (11.12.05) at 06.00 hours the first of a series of explosions began, that resulted in a huge fire producing a massive visible smoke plume covering London and the South East of England. A major incident was declared at 06.08 hours and command and control set up near the site (operational) within minutes, with strategic command in place at the Hertfordshire Police Headquarters by 09.00 hours. A decision was made at 09.00 hours to evacuate those with damaged homes and workplaces, and to tell everyone under the plume to shelter, 'go in, stay in, tune in'. Strategic command continued until 18.30 hours on Day 4 (14.12.05). There was extensive media news coverage locally, nationally and internationally.

The co-ordination and management framework at any incident identifies three layers or tiers of inter-linked leadership and co-ordination:

- Operational - **Bronze**
- Tactical - **Silver**
- Strategic - **Gold**

Representation of all agencies deployed to resolve the Buncefield incident, was established through a meeting process known as the Strategic Co-ordinating Group (SCG) also known as Gold Command (UK resilience, 2006). This Group had its first multi-agency meeting at 09.00 hours on Sunday 11th December at Hertfordshire Police Headquarters which was chaired by the Police SCG Commander. The SCG remained in place until Wednesday 14th December. SCG relied on a process of advice and discussion to reach decisions that ensured that the implementation of strategic aims was delivered by the Tactical and Operational tiers. Health advice was provided to the Strategic Co-ordinating Group (SCG) by the Health Advice Team (HAT), which had representation from both the NHS and HPA (Department of Health, 2006).

The SCG provided opportunity for continuous collaboration and co-ordination with all present including police, fire, ambulance, NHS, Environment Agency, Local Authorities, Government Office for East of England and other agencies such as the Food Standards Agency. It also allowed for occupational health services for relevant organisations to become involved. LaRS and CHaPD provided continuous support throughout the duration of the SCG.

The provision of accurate, timely public information is vital in an emergency and on this basis the Communications Division of the Health Protection Agency was able to inform and reinforce the health advice provided by strategic gold. The Communications Division ensured that the residents of Hemel Hempstead and the public in general had access to health advice via the Agency's website and through regular media statements. The Division adopted a networked approach to managing the huge volume of media enquiries and requests for information. The regional communications manager for the HPA East of England provided support to strategic health gold and was responsible for briefing and supporting local Agency spokespeople particularly the consultants in communicable disease control. The CHaPD communications team fielded the specialists in air pollution who were able to explain what was being investigated in terms of air quality monitoring. Additional support was provided by the communications managers based at the Health Protection Agency's London headquarters who briefed and supported the Agency's Chief Executive who acted as spokesperson for the Agency.

Once the fire was extinguished the regional communications manager worked in collaboration with the local primary care trust communications manager on media activities to explain the continued health monitoring and surveillance of residents and frontline workers involved in putting out the fire.

Section 2.1 outlines a timeline of CHaPD's involvement with the Buncefield incident especially with regard to air quality monitoring and modelling. The activities undertaken by HPA in other areas related to the incident are not included in this timeline, or only very briefly mentioned. These areas are:

(i) advice provided since 11 December on health impact assessment including health surveillance and epidemiological follow up

(ii) aspects in relating to early assessment of psychological impacts and psychologically-mediated health impacts

(iii) possible water contamination aspects and related human exposure/toxicology issues

Photo: Hertfordshire Fire and Rescue Service

Appendix 4 Atmospheric Modelling and Monitoring

2.1 CHaPD Buncefield incident timeline targeting air quality monitoring and modelling activities

Date	Time	Action
11/12/2005	06.00	Explosions at Buncefield oil depot.
	06.50	CHaPD informed of an explosion at an oil storage depot.
	08.15	CHaPD contacted the Met Office. A Chemical Meteorological (CHEMET) forecast had been run but; had not been requested. The Numerical Atmospheric-dispersion Modelling Environment (NAME) model was also being run. CHaPD requested that the results be forwarded to them.
	08.50	CHaPD arrived at SCG.
	08.50	CHaPD contacted Met Office to get models sent via email and fax.
	09.00	CHaPD, via SCG, advised members of the public to 'go in, stay in; tune in' and for those with houses damaged by the explosion to follow police advice to evacuate. CHaPD shown COMAH site plan and Material Safety Data Sheets for the products involved.
	09.45	CHaPD started collaborating with Local and Regional Services (LaRS) and the NHS on health impact assessment.
	10.30	CHaPD started organising locally targeted environmental sampling with help of Health and Safety Laboratory (HSL) and the Fire Brigade's Scientific Advisers.
	10.30	CHaPD started collaborating with Local and Regional Services (LaRS).and the NHS started organising surveillance activities.
	11.00	CHaPD started to receive satellite photographs, NAME models predicting plume dispersion over Southern England and across the Channel at different heights in the atmosphere.
	12.00	CHaPD involved with discussions about occupational health for responders.
	12.00	CHaPD started to provide advice about health surveillance activities via HAT at SCG.
	13.50	CHaPD consulted the UK's national Automatic Urban and Rural Network (AURN) to obtain real time data from UK fixed monitoring sites to advise Gold Command.
	16.00	HSL and Fire Brigade's Scientific Advisers arrived at SCG to agree sampling brief with CHaPD for locally targeted sampling.
	17.00	CHaPD contacted the Met Office. NAME model to be run for a 72 hour period.
	18.00	Results from HSL and Fire Brigade's Scientific Advisers start to arrive at SCG.
	20.00	Further results from HSL and Fire Brigade's Scientific Advisers arrive at SCG.
	21.30	Further meeting on locally targeted environmental sampling held at SCG.
12/12/2005	09.00	First discussions on possibility of further environmental sampling.
	09.35	CHaPD received NAME model outputs for different scenarios from the Met Office.
	10.45	CHaPD contacted Environmental Research Group (ERG) at Kings College for information regarding quality in London and the south east.
	12.30	CHaPD informed about sampling being undertaken by the FAAM plane.
	12.55	Received further NAME models and satellite information from the Met Office.
	14.10	CHaPD meet with Fire Brigade's Scientific Advisers and HSL on site close to Tactical (Silver) regarding air quality monitoring.
	17.45	CHaPD informed by Fire Brigade's Scientific Advisers and HSL of the results of their air quality sampling. They had not detected significant concentrations of any of the chemicals monitored.

Date	Time	Action
13/12/2005	07.00	CHaPD received atmospheric dispersion modelling using Atmospheric Dispersion Modelling System (ADMS) and AERMOD from the Environment Agency predicting the location of the plume if it were to ground.
	07.15	CHaPD request asbestos sampling from the HSL..
	09.05	CHaPD contact Defra's air quality division. Netcen have been sent to the site to monitor particulate matter less than 10 /m (PM_{10}) and volatile organic compounds (VOCs).
	09.55	HSL informed CHaPD that they did not detect any asbestos in the plume.
	11.10	CHaPD received preliminary information on air quality from Netcen.
	12.00	Decision made at CHaPD to sample soils and grasses using the results of the Environment Agency dispersion modelling and reports of the plume grounding.
	13.00	CHaPD contacted Netcen and requested hourly bulletins with air quality information.
	14.40	CHaPD received results of FAAM plane sampling.
	15.40	ERG set up an hourly email service to send detailed air quality information and summaries to
	19.00	CHaPD discussed VOC and particulate matter (PM) sampling with Netcen.
	19.25	Netcen results for the 12/11/05 sent to CHaPD. These did not indicate elevated concentrations of VOCs or PM.
14/12/2005	08.40	Fire Brigade's Scientific Advisers informed CHaPD that the results of the air quality sampling were typical of ambient levels of these chemicals for urban areas.
	09.00	Sampling teams mobilised by CHaPD to undertake sampling of soils and grasses.
	09.30	HSL inform CHaPD of the results of their polycyclic aromatic hydrocarbon (PAH) monitoring.
	12.10	CHaPD set up link with Surrey Health Protection Unit (HPU) requesting that if they receive any air quality information from their local authorities that they send it to CHaPD.
	18.30	SCG stood down.
	18.45	CHaPD informed by Fire Brigade's Scientific Advisers that levels of atmospheric chemicals detected at three schools were within ambient levels.
	19.30	Discussion for the need for an inter-agency liaison group started.
15/12/2005	09.00	Sampling strategy for further soil and vegetation sampling sent to RPD by CHaPD. Sample teams mobilised to the location of the peak ground level concentrations.
	11.45	Telephone conference to set up the Inter-Agency Liaison Group agreed.
16/12/2005	12.00	First meeting of Inter-Agency Liaison Group held at Drinking Water Inspectorate offices.
20/12/2005	16.05	CHaPD suggested that occupational health monitoring data for those on site during clean up could be used as surrogates for members of the public's exposure.

CHaPD has continued close contact with all agencies in assessing any ongoing air monitoring data to inform LaRS of any potential health impact. This work and other work are specified further in section 9.

Appendix 4 Atmospheric Modelling and Monitoring

3 Modelling of the plume

3.1 Chemical Meteorological (CHEMET) model

CHEMET is a service provided by the Emergency Response and Monitoring Centre (EMARC) within the UK Met Office as part of their responsibility for the provision of meteorological advice to the emergency services in the event of an accidental release of potentially hazardous substances into the atmosphere (Welch, 2006). The model quickly predicts an 'area at risk' which accounts for the likely path of the plume, as well as allowing for plume meander and drift. The model is routinely forwarded to CHaPD and other agencies for use in response to chemical incidents.

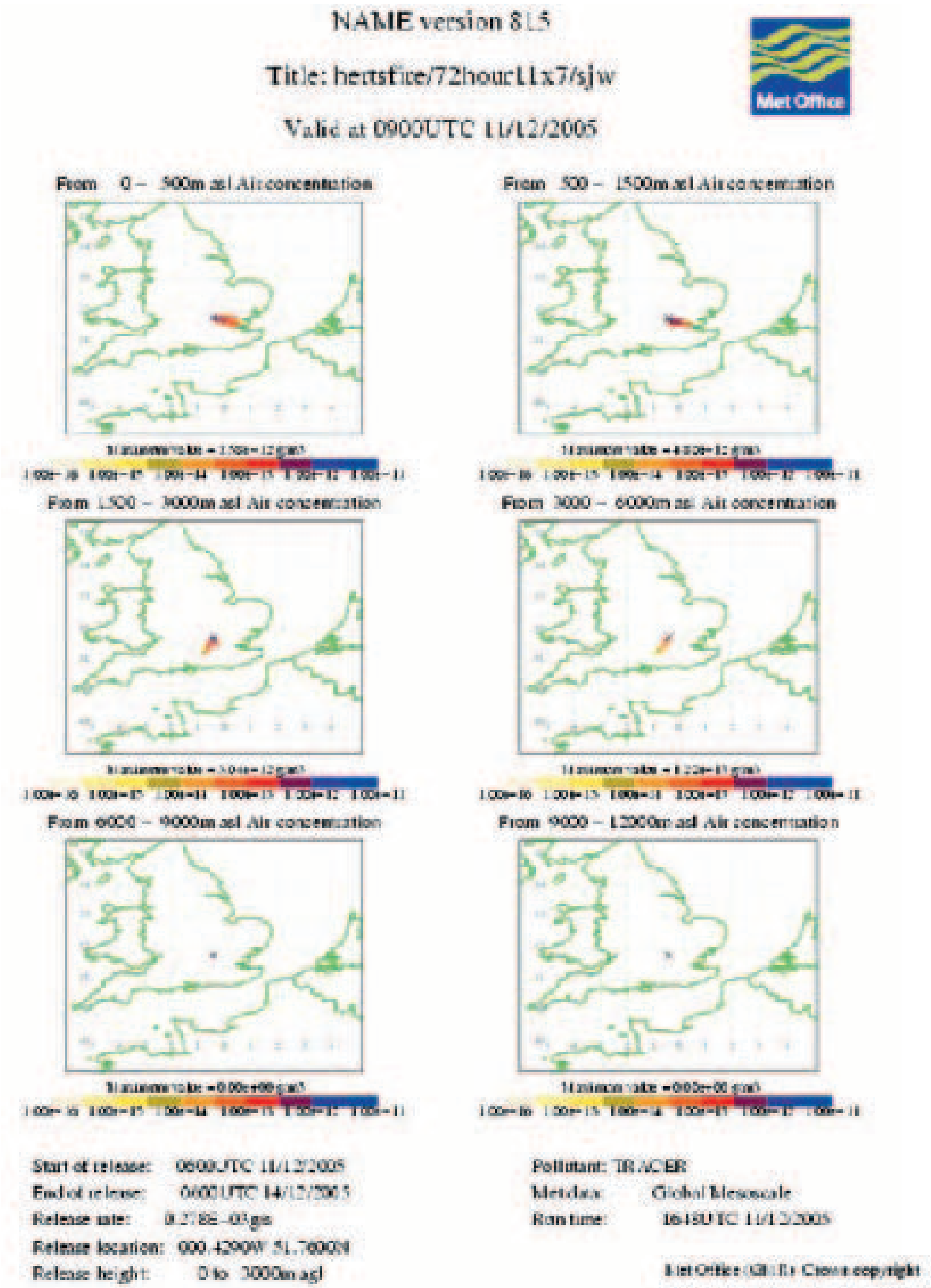
The first CHEMET model was requested by the fire brigade at 08.14 on 11th December and sent to CHaPD offices, via email and fax and also to the HAT at SCG. The CHEMET model was run continuously on a three hourly basis during the incident. This model is designed to be very simple and quick to run to aid decisions, for incident response. However, important factors such as the nature of the chemical release are not considered. As a result the more complex Numerical Atmospheric-dispersion Modelling Environment (NAME) was used to assist with exposure assessments.

Photo: Rob Holder

3.2 NAME (Numerical Atmospheric-dispersion Modelling Environment)

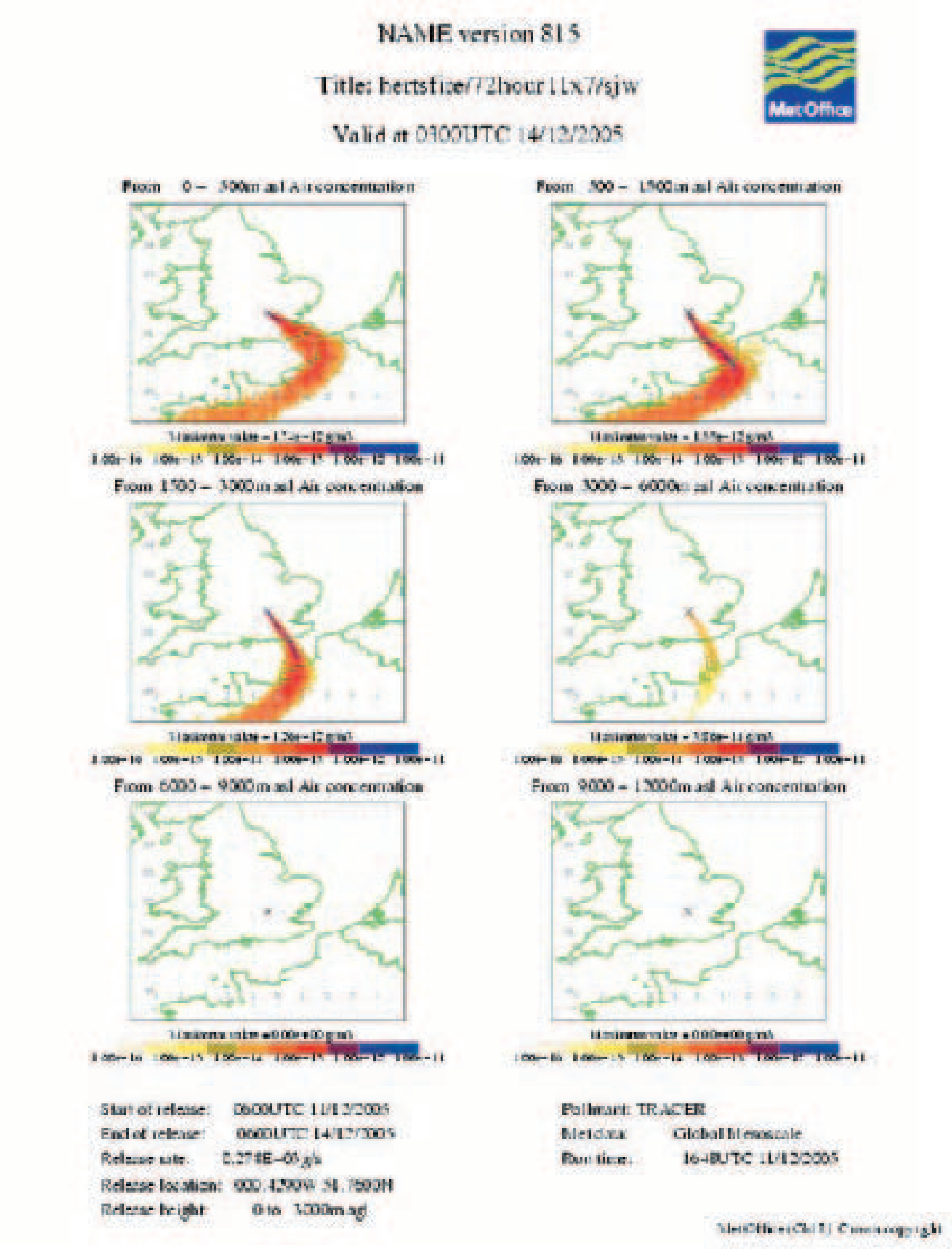
The NAME model was run at regular intervals by the Met Office during the Buncefield incident and sent to CHaPD offices and the Health Advisory Team (HAT) at SCG command. The NAME model is not routinely used for small scale chemical incidents and would only normally be used for larger scale incidents, involving the long range transport of atmospheric pollutants. The first NAME model outputs were received at approximately 10.00 on 11th December. The modelling predicted the spread of the plume over the time period of the incident, allowing HAT to determine where the areas of potential exposure were. The NAME model not only predicted the two dimensional spread of the plume, but also the plume spread at different heights (0 - 500 m, 500 - 1500 m, 1500 - 3000 m, 3000 - 6000 m, 6000 - 9000m and 9000 - 12000 m) in the atmosphere as seen in figures 1 and 2. Note that this modelling was done using an arbitrary release rate as is commonly done in emergencies when there is no accurate information about the source term, therefore, the predicted concentrations are not absolute concentrations, rather they show the distribution of the chemicals in the atmosphere. The model was regularly re-run with updated meteorological data and to incorporate additional release information, when it became available. This information together with advice from the Met Office informed CHaPD on the areas of potential exposure and allowed advice to SCG to be developed. The rapid delivery of these models to SCG aided quick decision making and allowed the potential for plume deposition to be considered.
The modelling also predicted deposition of the plume which helped identify if and where plume deposition would occur.

Figure 1: Output from the NAME model at different heights in the atmosphere at 09.00 on 11th December



Appendix 4 Atmospheric Modelling and Monitoring

Figure 2: Output from the NAME model at different heights in the atmosphere at 03.00 on 14th December



3.3 Satellite Imagery

Throughout the incident CHaPD received satellite images of the plume from the Met Office. These images gave an indication of the geographical spread of the plume during the incident and supported the modelling data that were received in the forms of CHEMETs, NAME and visual observations on the ground, thereby assisting CHaPD to confirm which fixed local air quality monitoring stations were most likely to identify whether the plume was grounding.

3.4 Environment Agency atmospheric dispersion modelling

The Environment Agency also conducted short-range atmospheric dispersion modelling using the models ADMS and AERMOD and the forecast meteorological data for the period 19.00 on 11th December to 24.00 on 14th December. ADMS and AERMOD are gaussian plume models widely used in the UK to predict atmospheric dispersion of chemicals (Carruthers *et al.* 1994, Colvile, Briggs, & Nieuwenhuijsen 2003, Chemical Hazards and Poisons Division, 2006).

In order to predict the short range spread of the plume and the location of the maximum ground level concentration of pollution if the plume were to ground modelling was undertaken that included different plume rises (ranging from 100 to 500 m). CHaPD received the results for plume rises between 100m and 200m on the mornings of the 13th and 14th of December for the time periods 09.00 on 13th December and 12.00 on 14th December. The modelling output was overlaid on a map which together with outputs from the NAME models, CHEMETs and visual observations assisted CHaPD in determining the areas where grass and soil sampling should be conducted.

4 Air quality monitoring

CHaPD considered that several strands of monitoring were required to provide advice for public health protection. These included:

- Locally targeted air monitoring
- Collection of samples from the plume
- Use of air quality monitoring networks
- Soil and grass samples from areas potentially at risk from plume deposition

4.1 Locally targeted monitoring

Two expert groups were identified to provide locally targeted monitoring. These were the Fire Brigade's Scientific Advisers and the Health and Safety Laboratory (HSL). Both groups worked in order to address issues identified at the SCG. Sampling sites were agreed by the HAT and both groups conducted sampling at the same locations as far as possible.

4.1.1 Fire Brigade's Scientific Advisers

Hertfordshire Fire and Rescue Service requested the attendance of a team from the Fire Brigade's Scientific Advisers (Bureau Veritas) to monitor atmospheric chemicals which were possibly released from the fire (Bureau Veritas, 2006). For over thirty years, the scientific advisers have assisted the fire service by providing advice on chemical hazards and when necessary, attending incidents to help with detection, identification and monitoring of hazardous materials.

The Fire Brigade's Scientific Advisers sampled for the following chemicals: carbon dioxide, carbon monoxide, sulphur dioxide, hydrocarbons, particulates, volatile organic compounds (VOCs), hydrogen sulphide, ammonia and hydrogen fluoride at various locations close to the fire on a number of occasions during the incident. The air quality monitoring around the Buncefield site was performed using Dräger tubes, a Hapsite Smart (Inficon), running in 15min loop mode after an initial survey using the survey mode to locate the highest concentration of VOCs, a Dräger Miniwarn gas handheld gas detector and two particulate monitoring devices (Casella Microdust and AMS 950).

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No samples were taken by the Fire Brigade's Scientific Advisers for further analysis. Some of the equipment deployed is designed to give immediate readings providing a snapshot of the local conditions although the Miniwarn and dust monitors were set up to give continuous real time readings.

As each stage of the monitoring was completed, the team's reports were communicated to SCG. The results of the sampling displayed in tables 1 - 4 indicate that the air sampling did not suggest that the Buncefield incident caused a deterioration of air quality.

Table 1: Air quality monitoring results from Fire Brigade's Scientific Advisers 11/12/05

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
St Albans Police Station Yard	17.55	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Organic Compounds	No significant quantities detected
Approximately 50 m downwind of of the fire	19.42	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Organic Compounds	No significant quantities detected

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

Table 2: Air quality monitoring results from Fire Brigade's Scientific Advisers 12/12/05

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Junction of Maxted Road and Maxted Close	12.45	Organic Compounds	No significant quantities detected
		Particulates	0.223mg/m^3 (maximum level)
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Carbon monoxide	Not detected
Junction of Wood Lane End and Maylands Avenue	13.15	Organic Compounds	No significant quantities detected
		Particulates	0.361mg/m^3 (maximum level)
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Carbon monoxide	Not detected
Adeyfield School	14.00	Organic Compounds	No significant quantities detected
		Particulates	0.245mg/m^3 (maximum level)
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Carbon monoxide	Not detected
RC Church car park, Ritcroft Street	15.45	Organic Compounds	No significant quantities detected
		Particulates	1.300mg/m^3 (maximum level)
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Carbon monoxide	Not detected

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Table 3: Air quality monitoring results from Fire Brigade's Scientific Advisers 13/12/05

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Tiny Toes nursery	10.10	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Hydrogen Fluoride	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (Casella Microdust Pro)	0.124mg/m^3 (Max) 0.095mg/m3(Mean)
		Particulates (AMS 950)	0.04mg/m^3 (Max) 0.03mg/m3(Mean)
Leapfrog Day Nursery	12.47	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Sulphur dioxide	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (AMS 950)	0.06mg/m^3 (Max) 0.02mg/m3(Mean)
		Particulate (Casella Microdust Pro)	0.114mg/m^3 (Max) 0.010mg/m3(Mean)
Three Cherry Trees Caravan Site	15.02	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected abovenormal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Hydrogen Fluoride	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (AMS 950)	0.1mg/m^3 (Max) 0.02mg/m3(Mean)
		Particulate (Casella Microdust Pro)	0.124mg/m^3 (Max) 0.094mg/m3(Mean)

Table 4: Air quality monitoring results from Fire Brigade's Scientific Advisers 13/12/05

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Two Waters School, High Ridge Road, Aps	12.45	Ammonia	Not detected
		Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.149 mg/m^3 (Max) 0.036 mg/m^3 (Mean)
Woodfield School, Malmes Croft, Leverstock Green	14.00	Ammonia	Not detected
		Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.105 mg/m^3 (Max) 0.059 mg/m^3 (Mean)
Abbots Langley School, Farsonage Close, Abbots Langley	14.45	Ammonia	Not detected
		Carbon Monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.148 mg/m^3 (Max) 0.097 mg/m^3 (Mean)

Appendix 4 Atmospheric Modelling and Monitoring

4.1.2 Air Sampling Strategy Used by HSL During the Buncefield Fire

At the request of CHaPD the Health and Safety Laboratory (HSL) also conducted targeted local sampling to determine the impact of the fire upon air quality. Operating as an agency of the Health and Safety Executive (HSE), the HSL support the HSE's mission to protect people's health and safety by ensuring risks in the changing workplace are properly controlled (Health and Safety Laboratory, 2006a).

- Methods summary

Sunday 11th December: Air sampling was undertaken at St Albans Police station and at the Buncefield Depot adjacent to the fire.

Samples were collected so that they could be subsequently analysed for total particulate, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAH). Samples for total particulates were collected in accordance with Health & Safety Executive publication 'Method for determination of Hazardous Substances (MDHS) 14/3 'General Methods for sampling & gravimetric analysis of respirable & inhalable dust'. In brief, this method involves drawing air at a rate of 2 litres/minute through a pre-weighed GFA filter held in an IOM sampling head (Health and Safety Executive, 2006). The filters are subsequently reweighed and the weight gain expressed as micrograms per metre cubed of air (mg/m^3).

The GFA filters and XAD2 sorbent tubes were submitted for analysis for PAHs. Samples for VOCs were taken actively (pumped at 50ml/minute) onto tenax and chromosorb 106 sorbent media in accordance with MDHS 70 'General methods for sampling airborne gases & vapours'.

Monday 12th December: Air samples were taken at the same locations as the Fire Brigades' scientific advisors. Sampling was undertaken as described previously, however, VOCs were sampled using passive rather than active sampling techniques so that the sampling period could be extended. This is in accordance with MDHS 80 volatile organic compounds diffusive/thermal desorption. Carbon dioxide (CO2) levels were screened using long-term diffusive sampling Dräger tubes.

As normal background levels were detected, no other sampling for CO2 was undertaken. Sampling and analysis for asbestos fibres in air was monitored in accordance with MDHS 39/4 'asbestos fibres light microscopy' (Health and Safety Laboratory, 2006b).

Tuesday 13th December: Air samples were again taken at the same locations as the Fire Brigades' scientific advisors. Samples were collected for subsequent analysis for PAH and VOC following the same approach as that taken on 11th December.

- Results Summary

The results of this sampling were verbally communicated to CHaPD staff as soon as they were available and the formal results were sent to CHaPD at a later date. The sampling results in tables 5 - 10 indicated that none of the concentrations of pollutants monitored close to the site were above background concentrations.

Photo: Rob Holder

Table 5: Results of air quality monitoring undertaken by HSL on 11th December

NA μ/m^3	ACL μ/m^3	AC μ/m^3	FL μ/m^3	PH μ/m^3	AN μ/m^3	FA μ/m^3	PY μ/m^3	BAAN μ/m^3	CHR μ/m^3	BBKFA μ/m^3	BAP μ/m^3	IP μ/m^3	DBAHA μ/m^3	BGHIP μ/m^3
St Albans 12410/05														
<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.002	0.002	0.003	0.003	0.005	0.003	<0.001	<0.001	0.002
Seat of fire Hemel Hempstead 12411/05														
<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.020	0.020	0.010	0.010	0.020	0.010	0.010	<0.001	0.010
Blank 12412/05														
<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Blank 12413/05														
<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6: Results of air quality monitoring undertaken by HSL on 11th December

Benzene *ppb*	Toluene *ppb*	Ethyl-benzene *ppb*	o/m/p Xylene *ppb*	Ethyltoluenes & trimethyl-benzenes *ppb*	nC5, nC6, nC7 *ppb*	nC8 to nC16 inclusive *ppb*	Total VOC *ppb*	Sample volume *(Litres)*
St Albans Police Yard 12414/05								
1.3	5.0	0.5	2.0	1.6	1.1	0.7	9	*18.37*
Seat of fire Hemel Hempstead 2415/05								
2.3	10.6	0.7	4.3	3.6	7.9	5.6	65	*10.76*
Blank 12416/05								
0.2	0.5	0.1	0.4	< 0.1	0.6	< 0.1	5	*15*
Blank 12417/05								
not reported								

Table 7: Results of air quality monitoring undertaken by HSL on 12th December

NA μ/m^3	ACL μ/m^3	AC μ/m^3	FL μ/m^3	PH μ/m^3	AN μ/m^3	FA μ/m^3	PY μ/m^3	BAAN μ/m^3	CHR μ/m^3	BBKFA μ/m^3	BAP μ/m^3	IP μ/m^3	DBAHA μ/m^3	BGHIP μ/m^3
Wood Lane End 12422/05														
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Our Lady RC Church 12423/05														
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Blank 12424/05														
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
12425/05														
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Abbreviations used in tables:
NA = Naphthalene; **ACL** = Acenaphthylene; **AC** = Acenaphthene; **FL** = Fluorine;
PH = Phenanthrene; **AN** = Anthracene; **FA** = Fluoranthene; **Py** = Pyrene; **BAAN** = Benzo(a)anthracene;
CHR = Chrysene; **BBKFA** = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture;
BAP = Benzo(a)pyrene; **IP** = Indeno(1,2,3-c,d)pyrene; **DBAHA** = Dibenzo(a,h)anthracene; **BGHIP** = Benzo(g,h,i)peryl

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Table 8: Results of air quality monitoring undertaken by HSL on 12th December

Benzene *ppb*	Toluene *ppb*	Ethyl-benzene *ppb*	o/m/p Xylene *ppb*	Ethyltoluenes & trimethyl-benzenes *ppb*	nC7 *ppb*	nC9 *ppb*	Total VOC *ppb*	Sample Time *(mins)*
Wood Lane End 12426/05								
interference	6	< 5	5	< 5	58	14	3000	*189*
Adeyfield School 12427/05								
24	7	< 5	6	< 5	51	< 5	1300	*195*
Our Lady RC Church 12428/05								
35	54	< 5	15	< 5	113	15	3000	*85*
Blank 12429/05								
46	5	< 5	9	< 5	58	< 5	1300	*150*
Blank 12430/05								
51	12	< 5	9	< 5	61	< 5	2000	*150*

Table 9: Results of air quality monitoring undertaken by HSL on 13th December

NA *μ/m³*	ACL *μ/m³*	AC *μ/m³*	FL *μ/m³*	PH *μ/m³*	AN *μ/m³*	FA *μ/m³*	PY *μ/m³*	BAAN *μ/m³*	CHR *μ/m³*	BBKFA *μ/m³*	BAP *μ/m³*	IP *μ/m³*	DBAHA *μ/m³*	BGHIP *μ/m³*
Leverstock Green school, Hemel Hempstead 12438/05														
0.37	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Leverstock Green school, Hemel Hempstead 12439/05														
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.0
Leapfrog Nursery, Wood End Lane Hemel Hemp 12440/05														
0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.0
Leapfrog Nursery, Wood End Lane Hemel Hemp 12441/05														
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.0
Blank 12442/05														
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.0
Blank 12443/05														
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Abbreviations used in tables:
NA = Naphthalene; ACL = Acenaphthylene; AC = Acenaphthene; FL = Fluorine;
PH = Phenanthrene; AN = Anthracene; FA = Fluoranthene; Py = Pyrene; BAAN = Benzo(a)anthracene;
CHR = Chrysene; BBKFA = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture;
BAP = Benzo(a)pyrene; IP = Indeno(1,2,3-c,d)pyrene; DBAHA = Dibenzo(a,h)anthracene; BGHIP = Benzo(g,h,i)peryl

Table 10: Results of air quality monitoring undertaken by HSL on the 13.12.05

Benzene *ppb*	Toluene *ppb*	Ethyl-benzene *ppb*	o/m/p Xylene *ppb*	Ethyltoluenes & trimethyl-benzenes *ppb*	nC7 *ppb*	nC9 *ppb*	Sorbent Type *ppb*	Sample Time *(mins)*
Leverstock Green School, Hemel 12444/05								
11	9	~	< 5	~	37	< 5	TA	*280*
Leverstock Green School, Hemel 12445/05								
31	10	~	< 5	~	29	< 5	C106	*280*
Leapfrog Nursery, Wood End Lane, Hemel 12446/05								
17	5	~	< 5	~	32	< 5	TA	*240*
Leapfrog Nursery, Wood End Lane, Hemel 12447/05								
67	13	~	12	~	28	< 5	C106	*240*
Blank 12448/05								
11	< 5	~	< 5	~	29	< 5	TA	*250*
Blank 12449/05								
11	< 5	~	< 5	~	34	< 5	TA	*250*
Blank 12450/05								
75	10	~	< 5	~	26	< 5	C106	*250*
Additional Blanks 12451/05 12452/05 12453/05								
Not Analysed								

4.1.3 Locally targeted monitoring carried out by Netcen

Netcen conducted targeted air quality sampling during the incident, monitoring particulate matter (PM10) and volatile organic compounds (VOCs) at different locations around the site. The results of some of this sampling were made available to CHaPD by the evening of 13th of December.

4.2 Facility for Airborne Atmospheric Measurements (FAAM) aircraft samples

The FAAM research aircraft, which the Met Office jointly operates with Natural Environment Research Council (NERC), was deployed on 12th and 13th of December to take *in situ* measurements of the plume (Met Office, 2006). This had two purposes: firstly, to determine the location of the plume and secondly to determine the chemical composition of the plume. The results of the sampling were available at approximately 15.00 hours on 13th December. These indicated that the plume was at a high level in the atmosphere between approximately 600 and 1500 m, suggesting that exposures of members of the public should be low. The information on the concentrations of particulate matter in the plume and the chemical composition of the particulates that was available at this stage of the incident indicated that the main constituent was black carbon (soot) and that the concentrations of polycyclic aromatic hydrocarbons (PAHs) in the plume were low

4.3 Defra automated network

During the response to the incident, CHaPD used information from the UK's national Automatic Urban and Rural Network (AURN) which continuously monitors the following chemicals: particulate matter (both PM10 and $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3) in near real-time by using the AURN website (NETCEN, 2006).

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4.4 Automated monitoring network managed by Environmental Research Group (ERG) King's College London

4.4.1 Background

Air pollution in London and the Home Counties is measured by four regional air quality monitoring networks comprising over 140 monitoring sites. These networks are managed by King's College London (KCL) on behalf of local authorities and Defra. The spatial resolution of the continuous monitoring sites in London is far greater than the AURN and is far greater than anywhere else in the UK. These combined networks therefore represent a unique resource for the quantification of exposure during local and regional PM_{10} events. Details of these networks can be found online (London Air Quality Network, 2006, Herts. & Beds Air Pollution Monitoring Network, 2006, Sussex Air Quality Steering Group, 2006, Kent & Medway Air Quality Monitoring Network, 2006). Measurements are collected from monitoring sites either hourly or twice daily and disseminated on network web pages. On the morning of Sunday 11th, in response to the Buncefield fire, the KCL Duty Team increased the frequency of data collection from PM_{10} monitoring sites to maximise the number of measurements available in near real-time to the public via the network web pages.

4.4.2 Detecting the Buncefield Plume

PM_{10} concentrations can be assumed to consist of a regional background of particulate from secondary and natural sources and a local primary component that is linked to oxides of nitrogen (NO_x) (Fuller *et al.*, 2002). However PM_{10} from fires and other local sources with high PM10:NO_x ratios are not accounted for by this model (Fuller and Green 2004). Deviation from the concentrations expected by this approach were, therefore, used to identify possible incidents of grounding of the Buncefield plume. Experience from the grounding of industrial plumes across London provides evidence that plume grounding incidents from sources several kilometers away are rarely measured at a single site only.

ERG have reported that there were several occasions when the plume appears to have had an impact on air quality (Kings College London, 2006). However, the only occasions when the plume was thought to have made a moderate impact upon air quality at ground level was on the evening of Sunday 11th and early in the morning of Monday 12th. The smoke from the fire was detected at monitoring sites in parts of east Surrey and Sussex causing PM_{10} particulate concentrations to reach 'moderate' levels in Horsham and Lewes.

Throughout the period of the fire, 'moderate' PM_{10} particulate concentrations were measured at several roadside sites in London. These were due to road transport sources and were not directly related to the smoke from the oil depot fire. 'Moderate' PM_{10} concentrations at the Chichester 1 site were due to nearby road resurfacing. On Tuesday 13th, an email data feed was established between KCL's operation centre and the CHaPD. This feed summarised the latest pollution measurements from regional network sites in London and the south-east. This 24 hourly data feed was supported by analysis from KCL's operations centre between 08.00 hours and 18.00 hours each working day.

4.4.3 Monitoring in Hemel Hempstead

On Tuesday 13th, KCL, the fire brigade's scientific advisors and Dacorum Borough Council established a NO_x and PM_{10} monitoring site in Hemel Hempstead. PM_{10} measurements were available from Wednesday 14th December. Concentrations remained 'low' for the remainder of the period of the fire and were similar to those measured at nearby St Albans.

4.5 Air quality monitoring by local authorities in Surrey

In addition to using information from the air quality networks mentioned above, information was also obtained on air quality in Surrey. Using the local Health Protection Unit's (HPU) links with local authorities, CHaPD were able to view information on air quality in Surrey. This link was established on the 14th of December. This did not indicate that the incident was causing any deterioration in air quality.

Table 11: Maximum 15 mean PM_{10} concentrations during the Buncefield incident thought by ERG to be due to the plume grounding (Kings College London, 2006)

Date	Time of max Concentration	Area	Site	Max 15 mean Conc µg m^{-3} (grav)
11-Dec	16:15	Surrey & Sussex	Mole Valley 3 - Dorking	156
	17:45	Surrey & Sussex	R'gate & Bans 1 - Horley	133
	19:15	Surrey & Sussex	Lewes 2	217
	22:45	Surrey & Sussex	Horsham 2	290
	20:30	Hertfordshire	St Albans - Fleetville	133
	18:30	North London	Haringey 2 - Priory Pk*	102
	18:45	North London	Haringey 1 - Tottenham	122
	19:15	North London	Islington 2 - Holloway Rd	137
12-Dec	02:30	North London	Brent 5 - Neasden	130
14-Dec	03:00	North London	Barnet 2	98
	07:30	Hertfordshire	Watford	114

* = Beta Attenuation Monitor (BAM) which has only hourly measurement resolution. The remaining concentrations were measured by Tapered Element Oscillating Microbalance (TEOM). Concentrations are expressed as gravimetric corrected; a conversion factor of 1.3 was aplied to TEOM measurements and a correction factor of 0.81 was applied to BAM measurements.

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5 Soil and Grass sampling conducted by CHaPD (Birmingham)

5.1 Introduction

In response to the Buncefield Fuel Depot fire of the 11th December 2005, the Health Protection Agency undertook an initial screening investigation of surface soils and grasses downwind of the fire in order to determine whether there was (1) any evidence of significant plume grounding and (2) a need for more detailed sampling. During the 14th and 15th December, teams from the HPA's Centre for Radiation, Chemicals and Environmental Hazards (CRCE) collected a total of 72 samples from 33 locations (including a control site and a site located upwind of the fire). Several wipe samples of dust and soot were also collected. All samples were collected before substantial rainfall in the area thereby avoiding the possibility of rain washing away any pollution attached to soil, vegetation or property.

5.2 Methods

5.2.1 Sampling

As recommended by Defra (1999), a single soil and grass sample was collected at each sample location with *ad hoc* samples being taken as required. One background and one upwind sample site were also included in the sampling strategy.

The sampling teams focused on two main areas:

a) The predicted point of maximum ground-level deposition using available plume dispersion models, particularly AERMOD/ADMS models developed by the EA, NAME models produced by the Met Office and CHEMETs requested by the Emergency Services during the fire.

b) Areas with documented visible plume at ground level or where there was possible fall-out from the fire (soot, debris *etc*).

The investigation focused on priority 'sensitive' sites, including schools, hospitals, housing estates, parks and nurseries.

In total, 72 samples were collected from 33 locations. One sample was a control (located in an urban area outside the affected region); one was located 2 km upwind of Buncefield and the other 31 located between 2 and 13 km downwind.

Grass samples were taken from a 1m^2 area at each sampling point. Soil core samples were taken at a diameter of 3.5 cm to a depth of 10 cm below ground level. Wipe samples for soot and dust were collected by wiping a piece of moistened sterilized paper over a representative hard upturned surface such as a car roof or letter box. All samples were double-bagged, labelled and kept refrigerated prior to analysis. Map 1 shows the sampling locations.

5.2.2 Analysis

Five groups of pollutants were selected for analysis based upon both scientific concerns (atmospheric sampling at the scene, knowledge of the materials involved, potential for formation within the plume and potential health impacts) and political/public concerns:

- Polycyclic aromatic hydrocarbons. These are reported for both 'total' PAH (US EPA Method 610) and benzo(a)pyrene.
- Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans).
- Heavy metals (V, Ni, Cd, Cr, Cu, Pb, Zn).
- Perfluorooctane sulphonate (PFOS, associated with foam used to fight the fire).
- Fluoride (produced from thermal decomposition of PFOS).

Samples were analysed at two UKAS accredited laboratories: the Environment Agency's National Laboratory Service (Leeds) and the commercial laboratory, TES Bretby (Burton on Trent).

5.3 Results

5.3.1 Heavy Metals

Vanadium and nickel were considered the most appropriate markers of oil combustion. The mean vanadium and nickel concentrations in soil and grass samples were unexceptional and comparable to that reported in the control and upwind sites and well within typical UK ranges for urban soils and grasses (Table G.12). Reported concentrations of other heavy metals were also unexceptional.

Map 1. Sample locations (by location).

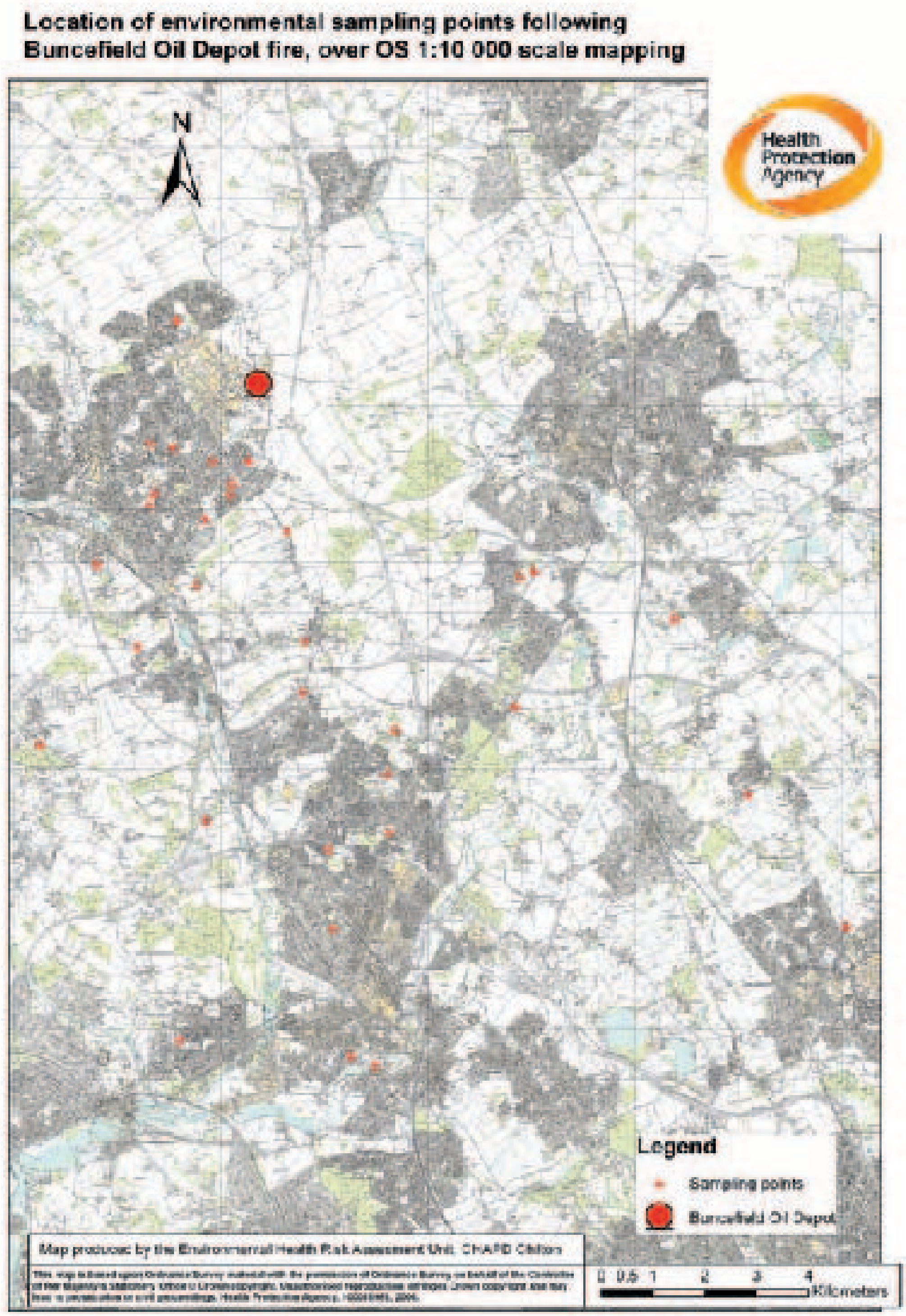

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Table 12: Summary of heavy metals data. All values are mg kg^{-1} (dry weight).

Heavy metal	SGV1[1]	UK soil Median range	Soil samples *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium	-	34.7- 83.0[2]	28.0	59.0	43.0	40.0	44.0
Nickel	50	15 - 47[3]	8.0	40.8	21.9	16.7	29.0
Cadmium	1	0.3 - 2.0[3]	0.1	2.91	0.8	0.39	1.01
Chromium	130	43 - 108[3]	23.9	43.9	30.8	27.0	29.2
Copper	-	2 - 250[4]	8.2	41.2	24.7	21.4	38.5
Lead	450	45 - 225[3]	43.6	103.0	69.3	60.2	44.4
Zinc	-	5 - 816[5]	44.0	257.0	156.1	138.0	146.0

Heavy metal	Maximum recommended concentration for production grass species	Grass samples *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium	-	1.0	22.2	8.8	9.3	5.9
Nickel	-	2.7	18.1	7.8	7.33	5.1
Cadmium	-	0.1	0.721	0.2	0.175	0.45
Chromium	-	1.06	29.4	11.6	10.8	7.18
Copper	250[6]	10.9	105.0	32.0	25.6	10.4
Lead	-	2.72	62.7	19.4	15.0	15.6
Zinc	1000[6]	26.3	90.5	53.7	50.7	54.5

Heavy metal		Wipe samples (mg $wipe^{-1}$) *Minimum*	*Maximum*	*Mean*	*Median*	*Control*
Vanadium		12.5	12.5	12.5	12.5	-
Nickel		17.2	25.8	21.5	21.5	-
Cadmium		4.09	17.9	11.0	11.0	-
Chromium		27.0	31.7	29.3	29.3	-
Copper		55.9	82.4	69.2	69.2	-
Lead		38.3	76.6	57.4	57.4	-
Zinc		525.0	3360.0	1942.5	1942.5	-

[1] residential with plant uptake
[2] both urban and rural sites Lark *et al* (2006)
[3] urban sites Fordyce et al (2005)
[4] both urban and rural sites Bowen (1985)
[5] both urban and rural Adriano (1986)
[6] DETR (1996)

Photo: Hertfordshire Constabulary and Chiltern Air Support Unit

5.3.2 Polycyclic Aromatic Hydrocarbons (PAH)

Total PAH concentrations in the majority of soils sampled downwind of the fire were within typical urban levels reported in the scientific literature and comparable with concentrations recorded at the control site and the upwind sites (Table 13). Concentrations reported in soils around Buncefield were also comparable with data collected by the Environment Agency in their unpublished Soil and Herbage Survey.

Three soil and two grass samples collected in South Watford (approximately 10 kilometres to the south of the depot) did show evidence of elevated PAH concentrations. However, it was concluded that on the balance of evidence, it was thought that this contamination was unlikely to be a result of the fire. It is not considered credible that the high concentrations in soil and grass could have been caused by grounding of the plume. There is no evidence of plume grounding, neither visually or from nearby air monitoring stations, in this area and no evidence of contamination by other pollutions that could be associated with the fire, such as nickel and vanadium. Historical contamination is a more probable cause and at one of these sites there is a plausible source of contaminated land (a nearby former power station).

5.3.3 Dioxins and Furans

Reported soil concentrations around Buncefield were consistent with published background data for soils and are comparable with concentrations reported at the control site (Table 14). Both the mean and median values fall within the typical range reported in UK rural environments and are also within the ranges for both urban and rural herbage reported by the EA's Soil and Herbage Survey (Barraclough, personal communication).

Table 13: Summary of total of 16 US EPA (Method 610) parent PAH data. All values are mg kg^{-1} (dry weight)

Media SPAH	UK urban (range)	Typical kerbside (range)	Buncefield samples				
			Minimum	*Maximum*	*Mean*	*Median*	*Control*
Soil[1] n=13	0.95 - 4.42	9.75 - 20.00	0.92	239	36.82	3.10	3.98
Grass[2] n=16	0.09 - 0.15	0.19	0.14	171	2.47	0.831	1.55

[1] Smith *et al*, 1995; Butler *et al*, 1984
[2] Meharg *et al*, 1998; Crepineau and Rychen, 2003

Table 14: Summary of dioxin and furan data (expressed as ng TEQ WHO kg-1 dry weight)

Media SI-TEQ	Typical UK urban (range)	Typical UK rural (range)	Buncefield samples				
			Minimum	*Maximum*	*Mean*	*Median*	*Control*
Soil[1] n=5	0.87 - 87	0.78 - 20	2.46	7.92	4.94	4.71	3.01
Grass[2] n=5	-	0.47 - 5.00	0.52	2.14	1.57	1.87	1.57

[1] Roots *et al*, 2004
[2] Eduljee and Gair, 1996 (expressed as ng TEQ NATO kg^{-1} dry weight)

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5.3.4 Perfluorooctylsulphonate (PFOS) and Fluoride

With the exception of two samples, PFOS and other PFAS concentrations were below the detection limit of 0.2 µg kg^{-1}. Measured concentrations of fluorides in soil downwind from Buncefield are consistent with urban environments and are more than an order of magnitude below reported maximum soil concentration limits (500 mg kg^{-1}) and are lower than the much stricter grass guideline (30 mg kg^{-1}) for agricultural land (DETR, 1996).

5.4 Conclusion of soil and grass sampling

Overall, it was concluded that the fire at the Buncefield Oil Depot did not result in substantial pollution of soil and grasses. A large number of measurements found that pollutant levels were, in general, unexceptional and typical of UK urban environments. While localised plume grounding cannot be discounted, this investigation supports the view that prolonged plume grounding downwind of the fire did not occur.

Table 15: Concentrations of benzene monitored starting on 27th December and continuing for 4 weeks

Location	Concentrations of benzene *(µg/m^3)*
Hunters Oak, Hemel	1.05
Finway Road, Hemel	1.74
Woodlane End, Hemel	1.81
Boundary Way, Alcon, Hemel	2.29
Boundary Way, Northgate, Hemel	2.41
Eaton Lodge	1.72
Punchbowl Lane Jct	2.36
Southend Farm	1.38
Old Jeromes	1.43
Hoggend Lane	1.27

6 Monitoring carried out by the local authority started on the 27th December 2005

Following the acute response stage of the incident the local authority carried out benzene sampling at various locations close to the site starting on 27th December and continuing for 4 weeks. The results displayed in table G.15 indicate that concentrations of benzene were lower than the long term Environmental Assessment Levels (EALs), set by the Environment Agency and were below the National Air Quality Strategy objectives for benzene (annual running mean of 16.25 ug/m^3).

7 Occupational exposure monitoring during site clean up at Buncefield oil depot 29 - 30 December 2005

The exposures of the employees working on the site clean up to VOCs were monitored by the HSL. Personal monitoring was conducted using passive (diffusive) lapel mounted sorbent tubes. For each worker sampled, parallel sampling was conducted with both Tenax TA (TA) and Chromosorb106 sorbent material (106) (Health and Safety Laboratory, 2006d). Samples from twelve workers were measured on the afternoon of 29th December and 16 workers were measured in the morning of 30th December. The results are displayed in tables 16 and 17.

Table 16: Occupational monitoring results from 29th December (Health and Safety Laboratory, 2006c)

Sample information			Results (parts per million)				
Type	Subject	Period	*Benzene*	*Toluene*	*Xylenes*	*Trimethyl benzenes*	*$C_7 - C_{12}$ HCs*
TA	Worker 1	12:03 – 15:45	0.03	0.05	0.10	0.05	0.05
106	Worker 1	12:03 – 15:45	0.05	0.46	0.10	<0.01	<0.01
TA	Worker 2	12:05 – 15:45	0.04	0.04	0.07	0.03	0.04
106	Worker 2	12:05 – 15:45	0.01	<0.01	0.08	<0.01	<0.01
TA	Worker 3	12:06 – 15:45	0.03	0.07	0.13	0.11	0.09
106	Worker 3	12:06 – 15:45	0.08	0.33	0.46	0.72	0.70
TA	Worker 4	12:08 – 15:45	0.06	0.07	0.14	0.10	0.08
106	Worker 4	12:08 – 15:45	0.02	0.03	0.12	1.11	2.46
TA	Worker 5	12:14 – 15:45	0.03	0.08	0.80	0.89	1.90
106	Worker 5	12:14 – 15:45	0.06	0.38	0.87	0.72	1.62
TA	Worker 6	12:15 – 15:45	0.20	0.13	1.20	0.70	1.53
106	Worker 6	12:15 – 15:45	0.03	0.11	0.76	1.30	0.26
TA	Worker 7	12:18 – 15:45	0.01	0.06	0.98	1.16	2.56
106	Worker 7	12:18 – 15:45	0.03	0.07	0.94	1.56	3.10
TA	Worker 8	13:35 – 15:45	0.18	0.10	0.21	0.07	0.26
106	Worker 8	13:35 – 15:45	0.10	0.25	0.23	0.32	0.41
TA	Worker 9	13:38 – 15:45	0.07	0.11	0.33	0.16	0.38
106	Worker 9	13:38 – 15:45	0.04	0.07	0.22	<0.01	0.18
TA	Worker 10	13:40 – 15:45	0.08	0.10	0.54	<0.01	1.73
106	Worker 10	13:40 – 15:45	0.06	0.06	0.38	<0.01	1.41
TA	Worker 11	13:48 – 15:45	SE	SE	SE	SE	SE
106	Worker 11	13:48 – 15:45	<0.01	0.22	<0.01	<0.01	<0.01
TA	Worker 12	13:49 – 15:45	0.06	0.29	0.07	0.04	0.11
106	Worker 12	13:49 – 15:45	0.08	0.13	0.08	0.04	0.12
TA	Blank		0.01	0.01	<0.01	<0.01	<0.01
106	Blank		0.02	0.01	<0.01	<0.01	<0.01
TA	Blank		0.05	0.02	0.02	0.02	0.01
106	Blank		<0.01	0.02	0.06	0.01	0.02

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Table 17: Occupational monitoring results from 30th December (Health and Safety Laboratory, 2006c)

Sample information			Results (parts per million)				
Type	Subject	Period	*Benzene*	*Toluene*	*Xylenes*	*Trimethyl benzenes*	*$C_7 - C_{12}$ HCs*
TA	Worker 1	07:15 – 13:50	0.01	0.04	0.10	0.10	0.10
106	Worker 1	07:15 – 13:50	<0.01	0.04	0.05	0.01	0.02
TA	Worker 2	07:16 – 13:04	0.01	0.03	0.04	0.01	0.03
106	Worker 2	07:16 – 13:04	0.01	0.01	0.03	<0.01	0.03
TA	Worker 3	07:17 – 13:52	0.01	0.03	0.06	0.06	0.13
106	Worker 3	07:17 – 13:52	<0.01	<0.01	<0.01	<0.01	<0.01
TA	Worker 4	07:18 – 13:06	0.02	0.09	0.10	0.04	0.09
106	Worker 4	07:18 – 13:06	0.01	0.04	<0.01	<0.01	<0.01
TA	Worker 5	07:21 – 14:07	0.01	0.03	0.06	0.09	0.13
106	Worker 5	07:21 – 14:07	0.01	0.01	0.03	0.01	0.08
TA	Worker 6	07:24 – 13:36	0.02	0.08	0.11	0.04	0.10
106	Worker 6	07:24 – 13:36	0.02	0.06	0.05	0.01	0.04
TA	Worker 7	07:33 – 13:42	0.01	0.01	0.09	0.05	0.10
106	Worker 7	07:33 – 13:42	0.01	0.02	0.05	0.01	0.03
TA	Worker 8	07:35 – 13:45	0.01	0.03	0.04	0.02	0.06
106	Worker 8	07:35 – 13:45	0.01	0.03	0.01	<0.01	0.02
TA	Worker 9	07:35 – 13:46	0.01	0.03	0.05	0.02	0.06
106	Worker 9	07:35 – 13:46	0.05	0.04	0.02	0.01	0.01
TA	Worker 10	07:37 – 14:07	0.01	0.07	0.57	0.27	0.57
106	Worker 10	07:37 – 14:07	0.01	0.03	0.33	0.10	0.35
TA	Worker 11	07:40 – 14:07	0.01	0.03	0.12	0.08	0.12
106	Worker 11	07:40 – 14:07	<0.01	0.01	0.04	0.01	0.05
TA	Worker 12	07:47 – 13:50	0.02	0.07	0.28	0.10	0.65
106	Worker 12	07:47 – 13:50	<0.01	<0.01	0.14	<0.01	0.08
TA	Worker 13	07:52 – 12:34	0.01	0.01	0.02	0.01	0.03
106	Worker 13	07:52 – 12:34	<0.01	<0.01	<0.01	<0.01	<0.01
TA	Worker 14	08:04 – 13:41	0.01	0.05	0.11	0.08	0.11
106	Worker 14	08:04 – 13:41	<0.01	0.01	0.04	<0.01	0.18
TA	Worker 15	08:07 – 13:24	0.02	0.05	0.29	0.24	0.44
106	Worker 15	08:07 – 13:24	0.02	0.04	0.09	0.04	0.25
TA	Worker 16	08:07 – 13:21	0.01	0.07	0.91	0.84	1.84
106	Worker 16	08:07 – 13:21	0.03	0.05	0.77	0.86	1.71
TA	Blank		0.01	0.01	ND	ND	ND
106	Blank		0.01	0.1	ND	ND	ND
TA	Blank		0.01	ND	ND	ND	ND
106	Blank		ND	ND	ND	ND	ND

The results are all lower than the Workplace Exposure Limits (WELs). The HSL concluded “that on 29th and 30th December , the hydrocarbon exposure by inhalation of the workers clearing spillages at the Buncefield oil depot were low when compared against UK workplace exposure limits” and that “Exposures of this order would not be considered excessive within the petrochemical industry, even under normal production conditions” (Health and Safety Laboratory, 2006c). These results were given to CHaPD on 13th January 2006.

8 Potential water contamination

In addition to the above work CHaPD have also been working with the Buncefield Inter-Agency Liaison Group (IALG) looking at the potential for surface and ground water contamination as a result of the Buncefield incident (Health and Safety Executive, 2006).

9 Conclusions and further work

This report details the air modelling and monitoring that have played an important part in assessing the potential public health risks from the Buncefield fire. The heat of the fire appears to have punched a hole in the inversion layer allowing the plume to rise to high altitude. The high plume buoyancy and the favourable meteorological conditions resulted in the plume being trapped aloft with minimal mixing to the ground.

Fortunately the explosions and fire resulted in few casualties and no deaths. Dynamic health impact assessment and environmental impact assessment were shared with Strategic Gold Command from 09.00 on 11th to 18.30 hours on 14th December. In addition these data were provided to the Civil Contingencies Secretariat. Information on the health impact of the fire was shared at the time of the incident with members of the public via media reports / press statements and the HPA website

This Defra/Netcen report will be referred to the Committee on the Medical Effects of Air Pollutants for advice of health aspects of this data at their June 2006 meeting.

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Police

Fire

Ambulance

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Met Office

Fire Brigade Scientific Advisers

Health and Safety Laboratory

Environment Agency

Environmental Research Group, King’s College, London

Netcen (Harwell)

Defra

Dacorum Borough Council

Pan London Local Authority Environmental Health Officers Network

Local Authorities in Surrey

National Poisons Information Service

Guy’s Poisons Unit

Occupational Health for responding agencies and organisations

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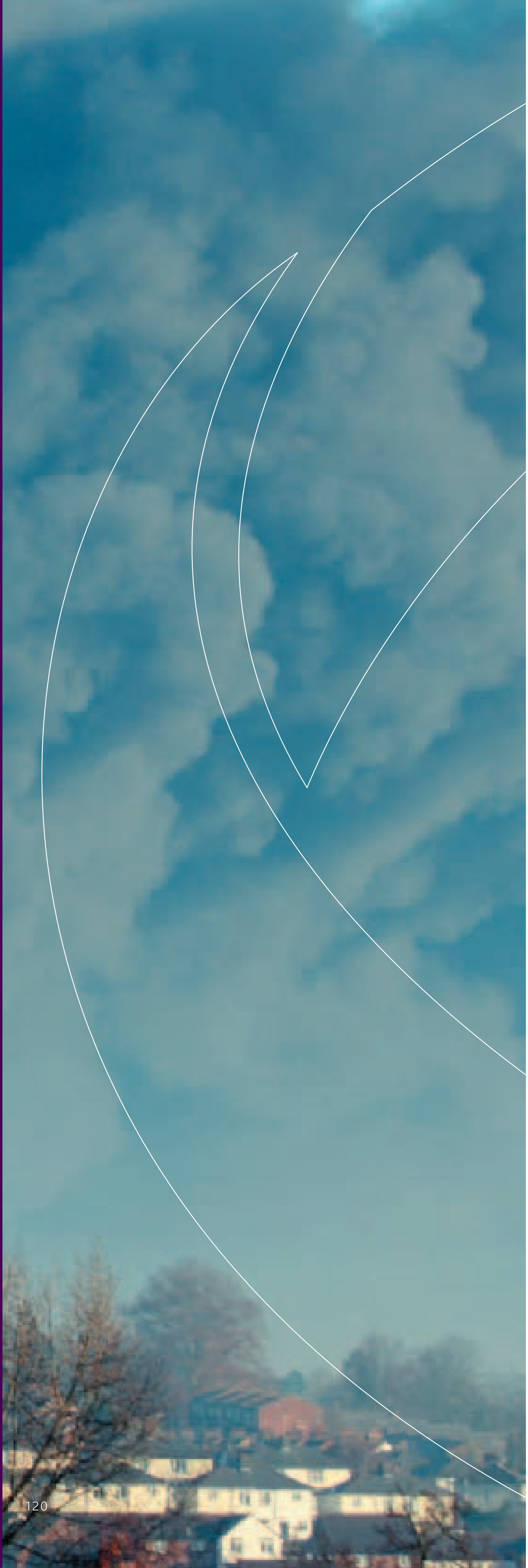

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