

Guidance

G2108

Occupational exposure to respirable dust

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1 Purpose

- 1.1 This guidance provides good practice solutions for the occupational exposure to respirable dust.
- 1.2 This guidance was produced for the construction of Crossrail.

2 Scope

- 2.1 This guidance may be used for projects that require management of occupational exposure to respirable dust.

3 Guidance

- 3.1 The unedited Crossrail good practice guide begins on the next page.

4 Responsibilities

- 4.1 The Deep Tube Tunnels Engineer is responsible for this guidance.

5 Supporting information

- 5.1.1 This guidance is one of a set that provide overall guidance on the life cycle requirements for Civil Engineering assets.
- 5.1.2 The complete set is as follows:

Document no.	Title or URL
G050	Civil Engineering – Common Requirements
G0051	Civil Engineering – Bridge Structures
G0052	Civil Engineering – Gravity Drainage Systems
G0053	Civil Engineering – Building and Station Structures
G0054A	Civil Engineering – Earth Structures
G0054B	Earth Structures – Guide for Slope Stability Analysis
G055	Civil Engineering – Deep Tube Tunnels and Shafts
G0056	Civil Engineering – Pumping Systems
G0057	Civil Engineering – Miscellaneous Assets
G0058	Civil Engineering – Technical Advice Notes
G1299	Guidance on Civil Engineering Asset Strategic and Tactical Risk Models
G1417	Grouting to control seepage in tunnels and structures
G2105	Construction Railway Operations
G2106	Sprayed concrete lining exclusion zone management
G2107	Pressure Systems
G2108	Occupational Exposure to Respirable Dust

5.1.3 The above give guidance and explanation in support of the following standards:

Document no.	Title or URL
S1050	Civil Engineering – Common Requirements
S1051	Civil Engineering – Bridge Structures
S1052	Civil Engineering – Gravity Drainage Systems
S1053	Civil Engineering – Building and Station Structures
S1054	Civil Engineering – Earth Structures
S1055	Civil Engineering – Deep Tube Tunnels and Shafts
S1056	Civil Engineering – Pumping Systems
S1057	Civil Engineering – Miscellaneous Assets
S1060	Civil Engineering – Bridges and Structures inspection standard
S1061	Civil Engineering – Bridges and Structures Assessment
S1062	Temporary Works
S1063	Civil Engineering - Cutting, grinding, drilling, fixing to and supporting from existing structures
S1064	Civil Engineering - Waterproofing
S1800	Cable Runs
S1801	Competence requirements for undertaking Civil Engineering Safety Critical Work

6 Person accountable for the document

Name	Job title
Keith Bowers	Principal Tunnel Engineer

7 Document history

Issue no.	Date	Changes	Author
A1	June 2016	Incorporation of Crossrail best practice guide into LU Standards suite	Mohammed Gajia

8 References

Document no.	Title or URL
	Occupational exposure to respirable dust, respirable crystalline silica and diesel engine exhaust emissions in the London tunnelling environment.

9 Attachments

SUMMARY

Crossrail is a 118-kilometre (73-mile) railway line under construction in England. Work began in 2009 and it is Europe's largest railway and infrastructure construction projects. During tunnelling projects exposures to potentially hazardous agents may occur due to the work being carried out in a confined space. Exposure measurements reported in the peer-reviewed literature suggest that all exposures are higher in underground work compared to outdoor construction workers. Relatively few studies have been conducted specifically looking at occupational exposures in tunnelling, and results from personal exposure measurements are especially lacking.

A series of measurement campaigns were undertaken to investigate exposure to respirable dust (RD), respirable crystalline silica (RCS) and diesel engine exhaust emissions (DEEE) of the workers involved in tunnel construction. Workers monitored included those working on TBMs (tunnel boring machines) and SCL (spray concrete lining) activities. Personal exposure measurements were obtained using cyclone sampling heads, with temporal variability and levels of black carbon (BC) (as a marker for DEEE) and RD being assessed using a MicroAeth AE51 and TSI SidePak fitted with a cyclone, respectively.

During SCL work job titles with the highest mean personal RD exposures were the back-up sprayer (Arithmetic Mean (AM) 2.40 mg/m^3) and sprayer (AM 1.55 mg/m^3). Both undertook the concrete spray activities and were observed to be in the restricted zone during excavation and spray activities. The inspector and pump men experienced the lowest mean RD exposures. All RD concentrations were below the Health and Safety Executive (HSE) Workplace Exposure Limit (WEL) for RD (4 mg/m^3), although there were several instances where 8-hr concentrations were in excess of 1 mg/m^3 (the IOM recommended exposure limit). The highest RCS exposure was observed for the back-up sprayer, with a maximum measured RCS concentration of 0.24 mg/m^3 . Concentrations in excess of 0.1 mg/m^3 , the 8-hr TWA WEL, for RCS were also reported for an engineer, lead miner and two plant operators. With respect to the SCL static samples, the highest mean (1.28 mg/m^3) and maximum RD concentration (1.4 mg/m^3) were measured within the restricted zone. The maximum RCS concentration of 0.04 mg/m^3 was also observed within the restricted zone.

All the REC concentrations measured with personal samples in the TBM environment were below the $100 \text{ } \mu\text{g/m}^3$ reference limit. All RD measurements collected in the TBM environment were below the WEL, although for the job titles segment lift, grout pump, ring building, rail extension and conveyor extension there were a number of instances where the RD exposures were in excess of 1 mg/m^3 (the IOM recommended exposure limit). The job titles with mean RD concentrations in excess of 1 mg/m^3 were the conveyor extension (AM 1.65 mg/m^3) and rail extension operators (AM 1.10 mg/m^3). The highest observed REC concentration was for a segment lifter ($37 \text{ } \mu\text{g/m}^3$) and the conveyor extension and rail



extension operators were reported to have the highest mean REC concentrations (AM 30 and 26 $\mu\text{g}/\text{m}^3$ respectively). For the static samples, the highest mean RD and REC concentrations were observed at the transfer hopper location (RD AM 1.38 mg/m^3 and REC AM 33 $\mu\text{g}/\text{m}^3$) and segment lift area (RD 1.38 and REC 40 $\mu\text{g}/\text{m}^3$ although this was based on only one sample). The maximum RD concentration was also reported in the segment lift area and the TBM bridge area (2.2 mg/m^3) with the maximum REC concentration also being observed at the TBM bridge area (52 $\mu\text{g}/\text{m}^3$).

Temporal direct reading measurements using the MicroAeth revealed the impact of excavation, vehicular and locomotive movements with peaks in BC concentrations usually coinciding with these activities. During the TBM monitoring period the supply air was turned down during surveying activities. The impact of this on BC concentrations was evident in the temporal data and concentrations were reduced when the supply air was returned back to the usual settings. BC concentrations were higher in the SCL environment in comparison to the TBM environment (mean SCL concentrations over measurement period ranged from 17-54 $\mu\text{g}/\text{m}^3$ in SCL environment compared to 3-8 $\mu\text{g}/\text{m}^3$ in TBM environment).

SidePaks were used to log the temporal trends in RD over the monitoring period. Similar trends as for the BC temporal and summary data were observed, with excavation, spray and vehicular activities leading to relatively higher concentrations in the SCL environment. The impact of the locomotive movement and the reduction in supply air was again demonstrated in the TBM SidePak data.

The results in our monitoring campaigns suggest that DEEE exposures are higher in the SCL environments than the TBM environment and it is considered that future monitoring campaigns should focus on assessing DEEE exposures in the SCL environment and necessary measures should be implemented to control exposure. In the SCL environment, exposure to RD and RCS could be significant. Engineering controls such as de-dusters should be appropriately located and used during tunnelling operations. Respiratory protection equipment is provided and refresher operator training should be given on how to use and wear these correctly. It is recommended that face-fit testing be undertaken to ensure that suitable and sufficient RPE is provided to the SCL operators.

Given the levels, further engineering control measures should be taken to reduce the RD exposure throughout the TBM but particularly in the conveyor extension area. The REC concentrations were lower than the SCL environment. However, measures should be taken to reduce exposures further, for example by replacing older, less efficient locomotives ('yellow' engines), and avoiding unnecessary running or idling of diesel engines. Efficient ventilation is needed to assist in the removal of RD and DEEE. The supply air to the TBM was turned down on two of the monitoring days and the impact of this on RD and REC was clearly observed. Further investigation is needed to ascertain why this practice takes place so that it can be eliminated or reduced.



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1 INTRODUCTION

Crossrail is a 118-kilometre (73-mile) railway line under construction in England. It is due to begin full operation in 2018, serving London and surrounding areas by providing a new east-to-west route across Greater London. Work began in 2009 and it is Europe's largest railway and infrastructure construction projects. The project's main feature is 42 km (26 miles) of new tunnels. There are five tunneled sections each with an internal diameter of 6.2 m (20 ft), totaling 21 km (13 miles) in length.

The Control of Substances Hazardous to Health (COSHH) Regulations require employers to control substances that are hazardous to health. The objective of the COSHH Regulations is to prevent, or to adequately control, exposure to substances hazardous to health, so as to prevent ill health. During large scale construction projects it is important to monitor exposures of workers to hazardous substances used in, or generated during the work to assess compliance with workplace exposure limits (WELs) set to protect workers' health and reduce exposures as low as is reasonably practicable. This is particularly the case during tunnelling projects where potential exposure to hazardous agents may occur due to work in confined spaces.

Measurements reported in the peer-reviewed literature have shown that exposures are generally higher in underground work compared to outdoor construction workers [Bakke *et al.*, 2002]. Although construction is one of the prominent industries on which the occupational hygiene community focuses, it is very diverse and extrapolation from one environment to the next, or even from one construction site to the next, is difficult [Bakke *et al.*, 2002]. Few studies have been conducted specifically looking at occupational exposures in tunnelling, and information from personal exposure measurements are lacking.

Exposures of interest in the tunnelling environment are primarily respirable dust (RD); respirable silica, carbon monoxide, nitrogen dioxide (NO₂) and diesel exhaust [Bakke, 2004]. Substantial exposure to total dust, RD and α -quartz were reported during tunnel construction work in Norway, while exposure to oil mist (from diesel exhaust and oil spraying) was high for shaft drillers [Bakke *et al.*, 2001]. Bakke *et al.* [2002] indicated that as much as 15% of total dust measurements, 5% of RD measurements and 21% of quartz measurements exceeded the Norwegian OELs of 10 mg/m³, 5 mg/m³ and 0.1 mg/m³, respectively. Exposure to NO₂ was also measured as well as elemental carbon (EC) as an index of exposure to diesel exhaust [Pronk *et al.*, 2009; Vermeulen *et al.*, 2010]. EC levels of 100-340 μ g/m³ were measured, indicating that even the lowest measured concentrations in these sites were above those considered to have an impact on health [van Tongeren *et al.*, 2013]. However, distinct differences in exposure levels and determinants were found for the different jobs conducted in tunnel construction work [Bakke *et al.*, 2002]. Important determinants associated with increased exposure were the type of drill rigs used, mechanical scaling, shotcreting, drilling, mucking and repairing of ventilation ducts.



Occupational exposure to respirable dust, respirable crystalline silica and diesel engine exhaust emissions in the London tunnelling environment

In the Crossrail project each of the five tunneled sections consists of two tunnels excavated at the same time using two Tunnel Boring Machines (TBMs) (Figure 1).

The tunnel linings are constructed from pre-manufactured concrete segments which are transported to the TBMs via locomotives for installation. The project uses eight 7.1m diameter TBMs from Herrenknecht AG (Germany). Two types are used; 'slurry' type for the Thames tunnel, which involves tunneling through chalk and 'Earth Pressure Balance Machines' (EPBM) for tunneling through clay, sand and gravel. At the front of the TBM is a full face cutter head which rotates at around 1 to 3 rpm. As the TBM advances forward the cutter head excavates the ground. The loosened material is removed from the cutter head via a screw conveyor, which moves the material through the back of the TBM and out of the tunnel via a conveyor belt. The concrete segments are transported by tunnel locomotives into the tunnels and loaded onto the TBM. As the TBM advances forward, the precast concrete segments are built into 23 tonne rings to line the tunnels behind the TBM cutter head. Diesel locomotives operate regularly behind the TBM transporting the personnel, materials etc. necessary for the operation. Exposure to DEEE is of concern (with respect to this programme of research) as well as RD and it was agreed that sampling will take place in two TBM environments.



Figure 1: TBM Sophia breaks ground at Plumstead Portal, Jan 2013. Image Copyright of Crossrail Ltd

In addition to the rail tunnels, the project involved the construction of the station platform tunnels, concourses and associated cross passages and escalator tunnels etc. The construction of these parts of the tunnels uses a technique called Spray Concrete Lining (SCL) where concrete is sprayed to provide support to the surrounding soil (Figure 2). This technique involves excavation followed by concrete spraying and is a continuous process. The SCL technique uses concrete formulated close to the site which is pumped down to concrete mixers located within the tunnel.



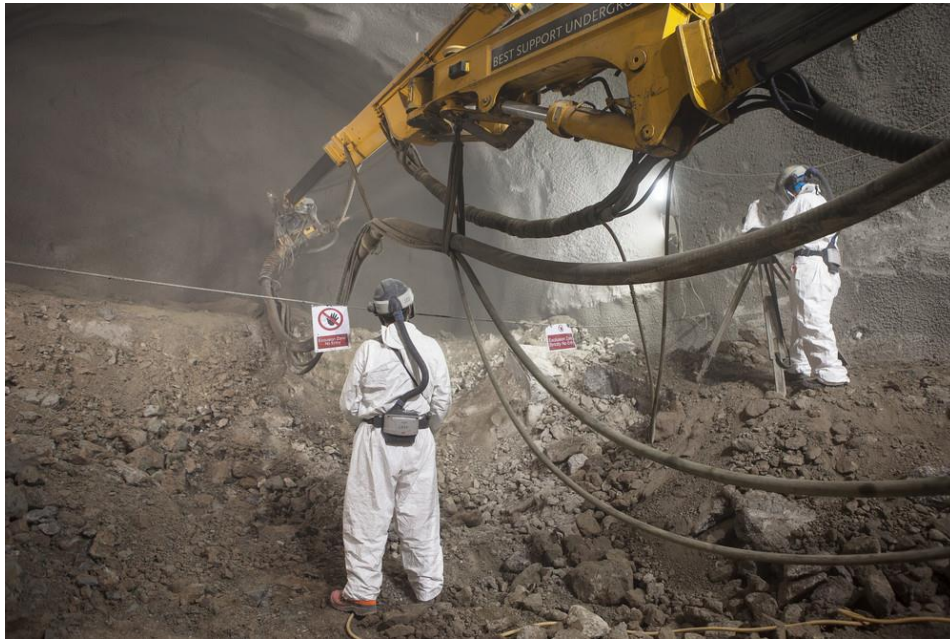


Figure 2: Sprayed concrete lining works (sprayer on left, engineer on right).
Note: operator exclusion zone. Image Copyright of Crossrail Ltd

A measurement campaign was carried out to investigate exposure to diesel engine exhaust emissions (DEEE), respirable crystalline silica (RCS) and RD of the workers involved in the work and compare these exposure levels with the UK WEL or, in the absence of a WEL, with other relevant European reference limits or recommended guidance levels.



2 AIMS AND OBJECTIVES

This research focusses on particulate exposure and more specifically on RD, RCS and DEEE (measured as respirable elemental carbon (REC)).

The specific aims and objectives of the programme of work were as follows:

1. To measure personal exposure to RD, RCS and REC during tunnelling projects carried out by or on behalf of Crossrail in London.
2. To estimate average exposure to RD, RCS and REC for those workers/occupations who are likely to have the highest exposure levels.
3. To explore temporal variability of black carbon (BC) in the various tunnels.
4. To compare average exposure levels to WELs where available or other relevant reference values and recommended guidance levels.

During initial discussion with representatives of Crossrail and their contractors it was agreed that the research would focus on the TBM and SCL environments and that different measurement strategies would be employed. In the SCL environment, the focus of the campaign was on exposure to RD and RCS whereas in the TBM environment the focus was on RD and REC. In addition, temporal variability of RD was also included in the study design. A sampling strategy was developed based on these discussions and agreements.

In addition, measurement data for the hazardous substances of interest to this study were made available to IOM on an anonymous basis by Crossrails' tunnelling contractors' occupational hygiene providers. These measurements were summarised and compared with the results obtained during the IOM measurement campaigns.



3 RELEVANT WORKPLACE EXPOSURE LIMITS AND GUIDANCE LEVELS

WELs are exposure limits set by the Health and Safety Executive (HSE) in Britain to protect the health of workers. WELs are concentrations of hazardous substances in the air, averaged over a specified period of time, referred to as a time weighted average (TWA). Substances that have been assigned a WEL are subject to the requirements of the COSHH Regulations. These Regulations require employers to prevent or control exposure to hazardous substances. Control is defined as adequate only if a) the principles of good control practice are applied, b) any WEL is not exceeded and c) exposure to asthmagens, carcinogens and mutagens are reduced as low as is reasonably practicable.

The absence of a substance from the list of WELs does not indicate that it is safe. For these substances, exposure should be controlled to a level to which nearly all the working population could be exposed, day after day at work, without any adverse effects on health.

Control of exposure to any kind of airborne dust is also required under COSHH, and WELs for respirable dust are set at 4 mg/m^3 (as a TWA over an eight-hour period) (HSE, 2011).

However, the IOM considers that the current British WELs for airborne dust are unsafe and employers should attempt to reduce exposures to help prevent further cases of respiratory disease amongst their workers. We suggest that, until safe limits are put in place, employers should aim to keep exposure to RD below 1 mg/m^3 (IOM, 2011). The value of 1 mg/m^3 for RD has been considered by other organisations to be a more appropriate guideline (BOHS, 2012).

The WEL for RCS is of 0.1 mg/m^3 8-hour TWA (HSE, 2011). The WEL for RCS is not a safe limit and given the serious health risk associated with this, employers are required to reduce exposure below the WEL.

For REC there is currently no existing WEL in the UK. A reference level for DEEE of $100 \text{ }\mu\text{g/m}^3$ was recently used in a European Union project on socioeconomic, health and environmental impact of possible amendments to the EU Carcinogens and Mutagens Directive (*SHEcan*)¹ (IOM, 2012). In Austria, technical guidance concentrations (TRK values) for diesel exhaust particles are given separately for underground mining and for other workplaces. The values are based on technical feasibility and do not consider health effects of diesel exhaust. The 8-hr TWA for underground mining is $300 \text{ }\mu\text{g/m}^3$. In Switzerland, EC in the respirable fraction of diesel exhaust particles is applied as the indicator substance for DEEE exposure and the 8-hr TWA is $100 \text{ }\mu\text{g/m}^3$ (OSHWiki, 2013). For this report, the value of $100 \text{ }\mu\text{g/m}^3$ is used as a reference limit for REC.

The term '8-hour reference period' relates to the procedure whereby the occupational exposures in any 24-hour period are treated as equivalent to a single uniform exposure for 8 hours (the 8-hour TWA) exposure.

¹ <http://www.occupationalcancer.eu>



Occupational exposure to respirable dust, respirable crystalline silica and diesel engine exhaust emissions in the London tunnelling environment

The 8-hour TWA may be represented mathematically by:

$$(C_1T_1+C_2T_2+...C_nT_n) / 8$$

Where:

C1 is the occupational exposure and T1 is the associated exposure time in hours in any 24-hour period.

The results from the measurement campaigns are presented as 8-hour TWAs.



4 STUDY OUTLINE

Four 3-day measurement surveys were carried out in tunnel environments.

Personal exposure to RD, RCS and REC was assessed for a duration representative of the operators working shift (no less than 50% of the workers shift, ideally 75% of the shift duration).

Real time monitoring of BC was used to investigate the temporal variability and levels of DEEE. Whilst not included in the original agreed proposal, we also used real time monitoring of particulates to investigate the temporal variability in RD.

The project originally aimed to collect 60 RCS and 60 REC personal samples (all of which would be analysed for RD) over the course of the sampling campaigns (depending on availability of operators for sampling), with direct reading instruments (measuring for BC and RD) being used on each day of sampling. It was however evident that there were insufficient operators available to obtain the required numbers of personal samples and so static sampling was also employed to achieve the required number.

During each day of sampling, relevant contextual information was documented (where possible) describing the observed activities and operators working practices. In addition, relative humidity and temperature were recorded, as were details of the tunnel environment.



5 METHODS

5.1 IDENTIFICATION OF MONITORING SITES

Crossrail representatives identified suitable environments for IOM personnel to visit and conduct the monitoring campaigns. These were selected with due consideration to the typical tunnelling activities scheduled to take place during the timescales of the project.

5.2 SAMPLING STRATEGY

During a preliminary scoping visit by IOM and Crossrail representatives on 16th June 2014 and the discussions that followed, it was decided that two distinct tunnelling activities would be assessed during the campaign – TBMs and SCL.

Diesel locomotives operate regularly behind the TBM transporting the personnel, materials etc. necessary for the operation. Exposure to DEEE is of concern (with respect to this programme of research) as well as RD and it was agreed that sampling will take place in two TBM environments.

Exposure to REC and RD was expressed as being the primary concern during SCL works (with respect to this programme of research) and it was agreed that sampling would take place in two SCL environments.

A summary of the measurement strategies are detailed in Table 1.

Table 1: Measurement strategies to be employed in tunnel environments

Measurement	SCL	TBM
Primary agent of interest	RCS & RD	DEEE & RD
Personal samples	RD & RCS analysis	RD & REC analysis
Direct reading instruments	RD & BC	RD & BC

On each day of sampling it was intended that up to 10 pumped measurements would be collected (either 10 RD/RCS or 10 RD/REC measurements depending on environment). However, the actual number of personal samples was dependent on the availability and willingness of operators to participate, also with due consideration to their work tasks and ensuring their safety would not be compromised through the wearing of the devices.

In the TBM environment the following operators were targeted *a priori* with final selection being decided following discussions with on-site personnel and the lead miner for the 'gang' working on each day of monitoring:

- TBM driver
- Grout pump operator
- Conveyor operator(s)
- Segment builder(s)
- Engineer

In addition, the locomotive driver was also targeted where possible.



In the SCL environments, the following operators were targeted *a priori* with final selection again being decided following discussions with on-site personnel on each day of monitoring:

- Nozzleman (spray operator)
- SCL surveyor
- Pump operator
- Operators involved in excavation activities
- Engineer

Static area sampling was also used to achieve the required sample numbers.

5.3 SAMPLING METHODS

5.3.1 Personal and static pumped air samples

Personal measurements (sampling for a duration representative of the operators full shift) was conducted amongst identified workers and who agreed to participate. Measurements were carried out using Higgins Dewell cyclones connected to a personal pump set at a flow-rate of 2.2 L/min. For measuring RCS the cyclones were loaded with a PVC filter, while for measuring REC heat-treated quartz filters were used. The cyclone sampling head was placed within the breathing zone (within 200mm of the nose and mouth) on the dominant side of the worker, normally on the lapel of the workers overalls. Operators were asked to avoid placing jackets / overalls over the sampling head and in instances where operators were required to wear face visors they were advised to ensure that the sampler was not covered by these.

Measurements were conducted at each tunnelling site for 3 consecutive days. Depending on shift patterns, repeat measurements were collected from some workers on different days.

Static samples were located in areas where operators may reasonably be positioned, concerns about exposure had been raised and/or where previous static monitoring had been undertaken by Crossrail contractors' occupational hygiene providers. The sampling head was located at typical adult breathing zone height.

Air sampling to determine personal exposures of RD, RCS and REC was carried out in accordance with HSE MDHS 14/4 – General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols (HSE, 2014). The flow rate was set using a calibrated flowmeter and checked at the start and finish of the sampling period. In instances where the sample flow rate deviated by 10% or more the sample was classed as void and not analysed.

For quality assurance purposes, field blanks for each sample medium were obtained on each day of the monitoring campaign. These samples were handled in an identical manner to the other samples with the exception that no air was drawn through them.



5.4 DIRECT READING INSTRUMENTS

A MicroAeth AE51 (hereafter referred to as MicroAeth) equipped with a microCyclone was used to measure BC and to investigate the temporal variability and levels of DEEE. The MicroAeth was set to log measurements at a time base of 60 seconds and a flow rate of 50ml/min. The BC concentrations recorded are presented in $\mu\text{g}/\text{m}^3$. Additional measurements were collected using the MicroAeth in the office area and during journey time from the researchers hotel and site to provide an indication of the background BC concentrations in a non-occupational environment.

TSI SidePak AM501 devices (hereafter referred to as SidePak), fitted with a cyclone, were also used to monitor RD in real time. The device logged measurements in mg/m^3 at a flow rate of 1.7 l/min, with a log interval of 1 minute, time constant 1 second. A calibration factor of 1 (factory setting) was used.

5.4.1 Environmental conditions

Relative humidity (RH) (%) and temperature ($^{\circ}\text{C}$) were logged at one-minute intervals during the measurement campaigns using a Lascar EL-USB-2. In addition, background environmental conditions for each day of sampling were obtained from www.wunderground.com.

5.4.2 PREPARATION OF SAMPLE MEDIA

Heat treated filters were supplied by Scientific Analysis Laboratories (SAL), Manchester, and used for sampling REC. Preparation, numbering and pre-weighing of sampling media to be used on-site was carried out by the IOM laboratory. Weighing of filters for use in the cyclone cassettes was carried out in accordance with IOM internal Instruction Manual 2 'Gravimetric analysis' (IOM, 2008).

5.5 SAMPLE ANALYSIS

The RCS samples were analysed to determine the gravimetric and RCS concentrations by IOMs analytical laboratory in Edinburgh in accordance with IOM Instruction manual IM 2 using modifications of HSE (2014) for RD and HSE (2005) for REC. The REC samples were analysed gravimetrically in the first instance by IOMs laboratory as detailed above. These heat-treated quartz filters were then analysed for REC by SAL, Manchester, using Analytik Jena 5000.

The analytical limit of detection (LOD) for the sample analysis was 0.05 mg for RD, 0.02 mg for RCS and 1.0 μg for REC.

5.6 DATA COLLECTION

A standardised proforma was used by the researchers to record key information from each sampling campaign. The form allowed for details of the sample number, details of the operator, the time on and time off, and the flow rates at the beginning and end of sampling to be recorded. In addition, behavioural observations and other relevant contextual information were recorded.



5.7 MEASUREMENT DATA FROM CONTRACTORS OCCUPATIONAL HYGIENE PROVIDERS

RD, RCS and REC 8-hr TWA measurement results collected during previous TBM and SCL activities were obtained on an anonymous basis from the contractors occupational hygiene providers. Due to the anonymous nature, limited contextual information was provided; however, details of the job title and sample location monitored were made available. IOM were advised that the data provided were collected from a number of different sites over an extended period of time (~Feb 2013–Aug 2014), as works progressed and control measures were implemented and upgraded. RD samples were typically collected using IOM heads loaded with polyurethane foams rather than the cyclone sampling heads employed in the current campaigns. In instances where RD was further analysed for RCS a cyclone sampling head was used.

5.8 DATA ANALYSIS

Measurements obtained using the direct reading instrument were downloaded and imported into MS Excel. On occasions negative values were observed in the MicroAeth data and these were removed for the data analysis. The temporal variability in concentrations was graphically displayed, with descriptive statistics of the measurements over each shift being calculated.

The pumped sampling results were reported as 8-hr TWA. Descriptive statistics were provided by sample type and occupational group / location for each of the measurement campaigns / tunnel environments. This included arithmetic mean (AM), median, standard deviation (SD), geometric mean (GM), geometric standard deviation (GSD), minimum (min) and maximum (max). Data obtained from the contractors occupational hygiene provider were also coded by IOM (where possible) by occupational group / location, with descriptive statistics being provided. For all the pumped sample measurement data, in the event of concentrations being recorded as less than the analytical LOD, a value of half the LOD was assigned for the purposes of the data analysis. The measurement results were compared with the measurements collected by IOM. In addition, the 8-hr TWAs were compared with the relevant WEL and reference levels.



6 RESULTS

6.1 Introduction

A total of four monitoring campaigns were completed, two monitoring in SCL environments and the remaining two during TBM works.

Table 2 summarises the dates when the monitoring campaigns were undertaken and the sites assessed.

Table 2: Details of monitoring campaigns completed

Campaign	Dates (2014)	Environment	Site
1	6-8 th Aug	SCL	Fisher Street
2	4-6 th Nov	SCL	Farringdon
3	25-27 th Nov	TBM	Stepney Green (Drive Y)
4	10-12 th Dec	TBM	Stepney Green (Drive Y)

The following sections detail the activities observed and assessed during the monitoring campaigns, descriptive summary statistics for the pumped samples obtained during the measurement campaigns and also from the contractors' occupational hygiene providers. The temporal trends in the direct reading instrument data are displayed, with summary statistics also being presented.

6.2 Environmental conditions

A summary of the environmental conditions within the tunnel environment (recorded using the Lascar data logger) during the monitoring period is provided in Table 3. In addition, details of the general outdoor environment, using measurements recorded at midday at the nearest weather station (www.wunderground.com) are also presented.

Table 3: Tunnel and outdoor environmental conditions

Tunnel conditions			Outdoor conditions		
Date	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)	Wind speed (m/s)
06/08/14	23	66	22	69	4.6
07/08/14	22	66	24	50	2.6
08/08/14	22	74	21	73	3.1
04/11/14	23	50	11	67	1.0
05/11/14	23	52	10	76	4.6
06/11/14	24	48	12	62	5.1
25/11/14	21	53	7	87	2.6
26/11/14	22	60	9	91	1.0
27/11/14	24	59	10	87	2.6
10/12/14	23	56	8	66	7.7
11/12/14	23	55	8	71	9.3
12/12/14	24	55	9	82	6.2



6.3 SITE OBSERVATIONS, PERSONAL MONITORED AND STATIC SAMPLING LOCATIONS

6.3.1 SCL monitoring campaigns

The first monitoring campaign took place at Fisher Street, Westbound Crossover Tunnel where cross passage 5 (CP5) was being excavated. Engineer reports were made available for each day of monitoring and a summary of the activities undertaken during each measurement period as recorded by the engineers is provided in Appendix 1. It is evident from the reports and also the observations during the sampling campaigns that activities were mostly focussed on excavation works and that concrete spraying activities only took place on the second day of monitoring.

The second SCL monitoring campaign took place at Farringdon. Monitoring was undertaken during SCL activities in both the East and Westbound running tunnels (RTE and RTW). Again, engineers' reports were made available and a summary of these for each of the monitoring days is provided in Appendix 1 (Tables A2 (RTE) and A3 (RTW)). It was evident that more spraying occurred during this monitoring campaign than the first.

Supply air was fed into the tunnel environments. The sprayer and back-up sprayers wore air fed visors during SCL activities due to their proximity to the face being sprayed. It was also observed that the engineer wore an air fed visor during spraying activities. Sprayers and engineers also wore disposable Tyvek overalls over their normal protective clothing. Other personnel in the SCL restricted area were provided and required to wear 3M 8835 P3 disposable respirators when concrete spraying activities were taking place.

In both SCL monitoring campaigns plant machinery operated in the tunnel environment to excavate and remove the London Clay earth, as well as to deliver the concrete mix for spraying. The composition of the Concrete mix P420 during the monitoring campaign (SSD mix design) was reported to be as follows: cement 420 kg/m³; limestone 629 kg/m³; sand mixture 1168 kg/m³ and water 145 kg/m³. It was reported that both the concrete mix and the London clay being excavated contain low levels of crystalline silica.

Personal samplers were worn by several operators, with their job titles being categorised as follows:

- Sprayer- responsible for operating the concrete spray equipment.
- Back-up sprayer – assists the sprayer.
- Engineer – responsible for surveying and ensuring excavation and spraying adheres to specification/plans.
- Plant operator- operate the various plant equipment that move around the tunnel environment, e.g. excavator, dumper truck.
- Lead miner- manages the SCL team activities.
- Crack injectors – repairing of cracks in concrete through rehabilitation injection.
- Pumpman – responsible for supply of concrete to spray equipment.
- Inspector – oversees the SCL process for the Client (Crossrail).

Occupational exposure to respirable dust, respirable crystalline silica and diesel engine exhaust emissions in the London tunnelling environment

Of these job titles, the sprayer, back-up sprayer and engineers are likely to experience the highest exposures due to their proximity to the spraying operation and face being excavated. Plant operators are also at risk due to the operation of diesel powered vehicles. Many other operators would typically be located either in or near the restricted area observing activities, waiting for progress to be sufficient to allow their particular work activities to take place. The SCL operators worked an 8-hour shift pattern.

In monitoring campaign 1, the direct reading instruments and a pumped sample were located on a hop-up in the general tunnel environment initially 12 rings (19 m from the SCL restricted zone, and approximately 30 rings (48 m) from the work face (Figure 3) although the distances increased on each day of monitoring as the work advanced. The samplers were located at head height.



Figure 3: Location of static samplers in monitoring campaign 1 (IOM)

In monitoring campaign 2, static samplers were installed within the restricted zone of both RTE and RTW (circled in Figures 4 and 5). In each location a SidePak and pumped cyclone sampler were located, with the MicroAeth also being located in RTE.



Occupational exposure to respirable dust, respirable crystalline silica and diesel engine exhaust emissions in the London tunnelling environment



Figure 4: Location of static samples (circled) in restricted zone, RTE (IOM)



Figure 5: Location of static samples (circled) in restricted zone, RTW. Location of sprayer and engineer also visible (IOM)

