FIRE FIGHTER EXPOSURE TO DIESEL EXHAUST AT QFRS FIRE STATIONS

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Diesel Exhaust Emission at Fire Station Engine Bay Areas and Implications for Station Work/Living Areas

Abstract

Diesel exhaust comprises of a complex mixture of both particulate matter and gaseous substances including diesel particulate matter (DPM), polyaromatic hydrocarbons (PAH), inorganic particles, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic materials (VOC's). Diesel exhaust has been classified as a class 2A - probable human carcinogen by the International Agency for Research on Cancer.

Queensland Fire and Rescue fire fighters have raised concerns about their exposure to diesel exhaust within fire stations. However, there is little if any data available to assess the extent of Queensland fire fighters exposure to diesel exhaust.

A variety of emission products were investigated and the values obtained compared to established workplace exposure standards. Where workplace exposure standards have not been established a value was selected after reviewing accepted industry standards. These standards were adopted as the levels of concern (LOC). The emission products characterised included:

- Diesel particulate matter (dpm) ;
- Polyaromatic hydrocarbons (PAH);
- Volatile organic compounds (VOC) such as benzene and formaldehyde; and
- Simple inorganic compounds like carbon monoxide.

The emission product of greatest concern is the dpm.

The study focused on characterising emissions within the context of the normal operation of a fire station and included specific activities and work areas. These included:

- ten hour environmental background measurement;
- ten hour exposure in areas such as office, engine bay and mess area;
- fire appliance - emergency response;
- fire appliance – returning to fire station; and
- fire appliance - start of operational shift check.

The study also considered fire fighter personal protective clothing storage.

Seven fire stations were selected to participate in the study after considering criteria such as turnout frequency, age and building design. The participating fire stations were: Cairns; Townsville; Rockhampton; Maroochydore; Caboolture; Loganlea; and Anzac Avenue (Toowoomba).

The exposure after ten hours to the diesel exhaust is summarised. In general, the VOC, simple inorganic compounds and PAH values were many hundreds of times less than the LOC and were similar to the external environmental values obtained. The average external dpm value was 0.002 mg/m^3 EC-elemental carbon (range: <0.001 to 0.007 mg/m^3 EC). The highest dpm value obtained in an engine bay was concentration (0.009 mg/m^3 EC) at Anzac Avenue. The average values in all areas of the station ranged from 0.002 to 0.003 mg/m^3 EC.

The exposure after the fire appliance emergency response to the diesel exhaust is summarised. The VOC, simple inorganic compounds and PAH values were below the established LOCs. The highest dpm value obtained was 0.027 mg/m^3 EC at Rockhampton fire station. The average value was 0.009 mg/m^3 EC and corresponds to *ca*. 10 times less than the LOC (0.1 mg/m^3 EC).

The exposure after the fire appliance return to station to the diesel exhaust is summarised. The VOC, simple inorganic compounds and PAH values were below the established LOCs. The highest dpm value obtained was 0.032 mg/m^3 EC at Rockhampton fire station. The average value was 0.013 mg/m^3 EC and corresponds to *ca*. 8 times less than the LOC (0.1 mg/m^3 EC).

The exposure after the fire appliance start of operational shift check to the diesel exhaust is summarised. The exposure was measured where possible the engine bay doors were closed and any mechanical ventilation ceased to simulate the worst case situation. The VOC and PAH values were below the established LOCs. Except in the case where a Firepac 3000 Mk 3 appliance used. The highest dpm value obtained (excluding the Firepac mark III 3000) was 0.08 mg/m^3 EC at Anzac Avenue fire station and is ca. 1.2 times less than the LOC. The average value was 0.044 mg/m^3 EC and corresponds to less than half the LOC (0.1 mg/m^3 EC). However, the Firepac 3000 Mk 3 appliance result was 0.73 mg/m^3 and ca. 8 times above the LOC.

The results concerning emissions from fire fighter protective clothing where detected were many times less than the corresponding LOC's.

The results suggest the fire fighter exposure to diesel exhaust emissions are less than the established LOC except in the case where the Firepac 3000 Mk 3 appliance was used during a start of operational shift check.

A series of recommendations have been provided to the QFRS for consideration to further reduce fire fighter exposures to diesel exhaust emissions. The recommendations included:

- Further investigate the Firepac 3000 Mk 3 performance and provide recommendations to minimise fire fighter exposure;
- Actions to further minimise fire fighter exposures and improve fire fighter personal protective clothing storage at the participating fire stations, other fire stations and future fire stations;
- Consider the purpose of the fire appliance start of operational shift check; and
- Communicate the findings to QFRS fire fighters.

INTRODUCTION

The Queensland Fire and Rescue Service (QFRS) urban operations are delivered from 239 urban fire stations across Queensland. Normal operations of fire appliances; start-up to leave a station, return to station and when they idle during shift checks, produce vehicle exhaust within the confines of the station. In 2006, the QFRS attended 64 882 callouts, 11 490 building fire safety inspections, 2662 community education visits, 15168 training courses, and 26731 public relations events from operational fire stations. QFRS personnel are exposed to diesel exhaust emissions at appliance start-up, leaving station, returning to station and during maintenance procedures.

Reports have shown that fire station design plays a major role in the exposure of fire fighters to diesel exhaust emissions. Station design influences include:

- Age and design of station;
- Engine bay doors and their locations in respect to outside influences;
- Fire appliance location in respect to internal station door locations;
- Idle time of fire appliances within stations; and
- Doorways, pole or other openings into living areas.

QFRS fire station designs reflect a number of influences ranging from age, location and history, and permanent or auxiliary/volunteer staffing models. The diesel based QFRS vehicles comply with the most current European diesel emission standard.[1]

Diesel Engines

Diesel engines, unlike typical petrol engines that use a spark to ignite a compressed air/fuel mixture, ignite fuel by the heat generated by compressing air. Diesel, a higher boiling fraction fuel than petrol, uses less fuel per unit of work performed, but produces more exhaust particulate matter per unit volume of fuel used.[2] Diesel engines running under low load produce less particulate matter and more organic associated compounds, whereas diesel engines running under high load produce more particulate matter, but less associated organic compounds.[2] Both the United States (US) and the European Union (EU) have developed and implemented a staged series of diesel emission standards[1] for new diesel vehicles.

The US process, defined under the *Clean Air Act Amendments* of 1990,[1] allowed manufacturers and users time to adjust to the new design and emissions standards over a number of years, Table 1.1.

US Emission Standards for Heavy-Duty Diesel Truck Engines (g/bhp·hr)			
Year of compliance	Carbon Monoxide	Nitrogen oxides	Particulate Matter
1985	15.5	10.7	-
1988	15.5	10.7	0.60
1990	15.5	6.0	0.60
1991	15.5	5.0	0.25
1994	15.5	5.0	0.10
1998	15.5	4.0	0.10
2004	15.5	2.0	0.10
2007	15.5	0.2	0.01

Table 1.1

The US diesel emission standards based on diesel fuel with a sulfur content of 500 ppm.

More recently, the US has adopted an on-Board Diagnostics (OBD) system standard similar to that mandated in Australia, and reduced the sulfur content in diesel fuel from 500 ppm to 15 ppm (wt.) from 2006.[1]

The European Union has also adopted a staged implementation with five levels of engine and exhaust controls. Table 1.2 contains a summary of the emission standards and their implementation dates.

EU Emission Standards for Heavy-Duty Diesel Truck Engines (g/kWh)						
Tier	**Date**	Carbon Monoxide	Hydrocarbons	Nitrogen oxides	Particulate Matter	Smoke
Euro I	1992	4.5	1.1	8.0	0.36 - 0.612	-
Euro II	1996	4.0	1.1	7.0	0.15 - 0.25	-
Euro III	*1999 - 2000*	*1.5 – 2.1*	*0.25 – 0.66*	*2.0 – 5.0*	*0.02 – 0.13*	*0.15 – 0.8*
Euro IV	2005	1.5	0.46	3.5	0.02	0.5
Euro V	2008	1.5	0.46	2.0	0.02	0.5

Table 1.2
The Euro emission standards for diesel vehicles.

From the Euro III standard (2000), a number of more stringent changes to engine and exhaust testing have occurred. The Euro VI emission limits, published in 2009, are comparable in stringency to the US 2010 standards, and become effective from 2013.[1]

The Australian vehicle emission standards for highway vehicles, listed through the Australian Design Rules (ADR),[1] apply to new petrol and diesel on-road vehicles and off-road passenger vehicles, but not off-road engines used in construction or agricultural machinery. Although the Australian heavy vehicle emission standards are based on European regulations, and include selected US and Japanese standards, the stated long term policy in Australia is to fully harmonize Australian regulations with the United Nations Economic Commission for Europe (UNECE) standards.

Australian vehicle emission standards adopt the following tiered process:

- Emission standards for light vehicle petrol engines commenced in the 1970s.
- New, more stringent emission standards equivalent to Euro II/III were adopted in 2002/2003 and progressively tightened to apply Euro IV standards in 2009:
    - ADR79/00, ADR79/01, and ADR79/02 for vehicles ≤3.5 t GVM;
    - ADR80/00, ADR80/01, ADR80/02, and ADR80/03 for vehicles >3.5 t GVM

1. The introduction of Euro III and Euro IV standards for medium- and heavy-duty diesel vehicles, via ADR 80/00 and ADR 80/01 respectively, adopts the technical requirements of European Directive 88/77/EEC as amended by 99/96/EC. ADR 80/01 has been replaced by ADR 80/02 effective 2007/8.

2. The introduction of Euro IV and Euro V standards for medium- and heavy-duty diesel vehicles, via ADR 80/02 and ADR 80/03 respectively, adopts the technical requirements of Directive 2005/55/EC as amended by 2005/78/EC and 2006/51/EC.

The date combinations show that for any new model with a manufacture date after 1 January of the compliance year must comply with the ADR, and from 1 January second year all new vehicles (regardless of the first production date for that particular model) must comply.

ADR Emission Standards for Diesel Truck Engine				
Description	GVM	02/03 Diesel	07/08 Diesel	10/11 Diesel
Medium	3.5 ≤ 12t	Euro III or US98[a]	Euro IV or US04, JE05	Euro V or US07, JE05
Heavy	> 12t	Euro III or US98[a]	Euro IV or US04, JE05	Euro V or US07, JE05

Table 1.3
The Australian emission standards for diesel vehicles.

A new smoke emissions ADR (ADR30/01) implemented in 2002/3 adopts the UN ECE R24/03 and allows the US 94 smoke standards as an alternative. The ADR 80/02 requires heavy-duty vehicles to have on board diagnostics (OBD) systems meeting the Euro IV (or Japanese) requirements to warn against functional failures. ADR 80/03 requires vehicles to have OBD systems meeting the Euro V requirements to directly monitor emission levels against set thresholds. To further reduce the diesel emissions, new diesel fuel specifications of sulfur content have been progressively adopted to reduce the sulfur content from 500 ppm in 2002 to the present level of 10 ppm.

The Australian Diesel Vehicle Emissions *NEPM* also complements the Australian diesel vehicle emissions standards for particles, nitrogen oxides (NOx) and smoke opacity in the Australian Vehicle Standards Rule (AVSR) 147A. These Standards take into account the emission standard to which a vehicle was originally constructed, normal deterioration of engine components under adequate maintenance regimes and the emissions level at which vehicle repair invariably produces an improvement in emission performance.

Diesel exhaust gases
Diesel exhaust comprises of a complex mixture of both particulate matter and gaseous substances including diesel particulate matter (DPM), polyaromatic hydrocarbons (PAH), inorganic particles, sulfur and nitrogen compounds, carbon monoxide, carbon dioxide, volatile organic materials (*e.g*. benzene and hydrocarbons).[3-9] The US-EPA has reported[10] that of the many organic materials formed in diesel exhaust, a number are have toxicological significance, *e.g*. formaldehyde, benzene and PAH's. Although these exhaust materials are similar in petrol and diesel engines, the distribution concentrations vary, particularly in older model diesel engines prior to prior to the emission standards. However, these differences have decreased substantially with newer engines.[10]

Diesel Exhaust Gases - Inorganic and other non-VOC
The gaseous components of diesel exhaust associated with health impacts include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO) and hydrogen sulfide (H_2S). Both NO_2 and SO_2 irritate the eyes, nose, throat, and respiratory tract of people.[3,4] Acute SO_2-related bronchial constriction may also occur in people with asthma. Exposure to NO_2 can cause acute or chronic bronchitis, but minimal mucous membrane irritation of the upper airway.[11] The effects of SO_2 have been largely reduced by the reduction of sulfur in diesel fuel from 500 ppm to 10 ppm. NO_2 is one of the target materials being reduced in Euro IV and higher engines by the addition of chemical or physical scrubbers to the vehicle exhaust system.

Carbon monoxide (CO) is a toxic with symptoms of exposure at low concentrations including fatigue, chest pain, flu-like symptoms that clear up in fresh air, while moderate to high concentrations can cause impaired vision and coordination; headaches; dizziness; confusion; nausea and fatality.[11,12]

Hydrogen sulfide (H_2S) is a flammable, toxic gas with symptoms of exposure at low concentrations including headaches and nausea.[11,12] It has a very low odour threshold of 1 – 5 parts per billion (ppb), which accounts for the ease of detection by people.

Diesel Exhaust Gases - Volatile Organic Compound
Volatile organic compounds (VOCs) are defined by the world health organisation (WHO) as organic compounds with boiling points between 50°C and 260°C, excluding pesticides. VOCs encompass a large group of chemicals, including aliphatic, aromatic and halogenated hydrocarbons, aldehydes, ethers, esters, acids, alcohols and ketones. Collectively, they termed total volatile organic compounds (TVOC). The health problems caused by individual VOCs depend on the concentration and time of exposure, their toxicity and carcinogenicity. The most common health issues are eye, nose, and throat irritations; headaches and nausea.

A number of individual components of the VOCs are of interest in this study due their presence in both petrol and diesel engines, namely benzene, toluene, xylene and hexane (BTXH).

Benzene is the simplest of the aromatic hydrocarbon compounds and recognised as a human carcinogen and mutagen with prolonged exposure.[11,12] Benzene is a regulated workplace chemical, which is generated as an airborne contaminant by a number processes including; high volume vehicle traffic, chemical manufacturing (including petroleum refining) and storage, petrol stations and cigarette smoking (including passive smoking). A study[33] of human exposure by the US-EPA reported that the main sources of human exposure are associated with personal, not the industrial activities. The report concluded that active smoking accounts for 50% of the total benzene exposure, while the remaining 50% was split between: (i) riding in vehicles, passive smoking, and exposure to consumer products; and (ii) outdoor ambient air concentrations due mainly to vehicle exhaust.

Toluene, like benzene, belongs to the aromatic hydrocarbon family and is a component of petrol and a common paint solvent. It is considered a safer solvent than benzene, but more recently has been replaced by xylene. Exposure to toluene may affect the central nervous system (CNS) in both acute and chronic exposures.[11] Symptoms of toluene inhalation include fatigue, sleepiness, headaches, and nausea. Chronic inhalation exposure can cause irritation of the upper respiratory tract and eyes, sore throat, dizziness, and headache.

Xylene, like benzene and toluene, belongs to the aromatic hydrocarbon family, but considered a safer solvent than both. Technical or commercial grade xylene is a mixture of the three isomers: *meta*-xylene, *ortho*-xylene, and *para*-xylene. Like toluene and benzene, xylene is a component of petroleum and a common solvent in the printing, rubber, leather, and paint and industries. Acute exposure to high xylene levels causes irritation of the skin, eyes, nose, and throat, difficulty in breathing and nausea. Both acute and chronic exposure to high concentrations of xylene can also cause a number of effects on the nervous system, such as headaches, lack of muscle coordination, dizziness, confusion, and changes in one's sense of balance.[11]

Hexane is used to extract edible oils from seeds and vegetables, as a special-use solvent, and as a cleaning agent. Acute inhalation exposure to high levels of hexane causes mild central nervous system (CNS) effects, including dizziness, giddiness, slight nausea, and headache.[11] Chronic exposure to hexane in air is associated with neurological disorders, with numbness in the extremities, muscular weakness, blurred vision, headache, and fatigue observed. Hexane is considered non-carcinogenic.

Aldehydes comprise a group of reactive organic compounds, characterised by the presence of a carbon-oxygen double bond (carbonyl group) that includes formaldehyde and acrolein. Both formaldehyde and acrolein, together with a number of other aldehydes occur at work, in homes, and outdoors. Inhalation of aldehyde vapours causes irritation and may increase non-

specific sensitivity to other agents in asthmatic people.[11,12] Many of these compounds show DNA and protein-binding properties. The three simplest and most common aldehydes of particular interest due their formation diesel exhausts, and their capacity as respiratory irritants and mucus membrane irritants are: formaldehyde (classified as a probable human carcinogen by IARC and US EPA); acrolein (classified as a possible human carcinogen by the US EPA); and acetaldehyde (classified as possible/probable carcinogen by IARC/US EPA).[12]

Diesel Exhaust Particulates

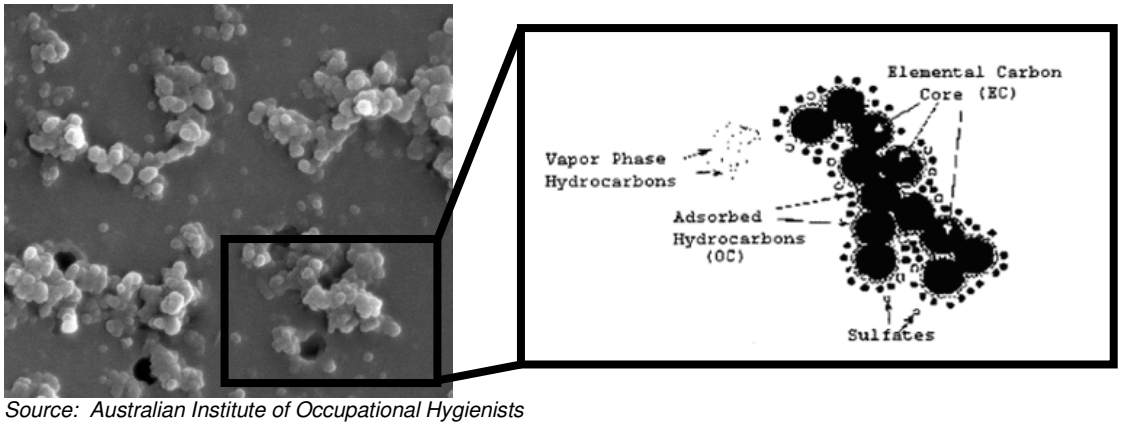
Diesel exhaust particles comprise of two main type of particles, namely polyaromatic hydrocarbons (PAHs) and diesel particulate matter (DPM). PAHs are organic compounds containing at least two fused benzene rings that are common combustion by-products from a number of hydrocarbon stocks including diesel fuel and road construction asphalt. Although PAHs form respirable particles, some sublime into the air, *e.g*. naphthalene.[13] Typically, PAHs, do not form as individual compounds, but as complex mixtures, such as diesel exhaust particulates. Although there is no conclusive evidence that PAHs are carcinogenic, the PAH benzo[a]pyrene has been definitively classified as carcinogenic by the International Agency for Research on Cancer (IARC). [12] The US-EPA[14] has shown the carcinogenic effect of other PAHs differs from that of benzo[a]pyrene, and published interim recommendations on quantitative risk assessment of PAHs, through a number of equivalency factors based on the estimated "order of potential potency" rather than "toxicity equivalency factors".

Compound	IARC Grouping[12]	Order of Potential Potencies[14]
Benzo[a]pyrene	1	1 (index compound)
Benz[a]anthracene	2B	0.1
Benzo[b]fluoranthene	2B	0.1
Benzo[k]fluoranthene	2B	0.01
Chrysene	2B	0.001
Dibenz[a,h]anthracene	2A	1.0
Indeno[1,2,3-cd]pyrene	2B	0.1
Benzo[ghi]perylene	3	-
Pyrene	3	-
Fluoranthene	3	-
Anthracene	3	-
Phenanthrene	3	-
Fluorene	3	-
Acenaphthene	3	-
Acenaphthylene	-	-
Naphthalene	-	-

Group 1 – carcinogenic to humans
Group 2A – probably carcinogenic to humans
Group 2B – possibly carcinogenic to humans
Group 3 – not classifiable as carcinogenic to humans

Table 1.3
The IARC cancer grouping and the US-EPA potential potency equivalency factors of common polyaromatic hydrocarbons (PAHs).

Together with PAHs, diesel exhaust particles are mainly composed of a central carbonaceous core (elemental carbon or EC), an outer adsorbed organic layer largely from unburned fuel (organic carbon or OC), and small amounts of sulfates and other inorganic compounds. Diesel exhaust particles, typically called diesel particulate matter (DPM), form through agglomeration as the exhausts cool through nucleation, coagulation and condensation of EC and OC. DPM consists of fine particles (diameter <2.5 µm) and ultrafine particles (diameter < 0.1 µm). The small size of DPM explains why organic molecules are readily adsorbed, and why they penetrate deeply into the lungs of people. Davies[15], *et al*, reported that DPM in Australian mines was mainly spherical in nature with a tendency to form agglomerations of irregular stacked graphitic structures (elemental carbon), figure 1.1.



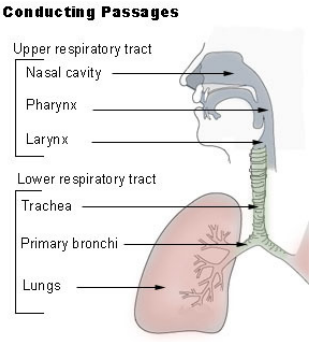
Source: Australian Institute of Occupational Hygienists

Figure 1.1

Scanning electron micrograph and schematic diagram of typical diesel exhaust matter.

Diesel Exhaust - Particulate Matter Route of Entry

The possible routes of entry of diesel exhaust products into the body include: inhalation, ingestion, dermal and injection. The most significant route of entry of diesel exhaust products into the body is through inhalation.[12] Exhaust gases pass into the body through the lungs. The human respiratory system is divided into two regions, namely the:



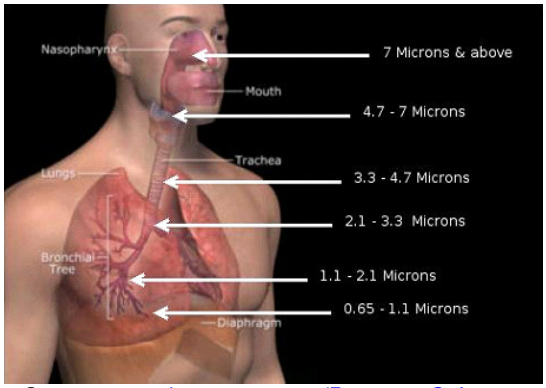
- The Upper Respiratory Tract, where gases are inhaled into or exhaled out of the body, consists of the nose and nasal passages, throat and pharynx,
- Lower Respiratory Tract, where exchanges of gases with blood stream occur, consists of the:
  - respiratory airways – trachea and bronchioles, and
  - lungs – respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli.

http://en.wikipedia.org/wiki/Upper_respiratory_tract

Figure 1.2

Typical human respiratory system.

The inhalation of and rate of inhalation of particulate matter, and entry into the human respiratory system is very dependant on the nature and size of the particle. The rate of particulate inhalation decreases rapidly as a function of size. Only particulate matter present in the breathing zone and less than 10 micrometers (<10 µm) will be inhaled into the body. Typically, respirable particulate matter greater than 5 micrometers (>5 µm) does not pass the upper respiratory tract, but particulate matter <5 µm can pass into the lower respiratory tract and the lungs. Ultrafine particles < 2.5 µm can also pass from the lungs and deposit in the alveolar region where gas exchange occurs during both inhalation and exhalation.



Source: www.docep.wa.gov.au/ResourcesSafety

Figure 1.3

Particulate matter penetration into a typical human respiratory system.

These ultrafine particles can then be transported to the digestive tract, and potentially absorbed into the body. The combination of the small size, potential to penetrate deep in the

respiratory system, and the amount of material that can be inhaled, is the basis for concern on adverse health effects. Thus, the small sizes (≤ 2.5 µm) and the absorbed organics on DPM make it a high respirable lung hazard. Toxicologically relevant mutagenic and/or carcinogenic organic compounds that can adsorb onto DPM are present in the diesel exhaust matrix.[10-12]

Exhaust gases and particulates generally will not penetrate the skin due to there size, chemical nature and time of exposure, and ingestion is significantly reduced or eliminated through good hygiene practices.[12] Thus, non-respirable particulate matter does not have a direct route into the body and is not considered a significant health hazard, especially with regular washing skin, area surfaces and clothing. Skin absorption is not considered a significant route of entry for diesel exhausts products.

Health Effects of Diesel Exhaust Exposure

Exposures to diesel exhaust vary significantly in intensity and duration depending on location and occupation. Diesel particulate matter (DPM) is typically used as a surrogate measure for the exposure to diesel exhaust and hence human health effects.[8] Highest exposures occur in occupational groups such as truck drivers, mineworkers and railroad workers, while other occupations with exposures include the emergency services (police, fire and ambulance officers), agricultural workers, toll-bridge workers and mechanics. The general public exposure to diesel exhaust is less frequent and at much lower concentrations.[1,8]

Numerous studies[1-13] have reported a possible link between an increase cancer risk and workers exposed to diesel exhaust. Epidemiological studies on the effects of diesel exhaust exposure indicate the primary exposure to diesel exhaust occurs through inhalation rather than ingestion and skin absorption.[8,16-18] The lung[12] is likely to be the main target organ of the toxic effects of diesel exhaust. One study of over 55,000 railroad workers found that the risk of lung cancer increased with duration of exposure to diesel exhaust,[19] while other studies on diesel exhaust exposure using animals showed a possible relationship between overwhelming the lung defences by particle overload and carcinogenicity.[20,21] The incidence of lung cancer in American males working in industries involving heavy and prolonged exposures to diesel exhaust, showed a higher lung cancer mortality than unexposed workers.[22] However, studies have shown that the relative risk of lung cancer for a typical male cigarette smoker is approximately 40 times higher than that of a male worker exposed to diesel exhaust.[8] Although a number of studies have found an association between diesel exhaust exposure and lung cancer, several have not[16,18].

A significant weakness in many studies is the relative paucity of human research data on the relationship between lung cancer and diesel exhausts. All studies are affected by the difficulty of correctly defining and quantifying exposures due to the various potentially contributing factors such as smoking, traffic volume and non-workplace exposures.[8] A number of classification systems by expert and/or government agencies have been used to categorise diesel exhaust as either a potential carcinogen or likely to be carcinogen. Below is a list of classifications for diesel exhaust from the US, Australia and Europe.

The UK Health and Safety Executive (HSE) reported[23] that there is insufficient evidence for diesel exhaust emissions to be classed as a carcinogen, but enough to classify them as a substance hazardous to health. The Australian Government through the Safe Work Australia Council does not have any policy on diesel exhaust exposures. A NSW Coal Industry study[24] showed no significant cancer risk for underground workers exposed to high levels of diesel particulate matter, and the Australian Institute of Occupational Hygienists (AIOH) has reported[24] there is uncertainty to the carcinogenic potential of DPM, but sufficient evidence to indicate over-exposure will give rise to irritation and potentially other non-malignant adverse health effects.

The International Agency for Research on Cancer (IARC) evaluation of diesel exhaust is similar to that of the US-EPA by categorising it as a Group 2A (probable human carcinogen) based on limited evidence in humans and sufficient evidence in animal studies.[25] However, subsequent research has shown that chronic high concentration exposure to respirable particulate matter other than diesel exhaust particulates (*e.g.* carbon black or titanium dioxide), has caused lung tumours in rats.[25]

The US-EPA has indicated that cancer research findings on rats should not be used to characterise the cancer hazard or quantify the cancer risk of diesel exhaust in humans. It also reports that diesel exhaust data is generally based on engines built prior to the mid-1990s, and that little data exists on new engines and diesel fuels at present. However, from the data available the US-EPA classifies diesel exhaust as "likely to be carcinogenic to humans by inhalation at any exposure condition".[26]

The United States Occupational Safety and Health Administration (OSHA) workplace exposure limits for some on the individual components of diesel exhaust, *e.g.* carbon monoxide, sulfur dioxide, benzene, acrolein, and respirable dust, but not for diesel exhaust as a whole. OSHA designates DPM as a Select Carcinogen, based on "The OSHA Cancer Policy".[27]

Also based on the OSHA Cancer Policy,[27] the United States National Institute for Occupational Safety and Health (NIOSH) recommends that "whole diesel exhaust be regarded as a potential occupational carcinogen".

The US Mine Safety and Health Administration (MSHA) reports exposure to diesel exhaust produces a link with respiratory diseases such as lung cancer, heart failure and other cardiopulmonary problems.[27]

The United States National Institutes of Health – National Toxicology Program (NTP) has classified diesel exhaust particulates as reasonably anticipated to be human carcinogens.[28]

The above agency classifications are summarised the following table.

Agency	Diesel Exhaust Health Rating
OSHA	select Carcinogen
MSHA	select Carcinogen
US-EPA	likely carcinogen to humans by inhalation at any exposure condition
ACGIH	likely human carcinogen
NTP	reasonably anticipated to be human carcinogens
NIOSH	potential occupational carcinogen
IARC	probably carcinogenic to humans
WHO	probable human carcinogen
UK HSE	insufficient evidence exists to be class DPM as a carcinogen
AIOH	uncertainty to the carcinogenic potential

Exposure Management

The term exposure has many meanings depending on the context of use and the intended use, *e.g.* the workplace or community exposure. The Australian Government through the Safe Work Australia Council defines occupational exposure (work place) through a tiered set of standards. The Safe Work Australia Council *exposure standard* means an airborne concentration of a particular substance in the worker's breathing zone, exposure to which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. The exposure standard can be defined by three forms:

- *Peak exposure standard (pk)* - a maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.

- *Short term exposure limit (STEL)* - a 15 minute TWA exposure which should not be exceeded at any time during a working day even if the eight-hour TWA average is within the TWA exposure standard. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL.

- *Time weighted average (TWA)* - the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week. This figure can be time adjusted to suit a specific length work shift.

Although to date there are no occupational exposure standards established for diesel exhaust, many of the component materials of diesel exhaust have gazetted occupational exposure standards, *e.g*. benzene, sulfur dioxide and carbon monoxide. Similarly, the Australian Government through the National Environment Protection Council (NEPC) has developed community exposure guidelines or National Environment Protection Measures (NEPM). One of these is the *Ambient Air Quality NEPM*, which is used to ensure the same national level of air quality protection for the six key air pollutants to which most Australians are exposed, namely; carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and fine or respirable particles. The NEPC is also developing the *Air Toxics NEPM* to cover other air pollutants that are typically present in low concentrations (parts per billion), but are of concern due to possible health effects at these low levels. At present the *Air Toxics NEPM* includes five compounds; benzene, toluene, xylenes, formaldehyde and benzo(a)pyrene (as a marker for polycyclic aromatic hydrocarbons).

In Australia, diesel engines are a significant source of the air pollutants included in the *Ambient Air Quality NEPM* and the *Air Toxics NEPM*. These include; nitrogen dioxide, sulfur dioxide, benzene, formaldehyde and particulate matter. Thus, a *Diesel Vehicle Emissions NEPM* was developed to complement other measures to reduce the impact of emissions from diesel vehicles such as new vehicle emission standards, improved fuel quality and travel demand management. These NEPM are not occupational exposure standards, but guidelines to help better manage the generation of these materials, *e.g*. the diesel NEPM provides guideline concentration concentrations of contaminants that my be present in a diesel engine exhaust.

Exposure Standards for Diesel Particulates

About 90% by mass of diesel exhaust particles are <1 µm in diameter. They are formed in the combustion chamber of the engine exhaust system and are released as respirable emissions into the atmosphere after agglomeration and condensation.[29] Collectively, particulate matter from diesel exhaust is termed diesel particulate matter (DPM).

The Australian Government has reported[30] various PAHs can be found in the Australian environment and in lipid tissues of both aquatic and terrestrial organisms. The types of PAH compounds identified in Australian cities from 1990 to present, are listed in Table 1.4. About 23 PAHs have been studied and their concentrations reported in the eight Australian studies and the NSW industrial self-monitoring results. The PAHs cancer marker, Benzo(a)pyrene, was the most reported PAH, its concentration was reported in all the studies. The most common PAHs found in Brisbane were naphthalene, phenanthrene, anthracene, fluoranthene, pyrene and chrysene.[30]

PAH	Qld	NSW	VIC	ACT	WA	TAS	NT
Acenaphthene (Ace)	X	X	X		X	M	M
Acenaphthylene (Acy)	X	X	X		X	M	M
Anthanthrene (Anh)			X				M
Anthracene (Ant)	X	X	X		X	M	M
Anthracene, 2-methyl (2M-Ant)	X						
Benz(a)anthracene (B(a)A)	X	X	X	X	X	M	M
Benzo(a)pyrene (B(a)P)	X	X	X	X	X	X	X
Benzo(b)fluoranthene (B(b)F)	X	X	X	X	X	M	M
Benzo(e)pyrene (B(e)P)	X		X		X		
Benzo(g,h,i)perylene (B(g,h,i)P)	X	X	X	X	X	M	M
Benzo(k)fluoranthene (B(k)F)	X	X	X	X	X	M	M
Chrysene (Chr)	X	X	X		X	M	M
Coronene (Cor)	X		X				M
Dibenz(a,h)anthracene (DB(a,h)A)	X	X	X	X	X	M	M
Fluoranthene (Fla)	X	X	X		X	M	M
Fluorene (Flu)	X	X	X		X	M	M
Indeno(1,2,3-c,d)pyrene (I(c,d)P)	X	X	X		X	M	M
Naphthalene	X	X	X		X	M	M
Naphthalene, 2-methyl (2M-Nap)	X				X		M
Perylene (Per)	X		X		X		
Phenanthrene (Phe)	X	X	X		X	M	M
Pyrene (Pyr)	X	X	X	X	X	M	M

"X": Data reported for compound *"M": Compound studied, but concentration of reported*

Table 1.4
The PAH compounds identified in Australian cities from 1990 to present.[30]

To date there are no general occupational or environmental exposure standards or guidelines published for either diesel exhaust or DPM, except for the mining industries. Although individual states own the responsibility for setting DPM exposure limits within the Australian Regulatory[15,24,31,32] framework, a level of consistency exists through the National Mine Safety Framework. Exposure to DPM in Australia is covered by a common target of achieving a peak (maximum) concentration of 0.1mg/m^3 elemental carbon (EC).

New South Wales has issued MDG 29 – Guidelines for the Management of Diesel Engine Pollutants in Underground Environments, which recommends test methods and exposure limits for diesel exhausts. Queensland and Western Australia have adopted the same DPM exposure guideline as NSW, *i.e.* 0.1 mg/m^3 EC (peak). Research, primarily conducted in New South Wales and Queensland underground coal mines, shows DPM levels ranged between 0.01 - 0.37 mg/m^3 EC and 0.01 - 0.64 mg/m^3- total carbon (TC) dependent on working conditions and control strategies. Eye irritation and olfactory discomfort has been reported at levels in excess of 0.1 mg/m^3 EC or 0.2 mg/m^3 TC.

The Australian Institute of Occupational Hygienists (AIOH)[24] reports the potential for exposure to DPM exists whenever workers are in close proximity to operating diesel equipment, but that when operated in open areas the potential for excessive DPM exposures is significantly reduced, *e.g.* diesel locomotives (DPM concentration: <0.001 to 0.045 mg/m^3 EC) *c.f.* underground mines (DPM concentration: 0.01 to 0.42 mg/m^3 EC).

The US Mine Safety and Health Administration (MSHA) promulgated two diesel exhaust standards for underground coal mines (66 FR 5526 - A5-26) and underground metal and non-metal mines (66 FR 5706 - A5-27). These standards state that personal exposure to DPM in

an underground mine must not exceed an average eight-hour equivalent full shift airborne concentration0.160 mg/m^3 (total carbon), which is equivalent to 0.12 mg/m^3 EC.

European occupational exposure limits (OEL), like Australia, have established concentrations based on member states, *e.g.* Germany has a 0.3 mg/m^3 EC for tunnelling and mining, and the use of diesel particulate filters is mandatory. Non-EU European states have engine emissions based on EU limits, *e.g.* Switzerland has an OEL of 0.1 mg/m^3 EC for tunnelling and mining, and the use of diesel particulate filters is mandatory.

Diesel Particulate Exposure in Fire Stations

A recent literature review[33] on the occupational exposure to diesel exhaust found that fire fighter exposure to DPM in the United States ranged from not detected to < 0.05 mg/m^3 EC, which is similar to vehicle maintenance workers and wharf workers. The high end of this DPM atmospheric concentration is at least half of the US mandated underground coal mine DPM exposure limit of 0.1 mg/m^3. The authors further report that by closing windows between the inside of the station and the engine bay, levels of DPM detected inside the station were reduced. The DPM levels and fire fighter expose were further reduced by the installation of ceramic filters to the exhaust pipes of the appliances.

The majority of research into diesel exposure outside the mining sector has been in the rail yard and train work areas. To date, the majority of research into fire station exposures to diesel exhaust in both personal breathing spaces and fire stations work areas has been conducted by U.S. Department of Health and Human Services.[34-37] These studies have shown that depending on the work load in the station, the amount of detectable diesel exhaust increases. These reports showed that the engine bay and areas open to them recorded the highest levels of diesel exhaust. The living and work areas separate from the engine bay (typically mess and dormitories) were significantly lower (< 0.001 to 0.03 mg/m^3 EC), especially if openings were kept closed. One report[37] showed the affect of smoking significantly increases the exposure to particulate matter. All reports showed the typical diesel exhaust measurements outside the station confines ranged from 0.004 – 0.099 mg/m^3 EC.

Friones[38] *et al*, conducted one of the initial investigations into the exposure of fire fighters to diesel exhaust in 1987. No area monitoring was performed, except an initial station background (prior to commencement of personnel monitoring) and outside background measurements. This report, based on pre-exhaust controlled vehicles and high sulfur diesel, indicated that the amount of diesel exhaust particulate matter varied significantly depending on time of year (temperature effect), size of response area (city population etc.) and the number of station appliance departures/returns. The research found that one city had twice the outside (ambient) airborne concentration of particulates, and that the typical fire station background (0.04 mg/m^3 EC) was equal to or less than the outside levels (0.03 – 0.12 mg/m^3 EC). The authors of this reported also show that smokers within the fire station received significantly more (0.06 mg/m^3 EC) more particulate matter than non-smokers. The report indicates that due to the colder weather in the USA, stations are more often closed, with little ventilation.

As reported above, no industry exposure standard or public health exposure exists for diesel exhaust as a whole, or for diesel particulate matter (DPM). However, based on the available literature and the recommended limits used internationally within the mining industry, arguably the most diesel engine intense industry, the recommended guidance level of exposure for fire fighter within QFRS fire stations has been set at the underground coal mine level of 0.001 mg/m^3 EC peak limit during any shift.

Common risk control measures applied to fire stations – exhaust control

The risk control measures should follow the established hierarchal structure. These are: elimination, substitution, engineering, administration, and personal protective equipment. Any

impact(s) from diesel exhaust emissions in fire stations, on fire fighter health, will depend on the type of exhausts produced, the amounts produced and the time of exposure to them. The concentrations will depend on engine design, mechanical maintenance of engines, amount of activity, location with respect to industrial facilities and major roadways, and the intensity of work using diesel appliances at the station. Weather and time of year also may impact on the concentration of diesel exhausts within the station engine bays due to closure of the bay doors.

A number of studies and reports have been conducted into the effectiveness of diesel exhaust emission control strategies.[6,39-44] One report[41] on the effectiveness of three diesel exhaust control technologies, namely exhaust filtration systems, tailpipe exhaust ventilation, and dilution ventilation systems. It was concluded that the amount of diesel exhaust was reduced by 76 to 91 % by the addition of ceramic filters directly fitted to exhaust systems. However, all reports on diesel control measures typically showed that little difference was detected between the different types of diesel exhaust control measures. The most significant improvement in diesel exhaust management has come from the mandated reduction of sulfur in fuel and the vehicle exhaust system fitted during manufacture. Some of these include:

- Station design;
    - Air extraction systems fitted into the roof areas of engine bays;
    - Maximise natural ventilation and cross-ventilation for engine bays;

- Vehicle design/engineering controls
    - Flexible exhaust houses fitted over vehicle exhaust pipes and vented outside station confines;
    - Filters fitted onto exhaust systems;

- Station management practices
    - Minimising the time or limiting the number of shift checks per week;
    - Correct positioning of appliance within the engine bay;
    - Removing appliances with bad exhaust emissions from service until repaired;

The majority of risk control measures illustrated above are elimination and engineering controls. In the station proper the focus has been on the administrative controls.

All the above systems have been applied in various modifications, but generally there was no difference found in the efficiency between the physical exhaust systems fitted to vehicle exhaust pipes and the filters fitted to the vehicle exhaust systems.[42] This report displays that trials with exhaust control systems resulted in all concentrations in DPM being lower than the level of detection. However, whist little different existed between these two types of systems, there has been differences reported between different models of the flexible pipe exhaust systems.[40] The NIOSH[44] reported that most diesel exhaust control technologies offer potential reductions in diesel emissions that can be applied to curtail diesel emissions, but that caution should be exercised when interpreting the emission numbers given in the examples.

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Experimental Design

This section, describing the experimental approach adopted for the study, is separated into four components, namely:

- Identification and selection of fire stations;
- Survey asking fire fighters of their concerns;
- Experimental design; and
- Analytical methods.

Station selection and activities for analyses

The Queensland Fire and Rescue Service (QFRS) was created by the amalgamation of 89 independent Fire Boards across Queensland. During their existence, these Boards commissioned a variety of station designs to reflect the needs of the local community, equipment and Fire Board. Although these fire stations exhibited similar design features, the QFRS has developed common design criteria and has applied to new fire station construction across Queensland. The fire stations selected for this study were chosen to most widely represent the broad construction characteristics and activities undertaken across the QFRS. The selection criteria, developed in collaboration with the QFRS Service Delivery and Levy Management Unit, were incorporated with call-out frequency, number of appliances and design/age of station.

The AIRS (Australasian Incident Reporting System) data from 2007 was used as a basis to assess call-out frequency. The number of appliances assigned to the station was provided by the QFRS Technical Services and the building characteristics were supplied by the QFRS Service Delivery and Levy Management Unit. Four station profiles were chosen to best cover the range of permanently staffed fire stations designs, namely special purpose stations, urban new (< 15 years), urban mid (15 - 30 years) and urban old (>30 years).

Station Profile	Region	Station Name	Annual call-outs
Urban Special	Northern	Townsville	2736
Urban standard – new	North Coast	Maroochydore	1316
Post 1995	Brisbane	Caboolture	1758
Urban standard – mid	South Western	Anzac Avenue	1062
1970 – 1995	South Eastern	Loganlea	1302
Urban standard – old	Central	Rockhampton	1666
Pre 1970	Far Northern	Cairns	2124

Table 2.1

QFRS fire stations selected to participate in the testing program and their activities.

Survey of fire fighter concern

Anecdotal information suggested fire fighters were most concerned about the airborne contaminants present within the engine bay and station areas (duty office and dormitory) during the start of shift checks, appliance(s) responding to an emergencies (turn-out) and returning to station after an emergency (return to station). To ensure the areas selected for testing were consistent with the experiences and expectations of fire fighters, a questionnaire was provided to all operational personnel based at the stations participating in the trials. The questionnaire was completed anonymously and designed to allow fire fighters the opportunity to identify any areas of concern that were not recognised by the above process. A copy of the survey tool is provided in Appendix 2.

The survey results were collated and analysed using Microsoft Excel. Each area of concern within the fire station was scored from 1 (high concern) to 5 (least concern). The product of the fire fighter responses and location scores were summed and then divided by the total number of respondents, *i.e.* ∑(score x no. of responses) / (*no. of respondents).* The data is interpreted as follows:

- The lower the concentration the greater the concern of the respondents; and
- The greater the concentration difference between station responses illustrates the concern is less consistent between respondents.

Experimental Design

The experiments focussed on the five typical station activities:

- Typical urban background immediately adjacent to the fire station;
- Typical 10 hour (day shift) work day;
- Start of Shift checks;
- Turn-out from fire station of standard number of appliances; and
- Return to station of standard number of appliance.

The appliance start of shift and turn-out/return trials were based on the standard station appliance compliment and standard turn-out, except Cairns station where the technical rescue appliance was not present. In this trial a larger aerial appliance was used in its place. Thus, some stations have one appliance and others have two appliances turning out and returning to station for the trials.

Region	Station Name	Standard Turn-out Appliances	Start of Shift Appliances
Northern	Townsville	114 A (fleet no. 823) 114 T (fleet no. 785)	111 A (fleet no. 672) 114 A (fleet no. 823) 114 T (fleet no. 785)
North Coast	Maroochydore	474 A (fleet no. 858) 474 L (fleet no. 473)	474 A (fleet no. 858) 474 J (fleet no. 971) 474 B (fleet no. 720) 474 L (fleet no. 473)
Brisbane	Caboolture	528 A (fleet no. 1042) 528 K (fleet no. 780)	528 A (fleet no. 1042) 528 K (fleet no. 780) 528 B (fleet no. 811) 528 V (fleet no. 726)
South Western	Anzac Avenue	312 A (fleet no. 1045)	312 A (fleet no. 1045) 312 B (fleet no. 935) spare (fleet no. 597)
South Eastern	Loganlea	614 A (fleet no. 835)	614 α (fleet no. 835)
Central	Rockhampton	235 A (fleet no. 940) 235 K (fleet no. 945)	235 A (fleet no. 940) 235 K (fleet no. 945) 235 Y (fleet no. 681) 235 I (fleet no. 681)
Far Northern	Cairns	711 A (fleet no. 978) 711 J (fleet no. 978)	711 A (fleet no. 978) 711 L (fleet no. 908) 711 J (fleet no. 978) 711 Y (fleet no. 894)

Table 2.2

QFRS appliances at fire stations selected to participate in the testing program.

Experiments were designed to measure where diesel exhaust emissions were most likely to be greatest across the fire station and the cumulative exposure over a 10 hour workday. The day shift was selected because of the more frequent appliance movement, fire fighters being more active during the day and the greater potential for contribution to fire fighter exposure from external sources. Thus, information about the typical background levels of airborne contaminants immediately adjacent to the fire stations was required. The contaminants of interest were selected, based on the typical diesel combustion products, the chemical nature of the airborne contaminants (complexity contaminants such as formaldehyde or naphthalene), and the acute or chronic respiratory irritations they cause (such as sulphur dioxide and diesel particulate matter) are:

- Acid gases - carbon monoxide, hydrogen sulphide, sulfur dioxide and nitrogen dioxide;
- Total volatile organic compounds – tvoc
- Specific volatile organic compounds – Benzene, toluene, xylene and hexane;
- Oxygenated hydrocarbons – Aldehydes such as formaldehyde and acrolein;
- Particulates - Polyaromatic hydrocarbons (PAHs); and diesel particulate matter (DPM).

Background Airborne Contaminants
There is an environmental background of the airborne contaminants in the urban environment typically from motor vehicles or other human activity. The concentrations of airborne contaminants are influenced by many factors including weather, time, location, and adjacent industries. Determining the typical background the airborne contaminants at each station provides a reference to (i) establish a baseline for all seven fire stations; and (ii) comparative concentration by which to compare the results obtained at each station during the trials. This approach provided confidence in the data collected for fire fighter exposure during the 10 hr day shift was not biased by any external event.

Background concentrations were obtained during the same 10 hr time period as the station measurements, with small sampling location variations due to particular station characteristics. The measurement and sample collection devices were located outside the fire station engine bays and closest to the nearest/busiest roadway, typically at 10 - 15 cm from the ground.

Location	Measurement/Sampling Device	Analyte	Duration
Outside station	Multi-RAE	LFL/oxygen/CO/H_2S	Continuous 10 Hr
	RAE PID	Total VOC	Continuous 10 Hr
	Universal SKC pump / cartridge filter	Diesel particulate matter	Continuous 10 Hr
	Legacy SKC pump / PUF filter tube	Polyaromatic hydrocarbon	Continuous 10 Hr
	Aircheck SKC pump / DNPH	Oxygenated hydrocarbons	Continuous 10 Hr
	Aircheck SKC pump / Tenax	Volatile organic compounds	Continuous 10 Hr
	Evacuated canister	Volatile organic compounds	Continuous 10 Hr
	Passive diffusion badge / pDNPH	Oxygenated hydrocarbons	Continuous 10 Hr
	Passive diffusion badge / Tenax	Volatile organic compounds	Continuous 10 Hr
	Dräger tube	Benzene	Point sample
	Dräger tube	Nitrogen dioxide	Point sample
	Dräger tube	Sulphur dioxide	Point sample

Table 2.3
The mixture of continuous and instantaneous measurements, together with the active and passive sampling techniques used outside all QFRS Fire stations in the trials.

10 hr Day shift
A fire station has a background level of airborne contaminants and the concentrations are affected by many factors including weather, time, location and adjacent industries. The determination of fire fighter exposure during a 10 hour day shift provides information on typical station exposures, which can be compared to typical background levels and exposures at other stations participating in this study. Using survey responses, several station areas of concern were selected. Sampling locations located in the following areas of concern varied slightly between stations because of particular station characteristics:

- Engine bay – midway next to the exhaust pipe of the main appliance (ca. 1.5 m from floor);
- Duty office – desk or other furniture (ca. 0.8 m from floor) and adjacent to door;
- Mess room - table (ca. 0.8 m from floor) nearest to engine bay entrance;
- Dormitory – closest to engine bay (ca. 0.4 m from floor) and adjacent to door; and

- PPE locker – adjacent to ensemble exhibiting greatest evidence of soot and marking (ca. 0.5 m from floor).

The sampling heights best represented the likely breathing zones of the fire fighters undertaking activities in these areas.

Locations	Measurement/Sampling Device	Analyte	Duration
Engine Bay and Duty Office	Multi-RAE RAE PID Universal SKC pump / cartridge filter Legacy SKC pump / PUF filter tube Evacuated canister Passive diffusion badge / pDNPH Passive diffusion badge / Tenax	LFL/oxygen/CO/H_2S Total VOC Diesel particulate matter Polyaromatic hydrocarbons Volatile organic compounds Oxygenated hydrocarbons Volatile organic compounds	Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr
Mess Room/Lounge	Multi-RAE RAE PID Universal – cartridge filter Evacuated canister Passive diffusion badge / DNPH Passive diffusion badge / Tenax	LFL/oxygen/CO/H_2S Total VOC Volatile organic compounds Volatile organic compounds Oxygenated hydrocarbons Volatile organic compounds	Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr
Dormitory	Multi-RAE RAE PID Universal SKC pump / cartridge filter Legacy SKC pump / PUF filter tube Aircheck SKC pump / DNPH Aircheck SKC pump / Tenax Evacuated canister Passive diffusion badge / DNPH Passive diffusion badge / Tenax	LFL/oxygen/CO/H_2S Total VOC Diesel particulate matter Polyaromatic hydrocarbons Volatile organic compounds Oxygenated hydrocarbons Volatile organic compounds Volatile organic compounds Oxygenated hydrocarbons	Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr
PPE locker	Multi-RAE RAE PID Aircheck SKC pump / DNPH Aircheck SKC pump / Tenax	LFL/oxygen/CO/H_2S Total VOC Volatile organic compounds Oxygenated hydrocarbons	Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr Continuous 10 Hr

Table 2.4

The mixture of continuous and instantaneous measurements, together with the active and passive sampling techniques used within the QFRS Fire station trials.

Start of Shift Check

The start of shift check involves physically checking equipment and operation of all mechanical devices such as the appliance engine, generators and ancillary petrol driven equipment. The standard process was undertaken for all appliances housed in the engine bay. The engine bay doors (front and rear) were closed for the test duration (except Cairns and Townsville where the front engine bay doors were closed, but the rear doors were either absent). The exact sample location varied from station to station because of the particular engine bay characteristics. The measurement and sample collection devices were typically at 1.5 m from the ground and adjacent to the exhaust of the main appliance (*c.a.* behind the vehicle cab on the off-side of the appliance). The activity specific measurements ceased when the start of shift check was completed. Together with the 10 Hr engine bay continuous samplers, a number of instantaneous measurements and active sampling techniques were applied for the activities as listed in table.

Location	Measurement/Sampling Device	Analyte	Duration
Engine Bay	Universal – cartridge filter Aircheck - DNPH Aircheck - Tenax	Diesel particulate matter Oxygenated hydrocarbons Volatile organic compound	Short term < 60 minutes Short term < 60 minutes Short term < 60 minutes
Engine Bay Duty Office Dormitory Mess/Lounge PPE Locker	Dräger tube Dräger tube Dräger tube	Benzene Nitrogen dioxide Sulphur dioxide	Point sample Point sample Point sample

Table 2.5
The mixture of continuous and instantaneous active measurements for start of shift trials in selected QFRS Fire stations.

Turn-Out Simulations
The standard simulated turn-out scenario involved monitoring during the following activities;

1. simultaneously commencing monitoring, opening engine bay doors and starting the fire appliance(s),
2. idling fire appliance(s) for 60 seconds;
3. accelerating appliance to leave the station,
4. doors closed immediately after appliance(s) have left engine bay; and
5. Monitoring ceased two minutes after commencing the trial.

This simulation was repeated at least 10 – 15 times to ensure a sufficient volume of air was passed through the collection filters, and the subsequent laboratory analysis limit of detection (LOD) was appropriate for the occupational exposure concentrations. After completion of each simulation, all engine bay doors were opened for *ca*. 5 minutes to ventilate the engine bay before any further turn-out or return simulations were performed.

The sampling locations were the same as the start of shift sampling location for each station. Together with the 10 Hr engine bay continuous samplers, a number of instantaneous measurements and active sampling techniques were applied for the activities as listed in table 2.6 below.

Location	Measurement/Sampling Device	Analyte	Duration
Engine Bay turn-out	Dräger tube Dräger tube Dräger tube Universal – cartridge filter Aircheck - DNPH Aircheck - Tenax	Benzene Nitrogen dioxide Sulphur dioxide Diesel particulate matter Oxygenated hydrocarbons Volatile organic compounds	Instantaneous Point sample Instantaneous Point sample Instantaneous Point sample Short term - multiple 2 minute Short term - multiple 2 minute Short term - multiple 2 minute

Table 2.6
The mixture of continuous and instantaneous active measurements for turn-out trials in selected QFRS Fire stations.

Return to Station Simulations
The standard simulated return to station scenario involved monitoring during the following activities;

1. idling appliance for 60 seconds outside station with engine bay doors closed;
2. simultaneously commencing monitoring and opening engine bay doors;
3. fire appliance(s) driven into place and shut down as per normal procedure;
4. doors closed immediately after appliance(s) entered engine bay; and
5. Monitoring ceased two minutes after commencing the trial.

This simulation was repeated at least 10 – 15 times to ensure a sufficient volume of air was passed through the collection filters, and the subsequent laboratory analysis limit of detection (LOD) was appropriate for the occupational exposure concentrations. After completion of each simulation, all engine bay doors were opened for *ca*. 5 minutes to ventilate the engine bay before any further turn-out or return simulations were performed.

The sampling locations were the same as the start of shift sampling location for each station. Together with the 10 Hr engine bay continuous samplers, a number of instantaneous measurements and active sampling techniques were applied for the activities as listed in table 2.7 below.

Location	Measurement/Sampling Device	Analyte	Duration
Engine Bay Return to station	Dräger tube Dräger tube Dräger tube Universal – cartridge filter Aircheck - DNPH Aircheck - Tenax	Benzene Nitrogen dioxide Sulphur dioxide Diesel particulate matter Oxygenated hydrocarbons Volatile organic compounds	Instantaneous Point sample Instantaneous Point sample Instantaneous Point sample Short term - multiple 2 minute Short term - multiple 2 minute Short term - multiple 2 minute

Table 2.7
The mixture of continuous and instantaneous active measurements for return to station trials in selected QFRS Fire stations.

Table on how many turned out etc.

All stations recorded actual and simulated turn-out and return to station activities. These trials were performed one the day prior to the 10 Hr continuous monitoring due to time of trails and the amount of sampling required to obtain samples that could be analysed with a low enough level of detection. The number of simulation turn-outs was dependent on the minimum LOD required and operational requirements. The start of shift checks and continuous monitoring were performed on the second day of the trials. The table below shows the amount of appliance activity during the sampling trials.

Station Name	Region	Appliances involved in turn-out and trials	10 Hr vehicle movements
Cairns	Far Northern	1 x scania LP aerial 1 x scania type 3 pumper	5 turnout/leave station 5 return to station Different day 15 simulated turnouts 15 simulated returns
Townsville	Northern	1 x scania type 3 pumper 1 x Mercedes sprinter 1 x Firepac mark III 3000	7 turnout/leave station 7 return to station Different day 7 simulated turnouts 6 simulated returns
Rockhampton	Central	1 x Mercedes type 3 pumper 1 x Mercedes ET	8 turnout/leave station 8 return to station Different day 10 simulated turnouts 10 simulated returns
Maroochydore	North Coast	1 x scania LP aerial 1 x scania type 3 pumper or 1 x Mitsubishi pumper	5 turnout/leave station 5 return to station Different day 15 simulated turnouts 15 simulated returns
Caboolture	Brisbane	1 x Mercedes type 3 pumper or 1 x Isuzu type 2 (auxiliary) pumper 1 x Ford 550 ET	7 turnout/leave station 7 return to station Different day 10 simulated turnouts 10 simulated returns
Loganlea	South Eastern	1 x Le France type 3 pumper	2 turnout/leave station 2 return to station Different day 10 simulated turnouts 10 simulated returns
Anzac Avenue	South Western	1 x Mercedes type 3 pumper	4 turnout/leave station 4 return to station Different day 10 simulated turnouts 10 simulated returns

Table 2.8

The number of appliance movements during the measuring periods in the selected QFRS fire stations.

Analytical Methods
The limit of detection (LOD) is the smallest concentration that can be detected with reasonable certainty for a given analytical procedure, and the reporting limit (R.L) is the minimum concentration of an analyte that can be measured within specified limits of precision and accuracy of the analytical procedure. These are important distinctions and the concentrations from the analytical laboratory report refer to the reporting limit (R.L).

Colourimetric Dräger Tubes
A range of Dräger stain tubes were used to identify and semi-quantify the airborne contaminants; benzene, sulphur dioxide, and nitrogen dioxide.

The measurements were obtained following the instructions provided by Dräger. A sealed colourimetric tube was broken at both ends and inserted into a Dräger hand pump. Typically 10 pumps were undertaken unless specified by the manufacturer and the tube held at about 1.5 m from the ground. The tube was directly read after the completion of the recommended pumps. The characteristics of each tube is shown in the following table

Dräger Tube	Serial Number	No. of pumps	Detection range (ppm)	Limit of Detection (ppm)
Benzene 0.5/c	81 01 841	20	0.5 - 10	≤ 0.5
Sulphur Dioxide 0.5/a	67 28 491	20	0.5 - 5	≤ 0.5
Nitrogen Dioxide 0.5/c	CH 30 001	5	0.5 - 10	≤ 0.5

Table 2.9
The Dräger tubes and their sensitivities used in QFRS station measurements.

Active Air Sampling using SKC pumps

Diesel Particulate Matter (DPM) sampling
DPM samples were collected following the principles of the reported method NIOSH Method 5040 using SKC universal PCXR4 variable flow meters.

The diesel particulate matter was collected on SKC 37-mm diameter cassettes with Quartz-Filter fibre (DPM cassettes). The cassettes were connected to SKC PCXR8 Universal Sample Pump using tygon tubing. Samples were typically collected at a flow rate of 1.8 – 2.0 L min^{-1} for the 10 Hr samples and 4.0 – 5.9 L min^{-1} for the 2 minute simulated trails. The flow rate of each pump was checked immediately prior to and at the completion of sampling period using a Bios International Corp. DryCal DC-Lite primary flow meter.

Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction of Elemental carbon (EC) and organic carbon (OC). The average OC loading for the travel blanks was 11.137 µg per filter, which represents roughly 30% of the average filter loading. The average EC loading for the travel blank filters was 0.012 µg per filter, which was 1.2% of average EC loading.

DPM analysis
All DPM Cassettes were analysed for total carbon (TC), organic (OC) and elemental carbon (EC) via the NIOSH Method 5040 by Coal Services Pty Ltd, using a Sunset Laboratories thermo-optical instrument.

Carbon speciation analysis was carried out by placing a 8.04 cm^2 punched section of a cartridge quartz fibre filter from a 37mm SKC DPM in helium purged flow furnace. The temperature was increased step wise (*ca.* 500 - 700°C) to initially remove all organic carbon

followed then by carbonates. Pyrolised products were flushed off as CO_2 and catalytically converted to CH_4 for detection by an FID detector. The oven was then cooled (*ca*. 25℃), a 2% O_2/He mixture introduced and the temperature again increased step wise (*ca*. 850℃) to oxidise elemental carbon which is then converted to methane (CH_4) for detection. The laser transmission was monitored through the filter during the cycle to minimise interferences caused by elemental carbon formed during the pyrolysis of organic carbon. A known volume of CH_4 was injected into the furnace for calibration purposes after each cycle.

An analysis LOD of ~0.001 mg/m^3 for organic, elemental or total carbon has been reported by the AIOH[26]. This figure is also quoted by the analyst on the basis of information from the instrument manufacturer.

Polycyclic Aromatic Hydrocarbons (PAH) sample collection
PAH samples were collected following the principles of the NIOSH Method 5515 sing SKC Leland legacy variable flow meters.

The PAH (particulate and vapour phase) was collected in SKC 22 x 100 mm borosilicate glass tubes, containing Polyurethane foam (PUF) / Tenax / PUF layers. The filters were connected to SKC Leland legacy pumps using tygon tubing, and samples collected at a flow rate of 4.0 – 5.0 L min^{-1}. The flow rate of each pump was checked immediately prior and after the completion of sampling using a Bios International Corp. DryCal DC-Lite primary flow meter.

Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction. The average PAH loading for the travel blanks was typically 20 – 30 ng per tube, which represents roughly <0.01% of the average filter loading.

PAH analysis
The PAH samples were analysed by the Qld Health Forensic and Scientific Services using the principles USEPA TO-13A Method. The PUF and Tenax layers were co-extracted using Accelerated Solvent Extraction (ASE) on a Dionex ASE100 using hexane as the extracting solvent. Prior to extraction the samples were spiked with a deuterated PAH mixture (1ng/µL) corresponding to the PAHs of interest. The ASE conditions were:

- Cell size: 34mL
- Temperature: 100℃
- Static Time: 5 min
- Flush Volume: 60%
- Purge Time: 250 s
- Static Cycles: 3

The extracting solvent was concentrated using Kuderna-Danish apparatus on a heated water bath. The final 200µL volume was analysed using GCMS. Quantification was achieved using a ratio of d-PAH:PAH in an external calibration curve. Analysis LOR was typically 2 ng/m^3 for individual PAHs as reported by QHFSS.

Note: Two concentrations were considered, one with and one without naphthalene due to the analysing laboratory caveats on the analysis - any result over 100,000 pg/m^3 is outside of the calibration range and should be viewed as an estimated result. This approach is likely to provide a more conservative concentration for naphthalene

Volatile Organic Compounds (VOC)

Sample collection onto Tenax
SKC aircheck 2000 variable flow meters were used to collect VOC samples onto SKC stainless steel tubes packed with a tenax/carboxyn/tenax matrix (spiked with the deuterated internal standards - dichlorethane, benzene, toluene, styrene, and dichlorbenzene), following the principles the US-EPA TO-17 method. The tubes were connected to SKC pumps using tygon tubing. Flow rates of 10 – 20 ml min^{-1} were typically used for samples collected over 10 hours, and 80 – 100 mL min^{-1} for samples collected over two minutes. The flow rate of each pump was checked immediately prior to and at the completion of sampling period using a Bios International Corp. DryCal DC-Lite primary flow meter. Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction. The VOC samples were analysed according to the established Qld Health Forensic and Scientific Services Method using the principles of US-EPA method TO-17. VOCs were thermally desorbed from the tubes and analysed by GC-MS spectrometry. The LOR for individual VOCs was typically 50ng per tube.

Sample collection into Canister
VOC samples were collected in SKC Silcosteel-treated interior (fused silica) 15 L canisters that had been put under vacuum and controlled with a 10 Hr restrictor regulator. The VOC samples were analysed according to the established Qld Health Forensic and Scientific Services Method using the principles of US-EPA method TO-15. VOC were collected in syringes from the canisters and analysed by GC-MS spectrometry. The LOR for individual VOCs was typically 1 part per billion (ppb).

DNPH-Aldehydes
The aldehyde samples were collected following the principles of the USEPA TO-11A method using SKC aircheck 2000 variable flow meters. The aldehydes were collected on a hydroxymethyl piperazine (DNPH) matrix housed in glass sorbent tubes (manufactured by Supelco, Inc.). The tubes were connected to SKC Aircheck 2000 pumps using tygon tubing. Samples were typically collected at a flow rate of 80 – 100 mL min^{-1} for the samples collected over 10 Hr, and 180 – 200 mL min^{-1} for samples collected over two minutes. The flow rate of each pump was checked immediately prior to and at the completion of sampling period using a Bios International Corp. DryCal DC-Lite primary flow meter. Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction. The aldehyde samples were solvent extracted from the tubes and analysed using HPLC according to the established Qld Health Forensic and Scientific Services Method using the principles of US-EPA method TO-11A. The LOR for individual aldehydes ranged from 0.3 to 1 µg per tube.

Passive Tenax-Volatile Organic Compounds (VOC)
VOCs were collected onto SKC passive badges comprising of Tenax placed in a polypropylene housing containing a number of inlet holes. The sampler is opened by removing a cover to expose the holes to the air and is closed by replacing the cover. Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction. The VOC samples were analysed according to the established Qld Health Forensic and Scientific Services Method using the principles of US-EPA method TO-17. The VOC - both aliphatic and aromatic organics were thermally desorbed from the tubes and analysed by GC-MS spectrometry. The LOR for individual VOCs was typically 50ng per badge.

Passive DNPH-Aldehydes
The aldehydes were collected onto SKC passive badges comprising of silica gel filter paper treated with 2,4-dinitrophenylhydrazine (DNPH) placed in a polypropylene housing containing a number of inlet holes. The sampler is opened by sliding a cover to expose the holes to the air and is closed by replacing the sliding cover. The sampler contains two filter compartments.

Travel blanks were packed with samples at each station for transport to the analysing laboratory for blank subtraction. The aldehyde samples were solvent extracted from the badges and analysed according to the established Qld Health Forensic and Scientific Services Method using the principles of US-EPA method TO-6A. The LOR for individual aldehydes ranged from 0.6 µg per filter.

Lower Flammability Limit, Hydrogen Sulfide, Oxygen Carbon Monoxide
The four gases: carbon monoxide (CO); oxygen (O_2); lower flammability limit (LFL); and hydrogen sulfide (H_2S) were measured using a Rae Systems MultiRae Plus four gas detector. The instruments were calibrated at Queensland Health Forensic Scientific Services following the established process and challenged immediately prior to use. The flow rate was approximately 250 ml/min and all collected data was logged. The instrument characteristics are described below.

Multi-RAE	Detection range	Limit of Detection/ppm or resolution
Lower Flammability Limit	0 - 100 % of LFL	1%
Oxygen	0 - 30 % vol	0.1 ppm
Hydrogen Sulphide	0 - 100 ppm	1 ppm
Carbon Monoxide	0 - 500 ppm	1 ppm

Table 2.10
The MultiRae four gas detector sensitivities used in station measurements.

Total volatile hydrocarbons (TVOC)
The TVOC were measured using a Rae systems MiniRae 2000 Photoionisation detector and a ppbRae Photoionisation detector equipped with 10.6 eV UV lamps. The measurements are described against the calibrant gas (isobutylene), and logged over one minute averaging periods . The peak concentrations within these averaging periods are plotted against the time of day.

RAE PID	Detection range/ppm	Limit of Detection/ppm
MiniRAE 2000	0.1 - 10,000	0.1
ppbRAE	0.001 - 200	0.001

Table 2.11
The Rae Photoionisation detectors and their sensitivities used in station measurements.

Level of Concern
A workplace exposure standard (ES) represents an airborne concentration of a particular substance within the breathing zone of a worker, and exposure to which the present state of knowledge should not cause any health effects or undue discomfort to nearly all people. Exposure Standards have generally been developed on the basis of:

- 8 hour work shift;
- Average person is working at a “normal” level of intensity;
- Normal climatic conditions are present; and
- 16 hours break between shifts.

Safe Work Australia publishes the National Exposure Standards[45] for many airborne contaminants, but not mixtures. The established concentrations that exist have been used as

a basis to define levels of concern (LOC). The LOC for diesel particulate matter, which been discussed previously in chapter, is a peak concentration meaning that no limit should exceed the concentration in any work period. If the duration of a workers exposure is greater than 8 hours the ES can be revised by using the equation:

$$(\text{TWA}) = \frac{8 \times (24 - \text{hours of shift}) \times \text{Exposure Standard (8-hour TWA)}}{16 \times \text{hours of shift}}$$

Contaminant	8 hour level of Concern / ppm	10 hr Level of Concern / ppm
Benzene	1	0.7
Sulphur Dioxide	2	1.4
Nitrogen Dioxide	3	2.1
Formaldehyde	1	0.7
Acrolein		
Xylene	80	56
Toluene	50	35
Hexane	20	14
Total VOC	0.5	0.5
Hydrogen sulphide	10	7
LFL	10% of LFL	10% of LFL
Oxygen	20.9 %	20.9%
Carbon monoxide	30	21
PAH		
Naphthalene	10	7
DPM	EC 0.1 mg/m^3 peak	EC 0.1 mg/ m^3 peak

Table 2.12
The VOCs of interest for QFRS station measurements and their standard exposure levels of concern for 8 Hr and 10 Hrs.

Experimental Results

This section, describing the experimental results for the study, is separated into eight components, namely:

- Fire fighter survey data;
- Results of Cairns Fire Station – Far Northern Region;
- Results of Townsville Fire Station – Northern Region;
- Results of Rockhampton Fire Station – Central Region;
- Results of Maroochydore Fire Station – North Coast Region;
- Results of Caboolture Fire Station – Brisbane Region;
- Results of Loganlea Fire Station – South Eastern Region;
- Results of Anzac Avenue Fire Station – South West Region;

Survey Data

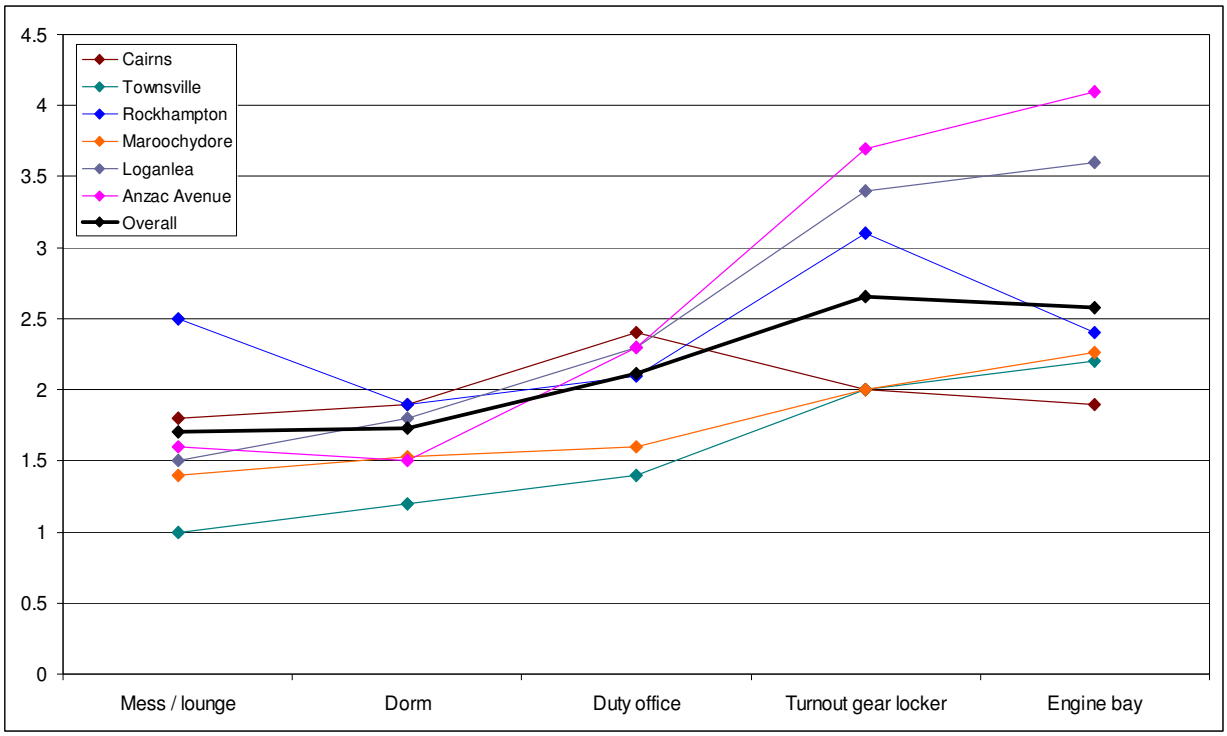
of

Fire fighter Concerns Regarding

Diesel Exhaust in Fire Stations

The surveys conducted prior to the studies performed at each station. The table below shows that even though the survey was anonymous, only 50% of respondents replied. This can be partially accounted for by sickness, transfer of fire fighters between stations due to shortages, and disinterest in the activity.

Station	No. of Respondents			Engine Bay	Duty Office	Dormitory	Mess / Lounge	PPE Locker
	Max	Returned	%					
Cairns	30	31	103	1.9	2.4	1.9	1.8	2.0
Townsville	30	5	17	2.2	1.4	1.2	1.0	2.0
Rockhampton	30	17	57	2.4	2.1	1.9	2.5	3.1
Maroochydore	30	15	50	2.3	1.6	1.5	1.4	2.0
Caboolture	30	0	0	-	-	-	-	-
Loganlea	20	8	40	3.6	2.3	1.8	1.5	3.4
Anzac Avenue	20	18	90	4.1	2.3	1.5	1.6	3.7
Over-all Score	**190**	**94**	**50**	**2.6**	**2.1**	**1.7**	**1.7**	**2.7**



The survey results show that in contrast to the initial brief that fire fighter concern was about diesel exhaust within engine bays and duty offices, both areas were generally of lower concern than the fire station living areas (dormitories and mess/lounges). The duty office was the next highest area of concern to fire fighters. The results do not show area data for the Brisbane station as no surveys were returned. Rockhampton (higher) and Townsville (lower) showed the greatest variation from the average data for mess/lounge results, while a large spread of results were seen for the areas of least concern, namely the ppe locker and engine bay.

Review of combined QFRS Fire Station Data

Fire fighter exposures to diesel and petrol exhausts generated from the typical fire station activities; start of shift checks, turn-out and return to station, are discussed as airborne contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulfur dioxide and nitrogen dioxide concentrations were measured during the station activities; start of shift checks, turn-out and return to station. Background measurements were performed outside the station prior to the commencement of station activities.

Fire Station	Cairns Townsville Maroochydore Caboolture		Rockhampton Anzac Avenue		Loganlea		**State Average**	
Sampling Location	NO_2 (ppm)	SO_2 (ppm)	NO_2 (ppm)	SO_2 (ppm)	NO_2 (ppm)	SO_2 (ppm)	NO_2 (ppm)	SO_2 (ppm)
Outside	n.d	n.d	n.d	n.d	n.d	n.d	**n.d**	**n.d**
Engine Bay	n.d	n.d	0.5 ss	n.d	0.75 ss	n.d	**0.25 ss**	**n.d**
Duty Office	n.d	n.d	n.d	n.d	n.d	n.d	**n.d**	**n.d**
Dormitory	n.d	n.d	n.d	n.d	n.d	n.d	**n.d**	**n.d**
Mess / Lounge	n.d	n.d	n.d	n.d	n.d	n.d	**n.d**	**n.d**
L2 PPE Locker	n.d	n.d	n.d	n.d	n.d	n.d	**n.d**	**n.d**

Note
No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).

Table 3.1

Instantaneous concentrations for the air-borne contaminants, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) using Dräger tubes at the beginning of each trial. In general, the measurement times exceeded the activity time, except during the background measurements.

The airborne concentration of sulphur dioxide (SO_2) was below the Limit of Detection (LOD) (< 0.5 ppm) for the all activities. The airborne concentration of nitrogen dioxide (NO_2) was below the LOD (< 0.5 ppm), except in the engine bays at Rockhampton (0.5 ppm), Loganlea (0.75 ppm) and Anzac Avenue (0.5 ppm). The highest Fire station concentration obtained was during the 33 minute start of shift checks at Loganlea (0.75 ppm), which is *ca*. half of the 10 Hr time corrected national exposure standard (ES_{10}) of 2 ppm.

The 24 Hr average ambient air concentrations of SO_2 for South East Qld, Gladstone and Townsville were 0.001 ppm, 0.002 ppm and <0.001 ppm respectively.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during the normal station activities for as close as practicable to the standard 10 Hr day shift. The measurements reported were peak concentrations over 1 minute averaging periods.

Sampling site location	Photo-ionisation detector (10.6 eV Lamp)	Multi Rae four gas detector	
		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing	
	Total VOC (ppm)	Hydrogen sulphide (ppm)	Carbon monoxide (ppm)
Cairns			
Outside	0.0	0.01	0.6
Engine Bay	0.02	0.01	0.1
Duty Office	0.0	0.1	2.1
Dormitory	0.0	0.01	0.6
Mess / Lounge	n/a	0.07	0.4
L2 PPE Locker	n/a	n/a	n/a
Townsville			
Outside	0.02	0.02	0.4
Engine Bay	0.16	0.1	0.4
Duty Office	0.0	0.1	0.9
Dormitory	0.02	0.01	0.6
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.0	0.03	1.6
Rockhampton			
Outside	0.0	0.4	0.8
Engine Bay	0.2	0.1	2.7
Duty Office	0.2	0.1	1.0
Dormitory	0.0	0.0	0.5
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.4	0.1	2.5
Maroochydore			
Outside	0.0	0.1	0.4
Engine Bay	0.0	0.1	1.0
Duty Office	0.0	0.1	0.9
Dormitory	0.1	0.0	0.05
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.0	0.0	0.5
Caboolture			
Outside	0.0	0.04	0.1
Engine Bay	0.1	0.01	1.3
Duty Office	0.2	0.05	0.04
Dormitory	0.1	0.1	0.1
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.0	0.09	2.0
Loganlea			
Outside	0.01	0.1	1.3
Engine Bay	0.04	0.1	2.1
Duty Office	0.08	0.1	0.8
Dormitory	0.0	0.3	1.6
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.6	0.1	0.5
Toowoomba			
Outside	3.6	0.2	1.1
Engine Bay	0.6	0.1	1.5
Duty Office	0.6*	0.1*	1.1**
Dormitory	0.7	n/a	n/a
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.6	0.1	1.1
State averages			
Outside	**0.5**	**0.1**	**0.7**
Engine Bay	**0.2**	**0.1**	**1.3**
Duty Office	**0.1**	**0.2**	**1**
Dormitory	**0.1**	**0.1**	**0.6**
L2 PPE Locker	**0.2**	**0.1**	**1.4**

* results for Toowoomba duty office and ppe locker are the same due to the entry to the duty officer being through the ppe locker

Table 3.2

Average concentrations of carbon monoxide (CO), hydrogen sulphide (H_2S) and total volatile organic compounds (tvoc) at fire stations over a 10 Hr day shift.

Atmospheric Contaminants – Carbon Monoxide

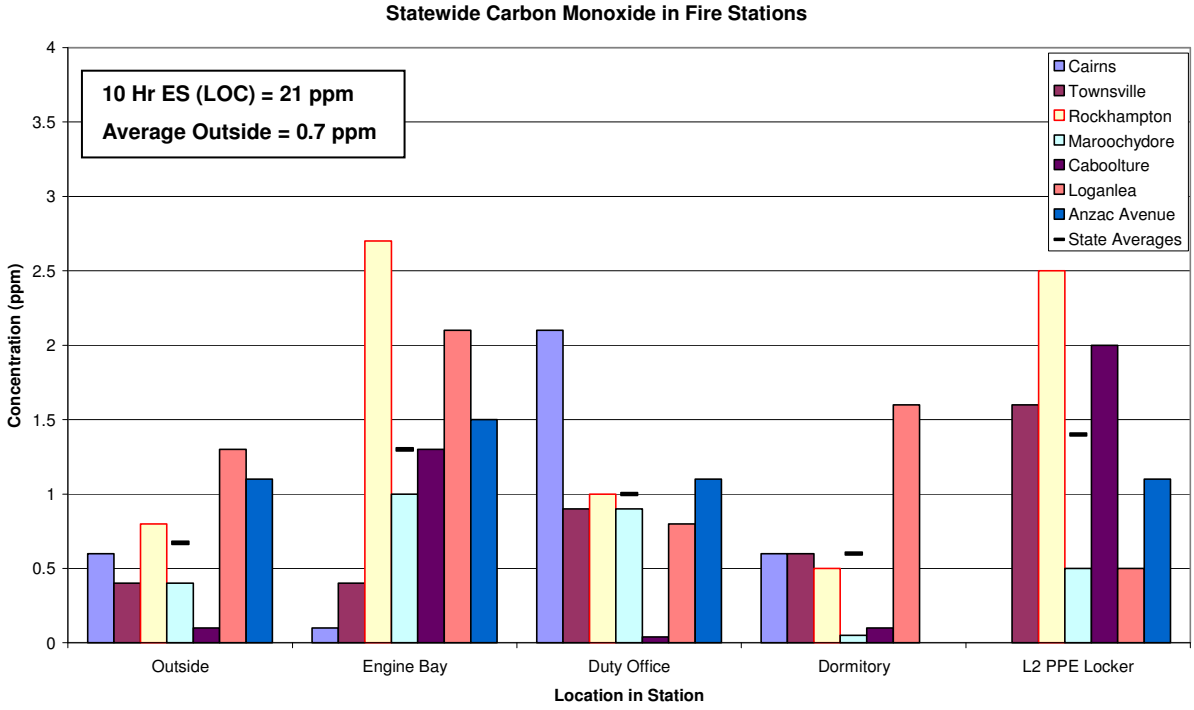


Figure 3.1
Average concentrations of carbon monoxide at fire stations over a 10 Hr day shift. The state averages (black bars in graph) are the mean concentrations of all station concentrations.

Outside Station (Background)
The average carbon monoxide (CO) background concentration obtained outside all fire stations was 0.7 ppm. The highest fire station carbon monoxide concentration (1.3 ppm), observed at Loganlea fire station, is more than 16 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 21 ppm and more than 6.5 times lower than the National Environmental Protection Measurement (NEPM) ambient air quality standard for CO (9.0 ppm). These background results are similar to the average CO concentration in South East Qld[46], which was shown to vary with location, range: 1.0 to 4.0 ppm with an average of 1.7 ppm.

Inside Station (Engine Bay)
The average CO concentration obtained within the engine bays was 1.3 ppm and is approximately 2 times the average background CO concentration. The highest fire station engine bay concentration was at Rockhampton (2.7 ppm), was more than 3 times higher than the outside Rockhampton, but more than 7.5 times lower than the ES_{10} (21 ppm).

Inside Station (Duty Office)
The average CO concentration obtained within the duty offices (1 ppm) is similar to the average background concentration (0.7 ppm). The highest fire station concentration was obtained at Cairns (2.1 ppm), which is more than 10 times lower than the ES_{10} (21 ppm). All stations, except Maroochydore, Caboolture, Loganlea and Anzac Avenue, duty offices to the side of the engine bays with direct access through doorways. The Caboolture, Loganlea and Anzac Avenue duty offices within the stations with indirect access to the engine bay through passageways within the station. The Maroochydore duty office had indirect access through the station, but a large window (often opened) with direct access to the engine bay.

Inside Station (Dormitory)
The average CO concentration obtained within the dormitories (0.6 ppm) was very similar to the average background concentration. The highest fire station concentration was obtained at Loganlea (1.6 ppm), which is more than 13 times lower than the ES_{10} (21 ppm) and more than 5 times lower than the NEPM (9.0 ppm).

Cairns, Townsville, and Anzac Avenue stations had dormitory rooms with direct access to the engine bay through a naturally vented passageway. Rockhampton, Caboolture, Maroochydore and Loganlea stations had dormitory rooms within the stations with indirect access to the engine bay through the station. The Loganlea dormitories were single rooms located towards the rear of the station. The dormitory selected for use was a spare room that was the closest to the engine bay entrance, and also used as a minor storage room.

Inside Station (PPE Locker)
The average CO concentration obtained within the PPE locker rooms or areas was 1.4 ppm, which is ca. 13 times lower than the average background concentration. The highest fire station concentration was obtained at Rockhampton (2.5 ppm), which is more than 8 times lower than the ES_{10} (21 ppm). The significant variance in results is possibly due to the different approaches adopted to store PPE within stations.

Townsville and Caboolture fire stations have small open PPE rooms adjoining the engine bay. Rockhampton fire station used a room closed to the engine bay, except for a hole in the wall that used to house an air conditioner. Maroochydore and Loganlea have small PPE lockers closed to the engine bay. Anzac Avenue uses the walk-way from the engine bay past the duty office to the living areas as a PPE locker, and Cairns uses hanging racks along the edges of the engine bay.

Atmospheric Contaminants – Hydrogen Sulfide

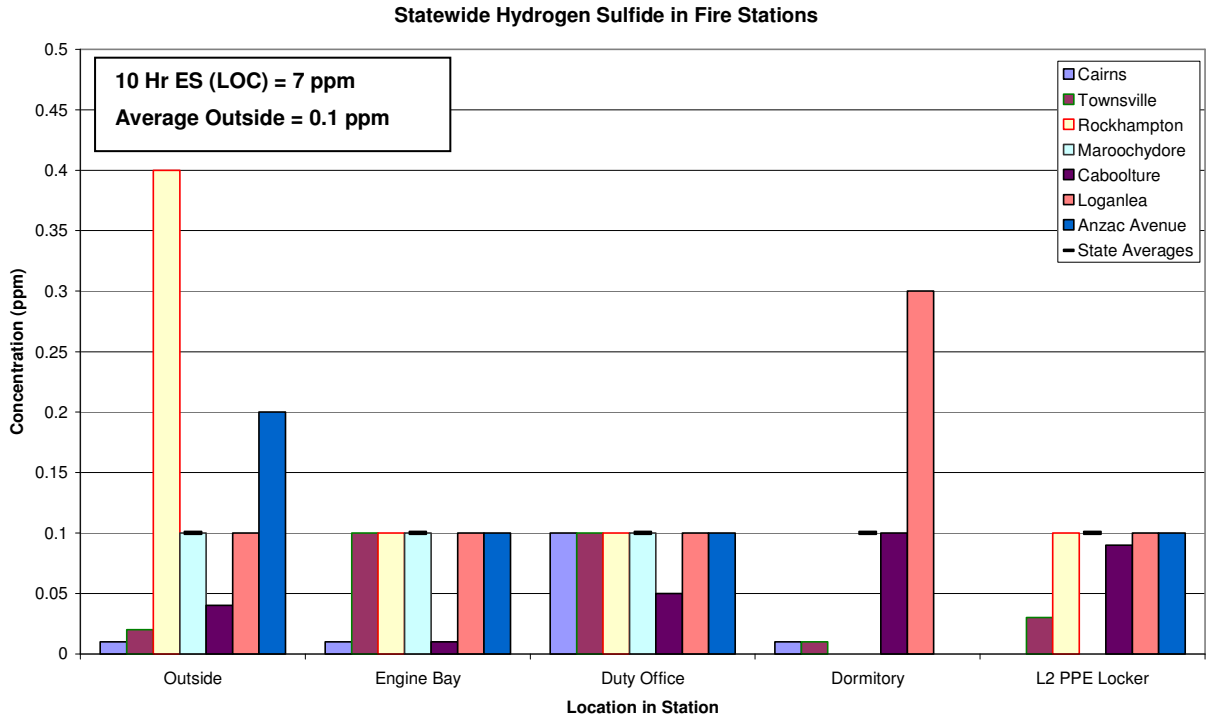


Figure 3.2
Average hydrogen sulfide concentrations within fire stations over a 10 Hr day shift. The state averages (black bars) are the mean concentrations of all station concentrations.

Outside Station (Background)
The average hydrogen sulfide (H_2S) background concentration obtained outside the fire stations was as at the LOD (0.1 ppm) for the MultiRae detector. The background concentrations at Rockhampton (0.4 ppm) and Loganlea (0.2 ppm) fire stations both exceeded the average background level from across the state. The Rockhampton background concentration (0.4 ppm) is more than 15 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 7 ppm. There is no established National Environmental Protection Measurement (NEPM) standard for H_2S and the odour threshold of H_2S is 0.001 – 0.005 ppm.

Inside Station (Engine Bay, Duty Office, Dormitory, PPE Locker)
The H_2S concentrations within the engine bays, duty office, dormitories and the PPE lockers were all at or below the LOD (0.1 ppm) for the MultiRae detector, except Loganlea (0.5 ppm), which is more than 10 times less than the ES_{10} of 7 ppm. The LOD concentration is more than 70 times less than the ES_{10} of 7 ppm.

Atmospheric Contaminants – total volatile organic compounds (isobutylene units)
The airborne concentration of total volatile organic compounds (tvoc) was measured using a Photoionisation detector (10.6 eV UV lamp) continuously during the normal station activities for as close as practicable to the standard 10 Hr day shift. The measurements reported were peak concentrations over 1 minute averaging periods reported as isobutylene units.

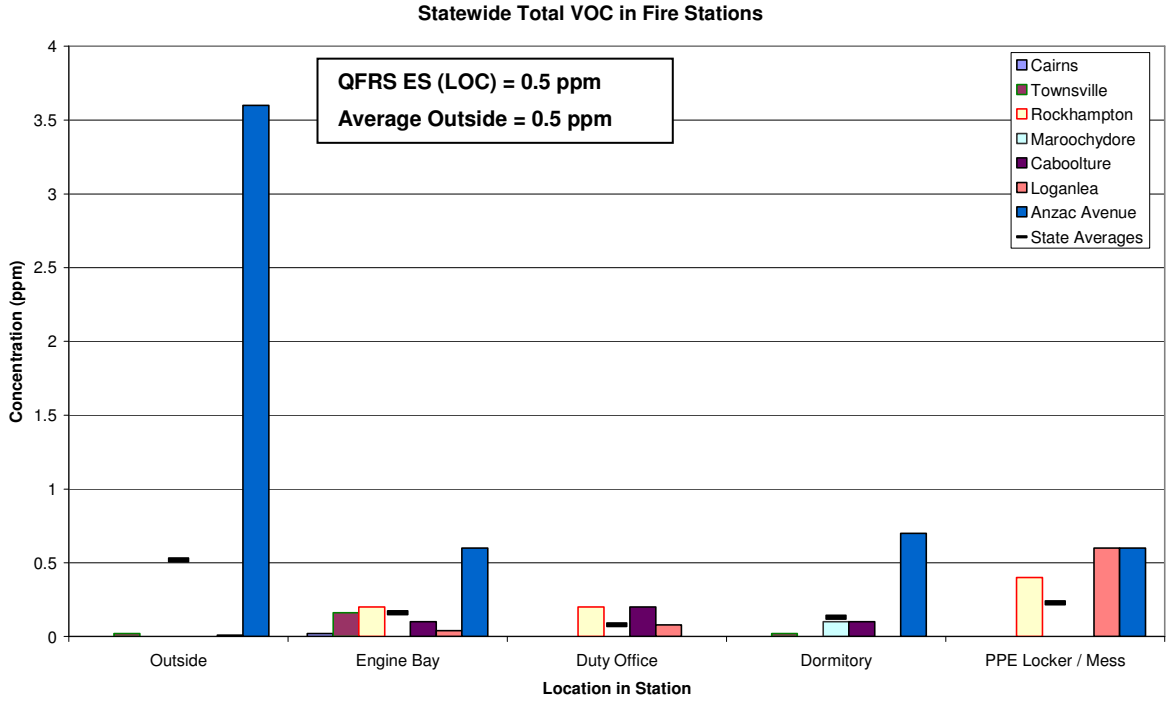


Figure 3.3
Average concentrations of total volatile organic compounds at fire stations over a 10 Hr day. State averages (black bars in graph) are the mean concentrations of all station concentrations.

Outside Station (Background)
The average tvoc background concentration obtained outside the fire stations was 0.5 ppm. There is no established national exposure standard for tvocs, however the QFRS adopts a level of concern (LOC) of 0.5 ppm for application at emergency incidents. The highest measurement outside a fire station was Anzac Avenue (3.6 ppm), which is *ca*. 7 times higher than the QFRS LOC of 0.5 ppm.

Inside Station (Engine Bay)
The average tvoc concentration obtained within the fire station engine bays was 0.1 ppm, which is 5 times less than the average background concentration and QFRS LOC. The highest fire station concentrations obtained were Townsville (0.2 ppm) and Rockhampton (0.2 ppm), which are 2.5 times lower than the QFRS LOC (0.5 ppm).

Inside Station (Duty Office)
The average tvoc concentration obtained within the fire station duty offices was 0.1 ppm, which is 5 times less than the average background concentration and QFRS LOC of 0.5 ppm. The highest fire station averages obtained were Townsville (0.2 ppm) and Caboolture (0.2 ppm), which is 2.5 times lower than the QFRS LOC (0.5 ppm).

All stations, except Maroochydore, Caboolture, Loganlea and Anzac Avenue, had duty offices to the side of the engine bays with direct access through doorways. Caboolture, Loganlea and Anzac Avenue had duty offices within the station with indirect access to the engine bay through passageways. Maroochydore duty office had indirect access through the station, but a large window (often opened) with direct access to the engine bay.

Inside Station (Dormitory)
The average tvoc concentration obtained within the fire station dormitories was 0.1 ppm, which is 5 times less than the average background concentration and QFRS LOC of 0.5 ppm. The highest fire station average obtained was Anzac Avenue (0.2 ppm) which is 2.5 times lower than the QFRS LOC (0.5 ppm). Cairns, Townsville, and Anzac Avenue stations had dormitory rooms with direct access to the engine bay through a passageway with little to no ventilation. Rockhampton, Caboolture, Maroochydore and Loganlea stations had dormitory rooms within the stations. Access to the engine bay was indirect through the station. Loganlea dormitories were single rooms towards the rear of the station.

Inside Station (PPE Locker)
The average tvoc concentration obtained within the fire station PPE locker rooms or areas was 0.2 ppm, which is 2.5 times below the average background concentration and QFRS LOC of 0.5 ppm. There was some variance most likely because of the historical exposure of the PPE and different approaches adopted to store PPE within the station. The highest fire station concentrations obtained was Loganlea (0.6 ppm), which is slightly higher than the QFRS LOC (0.5 ppm). This close concentration is within the instruments detection errors and can thus be considered the same.

Townsville and Caboolture fire stations have small open PPE rooms adjoining the engine bay. Rockhampton fire station used a room closed to the engine bay, except for a hole in the wall that used to house an air conditioner. Maroochydore and Loganlea have small PPE lockers closed to the engine bay. Anzac Avenue uses the walk-way from the engine bay past the duty office to the living areas as a PPE locker, and Cairns uses hanging racks along the edges of the engine bay.

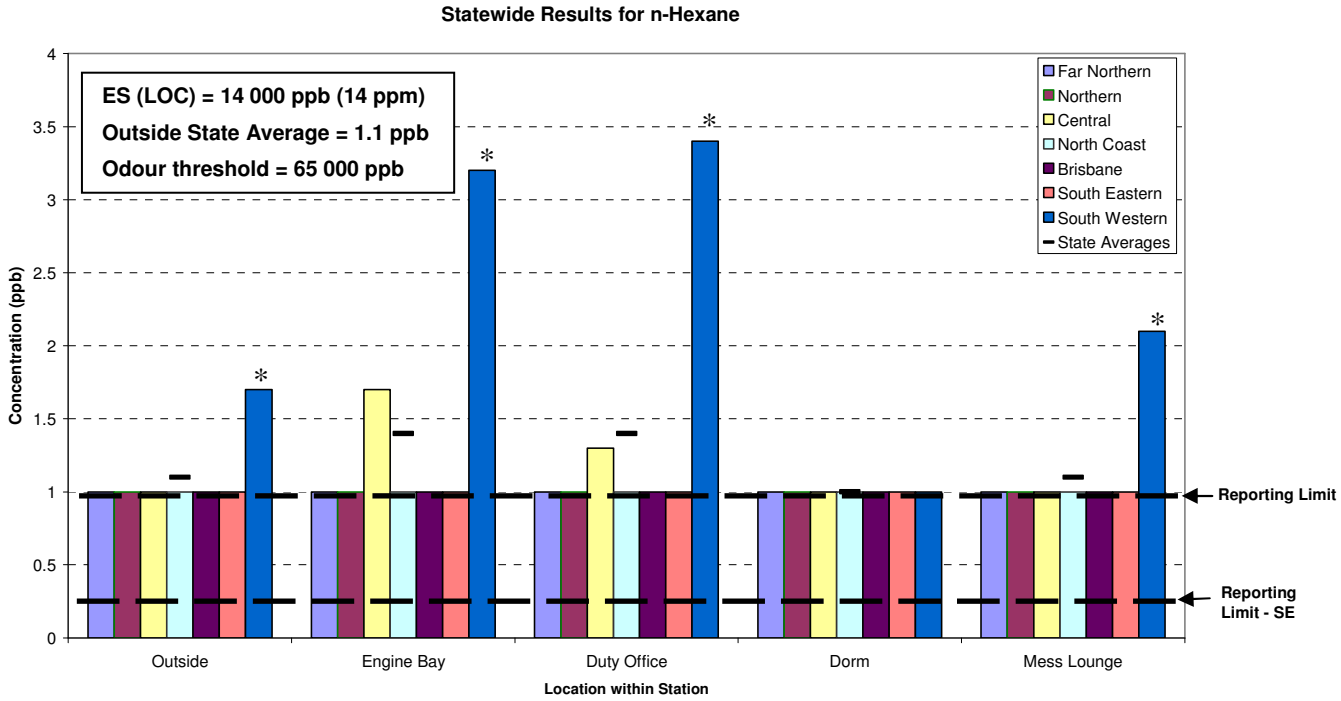
Atmospheric Contaminants – Specific VOCs – hexane, benzene, toluene and xylene
Many compounds contribute to the description of VOCs and several are of particular interest. VOCs are defined[31] as organic compounds with boiling points < 260° C at 1 atmosphere. Evacuated canisters and active and passive sorbent techniques were used to collect samples during normal station activities for the standard 10 Hr day shift. Instantaneous benzene measurements were performed during station activities. Reporting limit (R.L.) concentrations are reported if the laboratory reported <R.L.

Station	Benzene Dräger Tube	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	(ppm)	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Cairns															
Outside	<0.5	<2.8*	1	<1.7*	<2.3*	1	<1.6*	<2.0*	<2*	<4.5*	<2.6*	1	<1.7*	<47.3*	<29.2*
Engine Bay			1	<1.7*		1	<1.6*		<2*	<3.3*		1	<1.7*		<29.2*
Start of Shift	<0.5	2.8			8			6.9			<2.4*			<156*	
Turnout	<0.5	<91*			<77*			<67*			<85*			<140*	
Return	<0.5	<113*			<96*			<83*			<105*			<133*	
Duty Office	<0.5		1	<1.7*		1	3.7		<2.4*	<3.2*		1	<1.7*		<29.9*
Dormitory	<0.5	3.4	1	<1.7*	<2.9*	1	7.2	<2.5*	<2*	5.6	<3.2*	1	<1.7*	<43.4*	<30.5*
Mess / Lounge	<0.5		1	<1.7*		1	2.9		<2*	<3.9*		1	<1.7*		<29.5*
PPE Locker	<0.5	2.7			<2.3*			<2.0*			<2.5*			<41.1	
Townsville															
Outside	<0.5	<2.6*	1	<1.7*	<2.2*	1	<1.6*	<1.9*	<2*	<3.2*	<2.4*	1	<1.7*	<44.9*	<29.0*
Engine Bay			1	<1.7*		1	<1.6*		<2*	<3.3*			<1.7*		<28.9*
Start of Shift	<0.5	19			125			108			79.4			<247*	
Turnout	<0.5	<5.6*			<4.8*			<4.1*			<5.1*			<202*	
Return	<0.5	<67*			<56*			<48*			<59.6*			<210*	
Duty Office	<0.5		1	<1.7*		1	<1.6*		<2*	<3.2*		1	<1.7*		<28.4
Dormitory	<0.5	<3.8*	1	<1.7*	<3.2*	1	<1.6*	<2.8*	3.6	<3.2*	<3.4*	1	<1.7*	<35.6*	<29.0
Mess / Lounge	<0.5		1	<1.7*		1	<1.6*		<2*	<3.2*		1	<1.7*		<29.3
PPE Locker	<0.5	<2.2*			<1.8*			<1.6*			<2.0*			<37.6*	
Rockhampton															
Outside	<0.5	<2.6*	1	<1.7*	<2.2*	1	<1.6*	<1.9*	<1	<3.2*	<2.4*	<1	<1.7*	<46.7*	<29.3*
Engine Bay			1.9	<1.7*		7.8	24		1.2	<17.7*		1.7	<1.7*		<29.3*
Start of Shift	<0.5	119			170			141			161			<197*	
Turnout	<0.5	<3.8*			<3.2*			<2.8*			<3.4*			<164*	
Return	<0.5	<8.9*			<2.2*			<2.8*			<7.8*			<167*	
Duty Office	<0.5		1	<1.7*		1.3	<1.6*		<1	<3.2*		1.3	<1.7*		<29.3*
Dormitory	<0.5	3.8	1	<1.7*	<3.4*	1.3	<1.6*	2.5	<1	<3.2*	27.4	<1	<1.7*	<46.7*	<29.3*
Mess / Lounge	<0.5		1	<1.7*		1.2	<1.6*		<1	<3.2*		<1	<1.7*		<29.3*
PPE Locker	<0.5	4.1			20.2			10.1			15.3			<50.1*	
Maroochydore															
Outside	<0.5	<5.0*	1	NR	4.3	3	NR	3.7	<2.5	NR	<4.5*	<1	NR	<19.7*	<29.3*
Engine Bay			4.7	NR		4.1	NR		<2.9	NR		<1	NR		<28.5*
Start of Shift	<0.5	16.3			66.3			48.4			102			<247*	
Turnout	<0.5	<4.4*			5.6			<3.2*			4.0			<208*	
Return	<0.5	<5.3*			5.0			<3.9*			<4.8*			<214*	
Duty Office	<0.5		1	NR		1	NR		<2	NR		<1	NR		<28.8*
Dormitory	<0.5	<5.3*	1	NR	<5.1*	1.5	NR	<3.9*	<2	NR	<4.8*	<1	NR	<16.3*	<28.8*
Mess / Lounge	<0.5		1	NR		1.5	NR		<2	NR		<1	NR		<29.4*
PPE Locker	<0.5	<2.6*			<4.1*			<2.6*			<2.4*			<14.8*	
Caboolture															
Outside	<0.5	<6.3*	1	NR	<5.3*	1.8	NR	<4.6*	<2	NR	6.2	<1	NR	<17.0*	<29.1*
Engine Bay			1.3	NR		5.4	NR		3.4	NR		1.0	NR		<29.3*
Start of Shift	<0.5	31			101			83			272			<209*	
Turnout	<0.5	<3.1*			6.1			5.8			6.2			<211*	
Return	<0.5	<3.1*			4.5			4.1			9.4			<344*	
Duty Office	<0.5		1	NR		1.0	NR		<2	NR		<1	NR		<28.8*
Dormitory	<0.5	<6.3*	1	NR	8.2	1.3	NR	<4.6*	<2	NR	8.8	<1	NR	<17.2*	<29.2*
Mess / Lounge	<0.5		1	NR		1.9	NR		<2	NR		<1	NR		<28.4*
PPE Locker	<0.5	<6.3*			14.1			9.4			26.1			<20.0*	
Loganlea															
Outside	<0.5	<1.6*	1	N.R	5.7	3.1	N.R	12.5	<3	N.R	<1.6*	<1	N.R	<44.3*	<29.9*
Engine Bay			1	N.R		17	N.R		13.5	N.R		<1	N.R		<29.9*
Start of Shift	<0.5	48			>204*			276			26			<156*	
Turnout	<0.5	<10*			<10*			<10*			<10*			<140*	
Return	<0.5	<18*			<18*			<18*			<18*			<133*	
Duty Office	<0.5		1	N.R		1	N.R		<2	N.R		<1	N.R		<27.7*
Dormitory	<0.5	<2.6*	1	N.R	<10*	1	N.R	13.2	<2	N.R	<2.5*	<1	N.R	<53.9*	<29.3*
Mess / Lounge	<0.5		1	N.R		2.5	N.R		<2	N.R		<1	N.R		<29.3*
PPE Locker	<0.5	<10*			<10*			<10*			<10*			<50.8*	
Anzac Avenue (Toowoomba)															
Outside	<0.5	0.5	N.A	<1.6*	3.7	N.A	<1.5*	2.0	N.A	<2.8*	17	N.A	<1.6*	<43.5*	<29.3*
Engine Bay			N.A	<1.6*		N.A	10.1		N.A	6.5		N.A	3.2		<29.3*
Start of Shift	<0.5	18.2			60.8			40.8			19			<197*	
Turnout	<0.5	14.1			151			10.4			13			<177*	
Return	<0.5	12.5			28.1			16.6			14			<167*	
Duty Office	<0.5		N.A	<1.6*		N.A	6.9		N.A	<4.5*		N.A	2.1		<29.3*
Dormitory	<0.5	0.4	N.A	<1.6*	10.3	N.A	2.*	5.8	N.A	<2.8*	1.0	N.A	<1.6*	<44.4*	<29.3*
Mess / Lounge	<0.5		N.A	<1.6*		N.A	2.4		N.A	<2.8*		N.A	<1.6*		<29.3*
PPE Locker	<0.5	1.3			3.2			1.8			3.4			<49.3*	

Table 3.3

Volatile organic compound screen results for the analytes of interest, hexane, benzene, toluene and xylene. The individual aldehyde concentrations were added to obtain a total aldehyde concentration.

Hexane specific monitoring



* Results from passive badges

Figure 3.4

Hexane concentrations from evacuated canisters controlled by flow valves for a 10 Hr day shift. South west region concentrations are based on Tenax tubes and passive badges.

Outside Station (Background)

The hexane background concentration at all stations was at or below the reporting limit (1 ppb). The average hexane background concentration was 1.1 ppb. Although the highest concentration was obtained at Anzac Avenue fire station (1.7 ppb), some care should be exercised due to it being derived from a passive diffusion badge. Notwithstanding, the result is more than 8000 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 14000 ppb. The odour threshold is 65000 ppb. These background results are significantly less than the Brisbane[48] average airborne concentration of 19 ppb (range: 0.4 to 95 ppb).

Inside Station (Engine Bay)

In most instances the hexane concentration in the engine bays was at or below the reporting limit. The average hexane concentration obtained within the engine bays was 1.4 ppb which is similar to the background hexane concentration. The highest fire station concentration obtained was Anzac avenue (3.2 ppb), which is more than 4000 times lower than the ES_{10} (14000 ppb). Care should be shown with the Anzac Avenue result since it was derived from a passive diffusion badge.

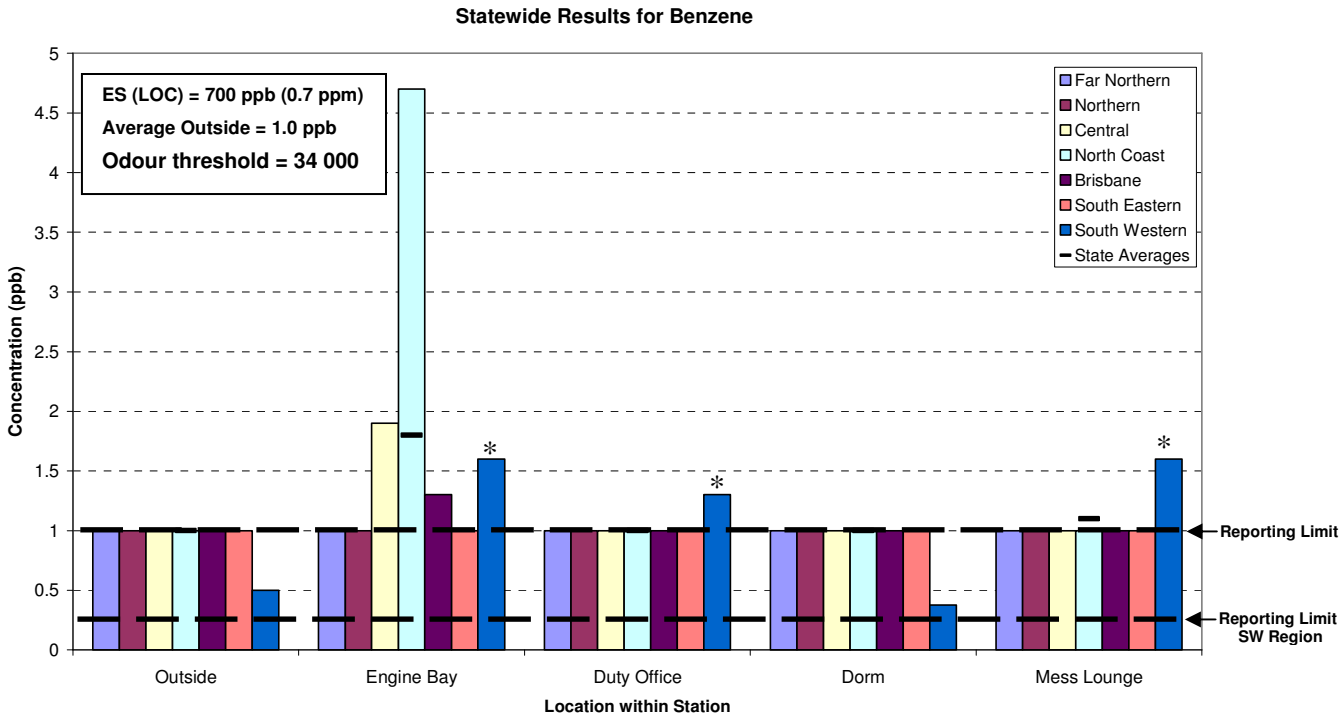
Inside Station (Duty Office)

In most instances the hexane concentration in the duty offices was at or below the reporting limit. The average hexane concentration obtained within the duty office was 1.1 ppb and is similar to the average background concentration. The highest concentration was obtained at Anzac Avenue Fire station (3.4 ppb). However, this result is at or below the reporting limit for the analytical sampling method used. It is more than 4000 times lower than the ES_{10} (14000 ppb).

Inside Station (Dormitory)
In all instances the hexane concentration within the dormitories was at or below the reporting limit (1 ppb), which is more than 14000 times lower than the ES_{10} (14000 ppb).

Inside Station (Mess/Lounge Room)
In most instances the hexane concentration within the mess areas was at or below the reporting limit. The average hexane concentration obtained within the mess areas was 1.1 ppb and is similar to the average background concentration. The highest concentration was obtained at Anzac avenue Fire Station (2.1 ppb) and is more than 6000 times lower than the ES_{10} (14000 ppb).

Benzene specific monitoring



* Results from passive badges

Figure 3.5
Benzene concentrations using evacuated canisters controlled by a flow valve for a 10 Hr day shift at fire stations. South west region concentrations are based on ATD Tenax tubes.

Outside Station (Background)
The benzene background concentration at all fire stations was at or below the R.L of 1.0 ppb, which is more than 700 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. The odour threshold of benzene is 34000 ppb. The average ambient air concentration of benzene in Eagle Farm[48] (Brisbane) was 3.3 ppb, and more generally for South East Qld[46,47] the average ambient benzene concentration in air is 0.8 ppb (range: 0.4 to 1.5 ppb).

Inside Station (Engine Bay)
All stations, except Cairns, Townsville and Loganlea, showed the benzene concentrations in the engine bays slightly above the reporting limit (1.0 ppb). The average benzene concentration obtained within the engine bays was 1.8 ppb, which is *ca.* 2 times above the background benzene concentration. The highest fire station concentration obtained was at Maroochydore (4.7 ppb), which is more than 140 times lower than the ES_{10} (700 ppb), and

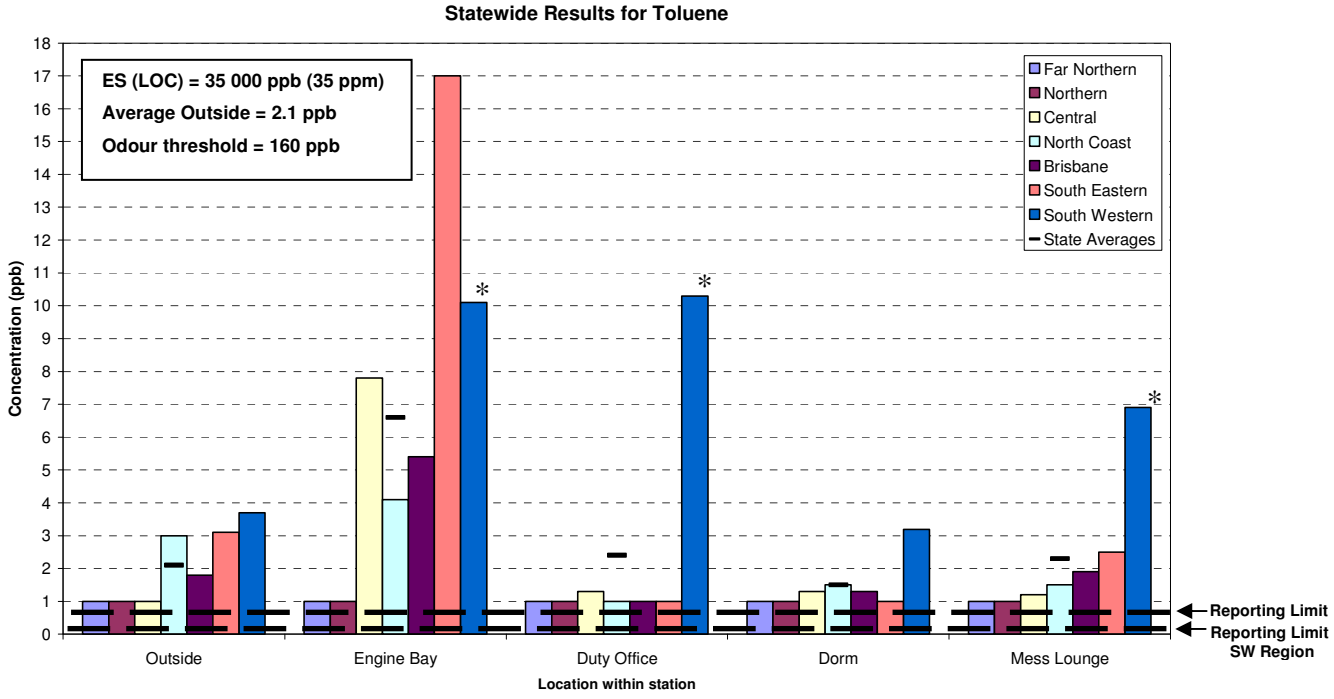
significantly below the odour threshold. In a report on ambient benzene levels, Wallace[49] reported data from US and German studies where the median indoor benzene concentration was 6.5 - 7 ug/m^3 (2 ppb), increasing to 10 – 11 ug/m^3 (3 ppb) when smokers were present. The average engine bay result is consistent with the figure, while the Maroochydore result is more than 2 times higher.

Inside Station (Duty Office)
In all stations, except Anzac Avenue, the benzene concentration in the duty office was at or below the R.L, which is similar to the average background concentration. The highest fire station concentration was obtained at Anzac Avenue (1.3 ppb), which is slightly higher than the background benzene concentration, but almost 700 times lower than the ES_{10} (700 ppb). The average duty office result and the Anzac Avenue results are lower than the Wallace indoor average (2 ppb).

Inside Station (Dormitory)
In all stations, except Anzac Avenue, the benzene concentration within the dormitories was at or below the reporting limit. The highest fire station concentration obtained at Anzac Avenue (1.3 ppb) is slightly higher than the background benzene concentration, but almost 700 times lower than the ES_{10} (700 ppb).

Inside Station (Mess/Lounge Room)
In most instances the concentration within the mess areas was at or below the R.L. The average benzene concentration obtained within the mess areas was 1 ppb and is similar to the average background concentration. The highest fire station concentration was obtained at Anzac avenue (1.6 ppb), which is more than 400 times lower than the ES_{10} (700 ppb).

Toluene specific monitoring



* Results from passive Tenax badges

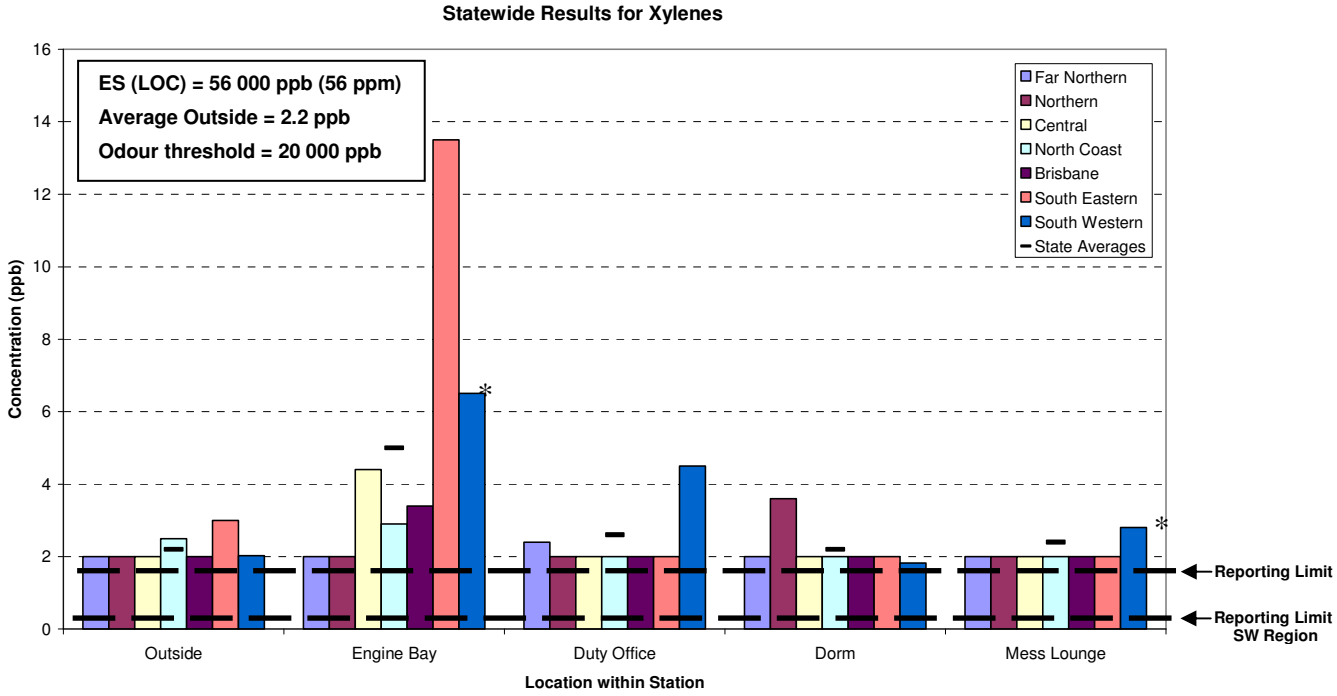
Figure 3.6
Toluene concentrations using evacuated canister controlled by a flow valve for a 10 Hr day shift. South west region concentrations are based on Tenax tubes and passive badges.

Outside Station (Background)
The toluene background concentrations for all stations, except Cairns, Townsville and Rockhampton, were above the reporting limit (1.0 ppb). The average toluene concentration was 2.1 ppb and the highest fire station concentration was Anzac Avenue (3.7 ppb), which is more than 17000 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 35000 ppb. The toluene odour threshold is 160 ppb. The average background toluene concentration is similar to the average toluene airborne concentrations in South East Qld[46] 1.6 ppb (range: 0.7 to 4.9 ppb) and less than Brisbane[48] toluene airborne concentration10.6 ppb (range: 1.8 to 83 ppb).

Inside Station (Engine Bay)
In all stations, except Cairns and Townsville, the engine bay toluene concentrations were above the reporting limit. The average engine bay toluene concentration was 6.1 ppb, which is *ca*. 3 times the background toluene concentration. The highest concentration was observed at Loganlea engine bay (17 ppb), which is more than 2050 times lower than the ES_{10} (35000 ppb), and significantly below the odour threshold.

Inside Station (Duty Office, dormitory and Mess/Lounge)
In all stations, except Anzac Avenue, the toluene concentrations in the duty office, dormitory and mess/lounge were at or below the reporting limit. The average toluene concentrations observed in the duty office (1.1 ppb), dormitory (1.2 ppb) and mess/lounge (1.5 ppb) were all less than the average background concentration. The highest duty office, dormitory and mess/lounge concentrations were observed at Anzac Avenue (10.3 ppb, 3.2 ppb and 7 ppb respectively). The duty office is more than 3000 times lower, the dormitory is more than 10000 times lower and the mess/lounge is more than 5000 times lower than the ES_{10} (35000 ppb). All are significantly below the odour threshold.

Xylene specific monitoring



* Results from passive Tenax badges

Figure 3.7
Xylene concentrations using evacuated canister controlled by a flow valve for a 10 Hr day shift. South west region concentrations are based on Tenax tubes and passive badges.

Outside Station (Background)
All stations, except Maroochydore, Loganlea and Anzac Avenue, have background xylene concentrations at or below the reporting limit (2 ppb). The highest fire station concentration was obtained at the Loganlea (3 ppb), which is more than 18000 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 56000 ppb. The average xylene airborne concentrations in South East Qld[46] is 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] is 3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as p-xylene data, but calculated as total xylene based on p-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the m-&p-xylene with the o-xylene. The xylene odour threshold is 20000 ppb.

Inside Station (Engine Bay)
All stations, except Cairns and Townsville, have xylene concentrations in the engine bays above the reporting limit (2.2 ppb). The average xylene concentration observed within the engine bays was 5.0 ppb, which is 3 times less than the background xylene concentration. The highest engine bay concentration was obtained was Loganlea (13.5 ppb), which is more than 4140 times lower than the ES_{10} (56000 ppb).

Inside Station (Duty Office)
All stations, except Cairns and Anzac Avenue, have a xylene concentration in the duty office at or below the reporting limit. The average xylene concentration observed within the duty office (2.6 ppb) is similar to the average background concentration. The highest fire station concentration was obtained at Anzac Avenue (4.5 ppb), which is almost 12500 times lower than the ES_{10} (56000 ppb).

Inside Station (Dormitory)
All stations, except Townsville and Anzac Avenue, have a xylene concentration within the dormitories at or below the reporting limit. The average xylene concentration observed within the dormitories was the same as the average background concentration (2.2 ppb). The highest fire station concentration was observed at Townsville (3.6 ppb), which is almost 9700 times lower than the ES_{10} (56000 ppb).

Inside Station (Mess/Lounge Room)
All stations, except Anzac Avenue, have a xylene concentration within the mess areas at or below the reporting limit. The average xylene concentration obtained within the mess areas was 2.4 ppb, which is similar to the average background concentration. The highest fire station concentration obtained was Anzac avenue (2.8 ppb), which is 20000 times lower than the ES_{10} (56000 ppb).

Atmospheric Contaminants – Aldehydes
Aldehyde compounds such as formaldehyde and acrolein are common VOCs. Samples were collected, using active and passive sorbent techniques, during the normal station activities for as close as practicable to the standard 10 Hr day shift. The concentration reported for an aldehyde is the summation of the aldehydes of interest (ensure related to the experimental chapter). If the result obtained was less than the reporting limit (<R.L.) the RL was used to illustrate the worst case concentration for a specific location.

Total Aldehyde specific monitoring

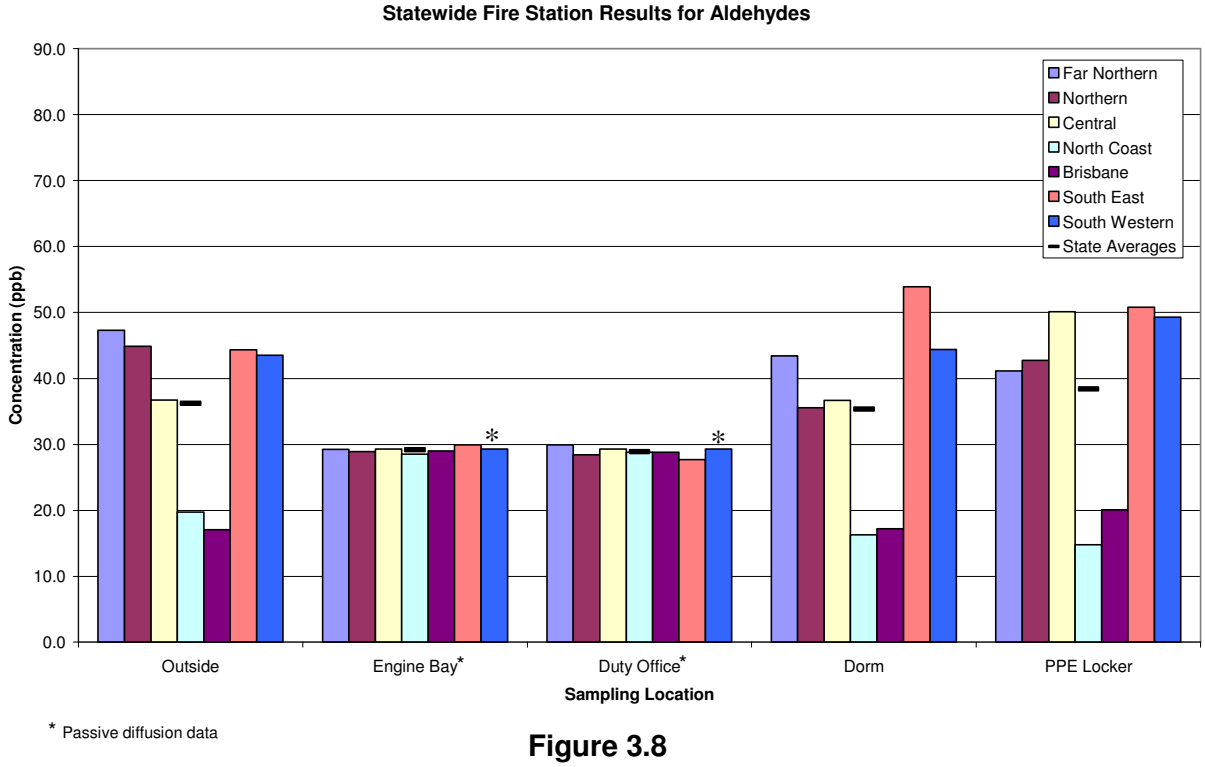


Figure 3.8
Aldehydes concentrations for a 10 Hr day shift at all fire stations across the state, based on the addition of active and passive data.

Outside Station (Background)
All stations, except Rockhampton, Maroochydore and Caboolture, are above the average aldehyde background concentration of 35 ppb. The highest fire station concentration was observed at Cairns (47 ppb). There is no established Exposure standard for total aldehydes in air, but a number of individual aldehydes such as formaldehyde have ES concentrations. The 10 Hr time corrected exposure standard (ES_{10}) for formaldehyde is 700 ppb. Care should be shown as results are derived from the addition of both passive diffusion badges (engine bay and duty office) and active collection tubes (outside, dormitory and PPE locker) results. The South East Qld[32] airborne aldehyde concentration, which incorporates three of the aldehydes measured in these trials (formaldehyde, acetaldehyde and propionaldehyde) is 1.7 ppb (range: of 2.0 to 7.2 ppb). The fire station concentrations were typically below the reporting limits for most aldehydes, and so the reporting limit concentrations have been used.

Inside Station (Engine Bay)
The average total aldehyde concentration observed within engine bays is 29 ppb, which is significantly lower than the outside average. The average aldehyde concentration(as formaldehyde) within the engine bay was 29 ppb, and the highest formaldehyde concentration observed was at Loganlea (30 ppb), which are both *ca*. 20 times less than the formaldehyde ES_{10} (700 ppb). Care should be shown with these results as they were based exclusively on passive diffusion badges. Typically, fire station concentrations were below the reporting limits and so the reporting limits concentrations have been used.

Inside Station (Duty Office)
The average total aldehyde concentration obtained within the duty office was 29 ppb, which is significantly lower than the average outside concentration. The average aldehyde concentration(as formaldehyde) within the duty office was 28.9 ppb, and the highest fire station formaldehyde concentration was at Cairns (30 ppb), which are both *ca*. 20 times less

than the formaldehyde ES_{10} (700 ppb). Care should be shown with these results as they were based exclusively on passive diffusion badges. Typically, fire station concentrations were below the reporting limits and so the reporting limits concentrations have been used.

Inside Station (Dormitory)
The average aldehyde concentration obtained within the dormitories was 32 ppb, which is similar to the average background concentration. The highest fire station concentration obtained was at Loganlea (54 ppb). The average formaldehyde concentration within the dormitory was 9 ppb, and the highest fire station formaldehyde concentration was Loganlea (22 ppb), which are both significantly less than the formaldehyde ES_{10} (700 ppb). Typically, fire station concentrations were below the reporting limits and so the reporting limits concentrations have been used.

Inside Station (PPE locker)
The average aldehyde concentration obtained within the PPE locker areas was 38 ppb, which is similar to the average background concentration. The highest fire station concentration obtained was at Anzac Avenue (51 ppb). The average formaldehyde concentration within the PPE locker was 7 ppb, and the highest fire station formaldehyde concentration was at Loganlea (11 ppb), which are both less than the formaldehyde ES_{10} (700 ppb).

Atmospheric Contaminants – Particulate Matter
The airborne concentration of diesel exhaust particulates; polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift.

Sampling location	PAH (ug/m^3)	DPM (mg/m^3)	Sampling location	PAH ($\mu g/m^3$)	DPM (mg/m^3)	Sampling location	PAH ($\mu g/m^3$)	DPM (mg/m^3)
Cairns			Maroochydore			Anzac Avenue		
Outside	0.13	0.001	Outside	0.12	0.002	Outside	0.22	0.002
Engine Bay	0.10	0.001	Engine Bay	0.51	0.003	Engine Bay	0.41	0.009
Start of Shift		0.002	Start of Shift		0.06	Start of Shift		0.08
Turnout		0.001	Turnout		0.01	Start of Shift - Firepac		0.73
Return		0.001	Return		0.01	Turnout		0.01
Duty Office	0.20	0.001	Duty Office	0.24	0.001	Return		0.02
Dormitory	0.25	0.001	Dormitory	0.26	0.001	Duty Office	0.26	0.005
Townsville			Caboolture			Dormitory	0.28	0.002
Outside	0.08	0.007	Outside	0.17	0.002			
Engine Bay	0.32	0.001	Engine Bay	0.82	0.005			
Start of Shift		0.011	Start of Shift		0.06			
Turnout		0.002	Turnout		0.01			
Return		0.007	Return		0.02			
Duty Office	0.25	0.001	Duty Office	0.37	0.001			
Dormitory	0.29	0.001	Dormitory	0.24	0.001			
Rockhampton			Loganlea			State averages		
Outside	0.05	0.001	Outside	0.23	0.001	Outside	0.14	0.002
Engine Bay	0.88	0.002	Engine Bay	1.40	0.003	Engine Bay	0.63	0.003
Start of Shift		0.06	Start of Shift		0.036	Start of Shift		0.044
Turnout		0.027	Turnout		0.001	Turnout		0.019
Return		0.032	Return		0.001	Return		0.013
Duty Office	0.29	0.001	Duty Office	0.40	0.001	Duty Office	0.30	0.002
Dormitory	0.22	0.002	Dormitory	0.39	0.001	Dormitory	0.26	0.001

Table 3.4
Polyaromatic hydrocarbons (PAHs) and diesel particulate (DPM) state-wide results.

Polyaromatic Hydrocarbon (PAH) specific monitoring
The airborne Polyaromatic hydrocarbons (PAH) of interest are described in chapter 1. Of the 18 PAHs characterised, only Pyrene, Fluoranthene, Anthracene, Phenanthrene, Fluorene, Acenaphthene, Acenaphthylene and Naphthalene were detected above the reporting limit. All five are defined *as non-carcinogenic* by the US-EPA[14] and *not classifiable as to their carcinogenicity in humans* by the IARC.[13] Of particular note is the carcinogenic PAH marker compound benzo(a)pyrene, which was not detected above the reporting limit.

Although there are established Exposure Standards (ES) for a number of individual PAH compounds, there is no established Australian ES for total airborne PAHs. Thus, the US OSHA regulatory limit (0.2 mg/m^3 for 8 Hr) for total airborne PAHs has been adopted, and time adjusted for a 10 Hr shift, *i.e.* 10 Hr time corrected exposure standard (ES_{10}) of 140 µg/m^3 (0.14 mg/m^3). Similarly, although there is no odour threshold for total PAH compounds, there are established odour thresholds for a number of individual PAH compounds, *e.g.* naphthalene (0.14 ppm, 730 µg/m^3). Typically, the individual PAH concentrations measured were significantly below their odour thresholds. If the result obtained was less than the reporting limit (<R.L.) the R.L. was used to illustrate the worst case concentration for a specific location.

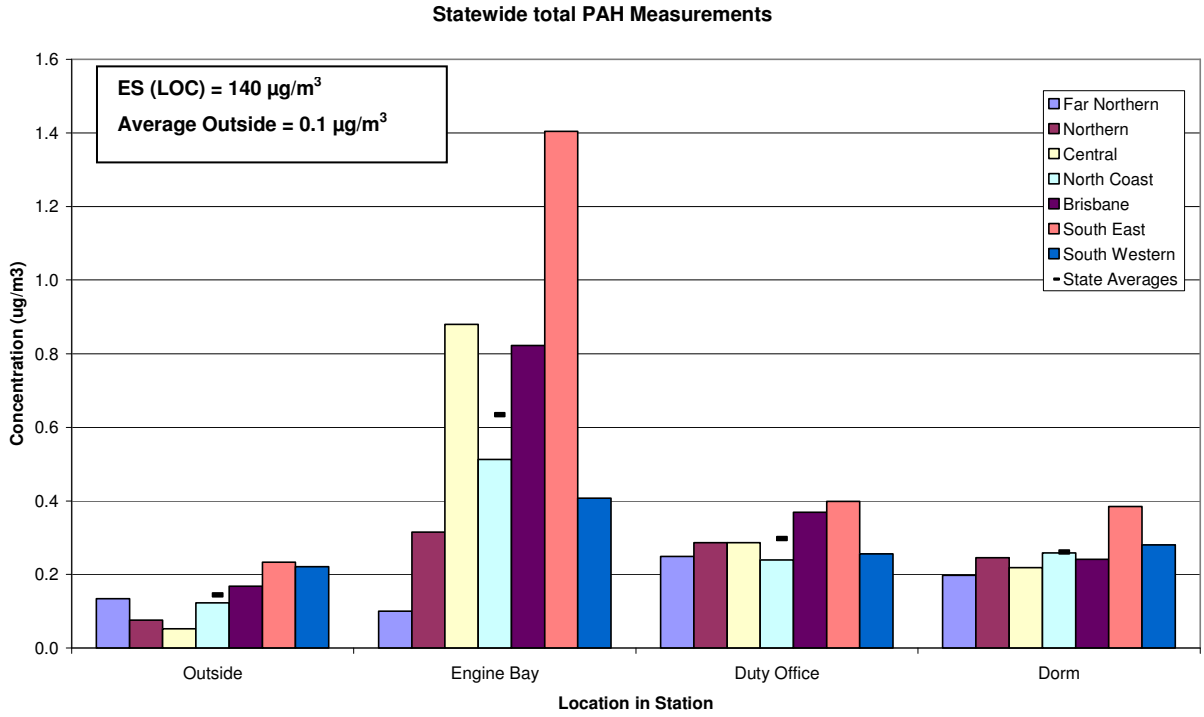


Figure 3.9
PAH concentrations for a 10 Hr day shift at all fire stations across the state.

Outside Station (Background)
All stations, except Caboolture, Loganlea and Anzac Avenue, are below the average PAH background concentration of 0.14 µg/m^3. The highest fire station concentration observed was at Loganlea (0.23 µg/m^3), which is more than 600 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 140 µg/m^3. Care should be shown with these total results as they are derived from the addition of mostly reporting limit concentrations. The majority of compounds were not detected above the reporting limits of the laboratory.

Inside Station (Engine Bay)
All stations, except Cairns, are above the average background concentration (0.08 µg/m^3), but only Rockhampton, Caboolture and Loganlea, are above the average PAH concentration observed within the engine bays (0.6 µg/m^3). The highest fire station concentration obtained was at Loganlea Fire station (1.4 µg/m^3), which is 100 times lower than the ES_{10} (140 µg/m^3).

Inside Station (Duty Office)
All stations are above the average background concentration (0.08 µg/m^3), but only Caboolture and Loganlea, are above the average PAH concentration observed within the duty office (0.3

µg/m^3). The highest fire station concentration observed was at Loganlea (0.4 µg/m^3), which is 350 times lower than the ES_{10} (140 µg/m^3).

Inside Station (Dormitory)
All stations are above the average background concentration (0.08 µg/m^3), but only Loganlea is above the average PAH concentration observed within the duty office was 0.3 µg/m^3. The highest fire station concentration was observed at Loganlea Fire station (0.4 µg/m^3), which is 350 times lower than the ES_{10} (140 µg/m^3).

Diesel Particulate Matter (DPM) specific monitoring
DPM measurements were performed outside stations, in engine bays, in duty offices and in dormitories over a standard 10 Hr day shift. Engine bay doors were generally closed, except for turn-out and return operations, and no mechanical ventilation was used during day. Cairns and Townsville had no or non-operational rear bay doors. Although there are no DPM Exposure Standards (ES) in Australia or internationally, the underground coal mine guideline limit of 0.1 mg/m^3 EC (using elemental carbon concentration as a surrogate) was adopted. A recent review [33] reported that US fire fighter DPM exposure is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

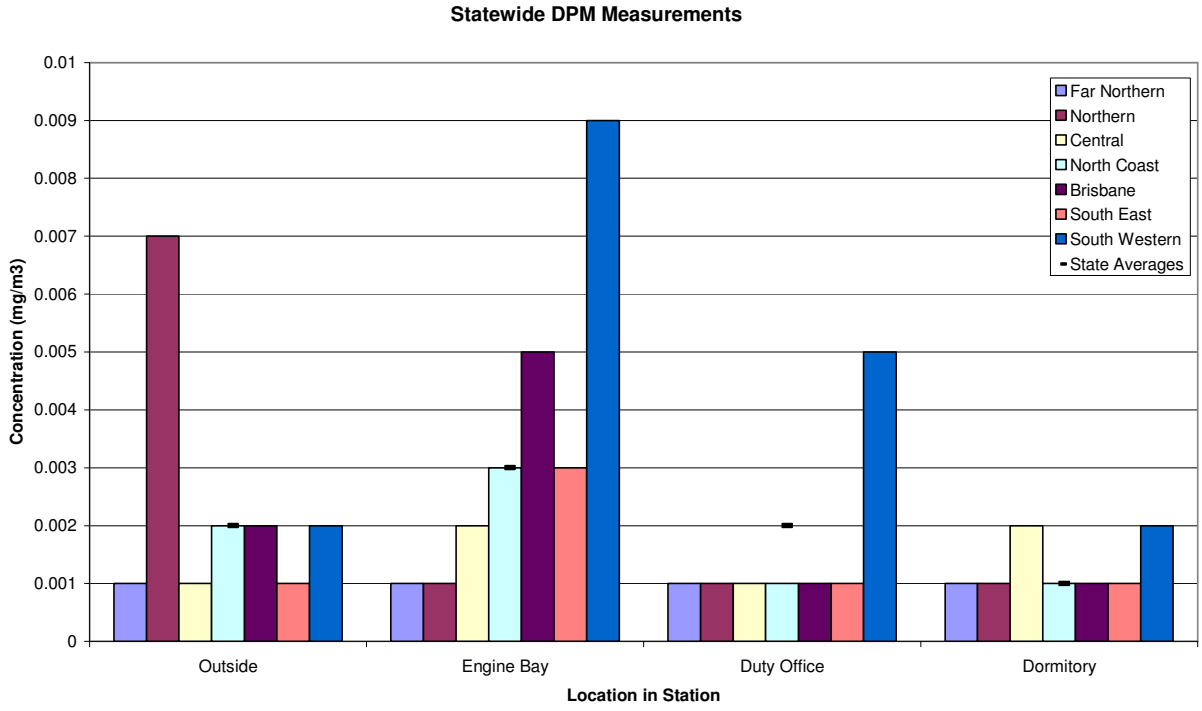


Figure 3.10
DPM concentrations within station areas for 10 day Hr shift.

Outside Station (Background)
All stations, except Townsville, are below the average DPM background concentration (0.002 mg/m^3 EC). The highest fire station concentration was observed at Townsville (0.007 mg/m^3 EC), which is 14 times lower than the DPM ES of 0.1 mg/m^3 EC.

Inside Station (Engine Bay)
All stations, except Townsville, are at or below the average background concentration(0.002 mg/m^3), but only Caboolture and Anzac Avenue, are above the average DPM concentration of 0.003 mg/m^3 EC observed within the engine bays. The highest fire station concentration was

observed at Anzac Avenue (0.009 mg/m^3 EC), which is more than 10 times lower than the DPM ES of 0.1 mg/m^3 EC. The average US fire fighter exposure to DPM is ≤50 mg/m^3 EC.

Inside Station (Duty Office)
All stations, except Anzac Avenue, are below the average background concentration (0.002 mg/m^3) and the average DPM concentration within the duty offices 0.002 mg/m^3 EC. The average DPM concentration observed within the duty office (0.002 mg/m^3 EC) and is similar to the average background concentration. The highest fire station concentration observed was Anzac Avenue (0.005 mg/m^3 EC), which 20 times lower than the DPM ES (0.1 mg/m^3 EC).

Inside Station (Dormitory)
All stations, were at or below the average background concentration (0.002 mg/m^3), but Rockhampton and Anzac Avenue are above the average DPM concentration within the dormitories 0.001 mg/m^3 EC. The highest fire station concentrations were observed at Rockhampton and Anzac Avenue (0.002 mg/m^3 EC), which are 50 times lower than the DPM ES (0.1 mg/m^3 EC).

Start if Shift, Turn-out and Return Trials
The start of shift, turn-out and return to station trials were designed to characterise emissions during specific activities. The engine bay doors were closed and no mechanical ventilation occurred during the start of shift check. DPM results for all station trials were based on the actual time of event (start of shift) or simulated times (turn-out simulation and return simulation). Typically, the start of shift checks were undertaken over 20 to 60 minutes. In the South West trial, a repeat measurement was undertaken and during the second trial, the appliance (Firepac mark III 3000) that was absent for the first trial was present. An almost 10 fold increase in DPM concentration was measured during the start of shift check, (Figure 3.11).

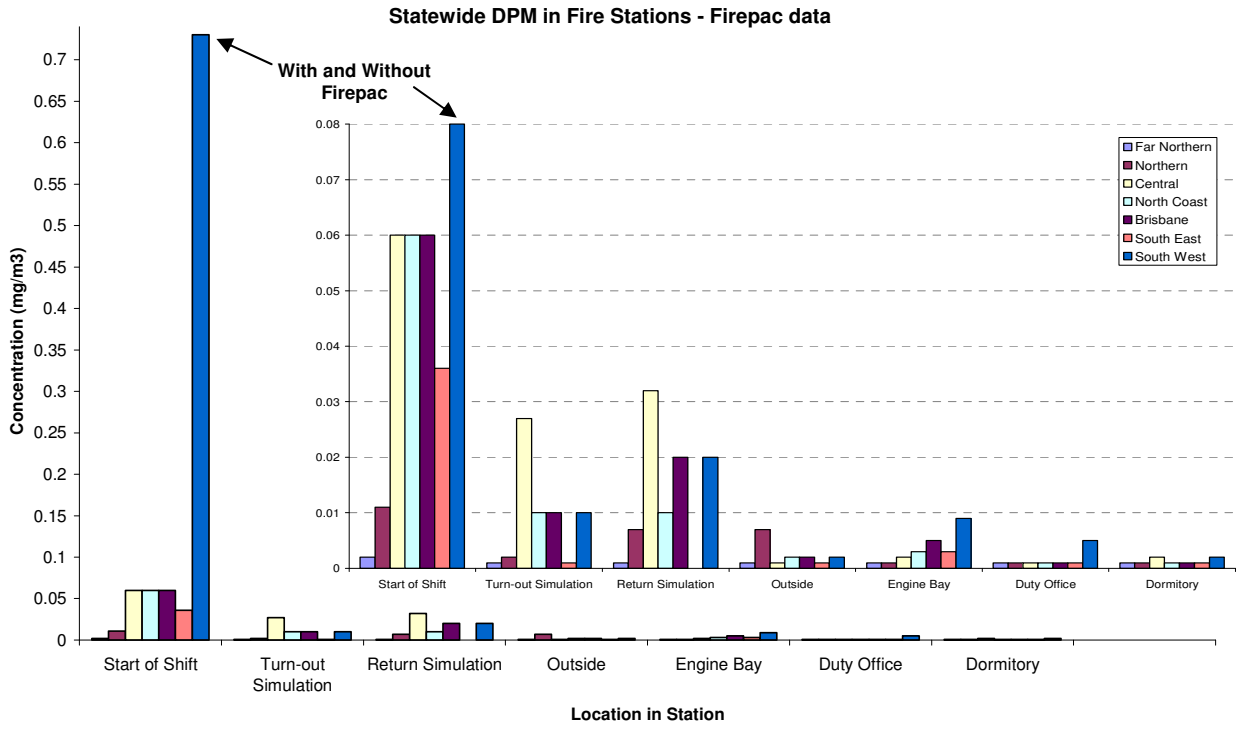


Figure 3.11

DPM results for all trial stations were based on 10 Hr shift (dorm, eng. Bay, duty office and outside) and actual or simulated times (start of shift, turn-out simulation and return simulation).

The inset graph shows that all measurement were below the DPM LOC (0.1 mg/m^3 EC) and the highest values were observed during the start of shift check. The average DPM concentration observed for the start of shift check without a Firepac 3000 Mk 3 appliance present was (0.044 mg/m^3 EC). The results demonstrate some variance between stations, and the variations are most likely explained by differences in appliances, station design and work practices.

The DPM concentration (0.73 mg/m^3 EC) observed during a start of shift trial with a Firepac 3000 Mk 3 appliance (at Anzac Avenue) was significantly above the established LOC. The origin of this result requires further investigation.

The average DPM concentration obtained for the turn-out simulation trials was 0.009 mg/m^3 EC and was higher than the background DPM concentration. The highest concentration obtained was at Rockhampton Fire station (0.027 mg/m^3 EC) and was more than 3 times lower than the DPM ES (0.1 mg/m^3 EC).

The average DPM concentration obtained for the return to station simulation trials was 0.013 mg/m^3 EC and was higher than the background DPM concentration. The highest fire station concentration obtained was at the Rockhampton (0.032 mg/m^3 EC), which was more than 3 times lower than the DPM ES (0.1 mg/m^3 EC).

Summary of All Fire Station Results

The seven stations used in the trials, Cairns, Townsville, Rockhampton, Maroochydore, Caboolture, Loganlea and Anzac Avenue (Toowoomba) showed that the ambient air quality in Fire stations across the state was typically at or below the outside ambient air, except for the short term activity start of shift when some engine bays showed elevated levels of the contaminates of concern. All result showed that at no time was the ambient within the stations above any 10 Hr corrected exposure standard.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The airborne concentration of sulphur dioxide was below the Limit of Detection (LOD) (< 0.5 ppm) for the all activities. Similarly, the airborne concentration of nitrogen dioxide was at or below the LOD (≤ 0.5 ppm) for the all activities, except the 33 minute start of shift checks at Loganlea Fire Station (0.75 ppm), which was *ca*. half of the 10 Hr time corrected workplace exposure standard (ES_{10}) of 2 ppm.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

An average carbon monoxide (CO) background concentration of 0.7 ppm (range: 0.1 to 1.3 ppm) was measured outside all fire stations, which is consistent with the 2007 Qld Ambient Air Quality Data[46] Brisbane CO average concentration of 1.1 ppm (range: 0.3 ppm to 3.9 ppm).

Generally, the highest concentrations of CO detected within the fire stations were in the engine bays and PPE lockers, which is consistent with station activities/design and where fire appliances/equipment are housed/used. A number of PPE lockers were open areas attached to the engine bays. The highest average CO concentration was measured during the 20 minute start of shift checks in the Rockhampton engine bay (2.7 ppm), which was *ca*. 4 times higher than the average outside concentration, but more than 7.5 times lower than the ES_{10} (21 ppm).

Generally, the average hydrogen sulfide (H_2S) concentrations obtained within the stations (0.1 ppm) was equal to the average outside concentration of H_2S (0.1 ppm - range: 0.01 to 0.4 ppm). The highest fire station area average was the Loganlea dormitory (0.3 ppm), which is

ca. 3 times higher than the average outside concentration, but *ca*. 23 times lower than the ES_{10} (7 ppm).

Atmospheric Contaminants – total volatile organic compounds
The total volatile organic compounds (tvoc) average background concentration obtained outside all fire stations was 0.5 ppm (range: <0.1 to 3.6 ppm). There is no established national exposure standard for tvocs, however the QFRS adopts a level of concern (LOC) of 0.5 ppm for application at emergency incidents. The highest outside average obtained was Anzac avenue (4.1 ppm), which is *ca*. 8 times higher than the QFRS LOC of 0.5 ppm.

Generally, the highest tvoc concentrations within the fire stations were in the PPE lockers, (average 0.6 ppm - range: from <0.1 to 0.6 ppm), which is similar to the CO results. This is consistent with station activities and design, where the PPE lockers were typically open areas attached to the engine bays. The highest fire station concentration was the Loganlea engine bay (0.2 ppm), which is *ca*. 3 times lower than the average background concentration, and *ca*. 2 times lower than QFRS LOC (0.5 ppm).

Atmospheric Contaminants –VOCs of Interest – hexane, benzene, toluene and xylene
The 2009 Qld Ambient Air Quality Data[46] for Brisbane shows an average hexane concentration of (1.1 ppb), benzene concentration(1.2 ppb), toluene concentration(1.3 ppb), and xylene concentration(25 ppb, based on 5 ppb of *p*-xylene which makes up 20% of total xylenes). The average background concentration obtained outside all fire stations for these vocs was; hexane 1.1 ppb (range: 1 to 1.7 ppb), benzene 1 ppb (range: 0.5 to 1 ppb); toluene 2.1 ppb (range: 1 to 3.7 ppb) and xylene 2.2 ppb (range: 2 to 3 ppb).

Generally, the levels of hexane and benzene were at or below the reporting limit (1 ppb) within the fire stations. However, higher concentrations of hexane were observed in the engine bay (3.2 ppb) and duty office (3.4 ppb) of Anzac Avenue, both of which are *ca*. 4000 times less than the ES_{10} (14000 ppb). Care should be taken with these higher results as they were obtained using passive diffusion badges. The major source of elevated benzene concentrations in the fire stations were in the engine bays. The highest measurement was in the Maroochydore engine bay (4.7 ppb), which is *ca*. 5 times higher than the average background benzene concentration, but *ca*. 140 times less than the ES_{10} (700 ppb). The Maroochydore concentration is similar to the ambient quality[33] in a Brisbane industrial suburb. Bitumen laying was occurring adjacent to Maroochydore station during the trial.

The average toluene background concentrations for all stations were generally at or below the reporting limit (1 ppb) of the analysis. Like the benzene result, the highest toluene concentrations were in the engine bays of the fire stations. The highest engine bay result was at Loganlea (17 ppb), which is more than 2050 times lower than the 10 Hr time corrected exposure standard (ES_{10}) of 35000 ppb, and significantly below the odour threshold (160 ppb). Anzac avenue had the highest readings in most areas of the station, which may have resulted from recent renovations (painting).

The average xylene background concentrations in all stations, except Maroochydore, Loganlea and Anzac Avenue, were at or below the reporting limit (2.2 ppb). In the same manner as benzene and toluene, the highest concentrations were observed in the engine bays. The highest fire station concentration obtained was Loganlea (13.5 ppb), which and *ca*. 2 times less than the corrected total xylene concentration(25 ppb) in ambient air, more than 4140 times lower than the ES_{10} (56000 ppb) and more than 1400 times less than the xylene odour threshold (20000 ppb).

These results show that no station area exceeded any occupational exposure limits for the vocs of interest.

Atmospheric Contaminants – Aldehydes

The average total aldehyde background concentration outside all fire stations was 35 ppb (range: 17 to 47 ppb). Generally, the highest aldehyde concentrations detected within the fire stations were in the dormitories and PPE lockers, which were both similar to the ambient outside concentrations. This would be expected due to outside air being drawn into the station areas through air conditioners, and little ventilation within the station areas *c.f* the engine bays. The highest fire station concentration was the Loganlea dormitory (54 ppb), which is *ca*. 1.5 times higher than the average outside concentration, but similar to the Loganlea outside average (44 ppb), and considerably less than the 10 Hr corrected exposure standards for any of the individual aldehydes such as formaldehyde and acrolein.

Atmospheric Contaminants – Particulate Matter

The average background concentrations of total Polyaromatic hydrocarbons (PAHs) and total diesel particulate matter (DPM) outside all fire stations was 0.14 µg/m^3 (range: 0.05 to 0.23 µg/m^3) and 0.002 mg/m^3 EC (range: <0.001 to 0.007 mg/m^3 EC), respectively. Generally, the highest concentrations of both PAHs and DPM within the fire stations were in the engine bay, which is expected due to the appliance engines being diesel based. The highest fire station PAH concentration was the Loganlea engine bay (1.4 µg/m^3), which is 10 times higher than the average outside concentration, and 100 times lower than the 10 Hr corrected exposure standard ES_{10} (140 µg/m^3). The highest fire station DPM concentration was the Anzac Avenue engine bay (0.009 mg/m^3 EC), which is *ca*. 10 times lower than the ES_{DPM} of 0.1 mg/m^3 EC.

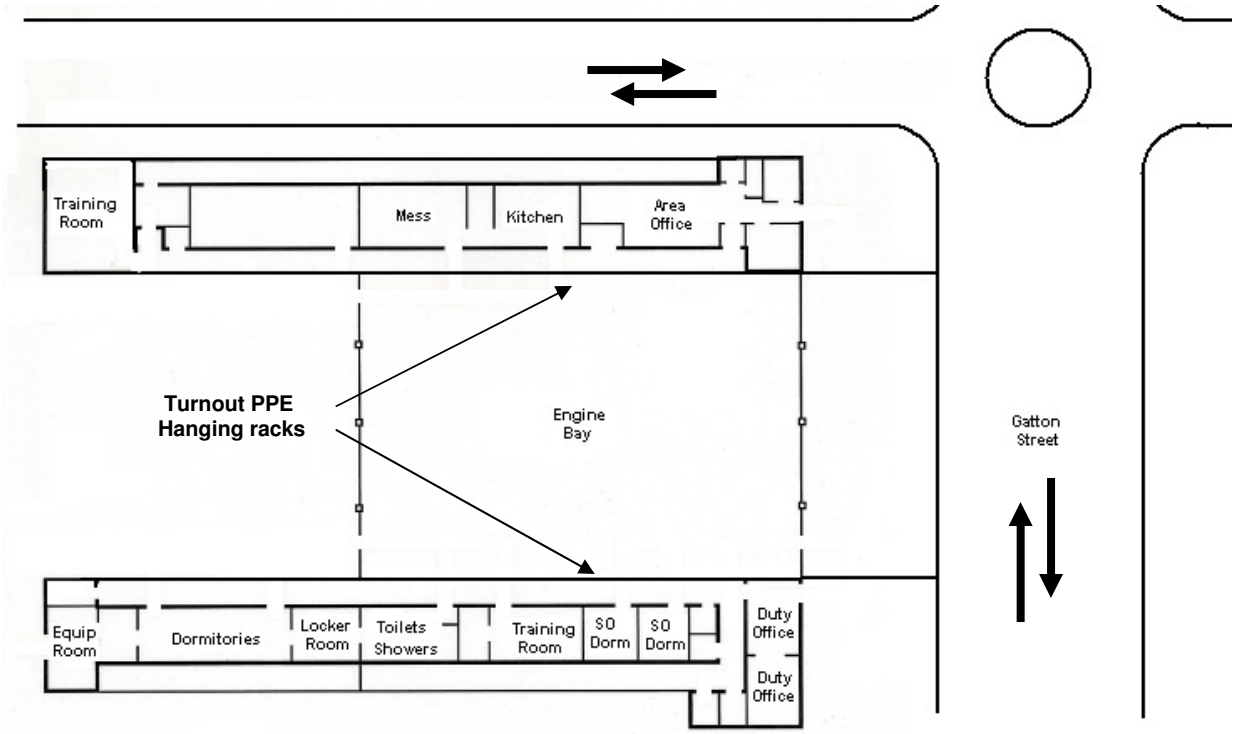
Of the three specific activities of interest, start of shift checks, turn-out and return simulations, the start of shift checks typically produced the highest concentrations of PAH and DPM. The average DPM concentration obtained for the start of shift check without a Firepac 3000 Mk 3 appliance present was 0.044 mg/m^3 EC, and with a Firepac 3000 Mk 3 appliance present was 0.14 mg/m^3 EC. The highest fire station concentrations were in Anzac Avenue engine bay (0.08 mg/m^3 EC without Firepac 3000 Mk 3 and 0.73 mg/m^3 EC with a Firepac mark III 3000). However, the concentration with the Firepac 3000 Mk 3 did not exceed the ES_{DPM} of 0.1 mg/m^3 EC.

Review of QFRS Fire Station Data

Far Northern Region

Cairns Fire Station

The Cairns fire station is an older style station built prior to 1970. It is the major station in Cairns area and is located on a significant suburban road within a residential area. The Cairns station has five fire fighting, hazmat and technical rescue appliances and support vehicles located at the station. The station is crewed by six fire fighters, a senior officer and one administration officer. The regional maintenance workshops are also located on the station grounds. In 2007 there were 2124 reported responses. It is located on a significant suburban road within a residential area.



Fire fighter exposures in the Cairns Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide and nitrogen dioxide concentrations were measured during the station activities: start of shift checks; turn out; and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results for all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Cairns – NO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Cairns – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.2 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.5

Instantaneous concentrations of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) air-borne contaminants in Cairns Fire Station.

The airborne concentration of nitrogen dioxide and sulfur dioxide were at or below the limit of detection (0.5 ppm) for all activities, and the average concentration obtained for all fire stations across the state. The time corrected exposure standards ES_{10} for NO_2 and SO_2 are 2 ppm and 1.4 ppm respectively. The average NO_2 and SO_2 airborne concentrations in South East Qld[46] are 6 ppb and 1 ppb respectively.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift. The volatile organic compound (voc) concentrations are reported as peak concentrations over 1 minute averaging periods. The airborne concentration of total volatile organic compounds (tvoc's) was measured continuously during the normal station activities for as close as practicable to the standard 10 hr shift. The measurements reported were peak concentrations over 1 minute averaging periods and are reported as isobutylene units.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**		**Multi Rae four gas detector**			
	Total VOC (ppm)		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing			
			Hydrogen sulphide (ppm)		Carbon monoxide (ppm)	
	Cairns Station	State Average	Cairns Station	State Average	Cairns Station	State Average
Outside	0.0	0.5	0.0	0.1	0.6	0.7
Engine Bay	0.02	0.1	0.0	0.1	0.1	1.3
Duty Office	0.0	0.1	0.1	0.2	2.1	1
Dormitory	0.0	0.1	0.0	0.1	0.6	0.6
Mess / Lounge	n/a	n/a	0.1	-	0.4	-
L2 PPE Locker	0.02*	0.2	0.0*	0.1	n/a	1.4

* note: The Cairns has no PPE locker, but storage shelves along the sides of the engine bay

Table 3.6

Average concentrations air-borne contaminants, total volatile organic compounds (tvoc as isobutylene units), hydrogen sulphide (H_2S) and carbon monoxide (CO).

Carbon Monoxide - total average concentrations

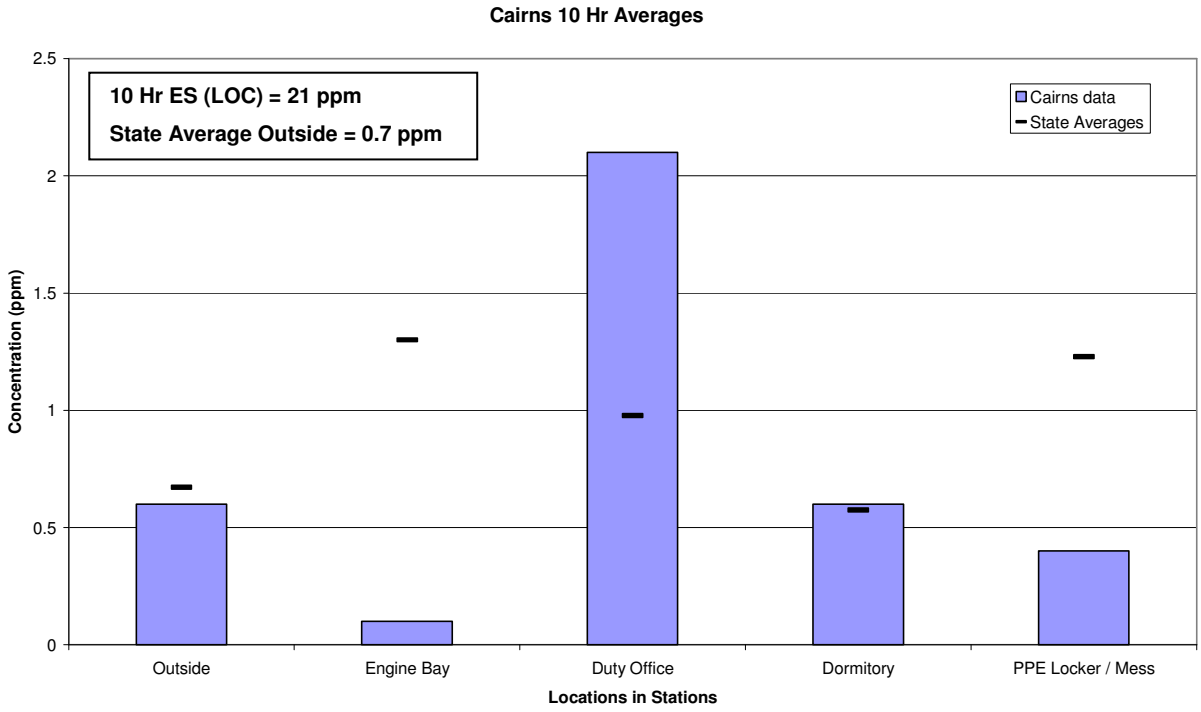


Figure 3.12
Average concentrations of carbon monoxide at Cairns fire station over a 10 Hr day shift. The state averages (black bars in graph) are the mean concentrations of all station concentrations.

Outside Station (Background)
The background carbon monoxide concentration (0.6 ppm) was slightly less than the average outside concentration (0.7 ppm) obtained across the state, and the average Brisbane[47] (1.1 ppm) and South East Qld[46] carbon monoxide (1 ppb) airborne concentrations.

Inside Station (10 Hr monitoring)
All average measurements within the station, except the duty office, were equal to or less than the average background concentration. The duty office (2.1 ppm) concentration exceeded the average concentrations (1 ppm) for the fire stations and Qld ambient air quality. However, the duty office concentration was 10 times less than the (ES_{10} – 21 ppm) and 4 times less than the NEPM ambient air quality standard (9 ppm). There are several reasonable explanations that may account for the discrepancy including location and office design, ventilation arrangements, and the presence of communications/computing equipment.

Carbon Monoxide - 10 Hr continuous monitoring
Figure 3.13 below illustrates there were six activities where carbon monoxide excursions were observed. These excursions corresponded to activities such as start of shift checks and appliances leaving and returning to station. In general, carbon monoxide excursions occurring during emergency response were measured only in the engine bay. The only non-engine bay excursion occurred in the officer's dormitory during the start of shift checks.

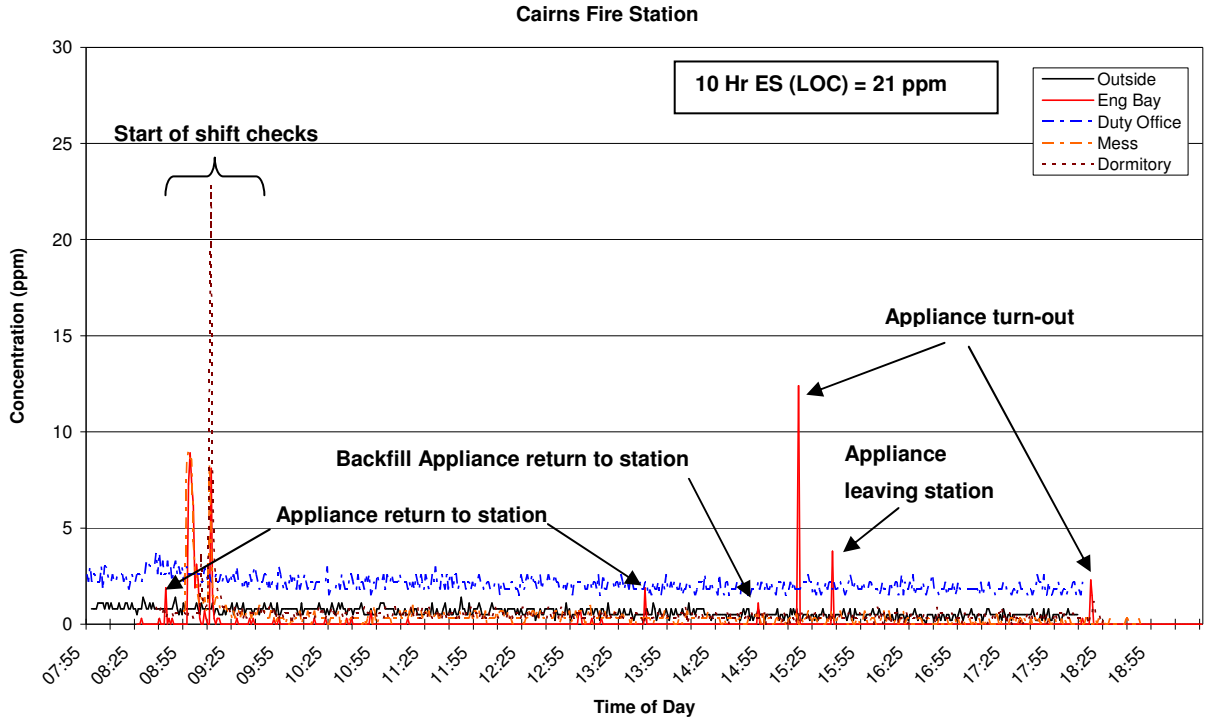


Figure 3.13
Carbon monoxide readings for a 10 Hr day shift at Cairns fire station.

The highest carbon monoxide (CO) concentrations were obtained during the 60 minute start of shift checks, *i.e.* officer's dormitory (23 ppm), engine bay (9 ppm), mess (9 ppm) and duty office (4 ppm). These results are consistent with the position of the appliances and the dormitory (door open) entry being immediately adjacent to the nearest appliance exhaust. The concentration within the dormitory exceeded the 10 Hr ES_{10} (21 ppm), however, it did not exceed the *NOHSC: Guidelines for the control of short-term excursions for Carbon Monoxide* 60 minute limit of 60 ppm.

The mess room carbon monoxide concentrations correspond closely to the engine bay concentrations because the prevailing breeze running across the engine bay towards the mess room and the mess bay windows facing the engine bay were open.

Hydrogen Sulfide - total average concentrations

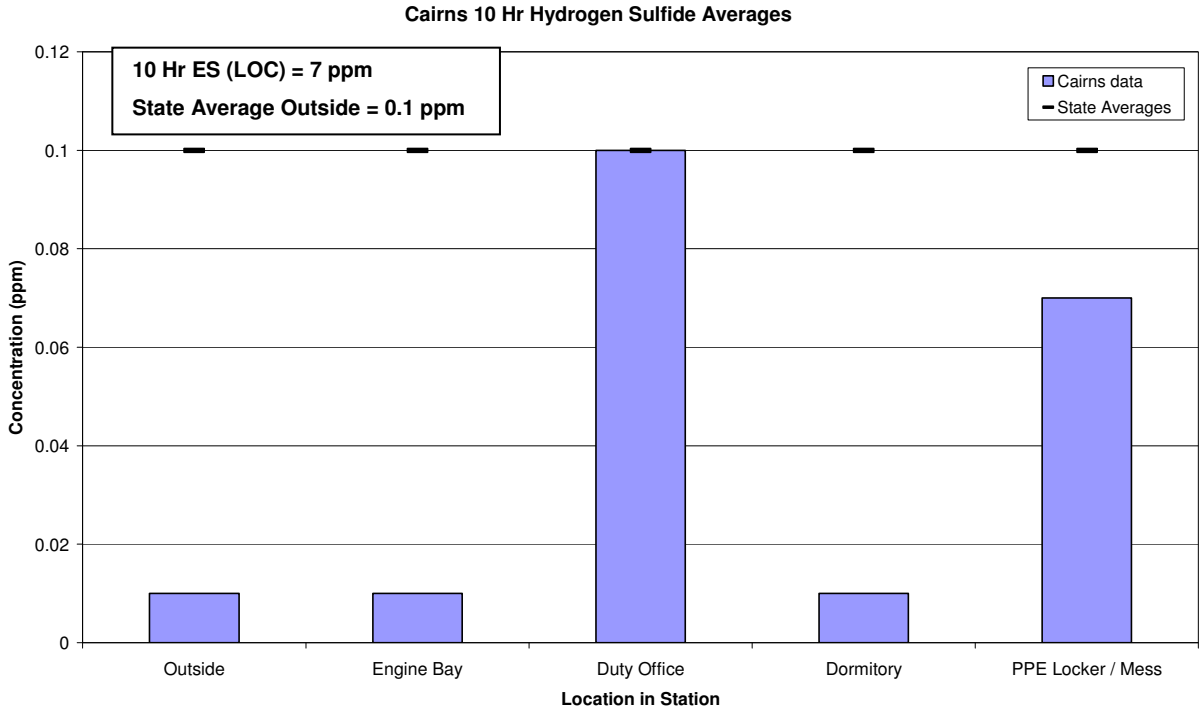


Figure 3.14
Average concentrations of hydrogen sulfide at Cairns fire station over a 10 Hr day shift. The state averages (black bars in graph) are the mean concentrations of all station concentrations.

Outside Station (Background)
The average background hydrogen sulfide (H_2S) concentration (0.01 ppm) is significantly less than the LOD for the MultiRae detector. An average H_2S concentration of 0.1 ppm was outside observed across the state.

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station were at or below LOD for the MultiRae detector. The highest concentration was observed within the duty office (0.1 ppm), which was at the MultiRae LOD, the average duty office concentration (0.1 ppm) for all fire stations, and 70 times below the ES_{10} (7 ppm) concentration.

Hydrogen Sulfide - 10 Hr continuous monitoring
Figure 3.15 (below) shows that all hydrogen sulfide (H_2S) concentrations were below the H_2S sensor LOD of 1 ppm, which is consistent with no 10 Hr averages exceeding the ES_{10} (7 ppm).

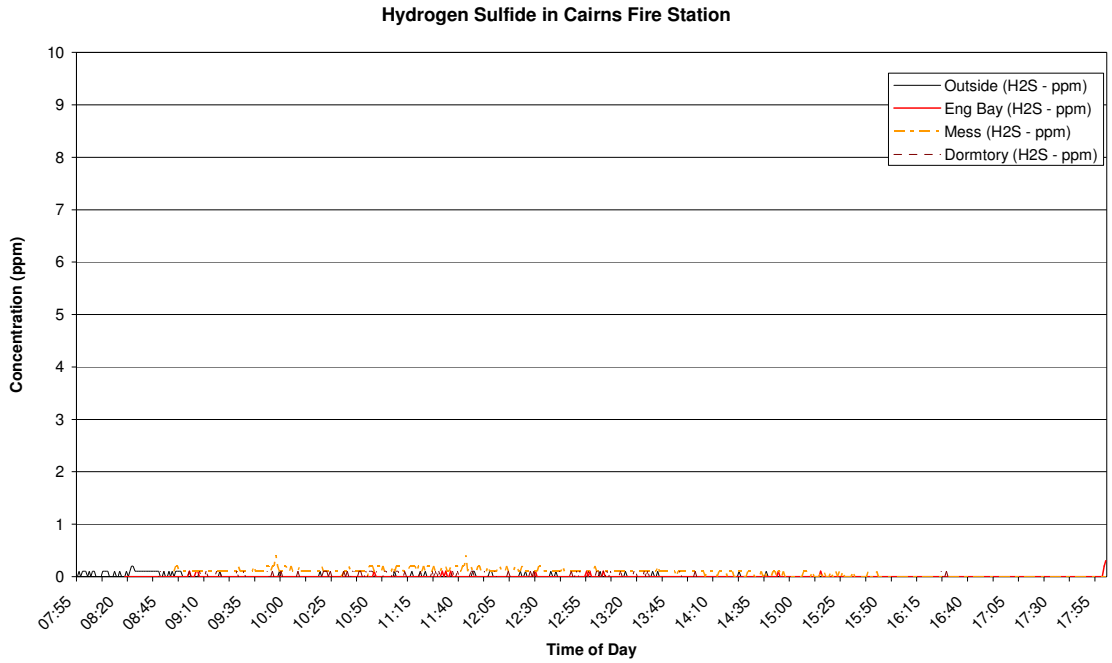


Figure 3.15
Hydrogen Sulfide concentrations for a 10 Hr day shift at Cairns fire station.

Atmospheric Contaminants – total volatile organic compounds of concern

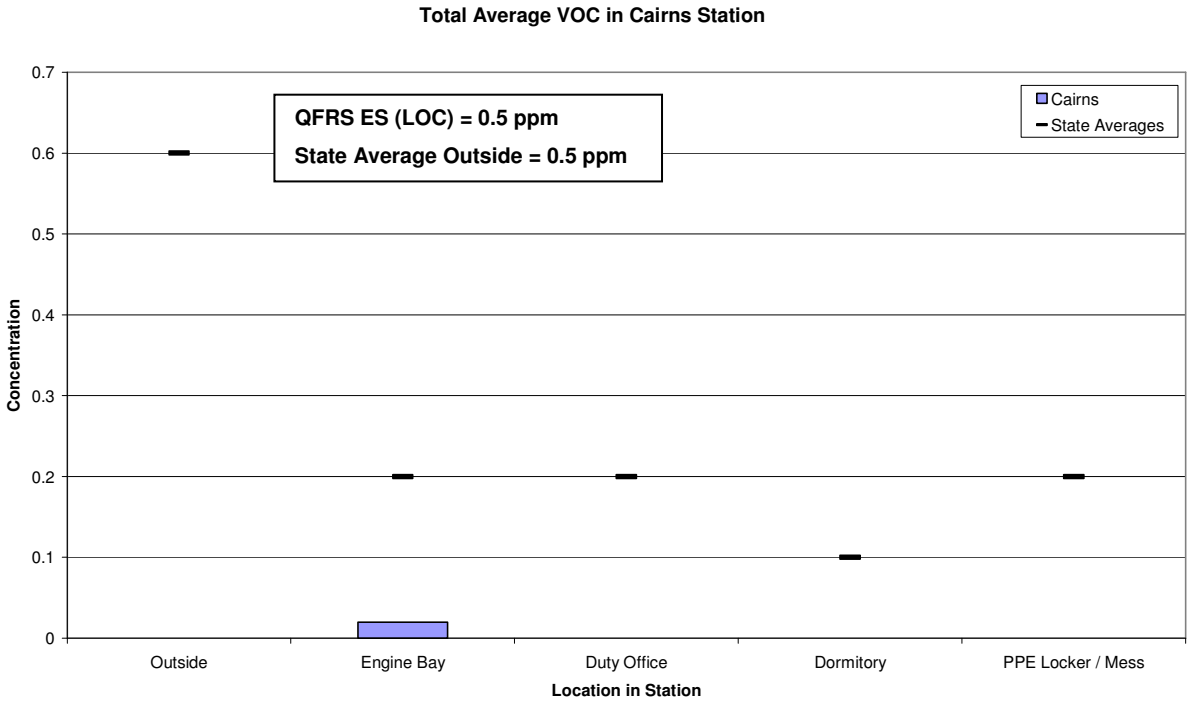


Figure 3.16
Average concentrations of total volatile organic compounds at Cairns fire station over a 10 Hr day shift. The state averages (black bars in graph) are the mean concentrations of all station concentrations.

Outside Station (Background)
The Cairns average background tvoc concentration (< 0.1 ppm) was significantly less than the average outside concentration (0.5 ppm) obtained across the state and the QFRS established level of concern (0.5 ppm).

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station were similar to the background concentration except in the case of the engine bay (0.02 ppm-isobutylene units), which is significantly less than the average state concentration (0.1ppm-isobutylene units) and the QFRS established level of concern (0.5 ppm).

Volatile organic compounds - 10 Hr continuous monitoring
The airborne concentration of total volatile organic compounds (tvoc's) was measured continuously during the normal station activities for as close as practicable to the standard 10 hr shift. The measurements reported were peak concentrations over 1 minute averaging periods and are reported as isobutylene units.

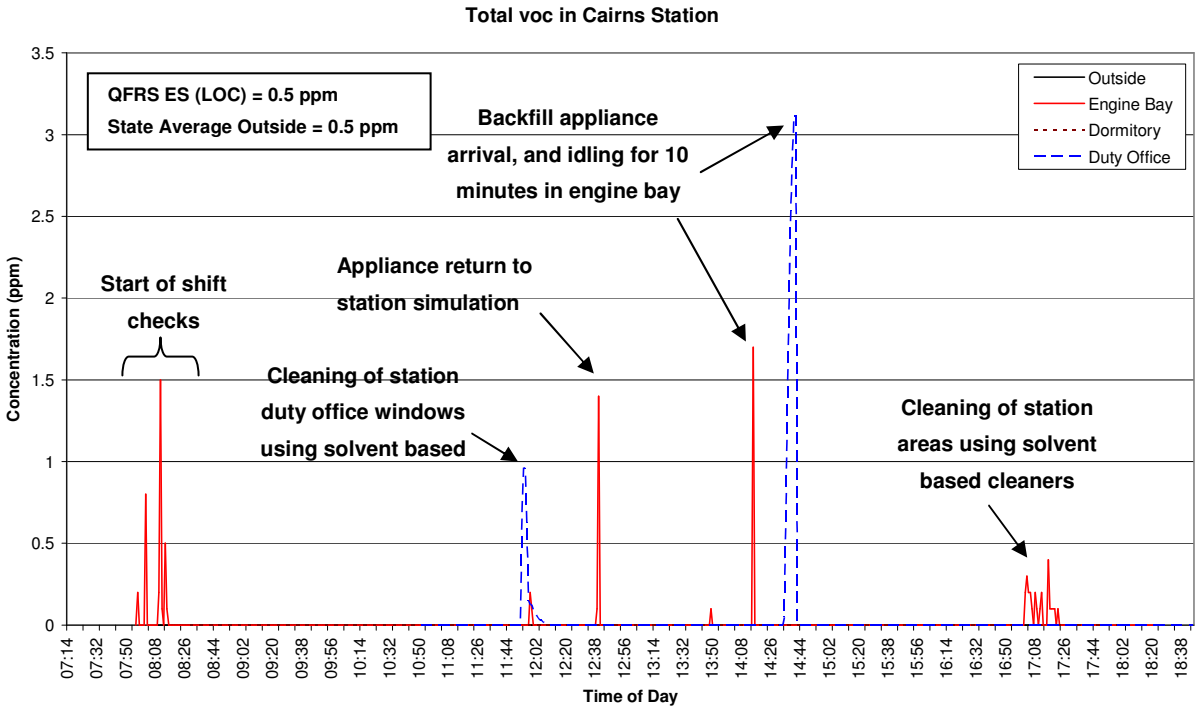


Figure 3.17
Volatile organic compounds concentrations for a 10 Hr day shift at Cairns fire station.

Figure 3.17, illustrates there were six occasions where excursions were observed. These excursions corresponded to activities such as start of shift checks, appliance turn-out and return to station. In general, tvoc excursions occurring during emergency response were measured only in the engine bay.

The highest total volatile organic compound (tvoc) concentrations were obtained during the start of shift checks (60 minutes) in the engine bay (1.5 ppm); cleaning of duty office windows (0.9 ppm); turn-out simulation in the engine bay (1.4 ppm); a backfilling appliance idling for 10 minutes within the engine bay (1.7 ppm) and duty office (3.1 ppm), and finally in the engine bay (0.4 ppm) during end if day station cleaning duties. This is consistent with the position of

the appliances and the duty office entry door (often opened) being immediately in front of the nearest appliance exhaust. No concentration exceeds the QFRS established level of concern (0.5 ppm).

Atmospheric Contaminants – hexane, benzene, toluene and xylene

The voc results for Cairns station used reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. Together with the above measurements of total volatile organic compounds, samples were collected using of evacuated gas canisters, absorbent tubes, and Dräger stain tubes to measure for the specific voc's of interest; aldehydes, hexane, benzene, toluene and xylene.

Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A mixture of evacuated canisters, active and passive sorbent techniques was used. Instantaneous measurements of benzene generated during the station activities were also obtained. If the result obtained was less than the reporting limit (<R.L) the R.L was used to illustrate the worst case concentration for a specific location.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<2.8*	1	<1.7*	<2.3*	1	<1.6*	<2.0*	<2*	<4.5*	<2.6*	1	<1.7*	<47.3*	<29.2*
Engine Bay			1	<1.7*		1	<1.6*		<2*	<3.3*		1	<1.7*		<29.2*
Start of Shift	<0.5	2.8			8			6.9			<2.4*			<156*	
Turnout	<0.5	<91*			<77*			<67*			<85*			<140*	
Return	<0.5	<113*			<96*			<83*			<105*			<133*	
Duty Office	<0.5		1	<1.7*		1	3.7		<2.4*	<3.2*		1	<1.7*		<29.9*
Dormitory	<0.5	3.4	1	<1.7*	<2.9*	1	7.2	<2.5*	<2*	5.6	<3.2*	1	<1.7*	<43.4*	<30.5*
Mess area	<0.5		1	<1.7*		1	2.9		<2*	<3.9*		1	<1.7*		<29.5*
PPE Locker	<0.5	2.7			<2.3*			<2.0*			<2.5*			<41.1	

Table 3.7

Concentrations of the voc's of interest, hexane, benzene, toluene, xylene and aldehydes measured at the Cairns fire station over a day shift.

Atmospheric Contaminants – hexane

Figure 3.18 (below) shows the hexane background concentration outside Cairns fire station was at or below the R.L (1.0 ppb) and was less than the average background concentration (1.1 ppb) across the state. The average concentrations in all areas within the station were at or below the R.L. These concentrations show the hexane concentration is more than 14000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 14 000 ppb (14 ppm) and more than 65000 times below the odour threshold (65 ppm, 65 000 ppb). These background results are significantly less than the Brisbane (Eagle Farm)[48] ambient airborne concentration range of 0.4 to 95 ppb and average concentration of 19 ppb.

The hexane concentration obtained after the start of shift check, turnout simulation, and return simulation were 2.5 ppb, 2.8 ppb and 2.8 ppb respectively. These concentrations are higher than the hexane background concentration and significantly less than the average state hexane concentrations obtained for these activities (92 ppb, 4.9 ppb, and 14.5 ppb respectively). The concentrations are approximately 5000 times less than the NES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions and these explanations readily account for the observations.

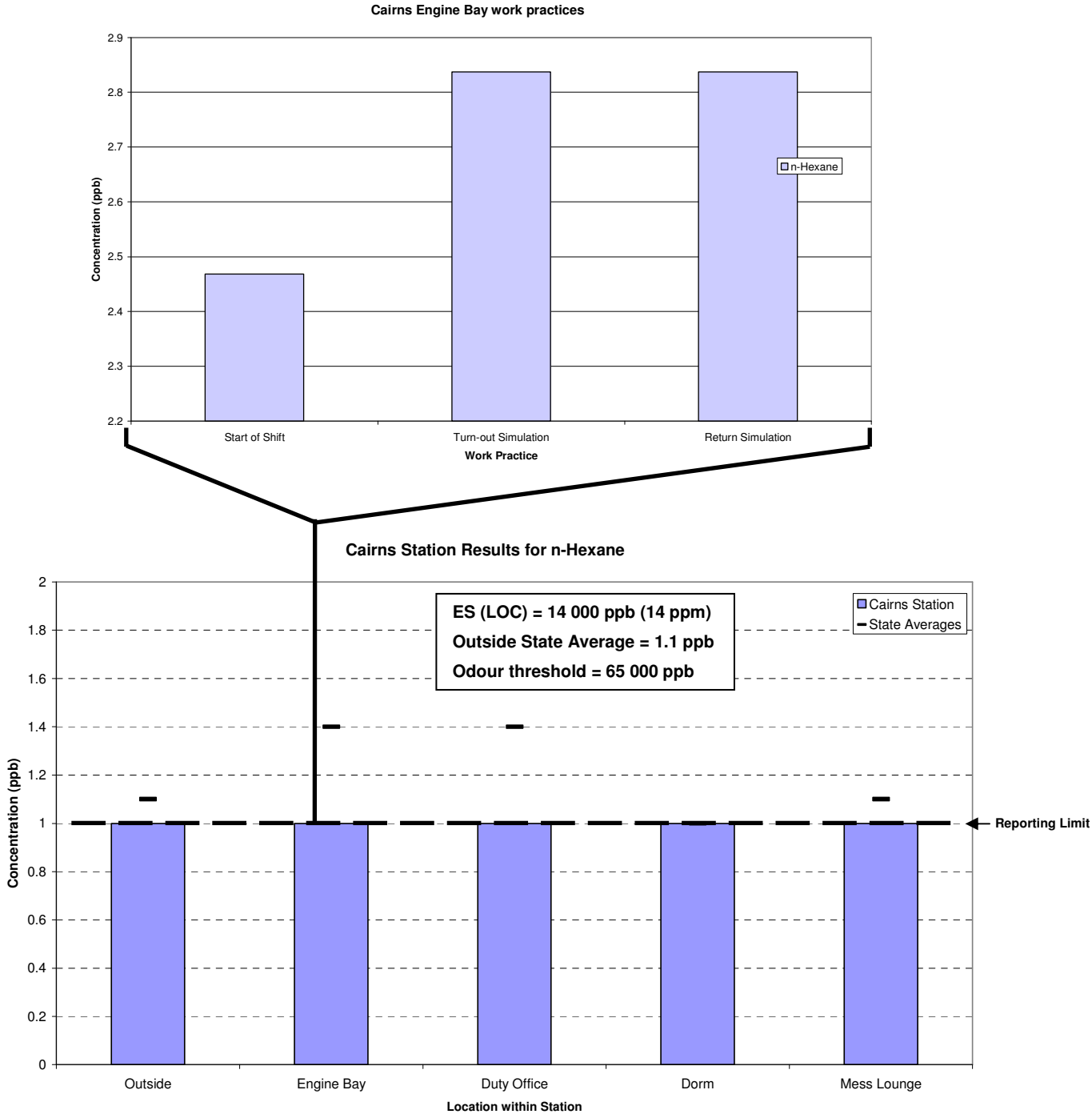


Figure 3.18
Hexane concentrations from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

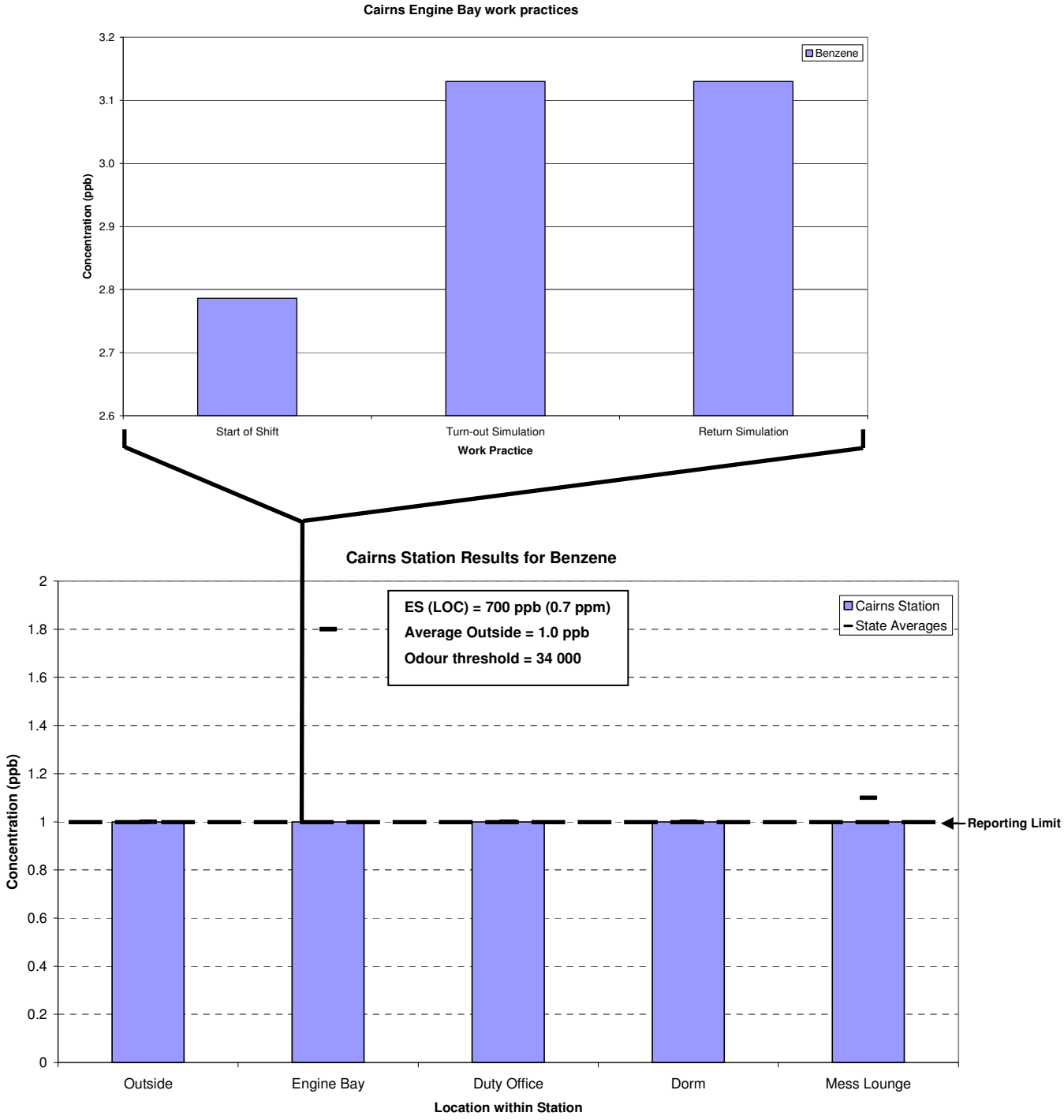


Figure 3.19

Benzene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

The background benzene concentration outside cairns fire station was at or below the R.L (1.0 ppb) and was similar to the average background concentration across the state (1.0 ppb). The average concentrations in all areas within the station were at or below the R.L, which indicates that the benzene concentration is at least 700 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb and more than 34000 times below the odour threshold

(34 000 ppb). These background results are also less than the benzene airborne concentrations in South East Qld[46] (range: 0.4 to 1.5 ppb with an average of 0.8 ppb) and Brisbane[47,48] (range: 0.4 to 10 ppb with an average of 3.3 ppb).

The benzene concentration obtained after the start of shift check (55 minutes), turnout simulation, and return simulation were 2.8 ppb, 3.1 ppb and 3.1 ppb respectively. These concentrations are higher than the Cairns background concentration, but the lowest obtained in the trials for these activities and significantly less than the average state concentrations obtained (28 ppb, 5.3 ppb, and 16.5 ppb respectively). The concentrations are approximately 230 times less than the ES_{10} of 700 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions and these may account for the observations.

Atmospheric Contaminants – toluene

The toluene background concentration outside Cairns fire station was at or below the R.L (1.0 ppb) and was similar to the average background (2.1 ppb) concentration across the state. The average concentrations in all areas within the station were at or below the R.L, which is 35000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb and more than 160 times below the odour threshold (160 ppb). The average airborne toluene concentration in Eagle Farm (Brisbane)[48] was 10.6 ppb.

The toluene concentration obtained after the start of shift check (55 minutes), turnout simulation, and return simulation were 8 ppb, 2.7 ppb and 2.7 ppb respectively. These concentrations are higher than the background concentration of toluene, but almost consistently the lowest obtained for these activities and significantly less than the average state toluene concentrations obtained (83.6 ppb, 6.0 ppb, and 14.5 ppb respectively). The concentrations are approximately 4300 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions and these explanations readily account for the observations.

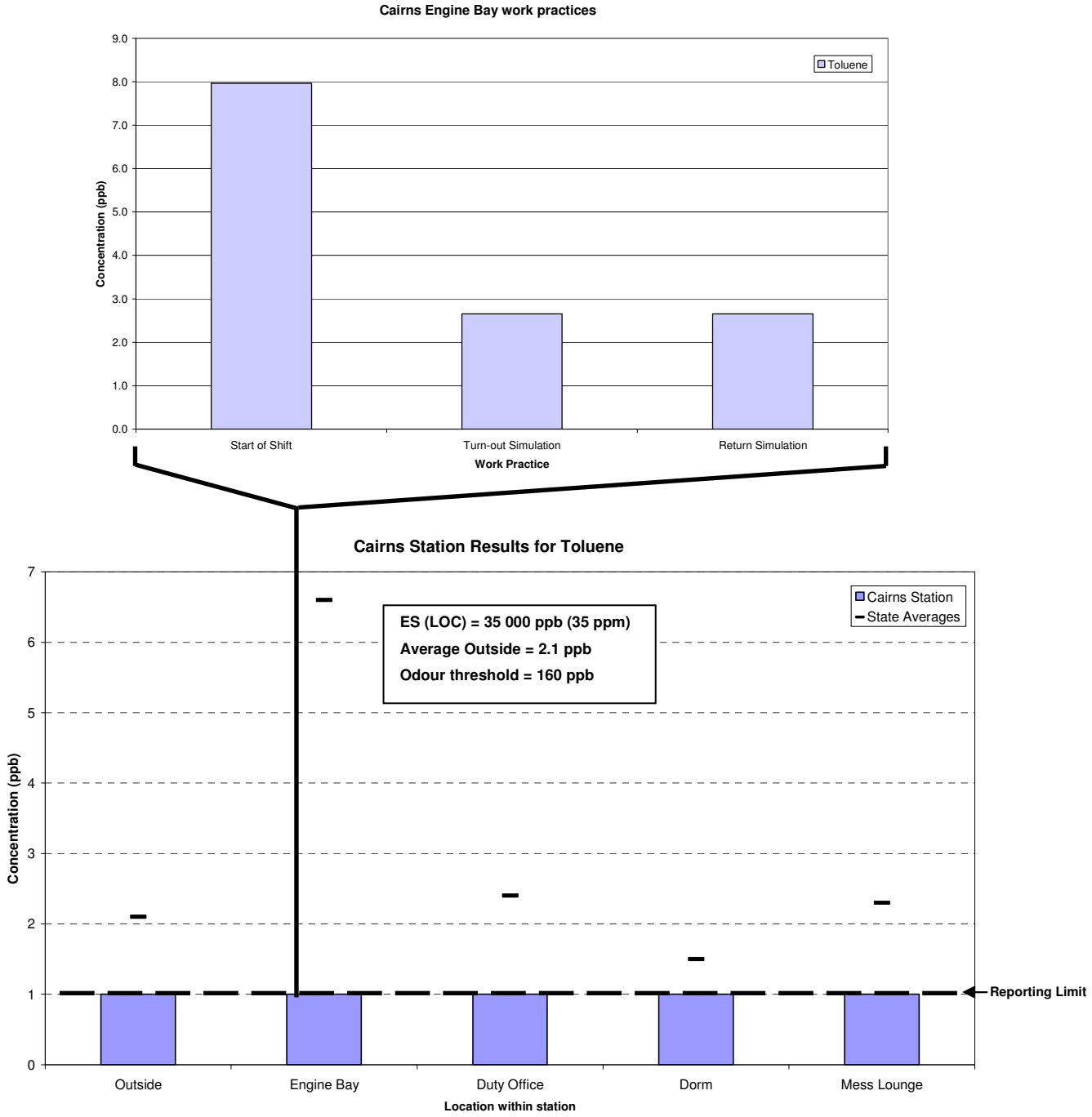


Figure 3.20
Toluene concentrations for a 10 Hr day shift at Cairns fire station areas. All other results are based on evacuated canister controlled by a 10 Hr flow concentration.

Atmospheric Contaminants – xylene

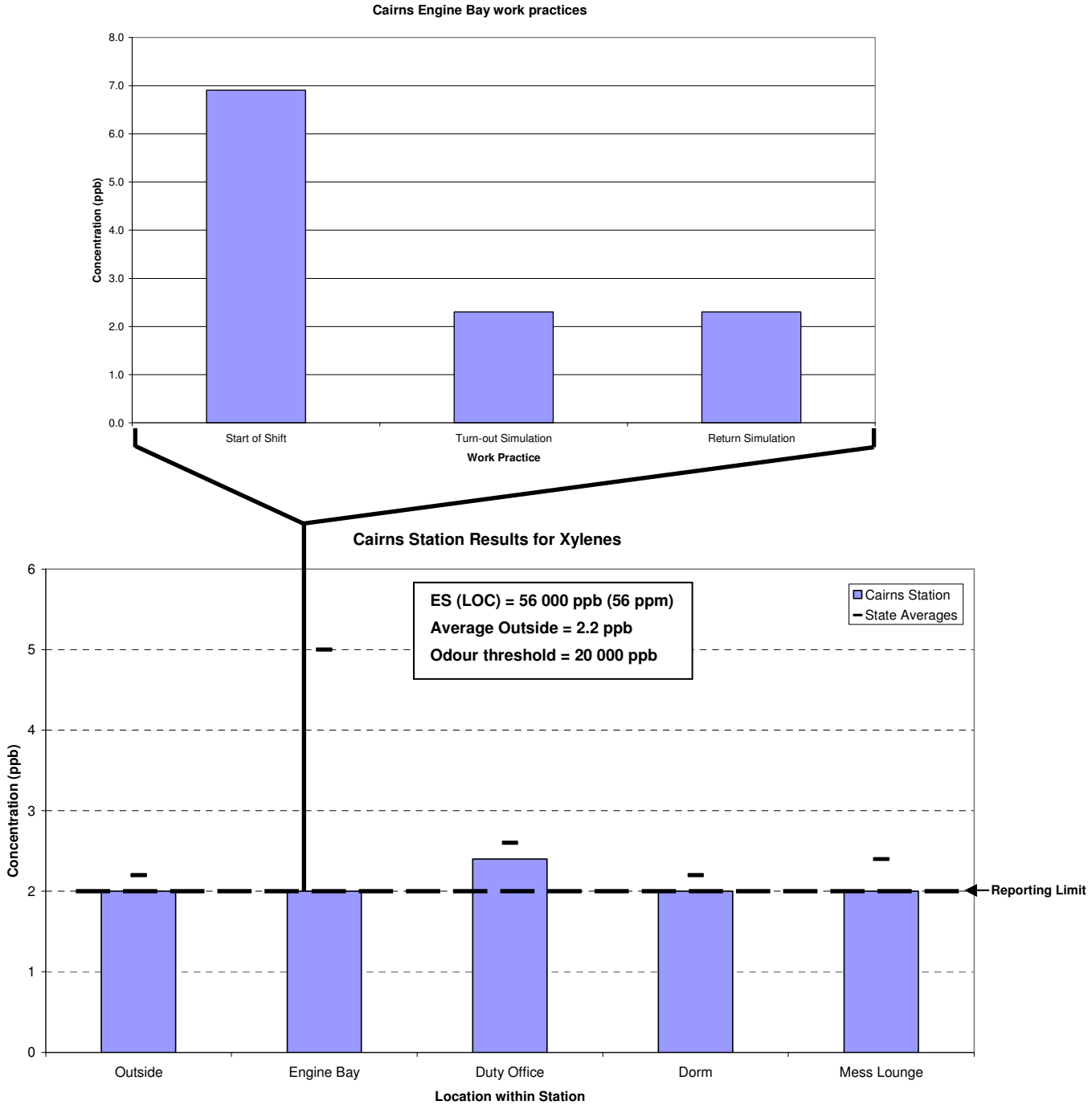


Figure 3.21
Xylene concentrations using evacuated canister controlled by a flow valve for a 10 Hr day shift.

The xylene background concentration outside Cairns fire station was at or below the R.L (2.0 ppb) and was similar to the average background (2.2 ppb) concentration across the state. The average concentrations in all areas within the station were at or below the R.L except the duty office, which was the same as the outside state average, less than the duty office state average (2.6 ppb) concentration. The duty office concentration is 20000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 56 000 ppb and more than 9000 times below

the odour threshold (20 000 ppb). These background results are similar to the average xylene airborne concentrations in South East Qld[46] 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] 3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as p-xylene data, but calculated as total xylene based on p-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the m-&p-xylene with the o-xylene.

The xylene concentration obtained after the start of shift check (55 minutes), turnout simulation, and return simulation were 6.9 ppb, 2.3 ppb and 2.3 ppb respectively. These concentrations are higher than the background concentration of xylene, but the lowest obtained for these activities and significantly less than the average xylene concentrations obtained (105 ppb, 5.3 ppb, and 12.5 ppb respectively). The concentrations are approximately 8000 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions.

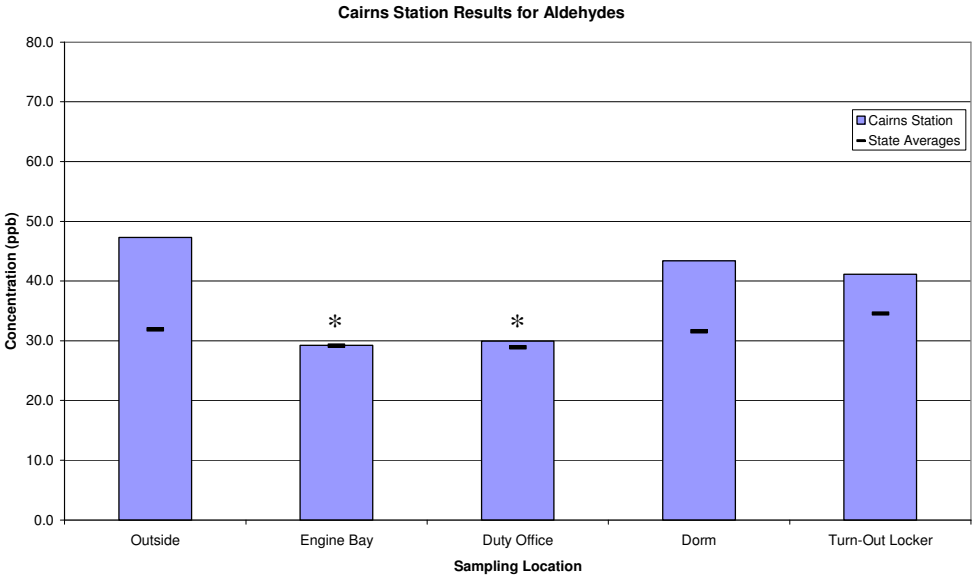
Atmospheric Contaminants – aldehydes

Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes. These voc's are important due to their presence in diesel exhaust and their potential as respiratory and eye irritants. Aldehydes are typically formed in combustion processes and so may form from diesel exhaust, fires where PPE is worn and potentially transported back to station and numerous industrial processes in nearby premises to stations.

The aldehyde concentrations included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario.

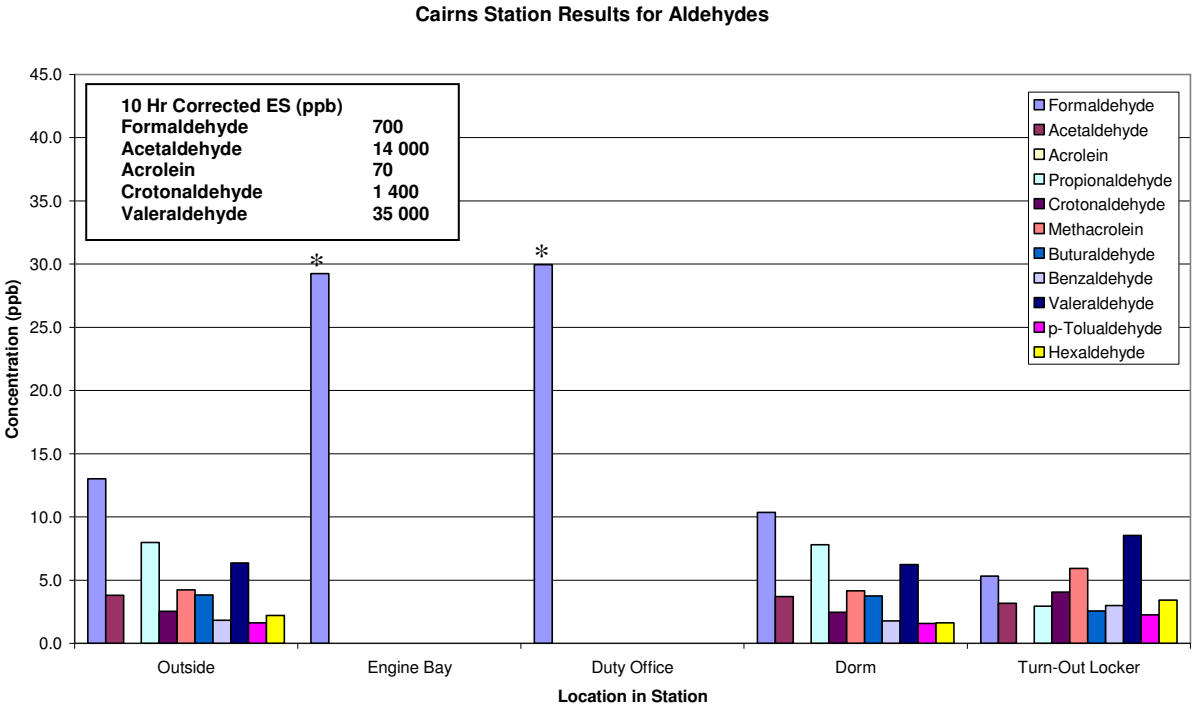
Figure 3.22 shows the total aldehyde concentration obtained from the summation of the concentrations of the following aldehydes: valeraldehyde; benzaldehyde; acrolein; formaldehyde. The total aldehyde background concentration outside Cairns fire station was 47 ppb, which was the highest of all concentrations measured. The total aldehyde concentration in the dormitory and turnout locker area was 43 ppb and 41 ppb respectively. These concentrations are greater than the total aldehyde state average concentrations (26.5 ppb and 35.9 ppb) for these areas.

The total aldehyde concentration within the engine bay, and duty office were 30 ppb and 29 ppb respectively, which are similar to the state average concentrations (28.5 ppb and 29.2 ppb). However, these latter results were obtained on passive diffusion badges and only formaldehyde was reported. The highest concentration is more than 23 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. All acrolein concentrations were at or below the R.L, which is more than 70 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}) of 70 ppb.



* Results from passive badges

Figure 3.22
Total aldehydes in areas of interest for a 10 Hr day shift at Cairns fire station.



* Results from passive badges

Figure 3.23
Aldehydes measured for a 10 Hr day shift at Cairns fire station.

Of the aldehydes detected in Cairns fire station, only formaldehyde (700 ppb), acetaldehyde (14 000 ppb), acrolein (70 ppb), crotonaldehyde (1 400 ppb) and valeraldehyde (35 000 ppb) have Australian exposure standards. Formaldehyde generally showed the highest concentrations, but one of the lowest exposure standards. The highest formaldehyde

measurement (passive badge 30 ppb), is more than 20 times lower than the formaldehyde ES_{10}. Acrolein was not detected.

Atmospheric Contaminants – Particulate Matter
Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

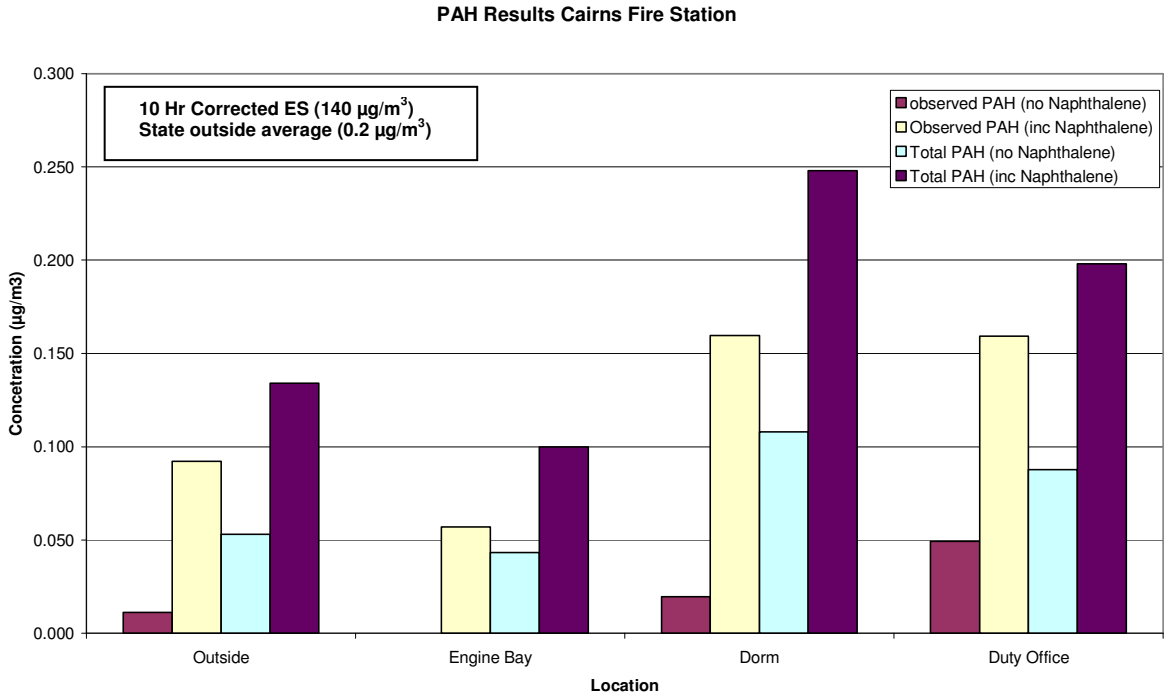
Polyaromatic Hydrocarbons
The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3), adjusted to a 10 hr exposure of 140 µg/m^3, was applied since no equivalent Australian Exposure standard existed. Some individual PAHs have established ES such as naphthalene - ES (52 mg/m³ or 52 000 µg/m^3) and a 10 Hr time corrected ES_{10} (36.4 mg/m³ or 36 400 µg/m^3). If the result obtained was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case concentration.

Outside Station (Background)
The Cairns PAH background concentration (0.13 µg/m^3) was greater than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs, Phenanthrene, fluorene and naphthalene were detected outside Cairns fire station.

Inside Station (10 Hr monitoring)
The PAH concentration within the engine bay was less than the PAH background concentration whilst the concentrations in all other areas were greater then the PAH background concentration. The concentrations were less than their respective average concentrations across the state. The highest PAH concentration observed is 500 times less than ES_{10} of 140 µg/m^3. The non-carcinogenic PAHs: phenanthrene, fluorene, acenaphthene and naphthalene were detected within the various Cairns station areas.

	Cairns Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	<RL	<RL	<RL
Fluoranthene	<RL	<RL	<RL	<RL
Anthracene	<RL	<RL	<RL	<RL
Phenanthrene	3600	<RL	23900	<RL
Fluorene	7570	<RL	25400	9230
Acenaphthene	<RL	<RL	<RL	10400
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	81000	57000	110000	140000
Reporting Limit	3500	3100	3200	7400
Observed PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.01	0.0	0.05	0.02
Total with Naphthalene (µg/m^3)	0.09	0.06	0.16	0.16
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from (pg/m^3) to (µg/m^3)				
Total without Naphthalene (µg/m^3)	**0.05**	**0.04**	**0.09**	**0.11**
Total with Naphthalene (µg/m^3)	**0.13**	**0.10**	**0.20**	**0.25**
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.8
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Cairns fire station.



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.24

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Cairns fire station. The data includes the observed data and the R.L concentrations added.

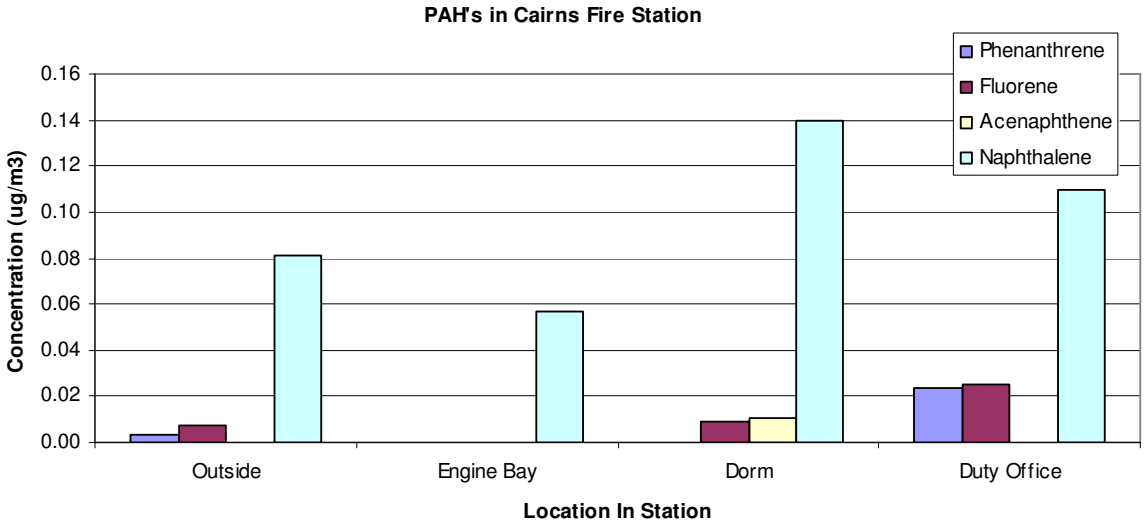


Figure 3.25

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Cairns fire station.

The figure demonstrates naphthalene is the most significant contributing PAH to the total PAH concentration. This trend is consistent across all areas of the fire station and few if any other PAHs are detected. The highest estimated naphthalene concentration in any area is more

than 260,000 times below the naphthalene ES_{10} 36 400 µg/m^3 and more than 1400 times below the naphthalene odour threshold (200 µg/m^3).

Diesel Particulate Matter
Diesel particulate matter (DPM) has been described extensively in chapter one. Although there is no established ES, a level of concern (LOC) of 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L), the R.L value was used. A recent review [33] reported that US fire fighter DPM exposure to DPM is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

10 Hr monitoring Station
The DPM background concentration was at or below the reporting limit (R.L – 0.001 mg/m^3 EC) and is less than the average background DPM concentration across the state (0.002 mg/m^3 EC). The average concentrations in all areas within the station were at or below the R.L. and less than the average concentrations obtained in all areas across the state.

Start if Shift, Turn-out and Return Trials
The DPM concentration measured from the start of shift check (55 minutes) was (0.002 mg/m^3 EC), which is significantly less than the average start of shift concentration (0.044 mg/m^3 EC – including Firepac 3000 Mk 3 measurement) across the state. This concentration is more than 50 times less than the established level of concern when the front engine bay doors are closed and no deliberate ventilation applied to remove exhaust emissions. The Cairns station has no aft engine bay doors and the engine bay design features possibly contributed to the result.

The DPM concentration obtained after the turnout simulation, and return simulation were at or below the R.L, which is more than 100 times less than the level of concern (0.1 mg/m^3 EC). These are the lowest results reported for these activities and are less than the state turn-out average (0.009 mg/m^3) and state return average (0.013 mg/m^3). There are several explanations to account for these results, including the engine bay design, ventilation and appliance performance.

The results demonstrate that the exposure of fire fighters whilst working at this station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern. In many instances there is no significant difference compared with the background concentrations and the averages across Queensland.

These Cairns station results show that no measurement exceeded the typical US fire fighter exposure[33] concentration of 0.05 mg/m^3 EC, during the 10 Hr day shift or any activity of interest.

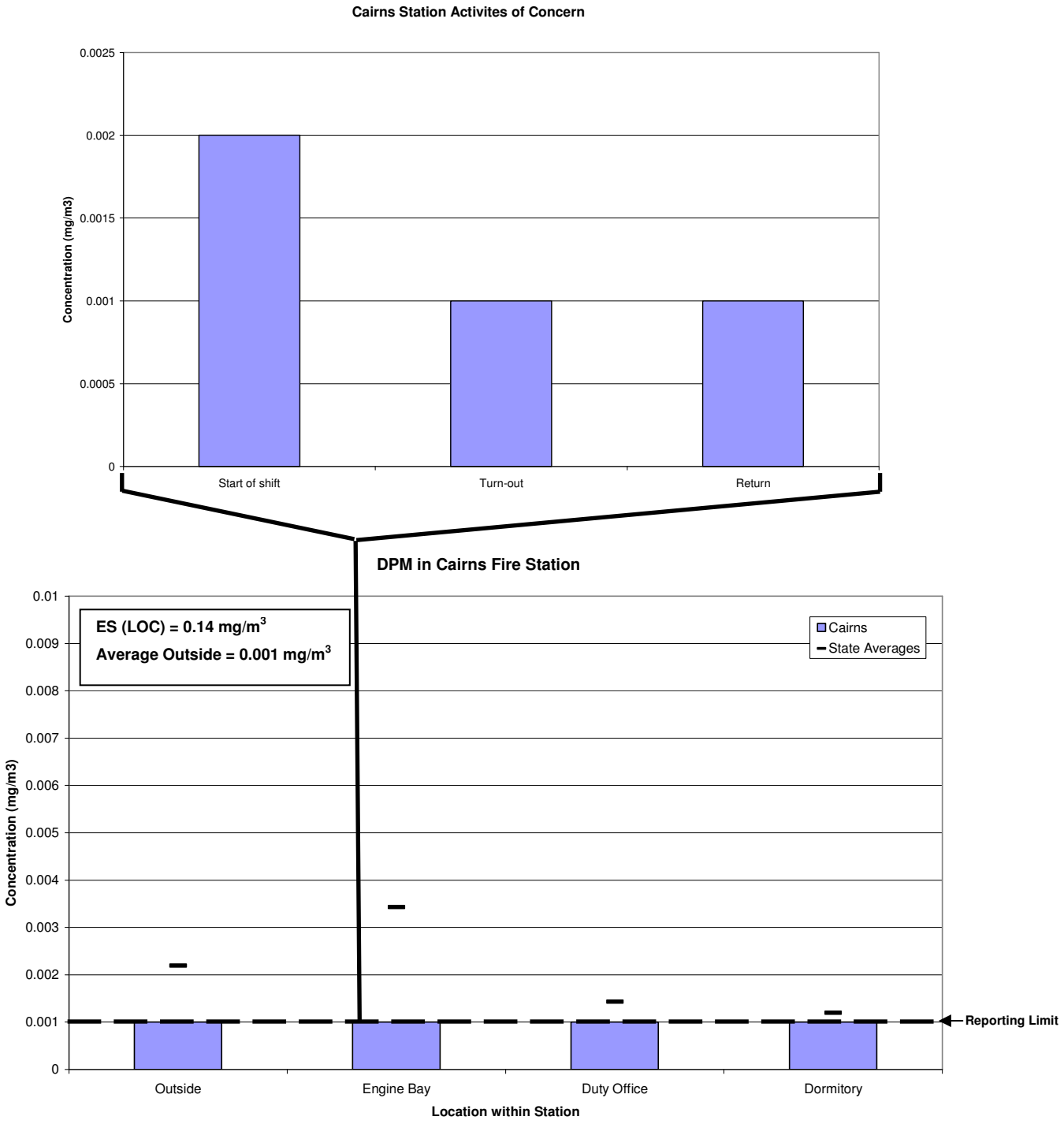


Figure 3.26

DPM concentrations for Cairns station was based on 10 Hr shift (dorm, eng. Bay, duty office and outside) and simulated activities (start of shift, turn-out simulation and return simulation).

Summary of Cairns Results

The Cairns station trials showed that no stations activity exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.13	0.001	1	1	<2	1	<47.3	<5	<5	0.6	0.0	0.0
Engine Bay	0.10	0.001	1	1	<2	1				0.1	0.0	0.02
Start of Shift		0.002	2.8	8	6.9	<2.4	<156	<5	<5			
Turnout		0.001	<91	<77	<67	<85	<140	<5	<5			
Return		0.001	<113	<96	<83	<105	<133	<5	<5			
Duty Office	0.20	0.001	1	11	<2	11	<29.9	<5	<5	2.1	0.1	0.0
Dormitory	0.25	0.001	1	1	<2	1	<43.4	<5	<5	0.6	0.0	0.0
Mess/Lounge			1	1	<2	1	<29.5	<5	<5	0.4	0.1	
PPE Locker			2.7	<2.3	<2.0	<2.5	<41.1	<5	<5			0.02

The greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

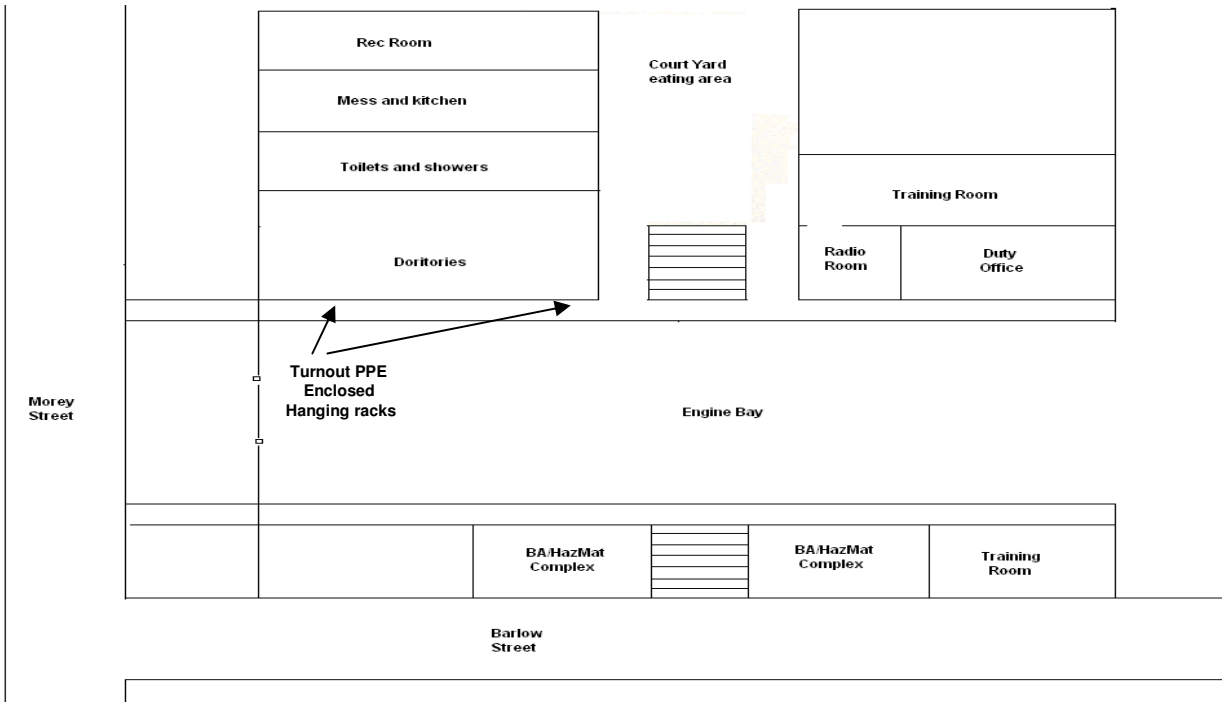
Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Review of QFRS Fire Station Data

Northern Region

Townsville Fire Station

The Townsville fire station is an older style station built prior to 1970. It is the major station in the Townsville area, housing five fire fighting, rescue, hazmat and technical rescue appliances and support vehicles. The station is crewed by six fire fighters, a senior officer and one administration officer, fire communications centre housing three staff. Townsville station is located at the interface between commercial and a light industrial suburb. It is adjacent to roads transiting to the port and around the industrial area. In 2007 there were 2736 reported responses.



Fire fighter exposures in the Townsville Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide and nitrogen dioxide concentrations were measured during the station activities: start of shift checks, turn out and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained for Townsville fire station and average results of all stations across the state.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Townsville – NO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Townsville – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.2 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.9

Instantaneous concentrations of airborne nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

The airborne concentration of nitrogen dioxide and sulfur dioxide were below the limit of detection (0.5 ppm) for all activities. The Townsville fire station results are at or below the average concentration obtained for all fire stations across the state and the August 2009 Ambient Air Quality Data[46] average Townsville sulfur dioxide (<1 ppb) and nitrogen dioxide (4 ppb) concentrations. The time corrected exposure standards ES_{10} for NO_2 and SO_2 are 2 ppm and 1.4 ppm respectively.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift. The measurements are reported as peak concentrations over 1 minute averaging periods.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**	**Multi Rae four gas detector**	
	Total VOC (ppm)	Note: LFL (0%) and oxygen (20.9%) were constant through-out testing	
		Hydrogen sulphide (ppm)	Carbon monoxide (ppm)
Cairns			
Outside	0.02	0.0	0.4
Engine Bay	0.16	0.1	0.4
Duty Office	0.0	1.0	0.9
Dormitory	0.02	0.0	0.6
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.0	0.0	1.6

Table 3.10

Time averaged concentrations for the air-borne contaminants, total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO) monitored over the 10 Hr day shift period.

Carbon Monoxide - total average concentrations

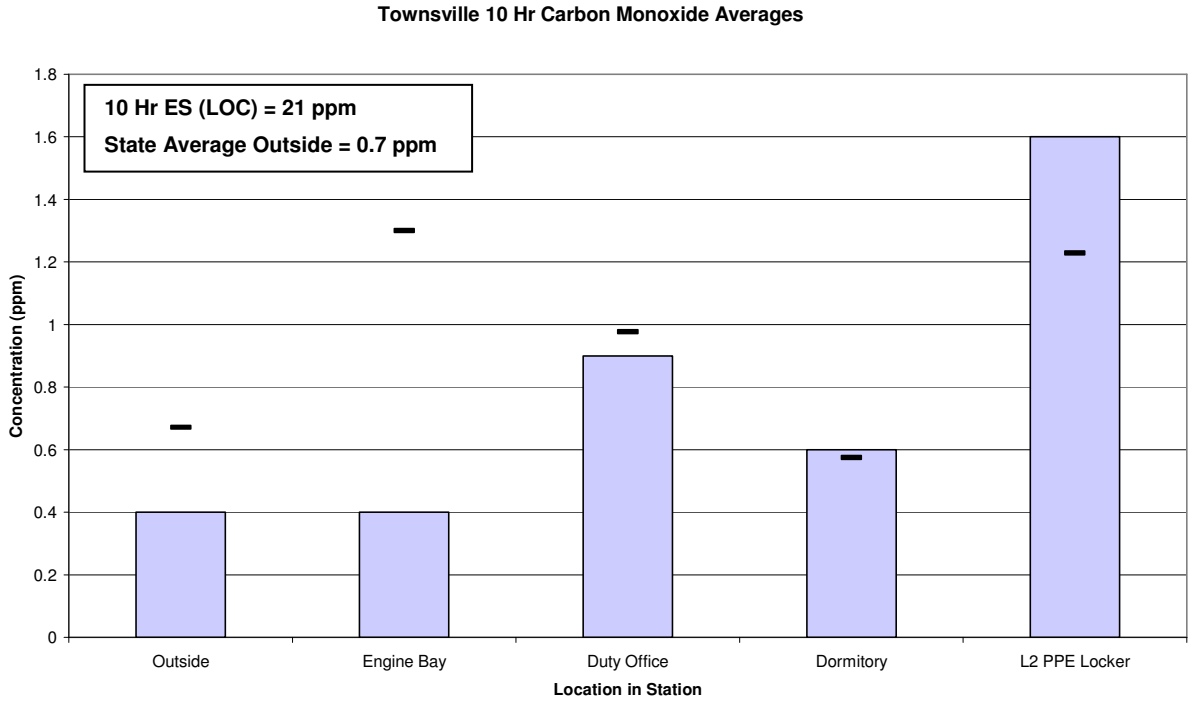


Figure 3.27
Time averaged carbon monoxide concentrations for a day shift at Townsville fire station.

Outside Station (Background)
The background carbon monoxide concentration(0.4 ppm) was less than the average outside concentration(0.7 ppm) obtained across the state, and the South East Qld[46] average concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station were generally higher than the average background concentration. The highest concentration occurred in the turnout PPE locker (1.6 ppm) and exceeded the average PPE locker concentration (1.4 ppm) for all fire stations across the state and was similar to the South East Qld ambient air quality. Nonetheless, this concentration was *ca*. 14 times less than the (ES_{10} – 21 ppm). There are several possible explanations that may account for the discrepancy including the location in relation to the appliance exhausts and the locker ventilation arrangements.

Carbon Monoxide - 10 Hr continuous monitoring
Figure 3.28, below, illustrates there were three activities where excursions were observed in the engine bay and PPE locker. These excursions corresponded to the arrival to station of a fire appliance, turn-out of a fire appliance and the start of shift checks. No excursions were observed elsewhere in the station.

The highest concentrations were obtained during the start of shift check (32 minutes), *i.*e. engine bay (31.5 ppm), and PPE locker (3.7 ppm). This is consistent with the position of the appliances and the adjacent PPE locker. Although the concentration within engine bay was higher than the 10 Hr exposure standard ES_{10} (21 ppm), it did not exceed the NOHSC: *Guidelines for the control of short-term excursions for Carbon Monoxide*[45] 30 minute limit of 100 ppm or 60 minute limit of 60 ppm.

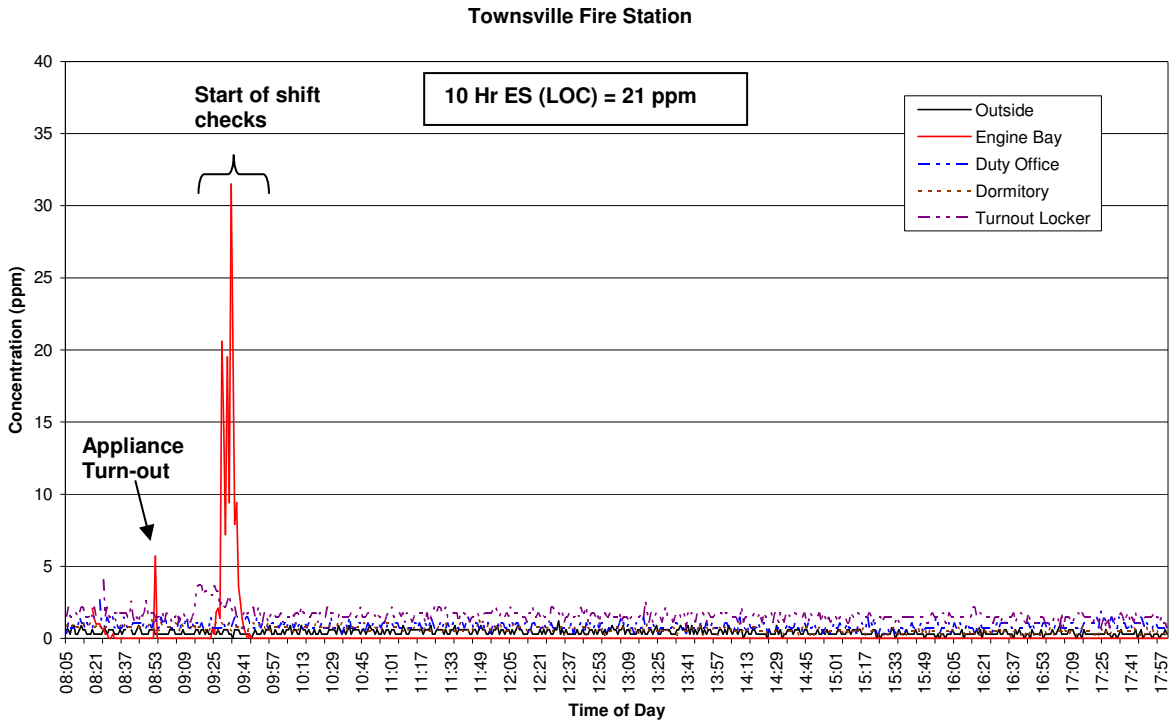


Figure 3.28
Carbon monoxide concentrations for a 10 Hr day shift at Townsville fire station.

Hydrogen Sulfide - total average concentrations

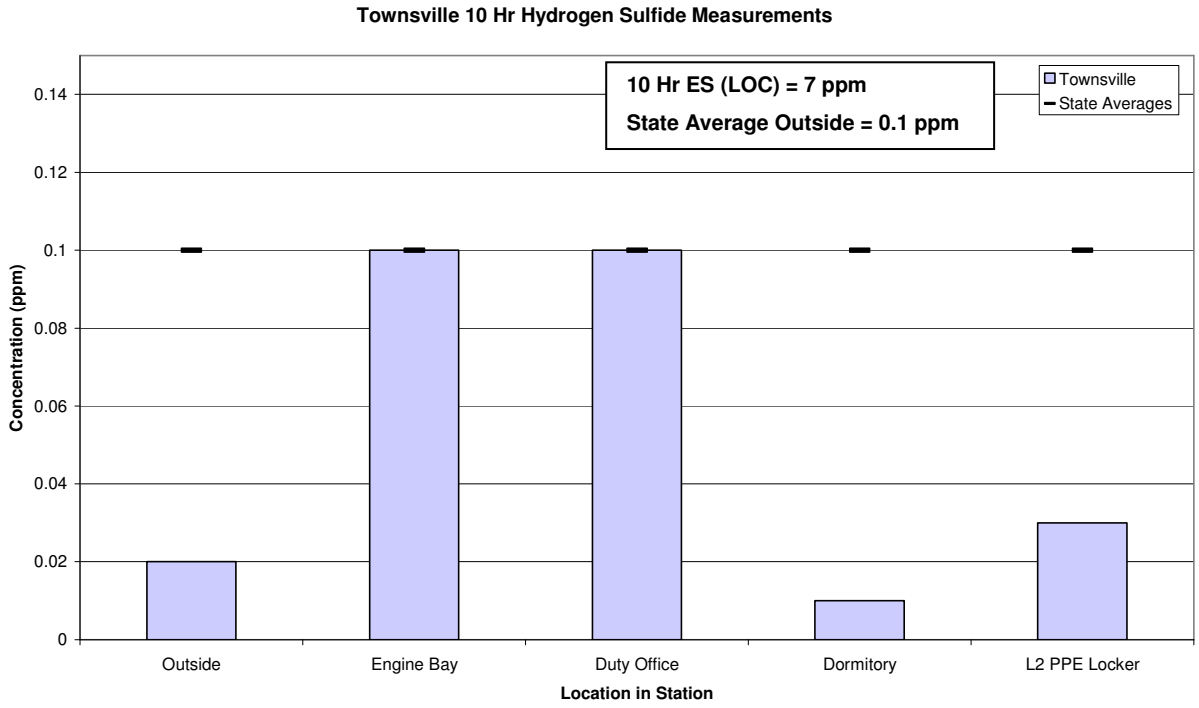


Figure 3.29
Time averaged hydrogen sulfide concentrations for a day shift at Townsville fire station.

Outside Station (Background)
The average background hydrogen sulfide (H_2S) concentration (0.01 ppm) is significantly less than the LOD for the MultiRae detector. An average H_2S concentration of 0.1 ppm was outside observed across the state.

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station were at or below LOD for the MultiRae detector. The two highest concentrations were the engine bay and duty office. All concentrations obtained are significantly less than the ES_{10} of 7 ppm.

Hydrogen Sulfide - 10 Hr continuous monitoring

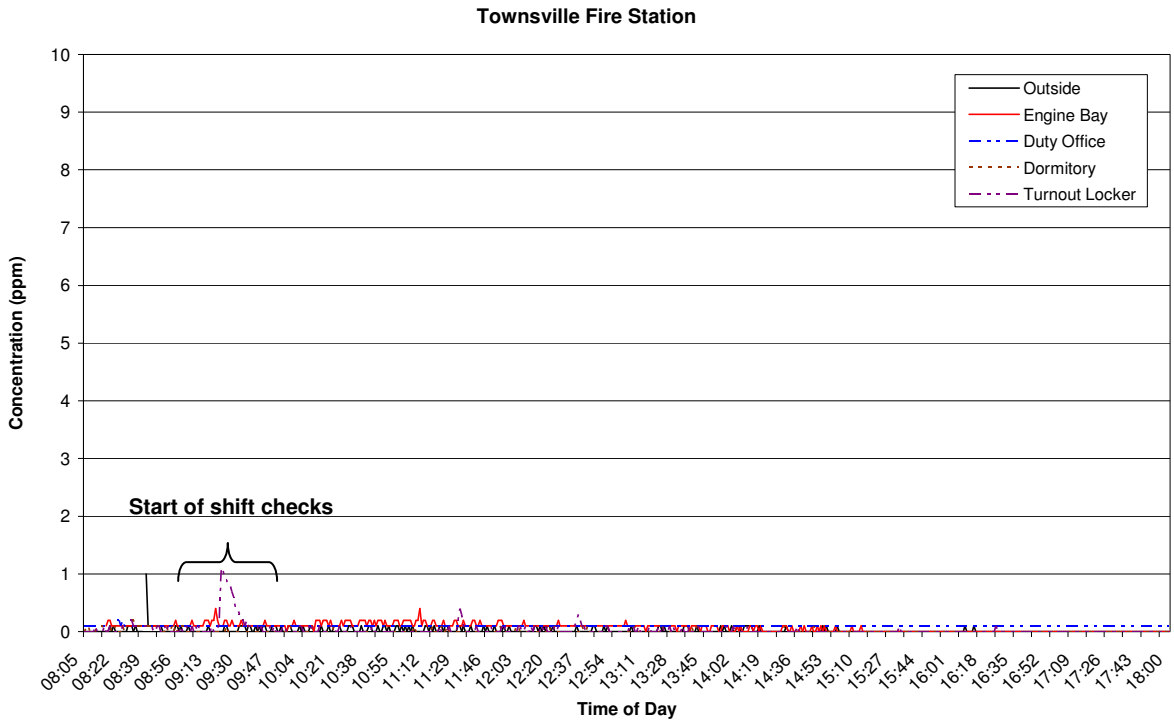


Figure 3.30
Hydrogen sulfide readings for a 10 Hr day shift at Townsville fire station.

The above figure shows that the start of shift checks was the only activity where an excursion was observed in the PPE locker. No excursions were observed elsewhere in the station.

The highest concentration obtained during the start of shift check (32 minutes), *i.*e. PPE locker (1.1 ppm) was significantly less than the ES_{10} of 7 ppm. This is consistent with the position of the appliances and the adjacent PPE locker.

Atmospheric Contaminants – total volatile organic compounds of concern
The airborne concentration of total volatile organic compounds (tvoc's) was measured continuously during the normal station activities for as close as practicable to the standard 10 hr shift. The measurements reported were peak concentrations over 1 minute averaging periods and are reported as isobutylene units.

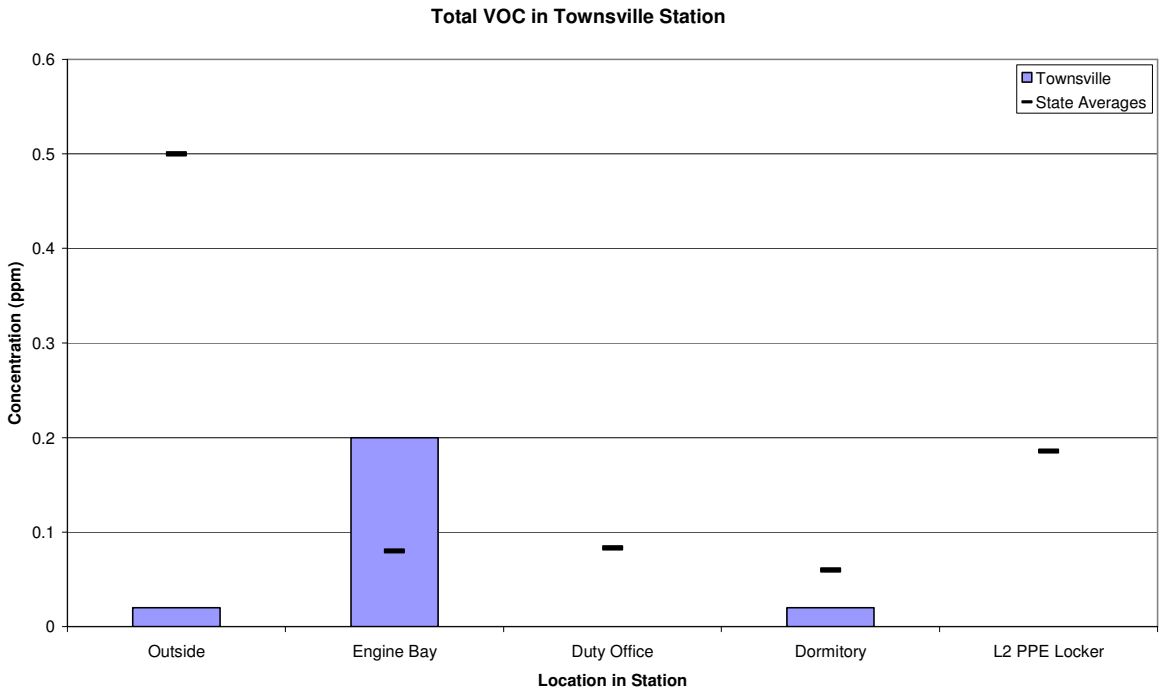


Figure 3.31
Volatile organic compounds readings for a 10 Hr day shift at Townsville fire station.

Outside Station (Background)
The total average Townsville background tvoc concentration (0.02 ppm) was significantly less than the average concentration (0.5 ppm) observed across the state and the QFRS established level of concern (0.5 ppm).

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station were similar to the background concentration except in the case of the engine bay (0.2 ppm), which is greater than the average state concentration (0.1 ppm), but less than the QFRS established level of concern (0.5 ppm).

Volatile organic compounds - 10 Hr continuous monitoring

Figure 3.32 below, illustrates that the start of shift checks was one occasion where excursions were observed. The highest concentration was 58.6 ppm which was significantly above the QFRS established level of concern (0.5 ppm) and the outside state average (0.5 ppm). However, once the activities had ceased, the tvoc concentrations quickly decreased to typical background levels.

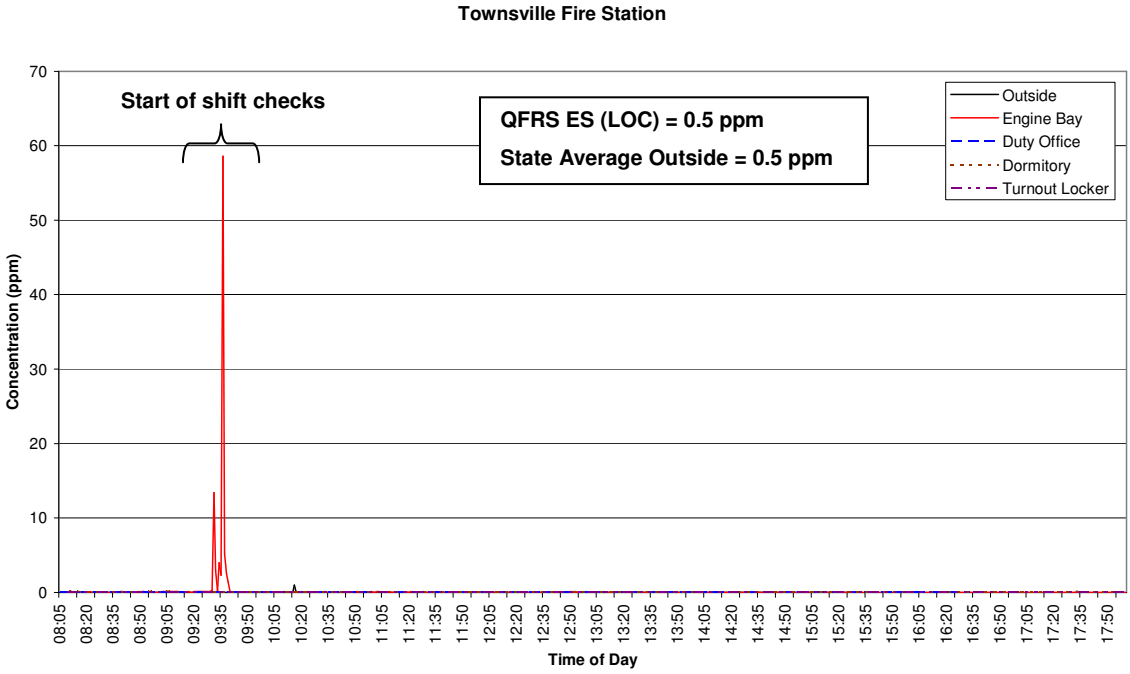


Figure 3.32

Total volatile organic compounds concentrations for a 10 Hr day shift at Townsville fire station.

Atmospheric Contaminants – hexane, benzene, toluene and xylene

The voc results for Townsville station used reporting limit concentrations where a result was less than the reporting limit to provide the worst case scenario. Samples were collected using of evacuated gas canisters, absorbent tubes and Dräger stain tubes to measure for the voc's of interest; hexane, benzene, toluene, xylene and aldehydes. These voc's are important due to their sources from petrol and diesel exhausts and the extensive use daily. Townsville station was on a major highway and had an adjoining light industrial suburb.

Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A mixture of evacuated canisters, active and passive sorbent techniques was used. Instantaneous measurements of benzene were measured during the station activities. If the result obtained was less than the reporting limit (<R.L.), the R.L. was used to illustrate the worst case.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<2.6*	1	<1.7*	<2.2*	1	<1.6*	<1.9*	<2*	<3.2*	<2.4*	1	<1.7*	<44.9*	<29.0*
Engine Bay			1	<1.7*		1	<1.6*		<2*	<3.3*			<1.7*		<28.9*
Start of Shift	<0.5	19			125			108			79.4			<247*	
Turnout	<0.5	<5.6*			<4.8*			<4.1*			<5.1*			<202*	
Return	<0.5	<67*			<56*			<48*			<59.6*			<210*	
Duty Office	<0.5		1	<1.7*		1	<1.6*		<2*	<3.2*		1	<1.7*		<28.4
Dormitory	<0.5	<3.8*	1	<1.7*	<3.2*	1	<1.6*	<2.8*	3.6	<3.2*	<3.4*	1	<1.7*	<35.6*	<29.0
Mess area	<0.5		1	<1.7*		1	<1.6*		<2*	<3.2*		1	<1.7*		<29.3
PPE Locker	<0.5	<2.2*			<1.8*			<1.6*			<2.0*			<37.6*	

Table 3.11
Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Townsville fire station over a day shift.

Atmospheric Contaminants – hexane
The hexane background concentration outside Townsville station was at or below the R.L (<1.0 ppb), which is less than the average background concentration (1.1 ppb) across the state. Similarly, the average hexane concentration in all areas of the station were at or below the R.L, which is more than 14000 times less than the ES_{10} of 14 000 ppb. The average Brisbane[48] airborne hexane concentration is 18.6 ppb. The odour threshold of 65 000 ppb

The hexane concentrations observed after the start of shift checks (32 mins), turnout simulations, and return simulations were 79.4 ppb, <R.L (5.1 ppb) and <R.L (59.6 ppb) respectively. The start of shift checks and return simulations results are similar to the average start of shift and turnout simulation concentrations across the state (92 ppb and 4.9 ppb respectively). The return simulation is higher than the average return simulation concentration (14.5 ppb), but the relatively high reporting limit accounts for the result. The highest concentration is approximately 170 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.

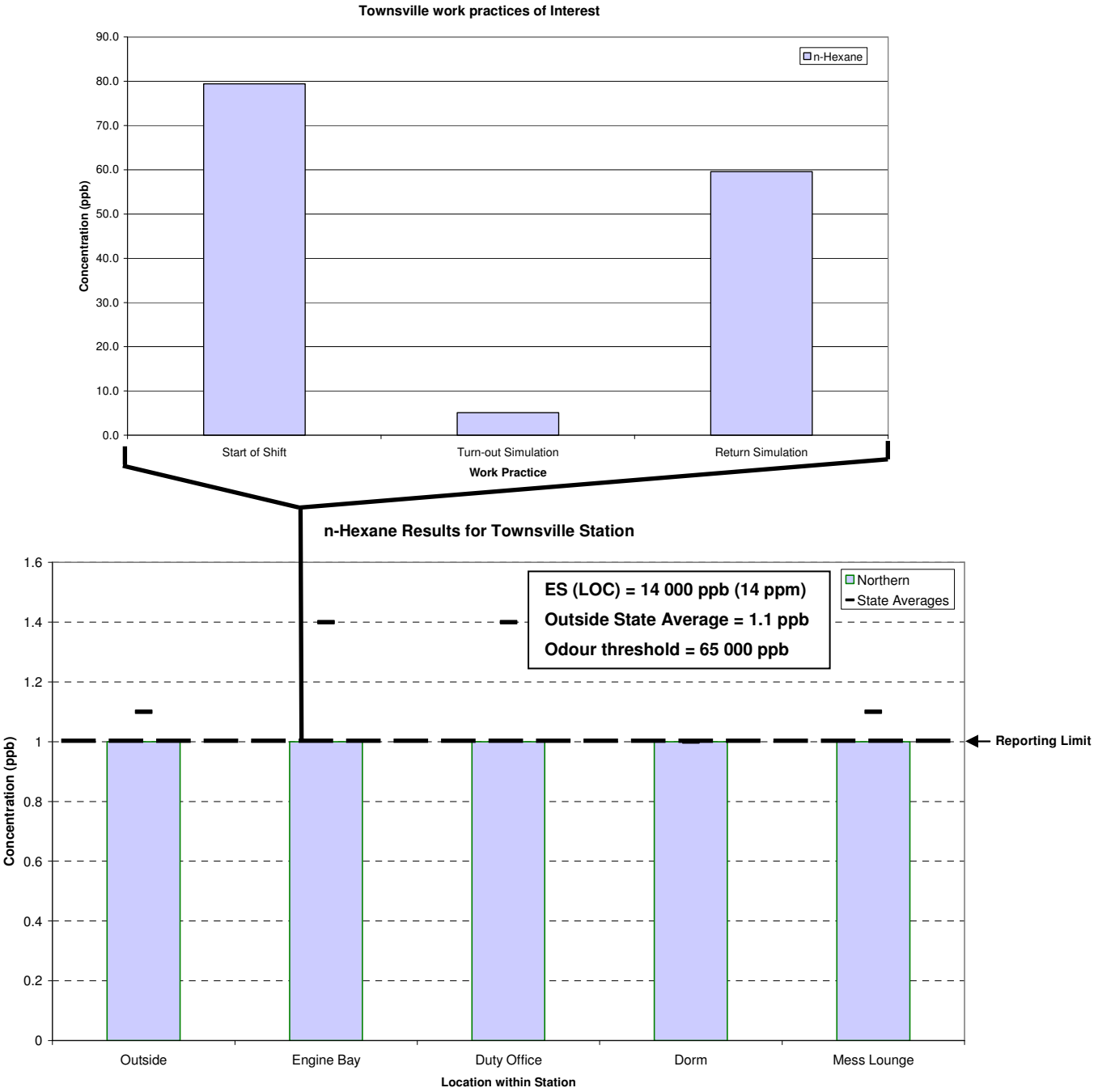


Figure 3.33
Hexane concentrations from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

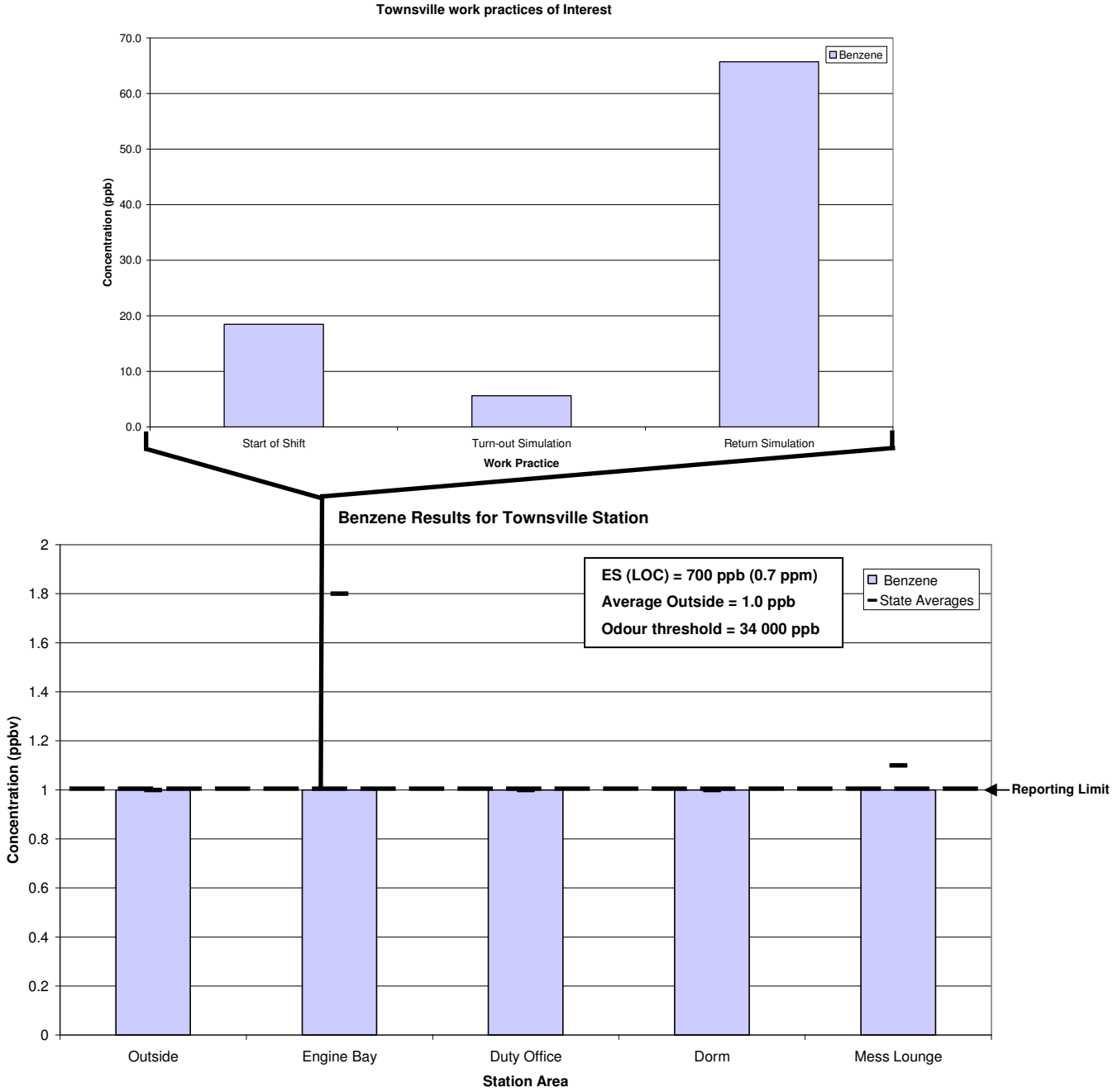


Figure 3.34
Benzene concentrations from evacuated canisters controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

The background benzene concentration outside Townsville fire station was at or below the R.L (1.0 ppb) and the average background concentration across the state (1.0 ppb). The average concentrations in all areas within the station were at or below the R.L, which is more than 700 times less than the ES_{10} of 700 ppb. The airborne benzene concentrations in South East Qld[46] and Brisbane[48] are 0.8 ppb (range: 0.4 to 1.5 ppb) and 3.3 ppb (range: 0.43 to 10.33 ppb) respectively. The odour threshold of benzene is 34 000 ppb.

The benzene concentration obtained after the start of shift check (32 minutes), turnout simulation, and return simulation were 19 ppb, <R.L. (5.6 ppb) and <R.L. (67 ppb) respectively. These concentrations are higher than the background concentration of benzene. The start of shift concentration is less than the average concentration (28 ppb), the turn out simulation concentration was similar to the average concentration (5.3 ppb), and the return to station concentration was greater than the average concentration (16.5 ppb). The highest concentration is approximately 10 times less than the ES_{10} of 700 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – toluene

Figure 4.35 shows the toluene background concentration outside Townsville fire station was at or below the R.L (1.0 ppb) and was similar to the average background (2.1 ppb) concentration across the state. The average concentrations in all areas within the station were at or below the R.L, which is 35000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb and more than 160 times below the odour threshold (160 ppb). This background result is similar to the average toluene airborne concentrations in South East Qld[46] - 1.6 ppb (range: 0.7 to 4.9 ppb) and Brisbane[48] - 10.6 ppb (range: 1.8 to 83 ppb).

The toluene concentration obtained after the start of shift check (32 minutes), turnout simulation, and return simulation were 125 ppb, <R.L. (4.8 ppb) and <R.L. (56 ppb) respectively. These concentrations are higher than the background concentration of toluene. The start of shift and return simulation toluene concentrations are greater than the average toluene concentrations concentration (83.6 ppb, 14.5 ppb respectively). The turnout simulation toluene concentration is similar to the average toluene concentration (6 ppb). The highest concentration is approximately 350 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

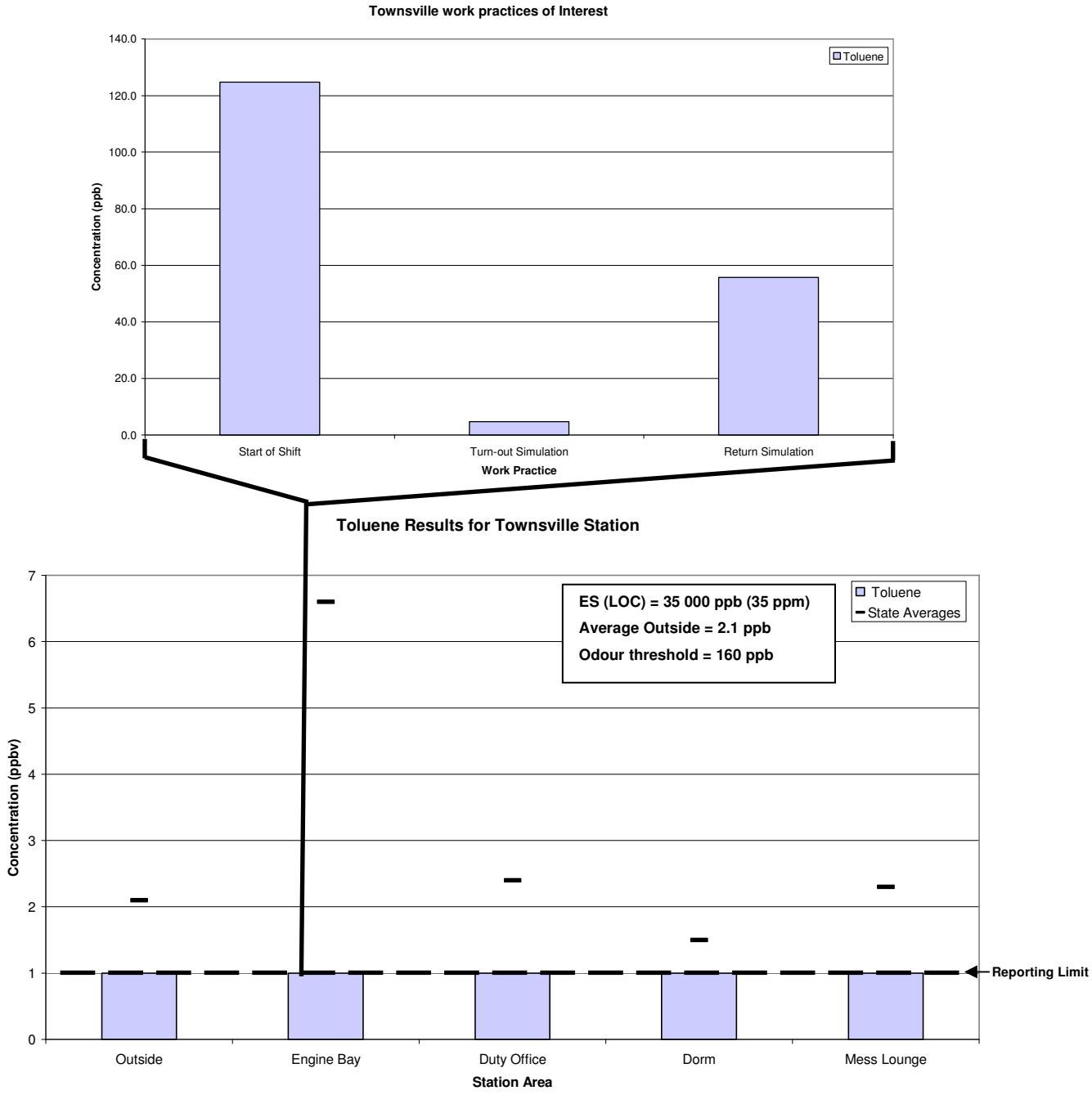


Figure 3.35
Toluene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – xylene

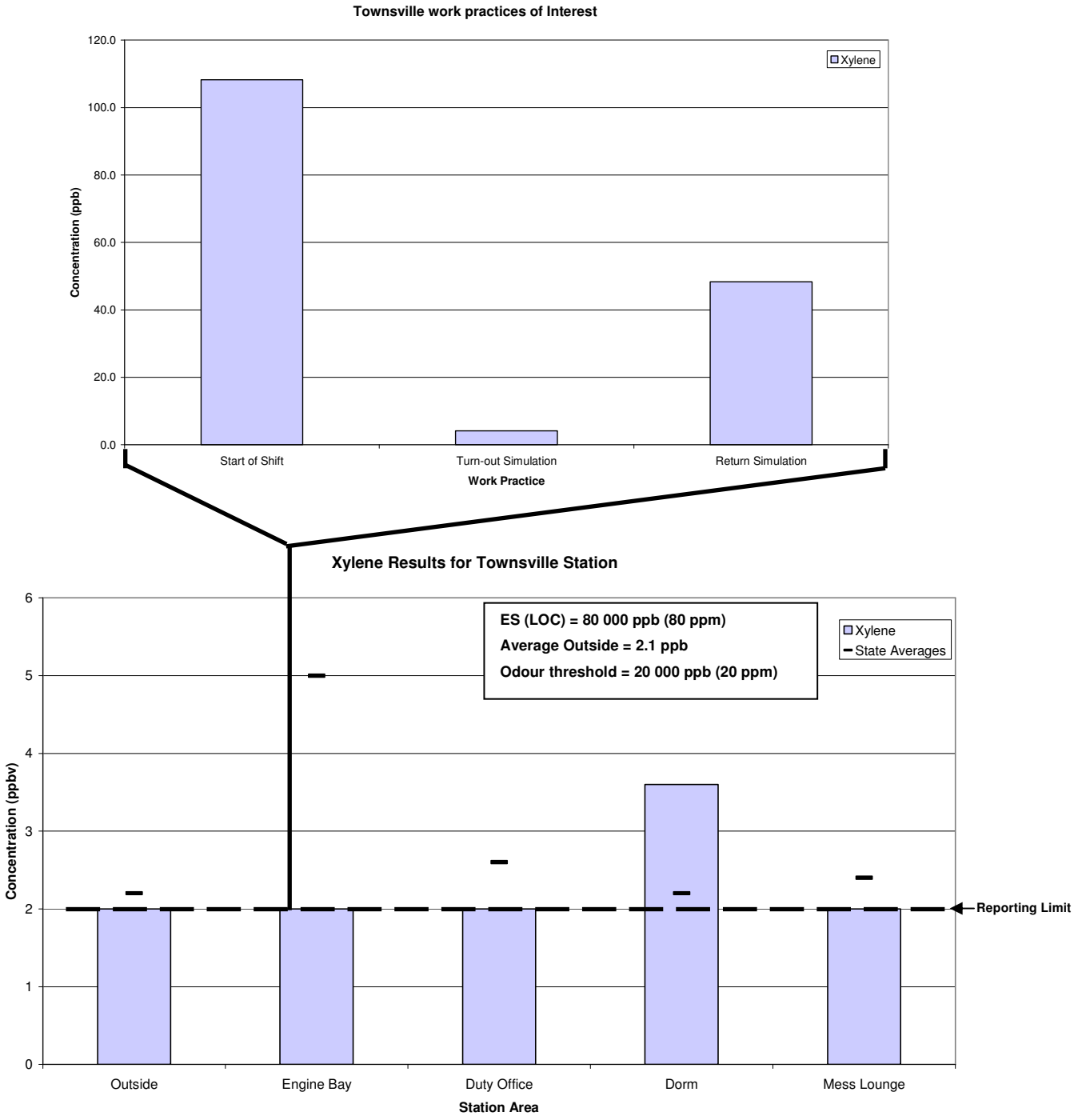


Figure 3.36
Xylene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

The xylene background concentration outside Townsville fire station was at or below the R.L (2.0 ppb) and similar to the average background concentration (2.2 ppb) across the state. The average station area concentrations were at or below the R.L except the dormitory (3.6 ppb), which is more than 15000 times less than the ES_{10} of 56 000 ppb. The xylene airborne concentration in South East Qld[46] is 4.5 ppb (range: 2.5 to 8 ppb). The South East Qld results

were reported as *p*-xylene data, but calculated as total xylene based on *p*-xylene being 20% of the total xylene concentration).

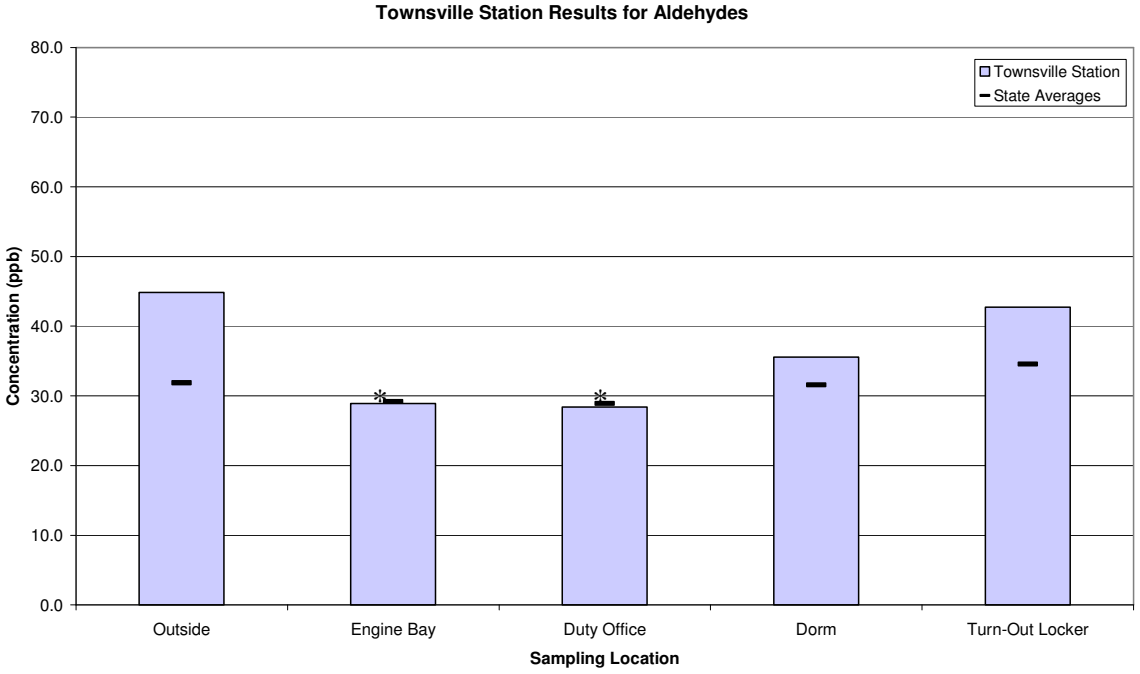
The xylene concentration observed after the start of shift check (32 minutes), turnout simulation, and return simulation were 108 ppb, <4.1 ppb and <48 ppb respectively. These concentrations are higher than the background concentration. The start of shift checks and the turnout concentrations are similar to the average concentrations across the state (105 ppb and 5.3 ppb respectively). The return concentration is higher than the average concentration across the state (12.5 ppb). The highest concentration is *ca*. 500 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – aldehydes

Aldehydes form part of the compounds of interest that form total volatile organic compounds because of their potential as respiratory and eye irritants. Aldehydes are typically formed in combustion processes and so may form from diesel exhaust, fires where PPE is worn and potentially transported back to station.

The total aldehyde concentration is obtained from the summation of the following aldehydes: valeraldehyde; benzaldehyde; acrolein; formaldehyde. The total aldehyde background concentration outside Townsville fire station was 45 ppb, which is higher than total aldehyde state outside average (31.9 ppb).

The total aldehyde concentrations within the engine bay (28.9 ppb) and duty office (28.4 ppb) were similar to the state average concentrations (28.5 ppb and 29.2 ppb). However, these results were obtained on passive diffusion badges and only formaldehyde was reported. All other station areas were at or below the Townsville background concentration. The highest concentration is more than 23 times less than the ES_{10} of 700 ppb.



* Results from passive badges

Figure 3.37

Total aldehydes in areas of interest for a 10 Hr day shift at Townsville fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

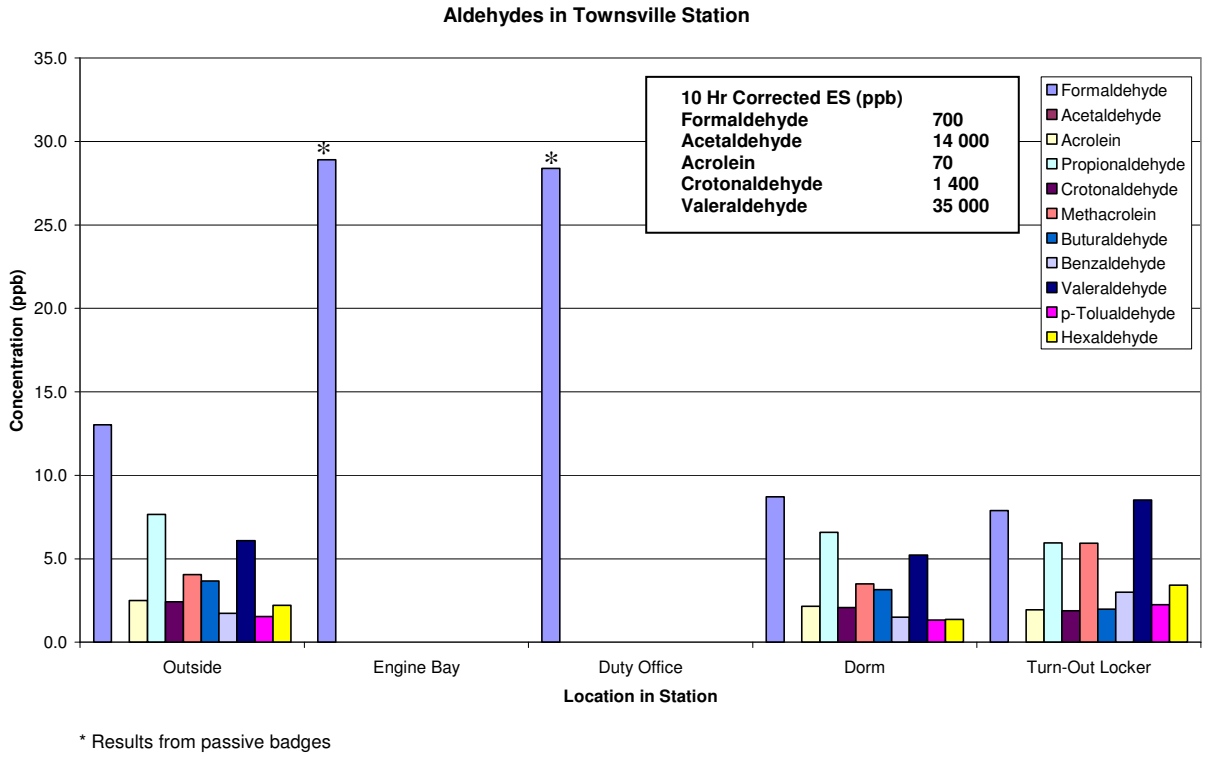


Figure 3.38
Aldehydes detected for a 10 Hr day shift at Townsville fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

Of the aldehydes detected at the Townsville fire station, only formaldehyde, acetaldehyde, acrolein, crotonaldehyde and valeraldehyde have Australian exposure standards. Formaldehyde typically showed the highest observed concentrations, but one of the lowest exposure standards. However, even the highest formaldehyde concentration (passive badge 29 ppb), is more than 20 times lower than the ES_{10} (700 ppb). The aldehyde with the lowest exposure standard, acrolein, was detected outside (2.5 ppb), in the dormitory (2.1 ppb) and in the PPE locker (1.9 ppb). The highest of these was 28 times below the acrolein ES_{10} (70 ppb).

Atmospheric Contaminants – Particulate Matter
Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

Polyaromatic Hydrocarbons
The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard. Some individual PAH have established ES such as naphthalene - ES (52 mg/m^3 or 52 000 µg/m^3) and a 10 Hr time corrected ES_{10} (36.4 mg/m^3 or 36 400 µg/m^3). If the result obtained was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case concentration for a specific location.

	Townsville Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	**4300**	<RL	<RL
Fluoranthene	<RL	**3710**	<RL	<RL
Anthracene	<RL	<RL	<RL	<RL
Phenanthrene	<RL	**6760**	**11200**	**7860**
Fluorene	**6170**	**5860**	**9420**	**11100**
Acenaphthene	<RL	<RL	<RL	<RL
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	29000	260000	170000	230000
Reporting Limit	3100	3400	4600	3100
Total PAH concentrations. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.01	0.02	0.02	0.02
Total with Naphthalene (µg/m^3)	0.04	0.28	0.19	0.25
Total PAH concentrations including RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted (pg/m^3) to (µg/m^3)				
Total without Naphthalene (µg/m^3)	0.05	0.05	0.08	0.06
Total with Naphthalene (µg/m^3)	**0.08**	**0.31**	**0.25**	**0.29**
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.12
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Townsville fire station.

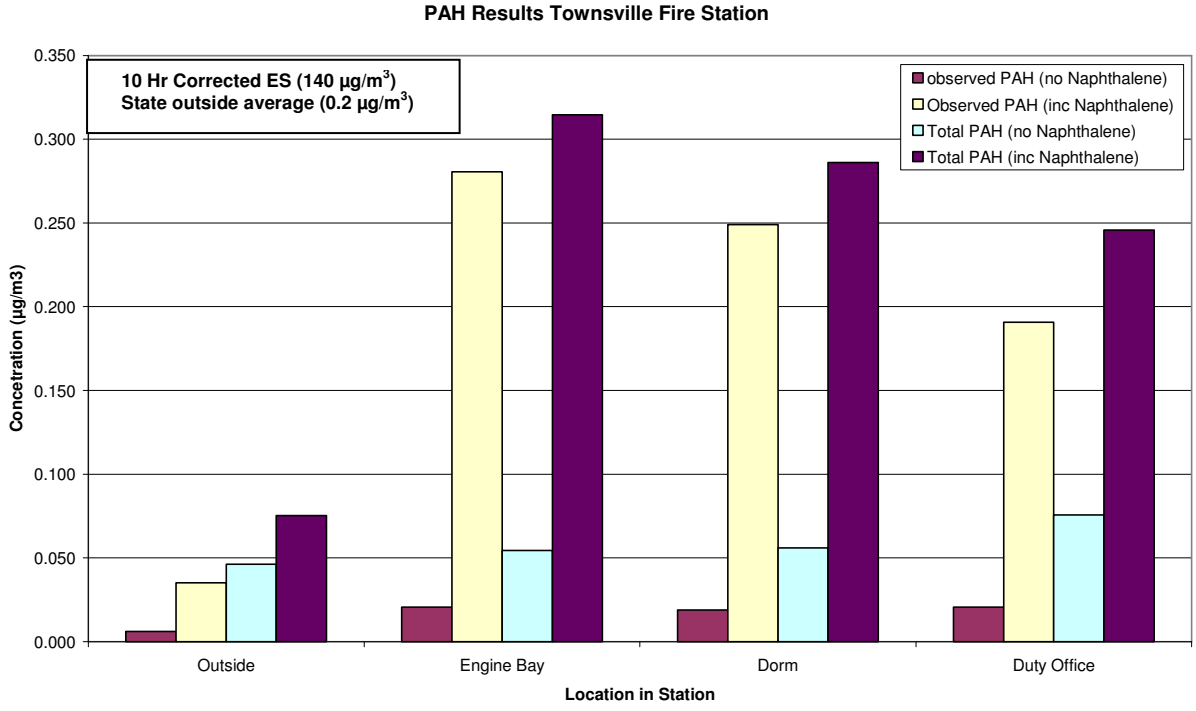


Figure 3.39
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Townsville fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

Outside Station (Background)
The PAH background concentration (0.08 µg/m^3) was similar to the average background PAH concentration across the state. Fluorene and naphthalene were detected outside the station. Care should be shown with these total results as they are derived from the addition of mostly reporting limit concentrations. The majority of compounds were not detected above the reporting limits of the laboratory.

Inside Station (10 Hr monitoring)
The PAH concentrations within the fire station were greater then the PAH background concentration. The concentrations were less than the average PAH concentrations obtained across the state except the dormitory concentration (0.2 µg/m^3). The highest PAH concentration obtained was in the engine bay, which was more than 400 times less than the ES_{10} of 140 µg/m^3.

Figure 3.40 below, shows that Pyrene, fluoranthene, phenanthrene, fluorene and naphthalene were detected in Townsville fire station. Only the latter three were detected in the office and dormitory areas. All these PAH detected are classified as non-carcinogenic category by the US EPA.

Naphthalene was the most significant contributing PAH to the Townsville total PAH concentration. This trend is consistent across all areas of the fire station and few if any other PAHs are detected. The highest estimated naphthalene concentration in any area is more than 35,000 times below the established ES_{10} 10 500 µg/m^3 and more than 650 times below the naphthalene odour threshold (200 µg/m^3).

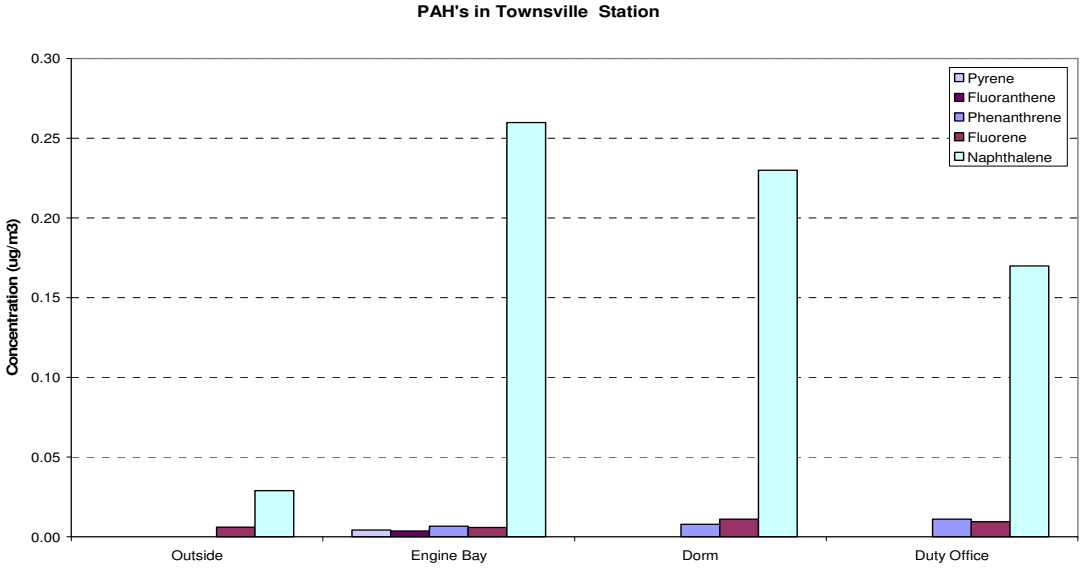


Figure 3.40
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Townsville fire station.

Diesel Particulate Matter
Diesel particulate matter (DPM) has been described extensively in chapter one. Although there is no established ES, a level of concern (LOC) of 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L), the R.L value was used. A recent review[33] reported that US fire fighter DPM exposure to DPM is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

10 Hr monitoring Station
The DPM background concentration was 0.007 mg/m^3 EC and the highest concentration reported. It is more than 14 times less the established level of concern (0.1 mg/m^3 EC). The average concentrations in all areas within the station were at or below the R.L (0.001 mg/m^3 EC) and less than the average concentrations obtained across the state. Thus, the DPM concentration within the station was less than the concentration outside the station.

Station Activity monitoring
The DPM concentration observed after the start of shift check (32 minutes) was (0.011 mg/m^3 EC and is significantly less than the average start of shift concentration (0.044 mg/m^3 EC – including the Firepac 3000 Mk 3 measurement). This concentration is more than 9 times less than the established level of concern when the front engine bay doors are closed and no deliberate ventilation applied to remove the exhaust emissions. Although Townsville fire station has aft engine bay doors, advice was that they are non-operatable during the trials. Thus, trials were performed with them open. The engine bay design features likely contributed to the result.

The DPM concentration observed after the turnout simulation, and return simulation were 0.002 mg/m^3 EC and 0.007 mg/m^3 EC respectively. These concentrations are less than the state turn-out average (0.009 mg/m^3) and return average (0.013 mg/m^3). There are several explanations to account for these results, including the engine bay design, ventilation and appliance performance. These concentrations are more than 14 times less than the LOC (0.1 mg/m^3 EC). There are several explanations to account for these results, including the engine bay design, ventilation and appliance performance.

The results demonstrate that the exposure of fire fighters during the 10 Hr day shift or any activity of interest are significantly less than the established levels of concern, and the typical US fire fighter exposure[33] concentration of 0.05 mg/m^3 EC.

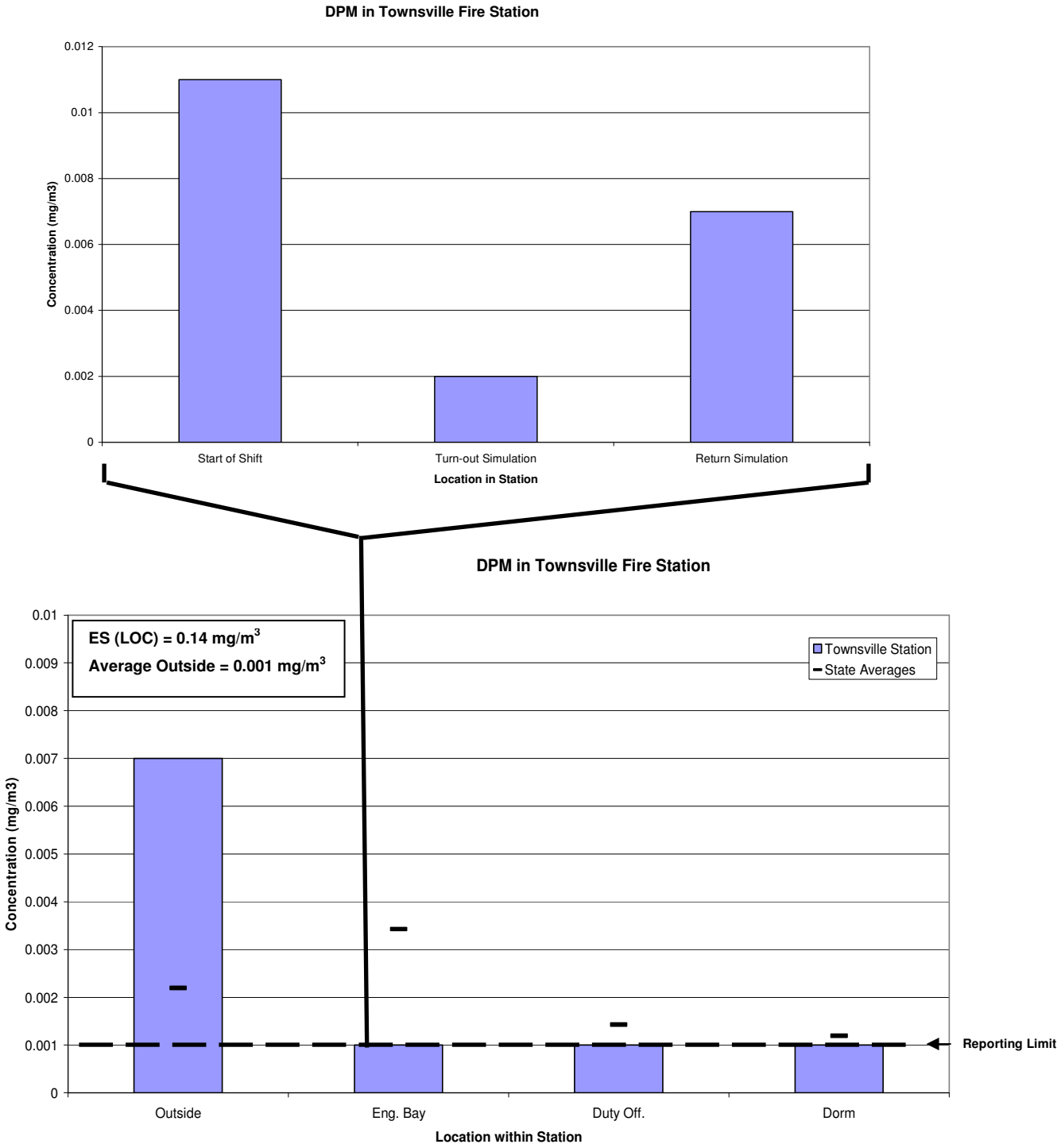


Figure 3.41
DPM results for Townsville station was based on 10 Hr shift (dorm, eng. Bay, duty office and outside) and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Townsville Results

The Townsville station trials showed that no stations activity exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.08	0.007	1	1	<2	1	<44.9	<5	<5	0.4	0.02	0.02
Engine Bay	0.32	0.001	1	1	<2	1				0.4	0.1	0.16
Start of Shift		0.011	19	125	108	79.4	<247*	<5	<5			
Turnout		0.002	<5.6	<4.8	<4.1	<5.1	<202*	<5	<5			
Return		0.007	<67	<56	<48	<59.6	<210*	<5	<5			
Duty Office	0.25	0.001	1	11	<2	11	<28.4	<5	<5	0.9	0.1	0.0
Dormitory	0.29	0.001	1	1	<2	1	<35.6	<5	<5	0.6	0.01	0.02
Mess/Lounge			1	1	<2	1	<29.3	<5	<5			
PPE Locker			2.2	<1.8	<1.6	<2.0	<37.6	<5	<5	1.6	0.03	0.0

The greatest generation of diesel exhaust occurred during the start of shift checks.

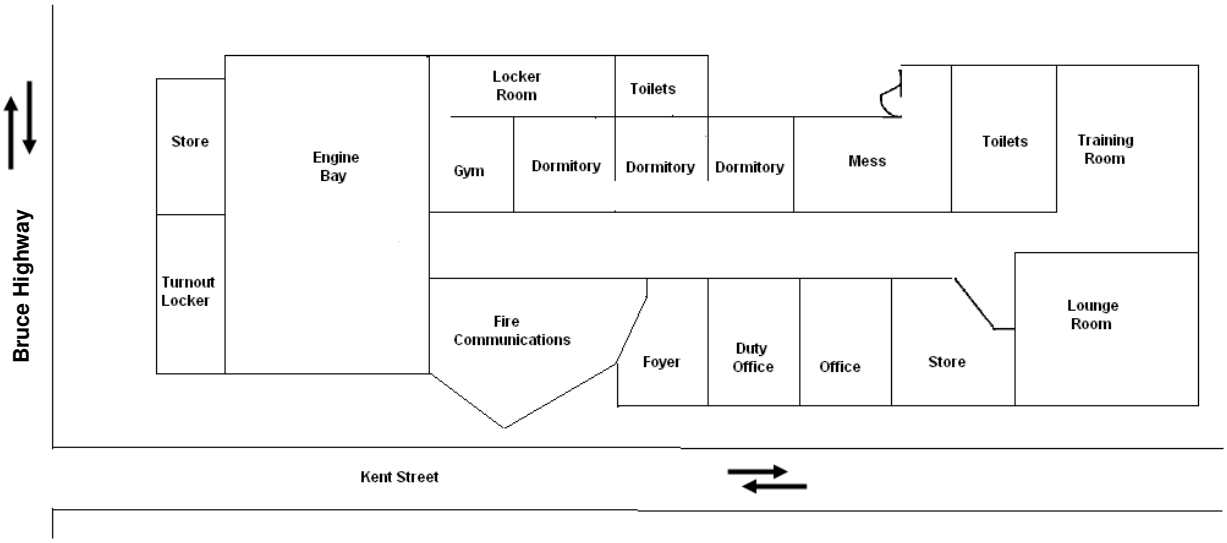
Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Review of QFRS Fire Station Data

Central Region

Rockhampton Fire Station
The Rockhampton fire station is an older style station built prior to 1970. It is the major station in the Rockhampton area, with three engine bays housing three fire fighting, one rescue and one appliance. The station is crewed by six fire fighters. A fire communications centre, above the engine bays, is staffed by three officers who are also impacted by the engine room activities. In 2007 there were 1666 reported responses.



Fire fighter exposures in the Rockhampton Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide
The instantaneous airborne sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations were measured during the station activities: start of shift checks, turn out and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results of all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Rockhampton – NO_2 (ppm)	n.d	0.5 ss	n.d	n.d	n.d	n.d
Rockhampton – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.2 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.13
Instantaneous concentrations of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) in Rockhampton fire station.

The airborne concentration of SO_2 and NO_2 were below the limit of detection (0.5 ppm) for the turn-out and return to station activities. The start of shift SO_2 concentration was below the limit of detection, but the NO_2 concentration was at the limit of detection of 0.5 ppm. The start of shift NO_2 concentration was above the state average of 0.2 ppm. The Rockhampton concentrations were less than the South East Qld[48] NO_2 (6 ppb) and SO_2 (1 ppb) and Brisbane[47] NO_2 (1.5 ppb) and SO_2 (8.2 ppb) average airborne concentrations.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentrations of carbon monoxide and hydrogen sulphide were continuously measured for as close as practicable to 10 Hr over a standard day. All measurements were recorded on instruments that logged peak concentrations over 1 minute averaging periods. All concentrations used in this study were peak concentrations to ensure any potential contamination by fire appliances was highlighted.

Sampling site location	Photo-ionisation detector (10.6 eV Lamp)		Multi Rae four gas detector			
	Total VOC (ppm)		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing			
			Hydrogen sulphide (ppm)		Carbon monoxide (ppm)	
	Rockhampton Station	State Average	Rockhampton Station	State Average	Rockhampton Station	State Average
Outside	0.0	0.5	0.4	0.1	0.8	0.7
Engine Bay	0.2	0.1	0.1	0.1	2.7	1.3
Duty Office	0.2	0.1	0.1	0.2	1.0	1
Dormitory	0.0	0.1	0.0	0.1	0.5	0.6
Mess / Lounge	n/a	n/a	n/a	-	n/a	-
L2 PPE Locker	0.4	0.2	0.1	0.1	2.5	1.4

Table 3.14

Time averaged concentrations for the air-borne contaminants, total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO) over a 10 Hr day shift.

Carbon Monoxide - total average concentrations

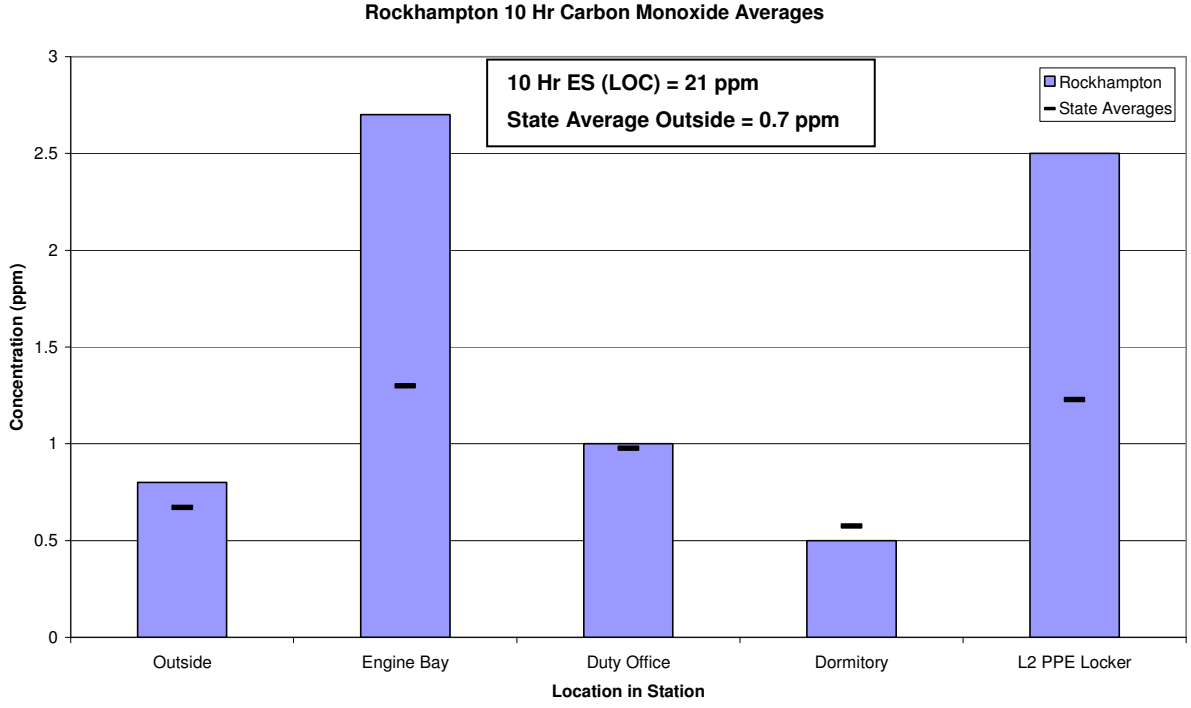


Figure 3.42

Time averaged carbon monoxide readings for a day shift at Rockhampton fire station.

Outside Station (Background)
The background carbon monoxide concentration (0.4 ppm) was less than the average concentration obtained across the state, and the South East Qld[46] airborne concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station were generally higher than the average background concentration. The highest concentrations were obtained in the engine bay (2.7 ppm) and turnout PPE locker (2.5 ppm), and both were above their respective state average concentrations. Nonetheless, both these concentration were *ca*. 14 times less than the (ES_{10} – 21 ppm) and lower than the NEPM concentration (9 ppm). There are several possible reasons for the discrepancy including location and office design, ventilation arrangements, and the presence of communications/computing equipment.

Carbon Monoxide - 10 Hr continuous monitoring
Figure 3.43 illustrates there were two activities where carbon monoxide excursions were observed within the station. These excursions corresponded to the start of shift check activities and station cleaning duties. In general, carbon monoxide excursions occurring during emergency response were measured only in the engine bay.

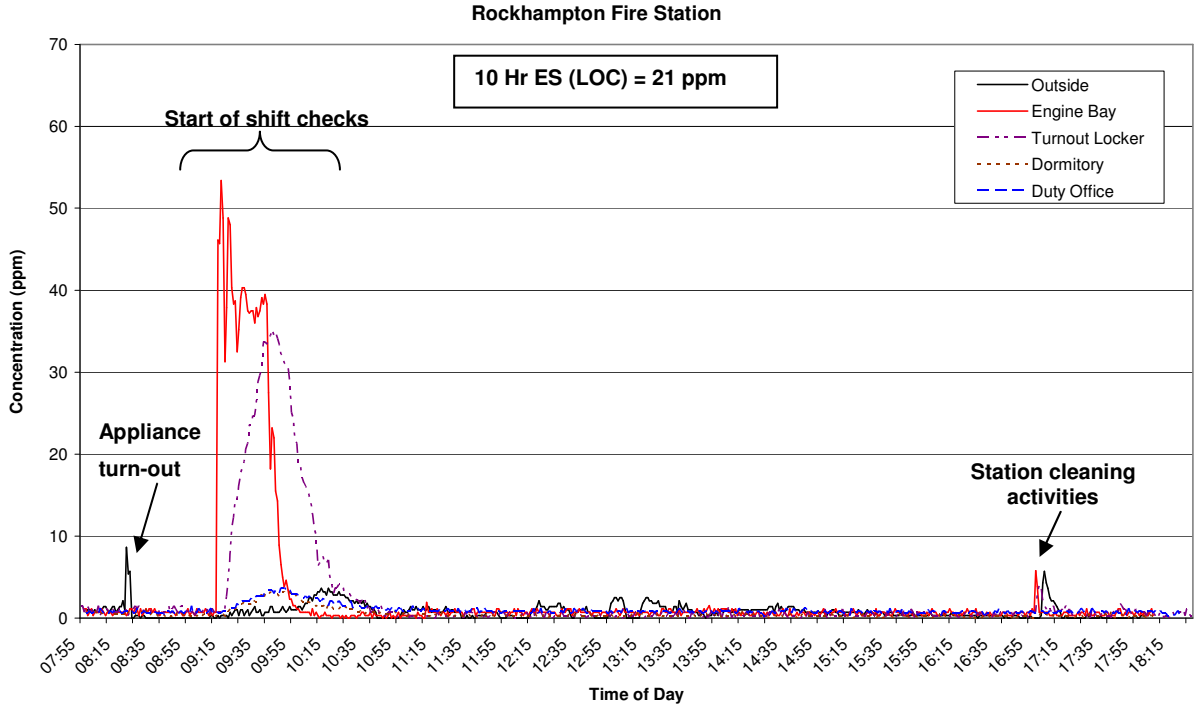


Figure 3.43
Carbon monoxide readings for a 10 Hr day shift at Rockhampton fire station.

The highest concentrations were obtained during the start of shift check (16 minutes), *i*.e. engine bay (53 ppm), and PPE locker (34 ppm). The PPE locker peak CO concentration occurs at a later time than the engine bay most likely because of the ventilation arrangements. Although the concentrations within the engine bay exceed the ES_{10} - 21 ppm, it did not exceed the NOHSC: *Guidelines for the control of short-term excursions for Carbon Monoxide* 30 minute limit of 100 ppm or 15 minutes limit of 200 ppm.

Hydrogen Sulfide - total average concentrations

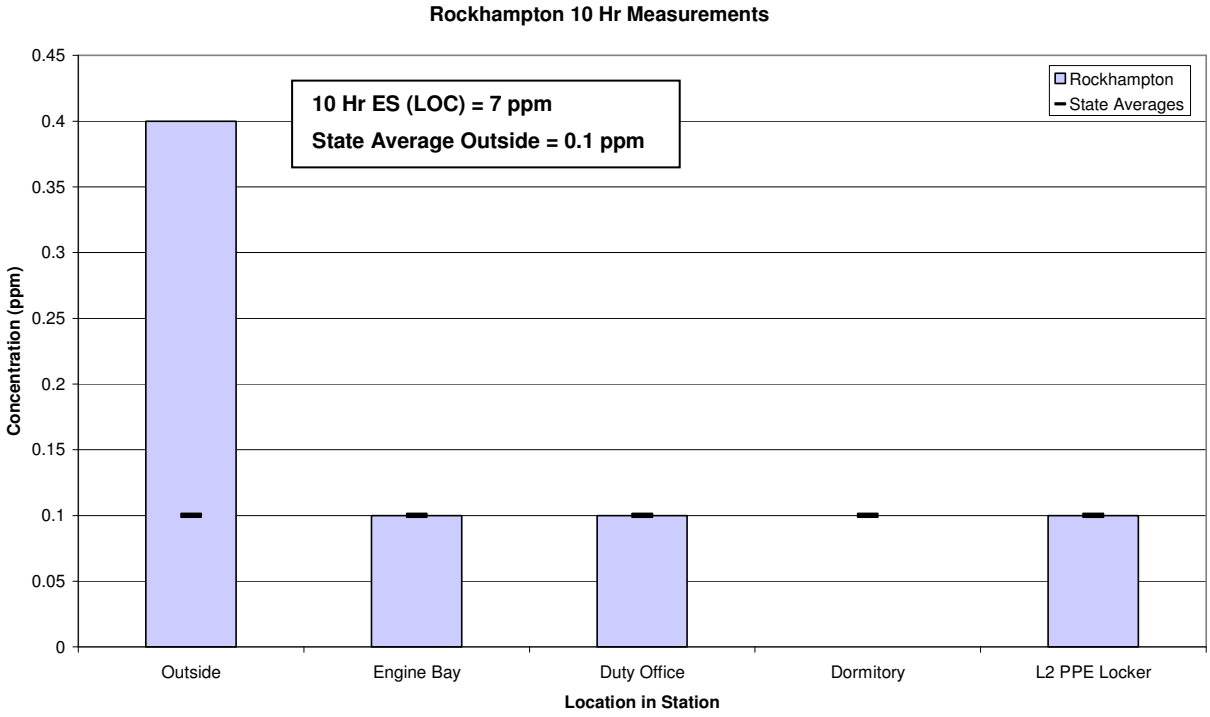


Figure 3.44
Time averaged hydrogen sulfide readings for a day shift at Rockhampton fire station.

Outside Station (Background)
The background hydrogen sulfide concentration (0.4 ppm) is significantly higher than the average background concentration (0.1 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station were equal to or less than the average background concentration, which is significantly less than the (ES_{10} – 7 ppm).

Hydrogen Sulfide - 10 Hr continuous monitoring
Figure 3.45 below, illustrates excursions occurred during the start of shift check (16 minutes) within the engine bay and the PPE locker. A further excursion was measured outside the station later during the day, which may be explained by heavy vehicle traffic driving past and idling at the intersection adjacent to the monitoring bay. The highest concentrations were obtained during the start of shift check, *i.*e. engine bay (2.6 ppm) and PPE locker (2.1 ppm), which is consistent with the position of the appliances and the PPE locker entry being immediately adjacent to the appliance exhausts. These concentrations do not exceed the ES_{10} of 7 ppm. The results could explain odours detected by fire fighters during shift checks etc.

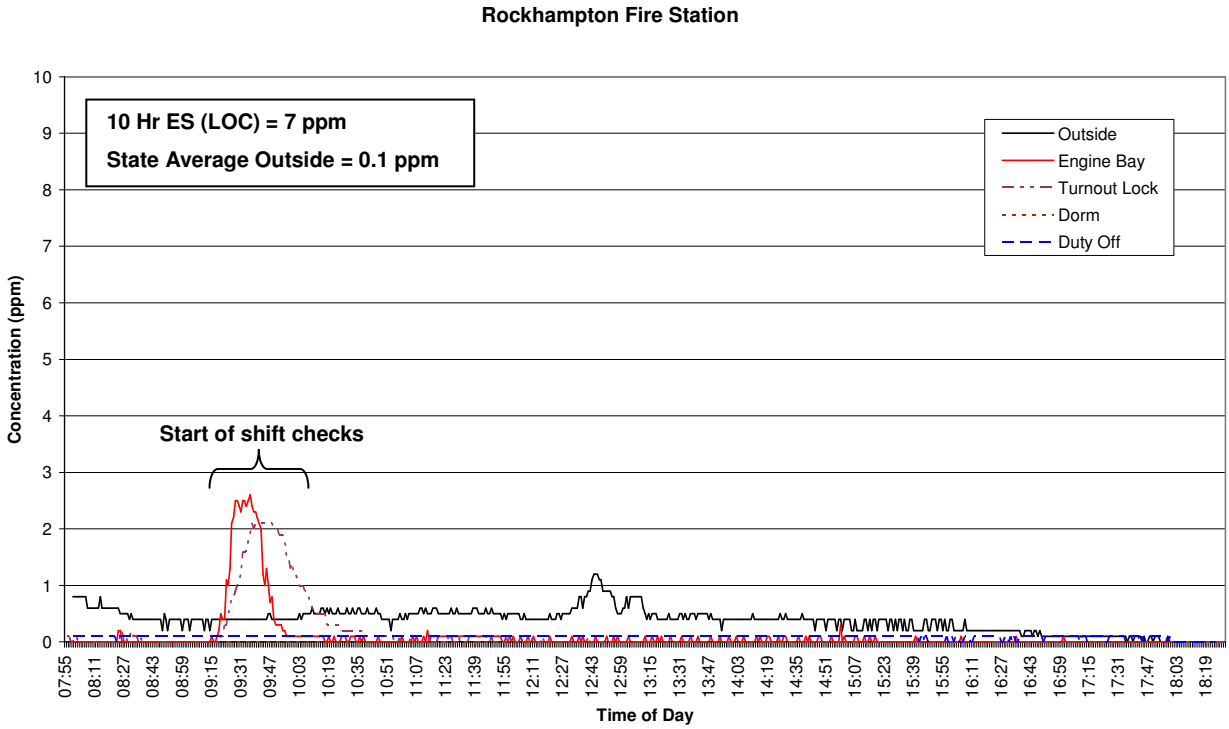


Figure 3.45
Hydrogen Sulfide readings for a 10 Hr day shift at Rockhampton fire station.

Atmospheric Contaminants – total volatile organic compounds of concern
The total volatile organic compounds (tvoc's) results for Rockhampton station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. The tvoc's were measured for as close as practicable to 10 Hr over a standard day. All measurements were continuously recorded on instruments that logged peak concentrations over 1 minute averaging periods to ensure any potential contamination by fire appliances was highlighted.

Outside Station (Background)
The Rockhampton average background concentration (< 0.1 ppm) was significantly less than the average concentration (0.5 ppm) obtained across the state and the QFRS established level of concern (0.5 ppm).

Inside Station (10 Hr monitoring)
Figure 3.46 below, shows the average concentrations obtained within the station were similar to the Rockhampton background concentration except in the engine bay (0.2 ppm), duty office (0.2 ppm) and the PPE locker (0.4 ppm), which are all above the Rockhampton outside measurement and their respective area state averages. However all areas are less than the QFRS established level of concern (0.5 ppm).

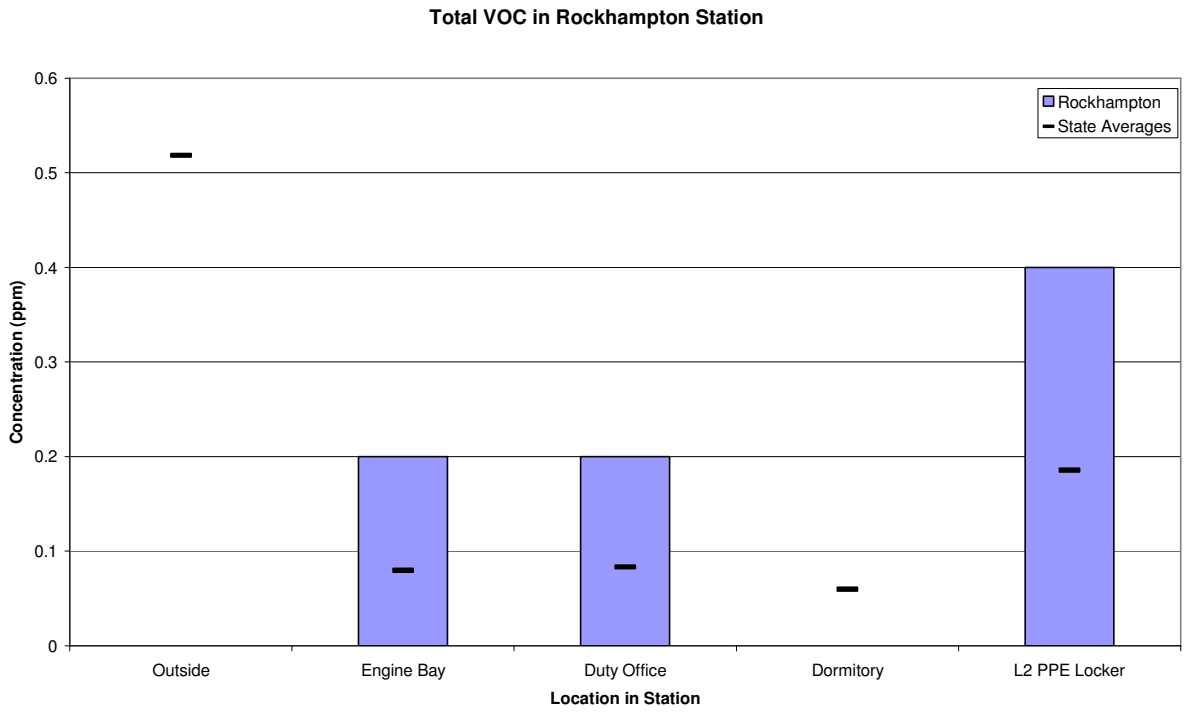


Figure 3.46
Volatile organic compounds readings for a 10 Hr day shift at Rockhampton fire station.

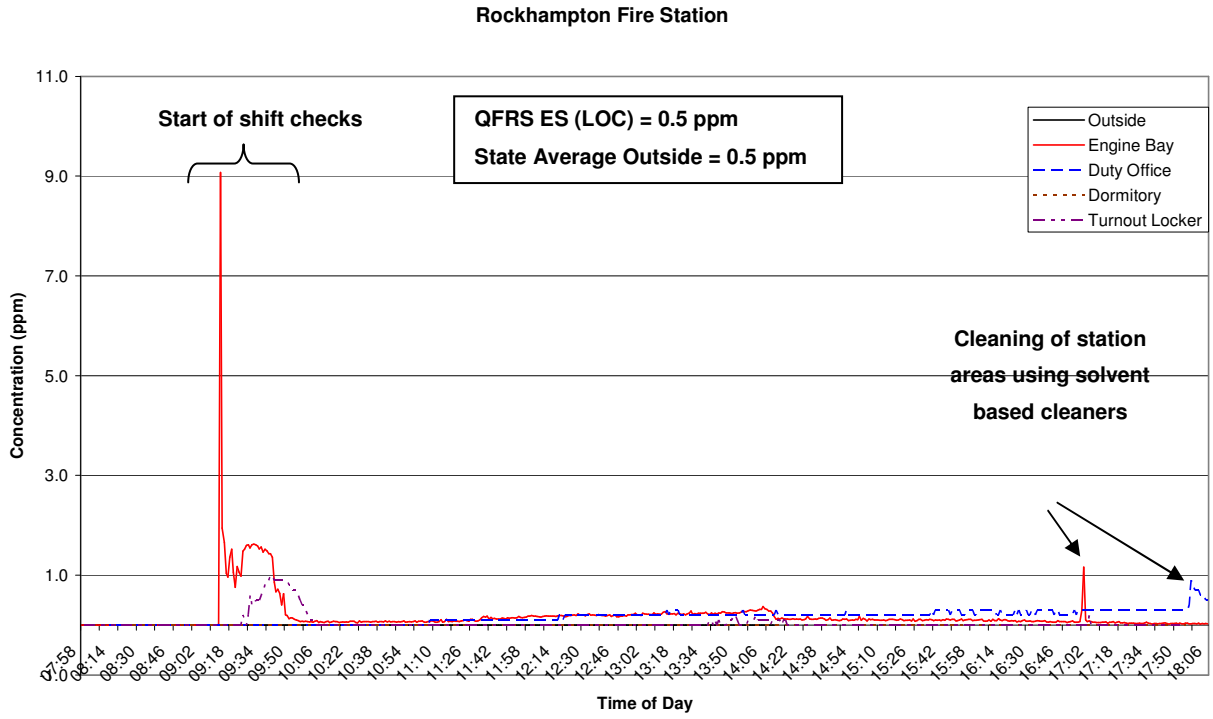


Figure 3.47
Total volatile organic compounds readings for a 10 Hr day shift at Rockhampton fire station.

The highest tvoc concentrations were observed during the start of shift checks (16 minutes) in the engine bay (9.1 ppm) and PPE locker (1.0 ppm). Both area measurements exceeded the

QFRS LOC of 0.5 ppm and the state outside average (0.5 ppm). However, once these tasks were performed and the engine bay doors opened, both areas quickly dropped to normal levels, *i.e*. less than the 0.5 ppm tvoc.

One other peak latter in the afternoon was detected in the engine bay (1.0 ppm) area, which coincided with station cleaning activities. A number of appliances had been returned to the station up to 30 minutes prior to the peak.

Atmospheric Contaminants – hexane, benzene, toluene and xylene

The voc results used for Rockhampton station used reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. Together with the above measurements of total volatile organic compounds, samples were collected using of evacuated gas canisters, absorbent tubes, and Dräger stain tubes to measure for the specific voc's of interest; aldehydes, hexane, benzene, toluene and xylene. These voc's are important due to their sources from petrol and diesel exhausts and the extensive use daily. Benzene is typically generated by diesel exhausts and hexane is typically found in petrol motor exhausts. The toluene and xylene are components of diesel exhausts, but also found as paint solvents and other degreasing mixtures. This is important as any stations or surrounding areas that had recent building activity and subsequent painting may have elevated levels.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<2.6*	1	<1.7*	<2.2*	1	<1.6*	<1.9*	<1	<3.2*	<2.4*	<1	<1.7*	<46.7*	<29.3*
Engine Bay			1.9	<1.7*		7.8	24		1.2	<17.7*		1.7	<1.7*		<29.3*
Start of Shift	<0.5	119			170			141			161			<197*	
Turnout	<0.5	<3.8*			<3.2*			<2.8*			<3.4*			<164*	
Return	<0.5	<8.9*			<2.2*			<2.8*			<7.8*			<167*	
Duty Office	<0.5		1	<1.7*		1.3	<1.6*		<1	<3.2*		1.3	<1.7*		<29.3*
Dormitory	<0.5	3.8	1	<1.7*	<3.4*	1.3	<1.6*	2.5	<1	<3.2*	27.4	<1	<1.7*	<46.7*	<29.3*
Mess area	<0.5		1	<1.7*		1.2	<1.6*		<1	<3.2*		<1	<1.7*		<29.3*
PPE Locker	<0.5	4.1			20.2			10.1			15.3			<50.1*	

Table 3.15
Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Rockhampton fire station over a day shift.

Atmospheric Contaminants – hexane

Figure 3.48 (below) shows the hexane background concentrations outside Rockhampton fire station was at or below the R.L. (<1.0 ppb) and the average background concentration (1.1 ppb) across the state. The average concentrations in all areas within the station were at or below the R.L. except the duty office and engine bay. All concentrations were below the average state hexane concentrations for station areas, except the engine bay (1.7 ppb), which is more than 7000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 14 000 ppb. The ambient benzene airborne concentrations in South East Qld[46] is 0.8 ppb (range: 0.4 to 1.5 ppb) and Brisbane[48] is 3.3 ppb (range: 0.43 to 10.33 ppb). The benzene odour threshold is 65 000 ppb.

The hexane concentrations obtained after the start of shift check, turnout simulation, and return simulation were 162 ppb, < R.L. (3.4 ppb) and <R.L. (7.8 ppb) respectively. These concentrations are higher than the background concentration and the start of shift concentration is *ca*. 86 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.

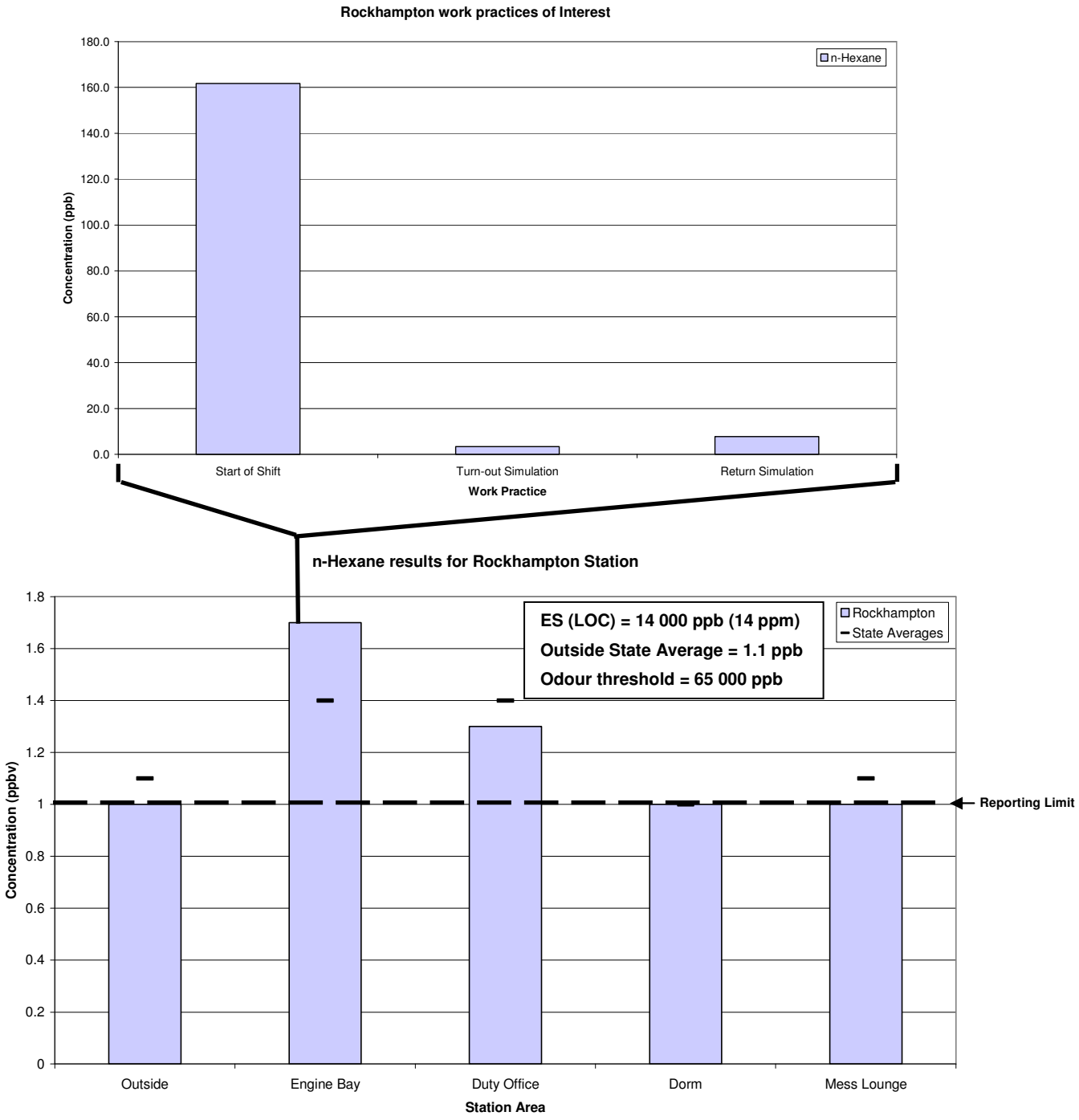


Figure 3.48
Hexane concentrations from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

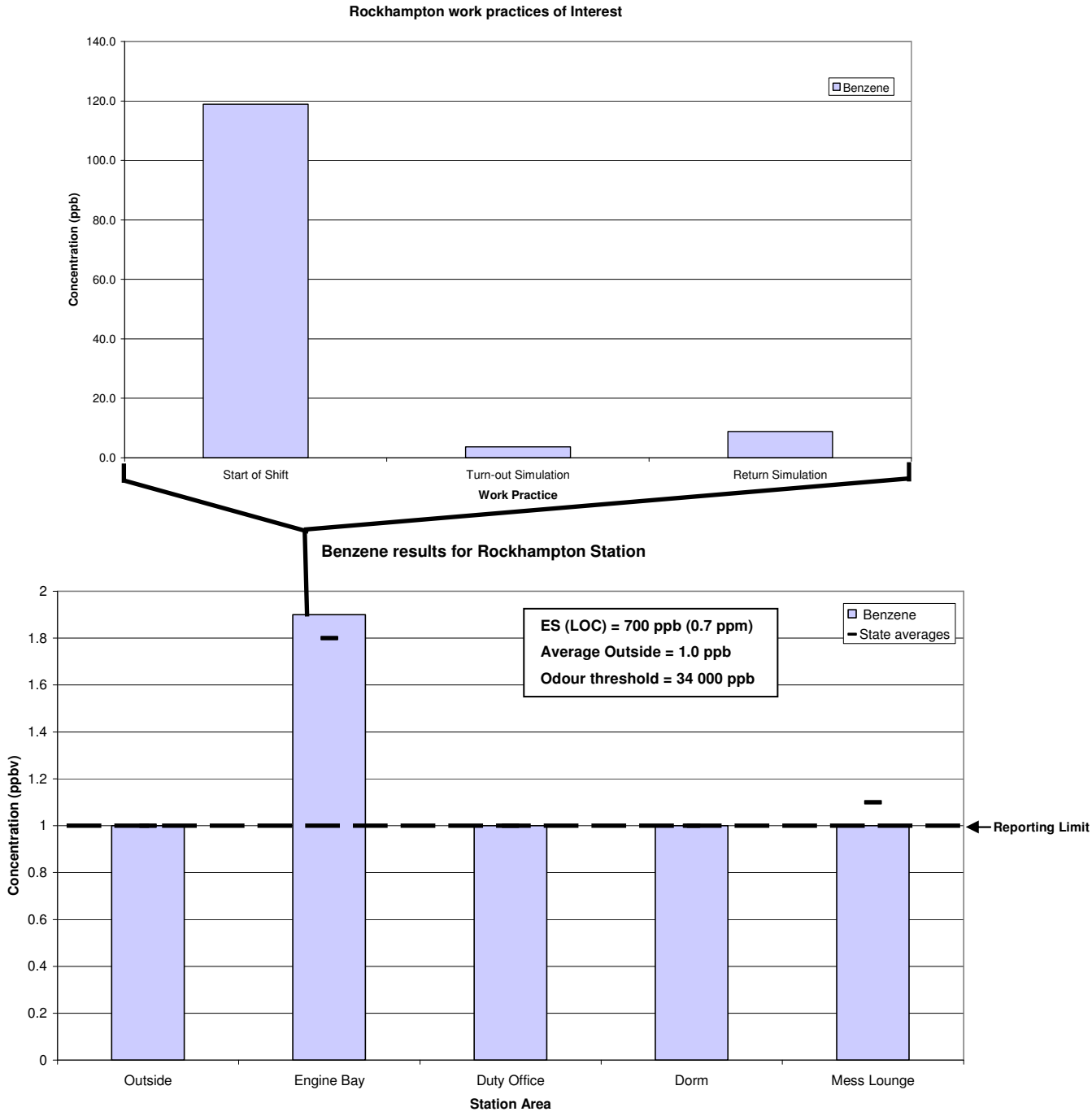


Figure 3.49
Benzene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

Outside Station (Background)
The benzene background concentration was at or below the R.L. (<1.0 ppb) and was similar to the average background concentration across the state. This background result is less than the benzene airborne concentrations in South East Qld[46] - 0.8 ppb (range: 0.4 to 1.5 ppb) and Brisbane[48] - 3.3 ppb (range: 0.43 to 10.33 ppb).

The average concentrations in all areas within the station were at or below the R.L., except the engine bay (1.9 ppb), which is more than 300 times less than the ES_{10} of 700 ppb. This background result is less than the benzene airborne concentrations in South East Qld[46] and Brisbane.[48] The benzene odour threshold is 34 000 ppb.

The benzene concentration observed after the start of shift check (16 minutes), turnout simulation, and return simulation were 119 ppb, <3.8 ppb and <8.9 ppb respectively. These concentrations are higher than the background concentration of benzene. The start of shift concentrations is greater than the average concentration (28 ppb) and the turn out/return simulation concentrations were less than the average concentrations (5.3 ppb and 16.5 ppb respectively). The highest concentration is *ca*. 6 times less than the ES_{10} of 700 ppb. The average benzene airborne concentration in Brisbane[48] was 3.3 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – toluene

Outside Station (Background)
Figure 3.50 below, shows the toluene background concentration was at or below the R.L. (<1.0 ppb) and similar to the average background concentration across the state. This background result is similar to the average toluene airborne concentrations in South East Qld[46] - 1.6 ppb (range: 0.7 to 4.9 ppb) and Brisbane[48] - 10.6 ppb (range: 1.8 to 83 ppb).

The average concentrations in all areas within the station were less than the average toluene concentrations obtained across the state, except the engine bay (7.8 ppb), which is *ca*. 4400 times less than the ES_{10} of 35 000 ppb. The odour threshold for toluene is 160 ppb.

The toluene concentration observed after the start of shift check (16 minutes), turnout simulation, and return simulation were 170 ppb, <3.2 ppb and <2.2 ppb respectively. These concentrations are higher than the background concentration. The start of shift concentration is greater than the average toluene concentration (83.6 ppb). The turn-out and return to station concentrations are less than the average toluene concentrations (14.5 ppb and 6 ppb respectively). The highest concentration is *ca*. 200 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

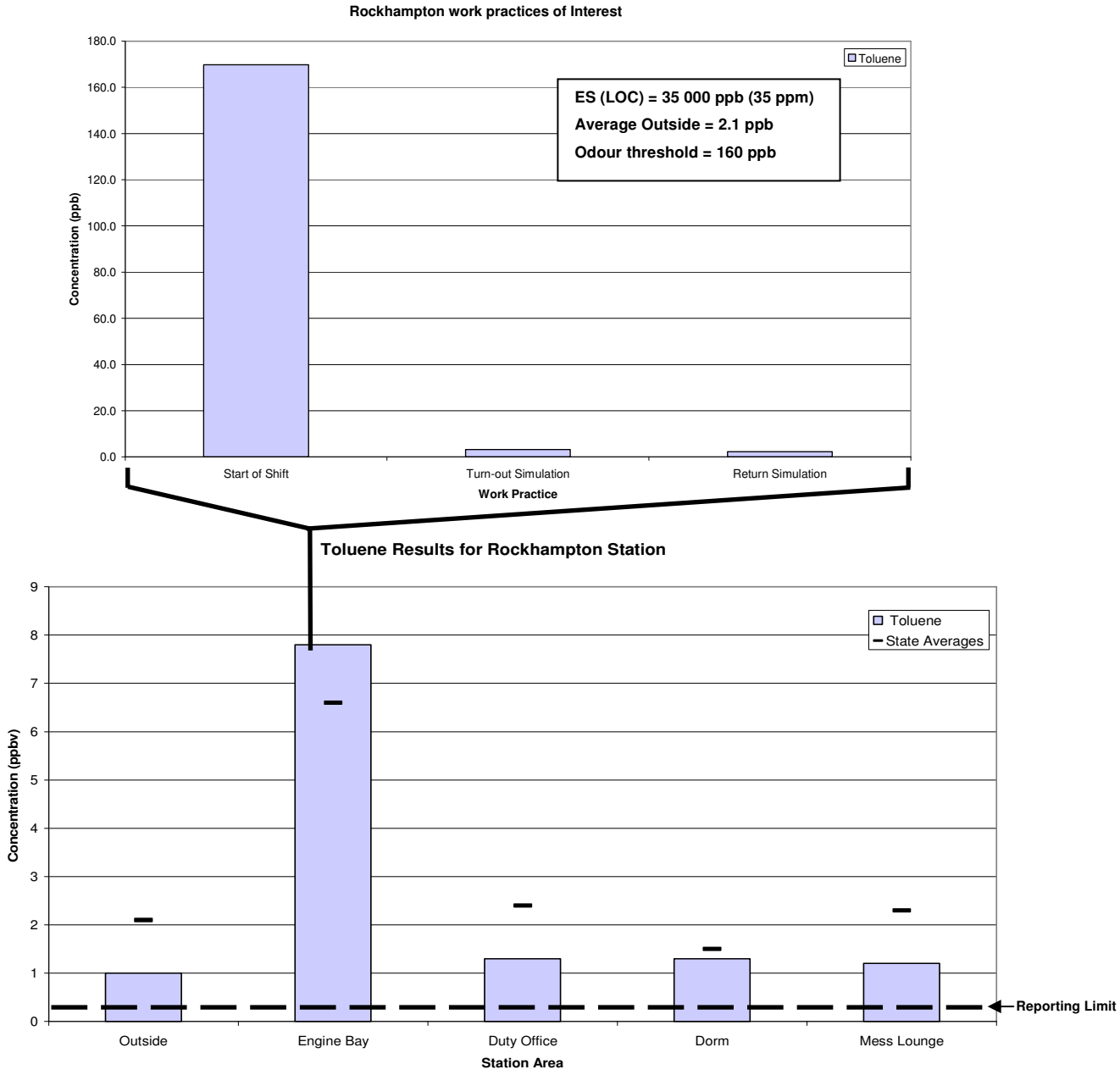


Figure 3.50
Toluene concentrations from evacuated canisters controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – xylene

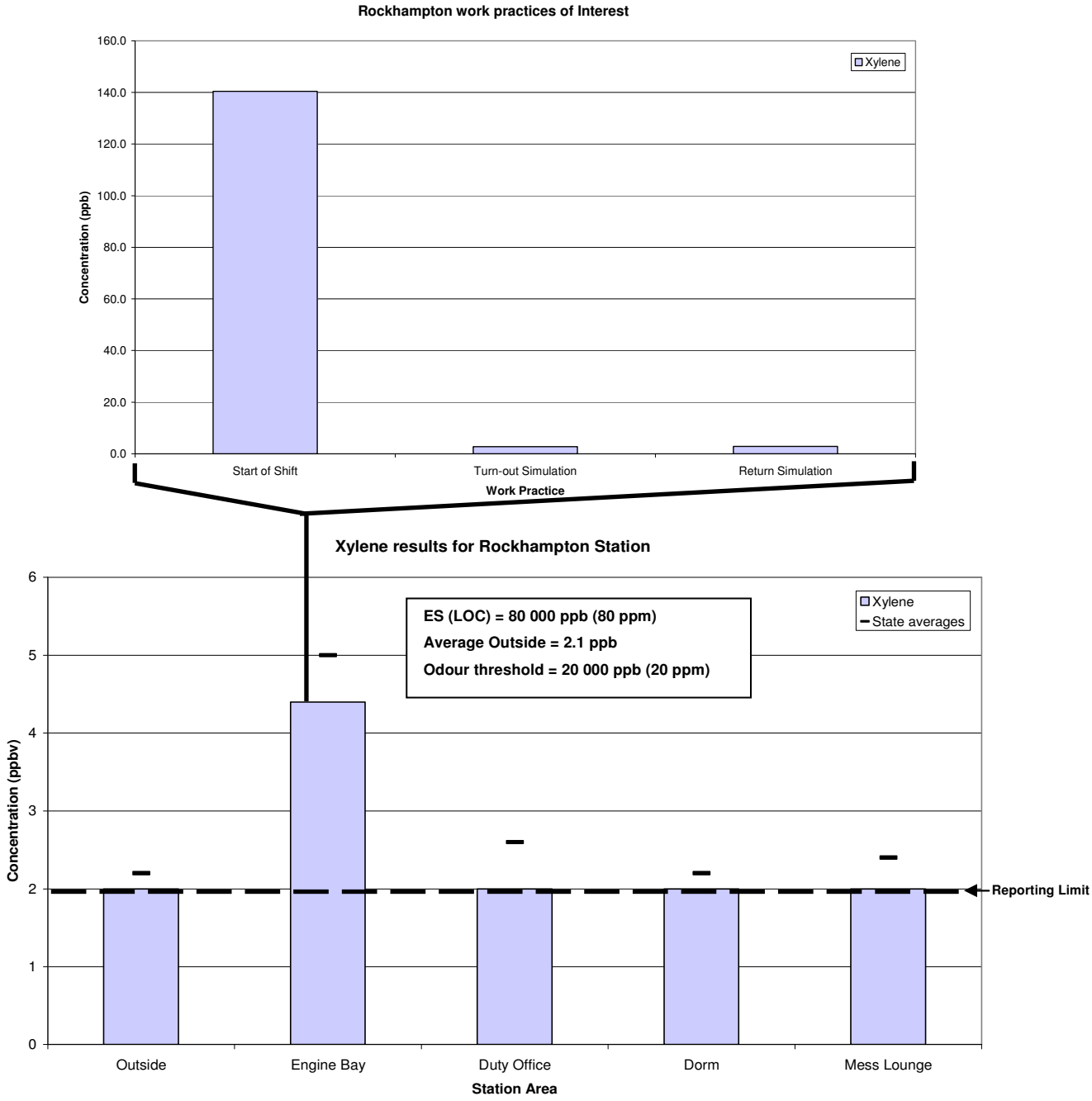


Figure 3.51
Xylene concentrations for a 10 Hr day shift at Rockhampton fire station areas. All canister analyses for xylene were reported as the isomers *m-* / *p*-xylene and *o*-xylene. For this report all concentrations were added to give total xylene concentration and the reporting limit was doubled (< 2.0 ppb).

Outside Station (Background)
The xylene background concentration was 2 ppb and less than the average background concentration across the state. This background result is significantly less than the xylene airborne concentrations in South East Qld[46] (range: 2.5 to 8 ppb with an average of 4.5 ppb) and Brisbane[48] (range: 0.2 to 28 ppb with an average of 3.4 ppb). The South East Qld results were reported as *p*-xylene data, but calculated as total xylene based on *p*-xylene being 20% of

the total xylene concentration). The Brisbane data was based on the addition and averaging of the *m-&p*-xylene with the *o*-xylene.

The xylene results for Rockhampton station showed all areas, except the engine bay (4.4 ppb), were lower than the Rockhampton outside (2.0 ppb), outside state average (2.2 ppb) and the respective state-wide averages for the station areas. Although the Rockhampton engine bay was higher then the outside measurements, it was lower than the engine bay state average (5.0 ppb). The engine bay measurement was more than 12 500 times below the ES_{10} of 56 000 ppb. The Brisbane[48] average xylene concentration in ambient air reported the air was 3.4 ppb (average of two means for o-xylene and m/p-xylene). The xylene odour threshold is 20 000 ppb.

The xylene concentration obtained after the start of shift check (16 minutes), turnout simulation, and return simulation were 141 ppb, <2.8 ppb and <2.9 ppb respectively. These concentrations are higher than the background concentration of xylene. The start of shift concentration was greater than the average xylene concentrations (105 ppb). The other concentrations are less than the average state concentrations. Nonetheless, the highest concentration is approximately 400 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions and these explanations readily account for the observations.

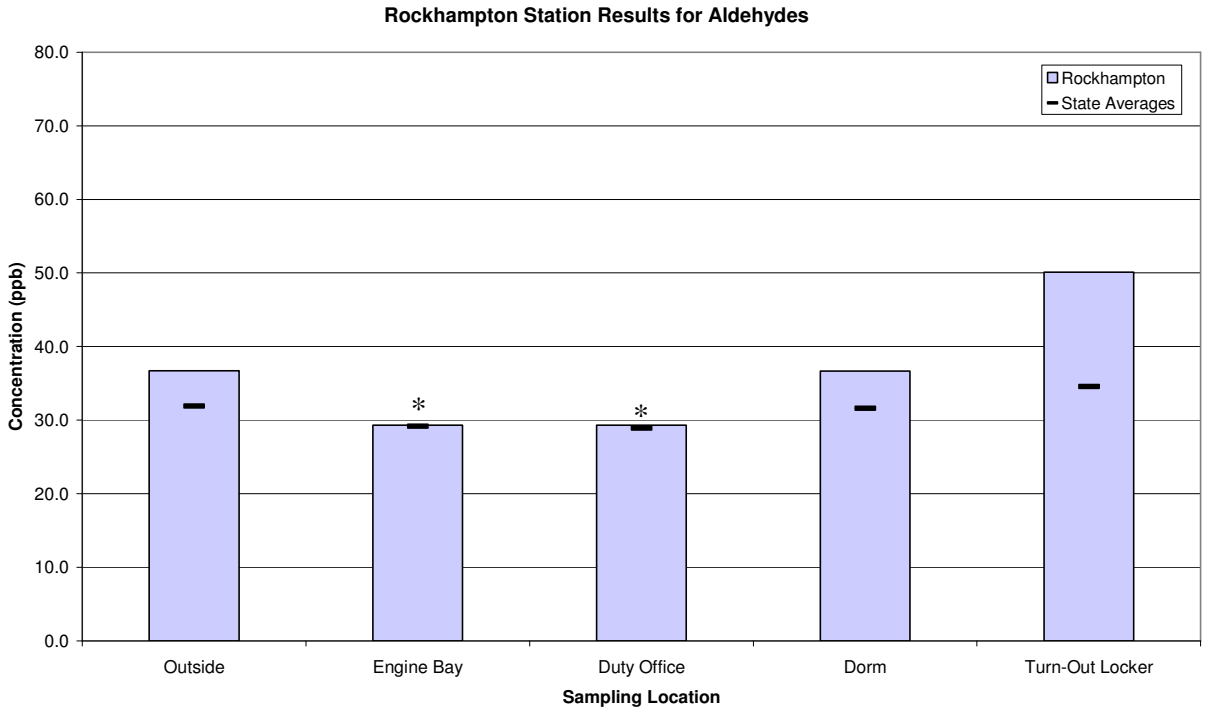
Atmospheric Contaminants – aldehydes

Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes. These voc's are important due to their presence in diesel exhaust and their potential as respiratory and eye irritants. Aldehydes are typically formed in combustion processes and so may form from diesel exhaust, fires where PPE is worn and potentially transported back to station and numerous industrial processes in nearby premises to stations.

Outside Station (Background)

Figure 3.52 below, shows the total aldehyde concentration is obtained from the summation of the concentrations of the following aldehydes: valeraldehyde, *p*-tolualdehyde, propionaldehyde, methacrolein, hexaldehyde, crotonaldehyde, buturaldehyde, benzaldehyde, acrolein, acetaldehyde, formaldehyde. The total aldehyde background concentration outside Rockhampton fire station (37 ppb) is similar to the average background (36 ppb) concentration across the state. All state area results, except the PPE locker (50 ppb), are at or below the Rockhampton outside. The total aldehyde concentration in the PPE locker area was higher than the state average (38 ppb).

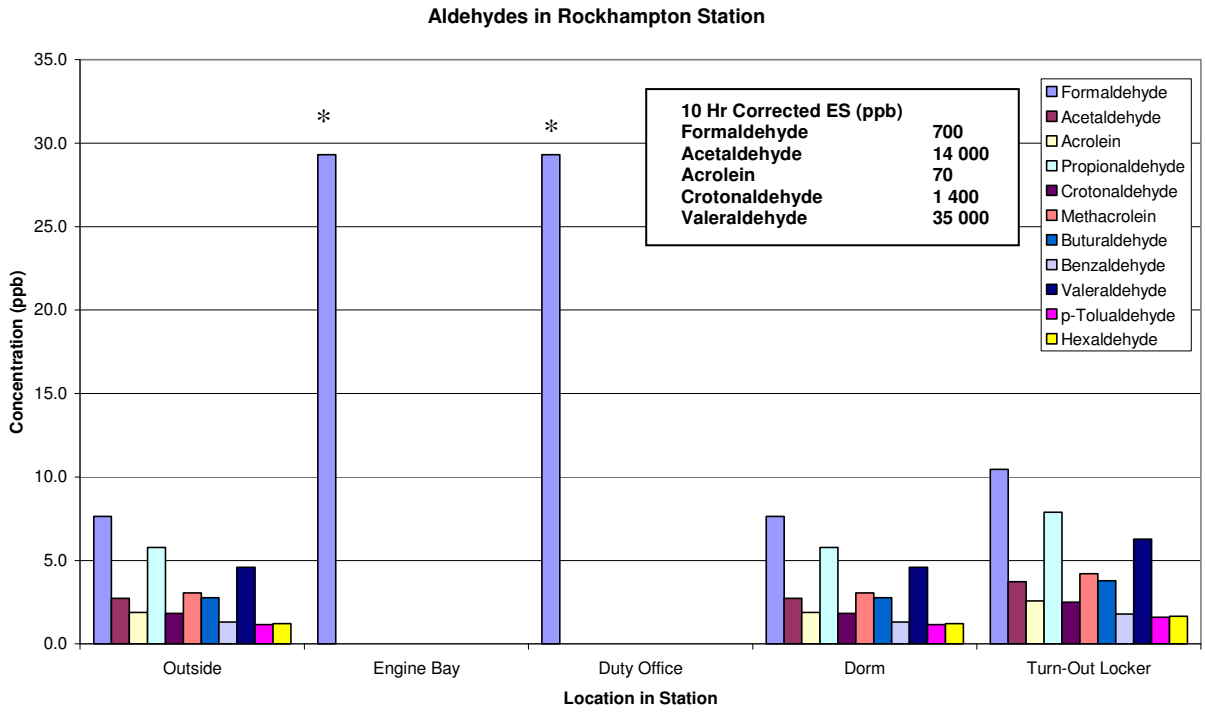
Figure 3.53 below, shows the total aldehyde concentrations within the engine bay and duty office were both 29 ppb, which is similar to the state average concentrations (28.5 ppb and 29.2 ppb). However, these latter results were obtained on passive diffusion badges and only formaldehyde was reported. The highest concentration is more than 24 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. All acrolein measurement were at or below the R.L, which is more than 70 times below the acrolein 10 Hr time corrected exposure standard ES_{10} of 70 ppb.



* Results from passive badges

Figure 3.52

Total aldehyde concentrations in areas of interest for a 10 Hr day shift at Rockhampton fire station. For this report when a result of <R.L occurred, the R.L concentration was used.



* Results from passive badges

Figure 3.53

Aldehydes detected for a 10 Hr day shift at Rockhampton fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

Atmospheric Contaminants – Particulate Matter
Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

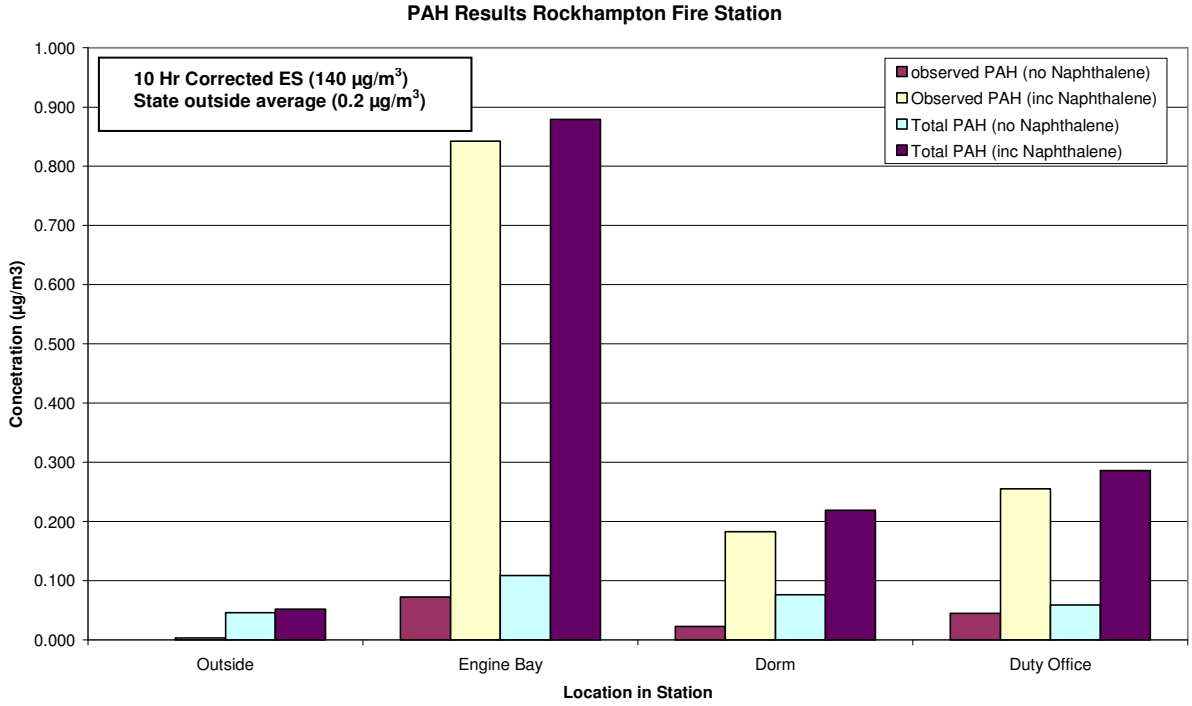
Polyaromatic Hydrocarbons
The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 and time adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard for PAH. Some individual PAH have established NES such as naphthalene - ES (52 mg/m³ or 52 000 µg/m^3) and a 10 Hr time corrected ES_{10} (36.4 mg/m³ or 36 400 µg/m^3). If the result was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case for a specific location.

	Rockhampton Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	**10700**	**3730**	<RL
Fluoranthene	<RL	**8020**	**3230**	<RL
Anthracene	<RL	**4450**	<RL	<RL
Phenanthrene	<RL	**21100**	**22700**	**14300**
Fluorene	<RL	**28000**	**15500**	**8670**
Acenaphthene	<RL	<RL	<RL	<RL
Acenaphthylene	<RL	**10700**	**3730**	<RL
Naphthalene	3500	770000	210000	160000
Reporting Limit	3500	4100	3100	3000
Total PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	<0.004	0.07	0.05	0.02
Total with Naphthalene (µg/m^3)	<0.004	0.84	0.26	0.18
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3) to better reflect a measurable quantity				
Total without Naphthalene (µg/m^3)	0.05	0.11	0.08	0.06
Total with Naphthalene (µg/m^3)	**0.05**	**0.88**	**0.29**	**0.22**
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.16
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Rockhampton fire station.

Outside Station (Background)
The PAH background concentration (0.05 µg/m^3) was less than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs, fluorene and naphthalene were detected outside the station. Care should be shown with these total results as they are derived from the addition of mostly reporting limit concentrations.

Inside Station (10 Hr monitoring)
The PAH concentration within the fire station were greater then the PAH background concentration. The concentrations were greater than the average PAH concentrations obtained across the state. The highest PAH occurred in the engine bay and was more than 150 times less than the PAH-ES_{10} 140 µg/m^3. The non-carcinogenic listed PAHs, Pyrene, fluoranthene, phenanthrene, fluorene and naphthalene were detected in the station.



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.54

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Rockhampton fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

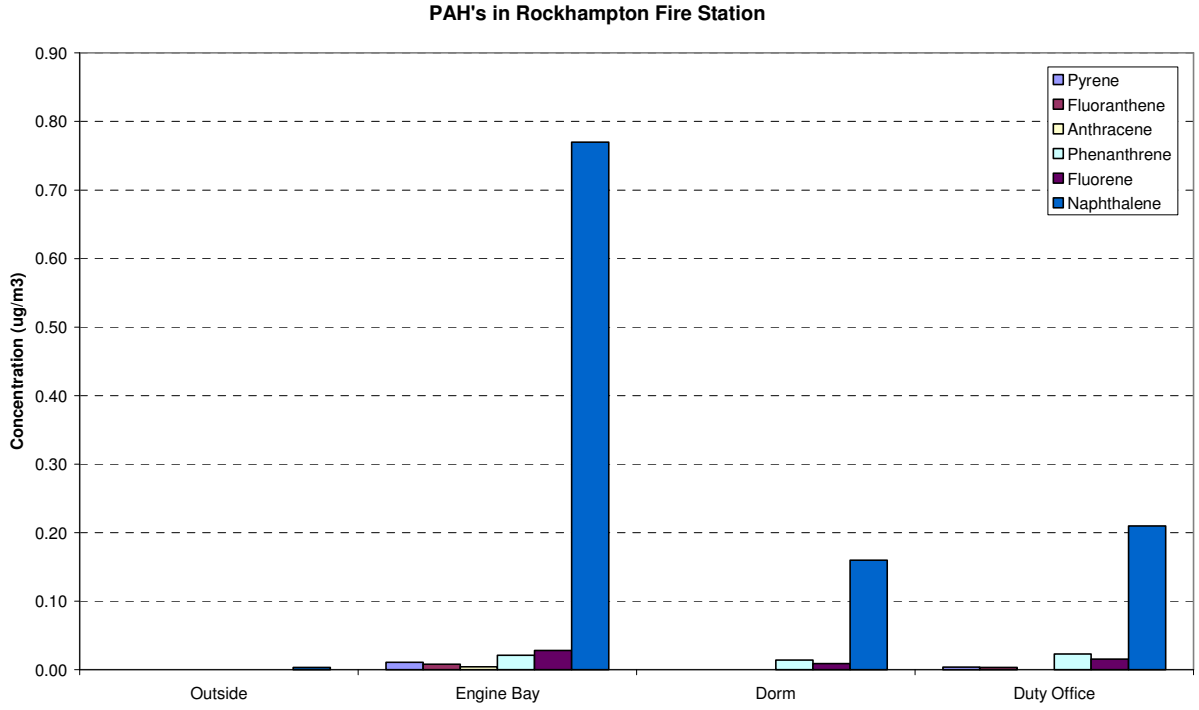


Figure 3.55

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Rockhampton fire station.

The results demonstrate naphthalene is the most significant contributing PAH to the total PAH concentration. This trend is consistent across all areas of the fire station and few if any other PAHs are detected. The highest estimated naphthalene concentration in any area is more than 50,000 times below the established ES_{10} 10 500 µg/m^3 and more than 950 times below the naphthalene odour threshold (200 µg/m^3).

Diesel Particulate Matter

Diesel particulate matter (DPM) has been described extensively in chapter one. Although there is no established ES, a level of concern (LOC) of 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L), the R.L value was used. A recent review[33] reported that US fire fighter DPM exposure to DPM is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

10 Hr monitoring Station

The DPM background concentration was at or below the reporting limit (R.L. – 0.001 mg/m^3 EC) and is less than the average background DPM concentration across the state (0.002 mg/m^3 EC). The DPM R.L. is more than 100 times less the established level of concern (0.1 mg/m^3 EC). The average concentration in the duty office was at or below the R.L., whilst the engine bay and dormitory were 0.002 mg/m^3 EC. The concentration for the engine bay is less than the average concentration obtained across the state, whilst the dormitory concentration is the equal highest concentration across the state. Nonetheless, the measured concentrations are more than 50 times less the established LOC (0.1 mg/m^3 EC).

Station Activity monitoring

The DPM concentration obtained after the start of shift check (16 minutes) was (0.06 mg/m^3 EC), which is greater than the state average start of shift concentration (0.044 mg/m^3 EC – including the Firepac 3000 Mk 3 measurement). This concentration is *ca*. 40% less than the established level of concern when the engine bay doors are closed and no deliberate ventilation applied to remove the exhaust emissions. The Rockhampton station engine bay design features and appliance density may have contributed to the result.

The DPM concentration obtained after the turnout simulation(0.027 mg/m^3 EC) and return simulation (0.032 mg/m^3 EC) were greater than the state turn-out average (0.009 mg/m^3 EC) and return average (0.013 mg/m^3 EC), but *ca*. half of the Rockhampton start of shift concentration. However, they are about 3 times less than the level of concern respectively.

The DPM concentration obtained after the turnout simulation, and return simulation were 0.027 and 0.032 respectively. These are the lowest results reported for these activities and are less than the state turn-out average (0.009 mg/m^3) and state return average (0.013 mg/m^3).

There are several explanations to account for these results, including engine bay design, ventilation, two appliance response and in particular the reversal of appliances into the engine bay after returning. Despite the two different fire appliance movement directions there is little difference between the results for the turnout and return to station.

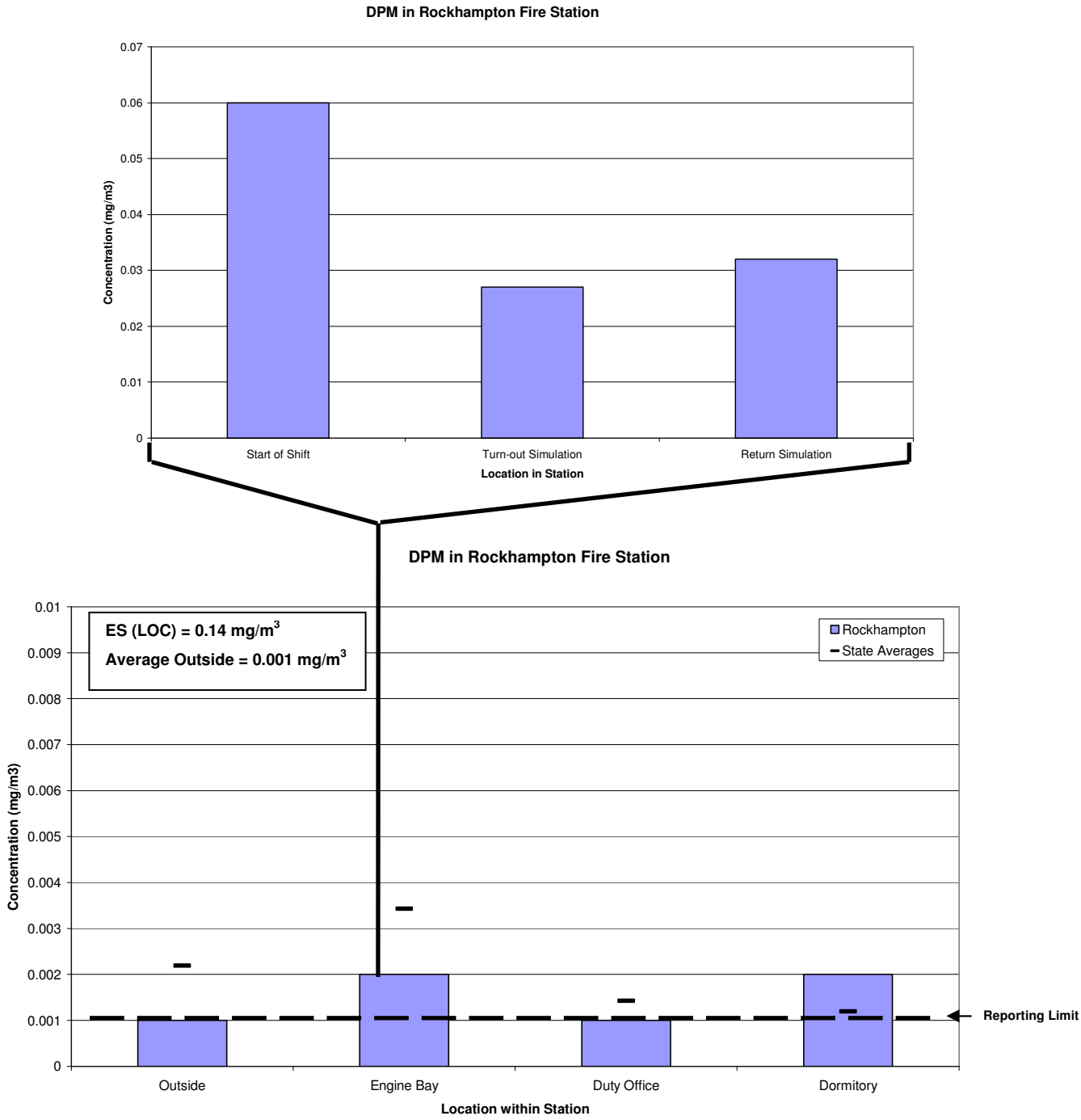


Figure 3.56

DPM concentrations for Rockhampton station was based on 10 Hr shift (dorm, eng. Bay, duty office and outside) and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Rockhampton Results

The Rockhampton station trials showed that the start of shift checks resulted in NO2 exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.05	0.001	1	1	<1	<1	<46.7	<0.5	<0.5	0.8	0.4	0.0
Engine Bay	0.88	0.002	1.9	7.8	1.2	1.7				2.7	0.1	0.2
Start of Shift		0.06	119	170	141	161	<197	0.5	<0.5			
Turnout		0.027	<3.8	<3.2	<2.8	<3.4	<164	<0.5	<0.5			
Return		0.032	<8.9	<2.2	<2.8	<7.8	<167	<0.5	<0.5			
Duty Office	0.29	0.001	1	1.3	<1	1.3	<29.3	<0.5	<0.5	1.0	0.1	0.2
Dormitory	0.22	0.002	1	1.3	2.5	<1	<46.7	<0.5	<0.5	0.5	0.0	0.0
Mess/Lounge			1	1.2	<1	<1	<29.3	<0.5	<0.5			
PPE Locker			4.1	20.2	10.1	15.3	<50.1*	<0.5	<0.5	2.5	0.1	0.4

The greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

Also replacing non-sealed or semi-sealable doors between the station areas and engine bay would reduce the potential for diesel exhaust entering the station areas.

The hole in the wall separating the engine bay and the PPE locker, which has a negative pressure with respect to the engine bay, results in diesel exhausts passing from the engine bay to the PPE locker.

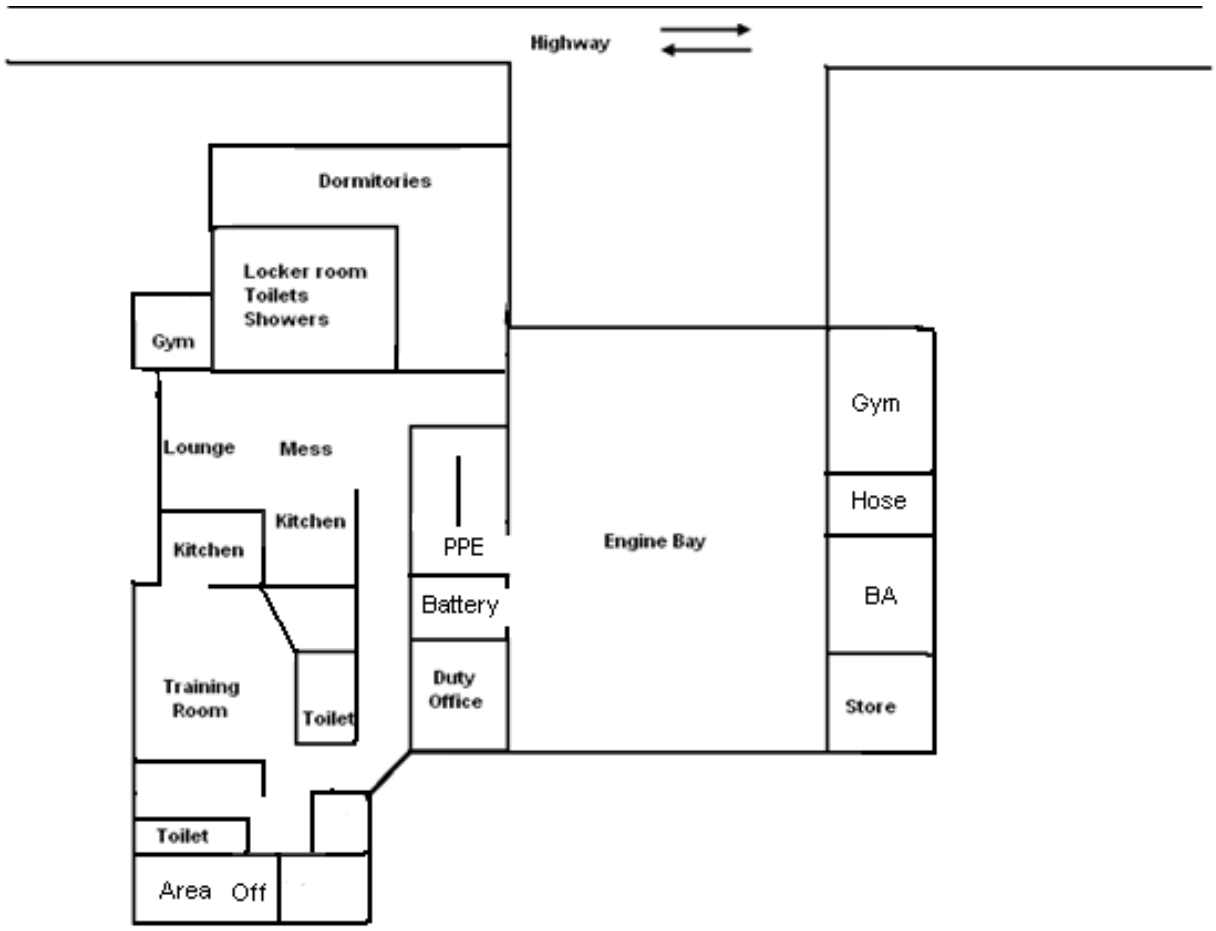
Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Review of QFRS Fire Station Data

North Coast Region

Maroochydore Fire Station

The Maroochydore fire station is a newer style station built in1995. It has two engine bays housing one fire fighting and one rescue appliances. The station adjoins to the local ambulance station and is staffed by six fire fighters. In 2007 there were 1316 reported responses.



Fire fighter exposures in the Maroochydore Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations were measured during the station activities: start of shift checks, turn out and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results of all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Maroochydore – NO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Maroochydore – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.2 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.17

Concentration of airborne nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

The airborne concentration of NO_2 and SO_2 were below the R.L (0.5 ppm) for all activities, which is at the average concentration for all fire stations. These concentrations are also less than the average airborne concentrations in South East Qld[46] NO_2 (6 ppb) and SO_2 (1 ppb) and Brisbane[47] NO_2 (1.5 ppb) and SO_2 (8.2 ppb).

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift. The measurements are reported as peak concentrations over 1 minute averaging periods.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**	**Multi Rae four gas detector**	
	Total VOC (ppm)	Note: LFL (0%) and oxygen (20.9%) were constant through-out testing	
		Hydrogen sulphide (ppm)	Carbon monoxide (ppm)
Cairns			
Outside	0.0	0.1	0.4
Engine Bay	0.0	0.1	1.0
Duty Office	0.0	0.1	0.9
Dormitory	0.0	0.0	0.0
Mess / Lounge	n/a	n/a	n/a
L2 PPE Locker	0.0	0.0	0.5

Table 3.18

Time averaged concentrations for the air-borne contaminants, total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO) monitored over the 10 Hr day shift period.

Carbon Monoxide - total average concentrations

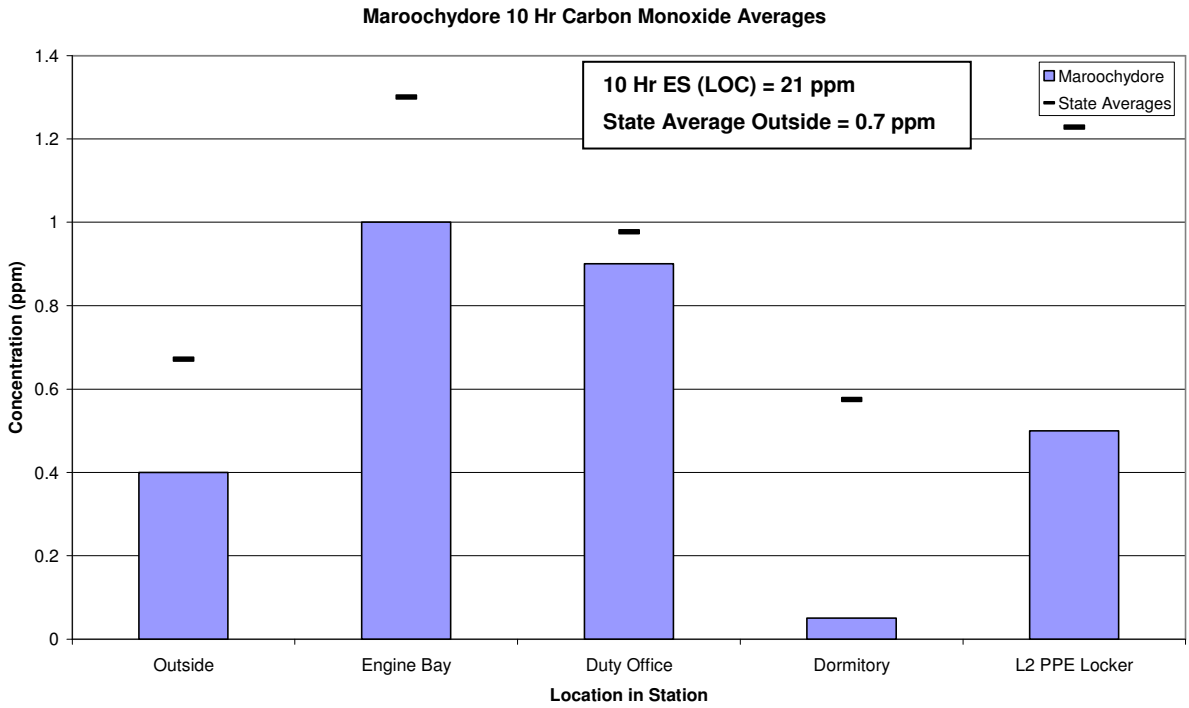


Figure 3.57
Time averaged carbon monoxide readings for a day shift at Maroochydore fire station.

Outside Station (Background)
The background carbon monoxide concentration(0.4 ppm) was less than the average outside concentration(0.7 ppm) obtained across the state, and less than the average South East Qld[46] airborne concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station, except the dormitory (0.05 ppm), were higher than the average Maroochydore background concentration. The highest concentrations were obtained in the engine bay (1 ppm) and duty office (0.9 ppm), both of which were below their respective state average concentrations. Both concentrations are *ca*. 21 times less than the (ES_{10} – 21 ppm) and *ca*. 9 times lower than the NEPM concentration (9 ppm).

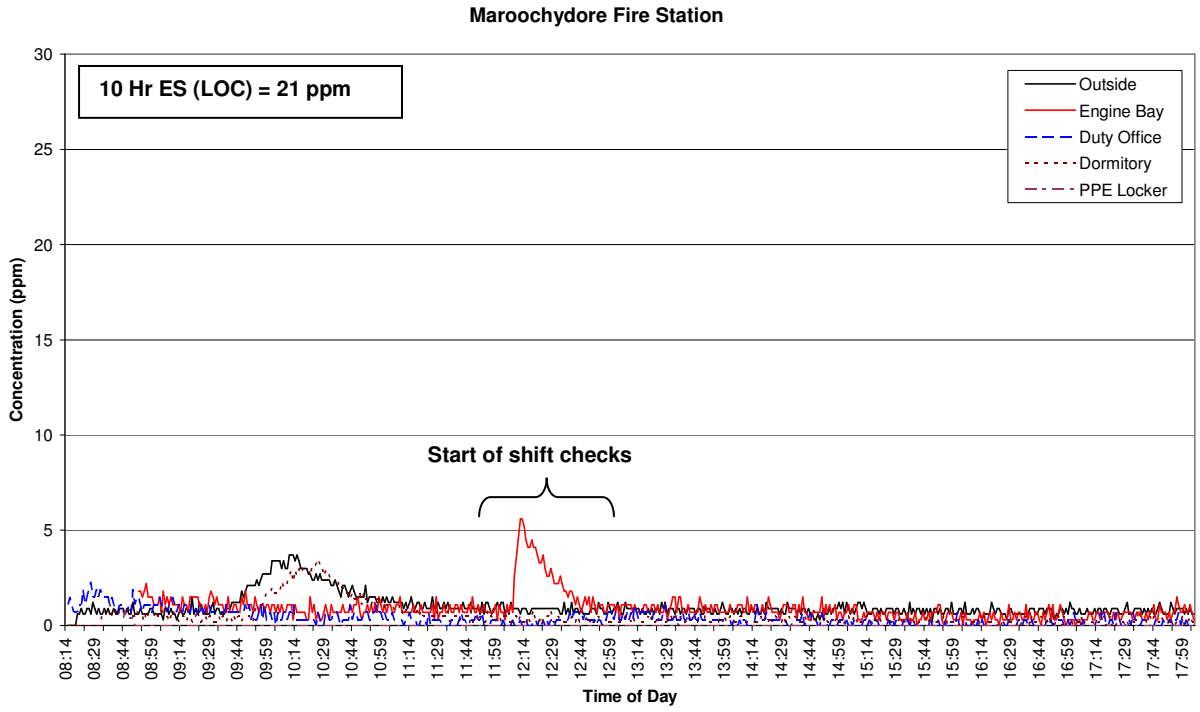


Figure 3.58
Carbon monoxide concentrations for a 10 Hr day shift at Maroochydore fire station.

Carbon Monoxide - 10 Hr continuous monitoring
Two excursions were observed during the 10 Hr day shift. The first excursion corresponded to an unknown event outside the station that appeared to migrate into the adjoining dormitory. The second excursion corresponded to the start of shift checks within the closed engine bay. Carbon monoxide excursions occurring during emergency response were measured only in the engine bay. The highest start of shift check (17 minutes) measurement (5.6 ppm) and the unknown excursion outside the station 3.7 ppm) were both above the CO sensor LOD of 1 ppm. The start of shift check measurement did not exceed the ES_{10} of 21 ppm.

The dormitory carbon monoxide measurements correspond closely to the concentrations obtained outside the station because the prevailing breeze running across the station towards the dormitory window.

Hydrogen Sulfide - total average concentrations
Outside Station (Background)
The background hydrogen sulfide concentration (0.1 ppm) is equal to the average outside concentration (0.1 ppm) obtained across the state. There is no established NEPM concentration. The background exceeds the established odour threshold of H_2S (0.001 – 0.005 ppm) which may add to concerns about odours within the fire stations.

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station were equal to or less than the average background concentration, which is significantly less than the (ES_{10} of 7 ppm).

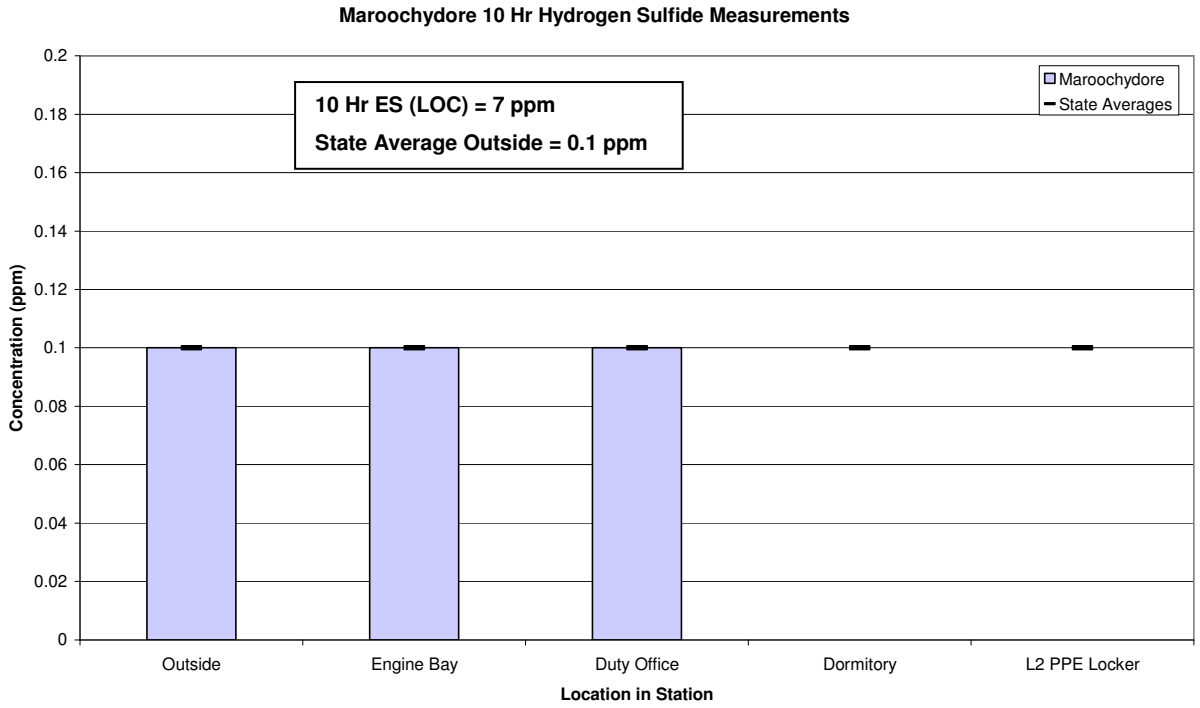


Figure 3.59
Time averaged hydrogen sulfide readings for a day shift at Maroochydore fire station.

Hydrogen Sulfide - 10 Hr continuous monitoring

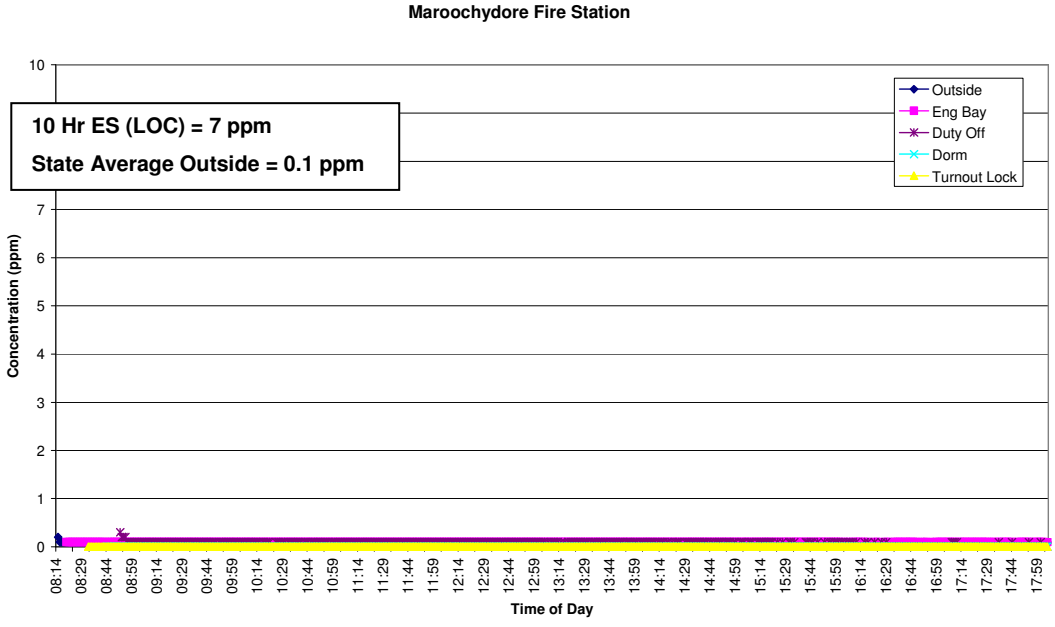


Figure 3.60
Hydrogen Sulfide readings for a 10 Hr day shift at Maroochydore fire station.

All hydrogen sulfide (H_2S) concentrations were below the H_2S sensor LOD of 1 ppm and the ES_{10} (21 ppm).

Atmospheric Contaminants – total volatile organic compounds of concern
The total volatile organic compounds (tvoc's) results for Maroochydore station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. The tvoc's were monitored for as close as practicable to 10 Hr over a standard day. All measurements were continuously recorded on instruments that logged peak concentrations over 1 minute averaging periods. Peak concentrations were used to ensure any potential contamination by fire appliances was highlighted.

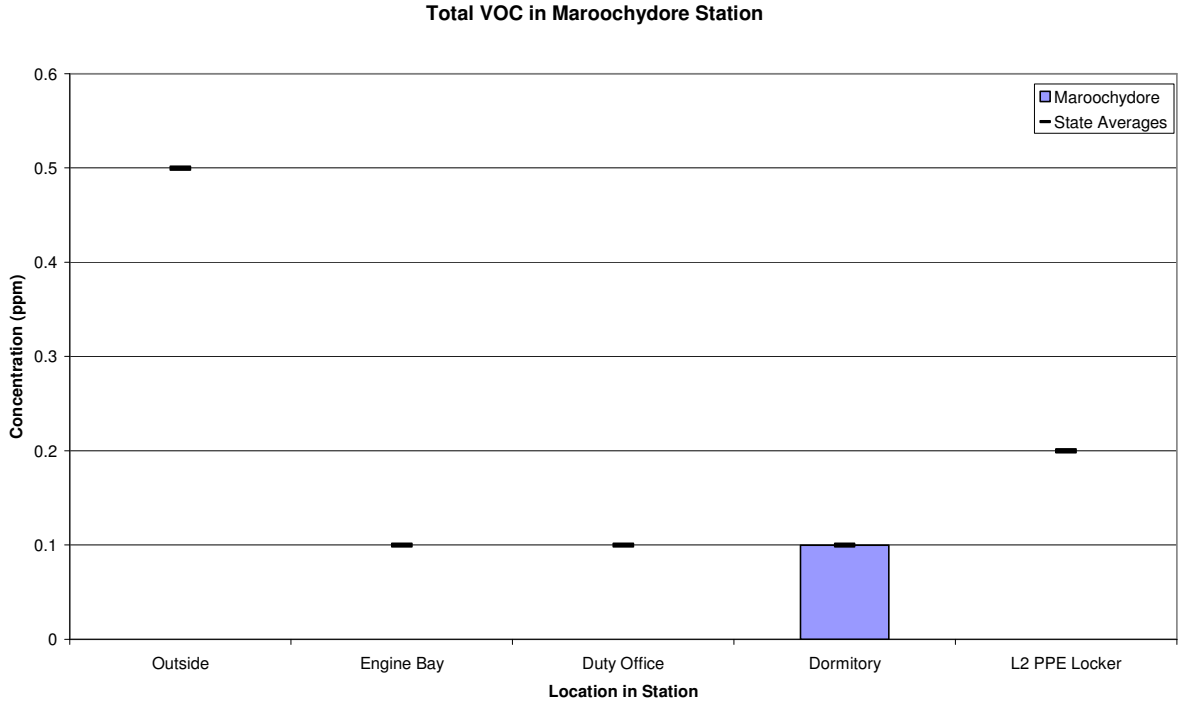


Figure 3.61
Volatile organic compounds readings for a 10 Hr day shift at Maroochydore fire station.

Outside Station (Background)
The Maroochydore average background tvoc concentration (< 0.1 ppm) was significantly less than the average outside concentration (0.5 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station show all areas, except the dormitory (0.1 ppm), were at or below the level of detection (0.1 ppm) and their respective area state averages. The dormitory is above the Maroochydore outside concentration (< 0.1 ppm), but less than or equal to the outside state average (0.5 ppm) and the dormitory state average (0.1 ppm). All Maroochydore results were significantly less than the QFRS established level of concern (0.5 ppm).

Volatile organic compounds - 10 Hr continuous monitoring

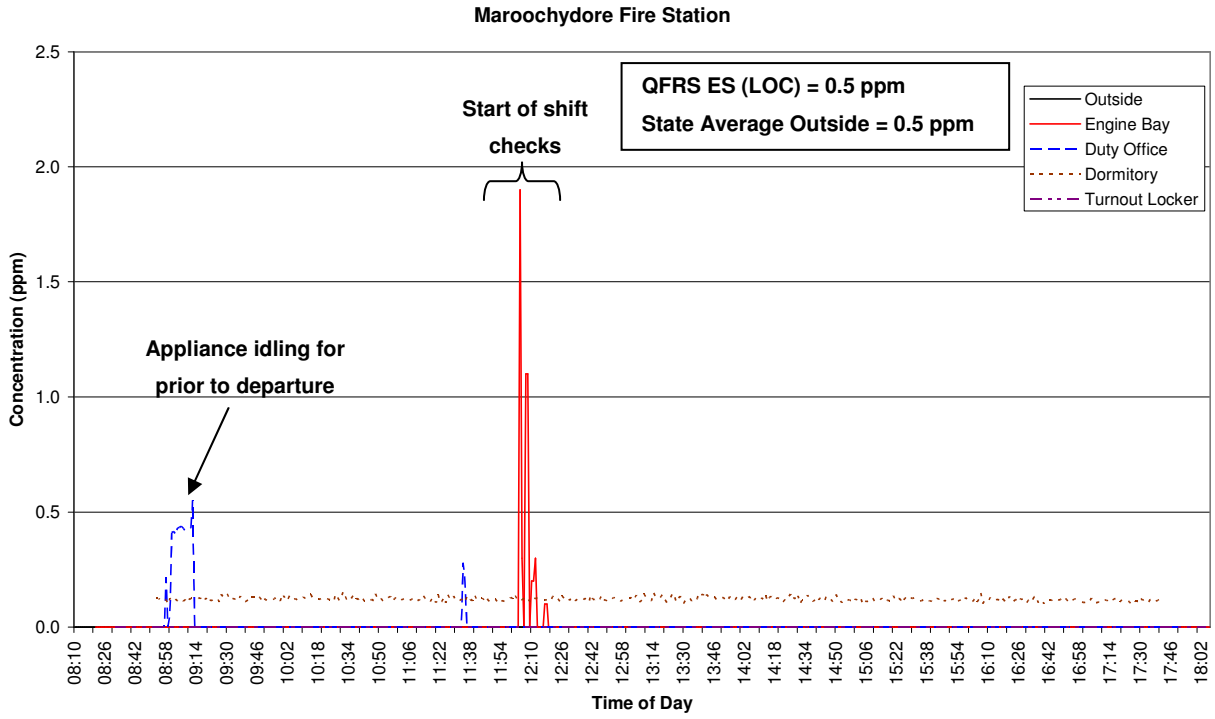


Figure 3.62
Tvoc concentrations for a 10 Hr day shift at Maroochydore fire station.

Three excursions were observed over the 10 Hr day, which corresponded to activities such as start of shift check and emergency response and returns to station. In general, tvoc excursions occurring during emergency response were measured only in the engine bay.

The average total volatile organic compounds (tvoc) results showed that the engine bay (1.9 ppm) and duty office (0.6 ppm) were the only areas with significant tvoc's levels measured over the 10 Hr shift. The major peak occurred in the engine bay during the start of shift checks. Other peaks detected were in the duty office (0.5 ppm and 0.3 ppm) during a non emergency response. This event occurred when a vehicle was idling ion the bay and directions were being given though an open window in the duty office.

Both the engine bay and duty office concentrations exceeded the QFRS LOC of 0.5 ppm and the state outside average (0.5 ppm). However, these peaks occurred over short durations, and both areas reported concentrations less than the 0.5 ppm for the 10 Hr shift duration.

Atmospheric Contaminants – hexane, benzene, toluene and xylene
Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A mixture of evacuated canisters, and active and passive sorbent techniques was used. Instantaneous measurements of benzene generated during the station activities were also obtained. If the result obtained was less than the reporting limit (<R.L) the R.L was used to illustrate the worst case concentration for a specific location.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<5.0*	1	Nd%	4.3	3	Nd%	3.7	<2.5	Nd%	<4.5*	<1	Nd%	<19.7*	<29.3*
Engine Bay			4.7	Nd%		4.1	Nd%		<2.9	Nd%		<1	Nd%		<28.5*
Start of Shift	<0.5	16.3			66.3			48.4			102			<247*	
Turnout	<0.5	<4.4*			5.6			<3.2*			4.0			<208*	
Return	<0.5	<5.3*			5.0			<3.9*			<4.8*			<214*	
Duty Office	<0.5		1	Nd%		1	Nd%		<2	Nd%		<1	Nd%		<28.8*
Dormitory	<0.5	<5.3*	1	Nd%	<5.1*	1.5	Nd%	<3.9*	<2	Nd%	<4.8*	<1	Nd%	<16.3*	<28.8*
Mess area	<0.5		1	Nd%		1.5	Nd%		<2	Nd%		<1	Nd%		<29.4*
PPE Locker	<0.5	<2.6*			<4.1*			<2.6*			<2.4*			<14.8*	

Table 3.19
Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Maroochydore fire station over a day shift.

Atmospheric Contaminants – hexane

Outside Station (Background)
Figure 3.63 shows the hexane background concentration outside Maroochydore fire station was at or below the R.L (1.0 ppb) and was less than the average background concentration (1.1 ppb) across the state.

The average concentrations in all areas within the station were at or below the R.L, which is more than 14000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 14 000 ppb (14 ppm) and more than 65000 times below the odour threshold of 65 000 ppb (65 ppm). The average hexane concentration in ambient in Brisbane[48] is 18.6 ppb.

The hexane concentration obtained after the start of shift check, turnout simulation, and return simulation were 102 ppb, <4.0 ppb and <4.8 ppb respectively. These concentrations are higher than the background concentration of hexane and significantly less than the average hexane concentrations obtained for these activities (92 ppb, 4.9 ppb, and 14.5 ppb respectively). The concentrations are approximately 5000 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.

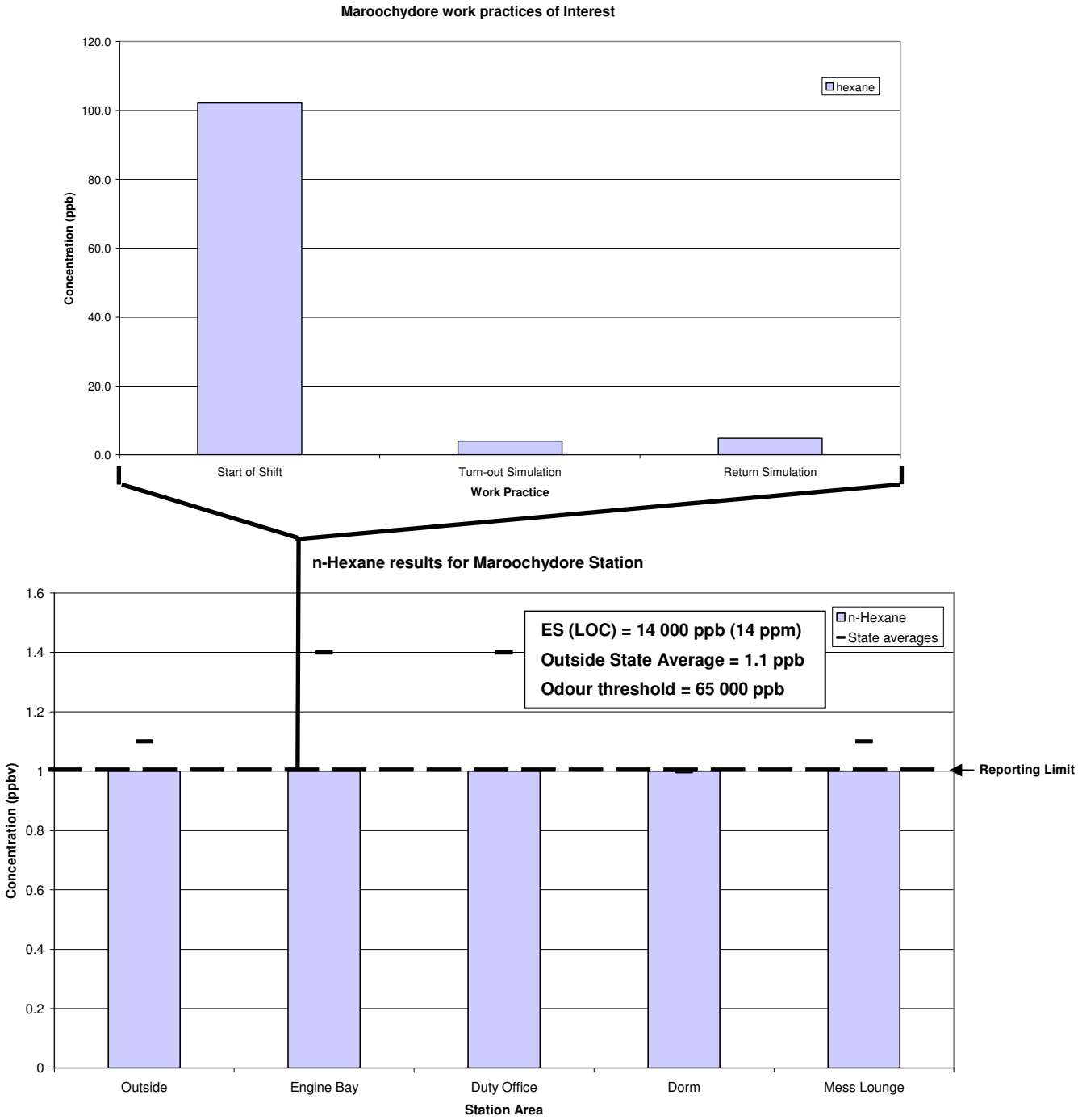


Figure 3.63
Hexane concentrations from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

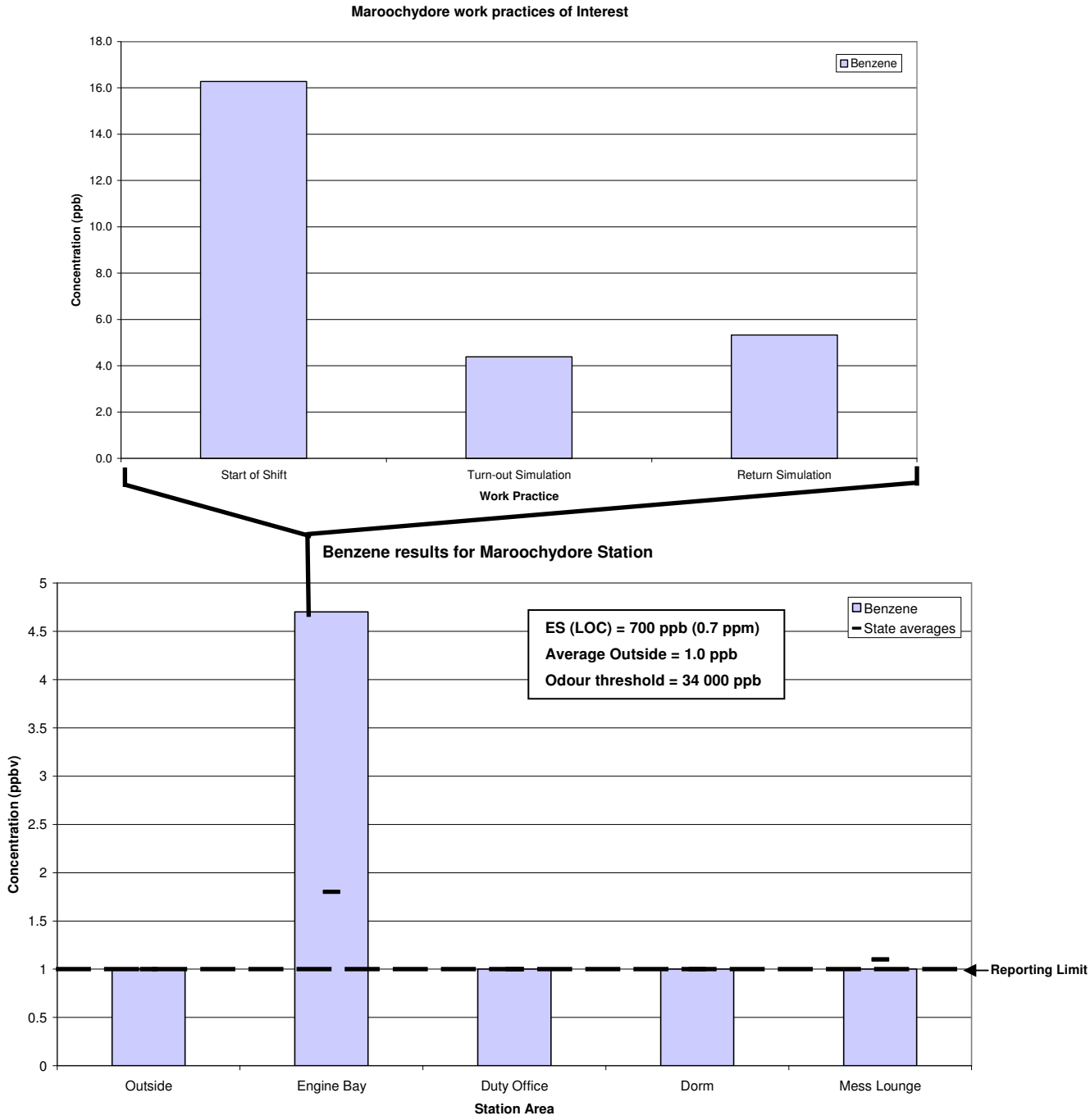


Figure 3.64
Benzene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

The background benzene concentration outside Maroochydore fire station was at or below the R.L (1.0 ppb) and the average background concentration across the state (1.0 ppb). The average concentrations in all other station areas, except the engine bay (4.7 ppb), within the station were at or below the R.L, which is more than 148 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb and more than 7000 times below the odour threshold (34 000 ppb). This background result is similar to the average benzene airborne

concentrations in South East Qld[46] - 0.8 ppb (range: 0.4 to 1.5 ppb) and Brisbane[48] - 3.3 ppb (range: 0.43 to 10.33 ppb).

The benzene concentration obtained after the start of shift check (17 minutes), turnout simulation, and return simulation were 16.3 ppb, <4.4 ppb and <5.3 ppb respectively. These concentrations are higher than the background concentration of benzene, but less than the state area averages (28 ppb, 5.3 and 16.5 ppb respectively). The highest concentration is approximately 43 times less than the ES_{10} of 700 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – toluene

Outside Station (Background)
The toluene background concentration outside Maroochydore fire station (3ppb) was above the R.L (1.0 ppb) and the average background (2.1 ppb) concentration across the state. This background result is similar to the average toluene airborne concentrations in South East Qld[46] - 1.6 ppb (range: 0.7 to 4.9 ppb) and Brisbane[48] - 10.6 ppb (range: 1.8 to 83 ppb).

The concentrations in all areas within the station were less than the state area average concentrations obtained across the state. The highest concentration was in the engine bay (4.1 ppb), which is approximately 8500 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb. The toluene odour threshold is 160 ppb.

The toluene concentration obtained after the start of shift check (17 minutes), turnout simulation, and return simulation were 66.3 ppb, <5.6 ppb and <5 ppb respectively. These concentrations are higher than the background concentration of toluene. These concentrations are less than the average toluene concentrations (83.6 ppb, 4.5 ppb and 6 ppb respectively). The highest concentration was the start of shift checks, which is approximately 500 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

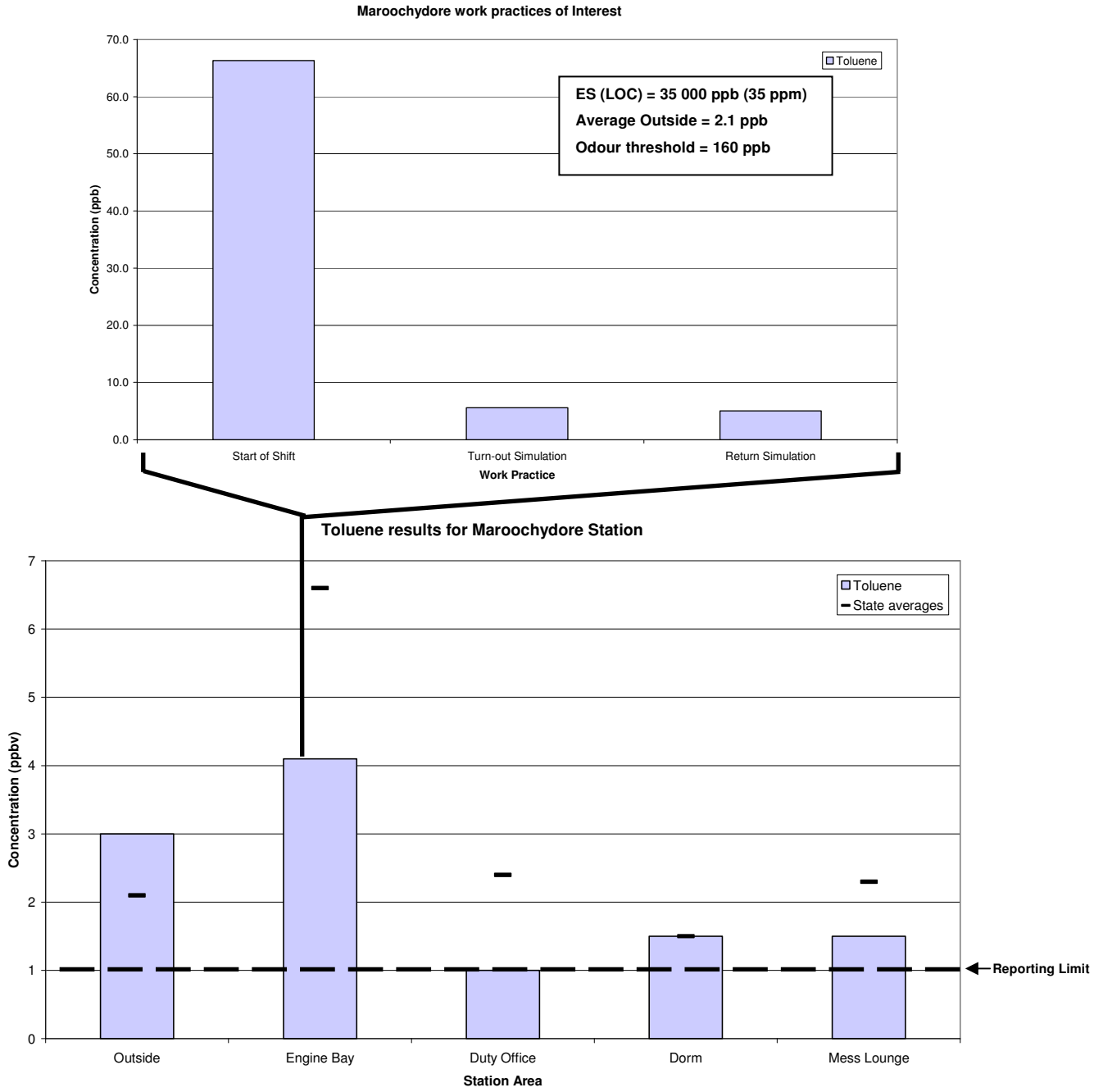


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Figure 3.65

Toluene concentrations from evacuated canister controlled by a 10 Hr flow concentration. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – xylene

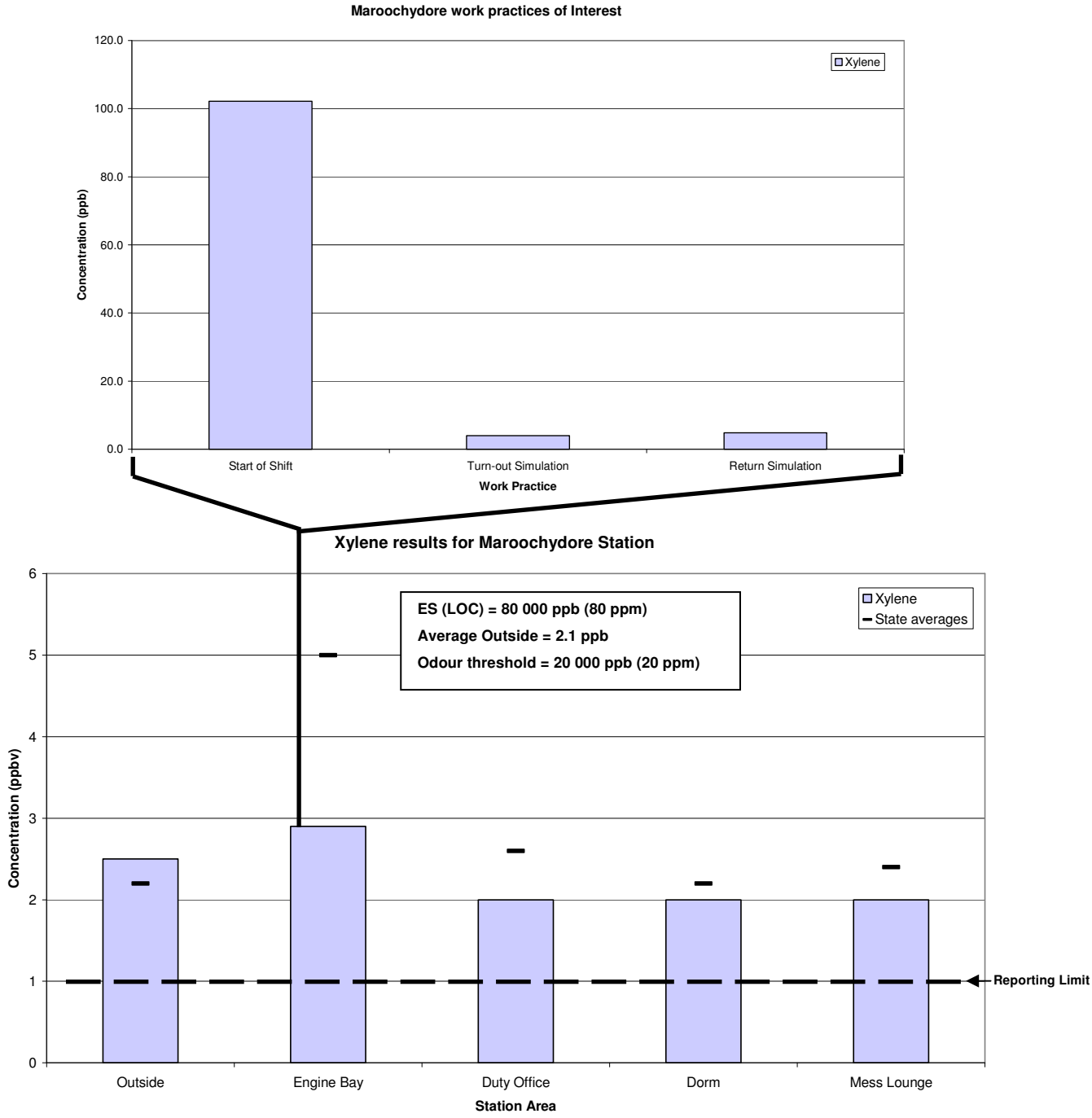


Figure 3.66
Xylene concentrations for a 10 Hr day shift at Maroochydore fire station areas. All canister analyses for xylene were reported as the isomers *m-* / *p*-xylene and *o*-xylene. For this report all concentrations were added to give total xylene concentration and the reporting limit was doubled (< 2.0 ppb).

Outside Station (Background)
The xylene background concentration outside Maroochydore station (2.5 ppb) was above the R.L (2.0 ppb) and the average background (2.2 ppb) concentration across the state. This background result is similar to the average xylene airborne concentrations in South East Qld[46]

- 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] - 3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as *p*-xylene data, but calculated as total xylene based on *p*-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the *m-&p*-xylene with the *o*-xylene.

The average concentrations in all areas within the station were below the state average concentrations. The highest concentration was obtained in the engine bay (2.9 ppb), which is more than 19000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 56 000 ppb. The xylene odour threshold is 20 000 ppb.

The xylene concentration obtained after the start of shift check (17 minutes), turnout simulation, and return simulation were 102 ppb, <4 ppb and <4 ppb respectively. These concentrations are higher than the background concentration of xylene, but less than the average xylene concentrations obtained (105 ppb, 5.3 ppb, and 12.5 ppb respectively). Nonetheless, the highest concentration is approximately 550 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions which may account for the observations.

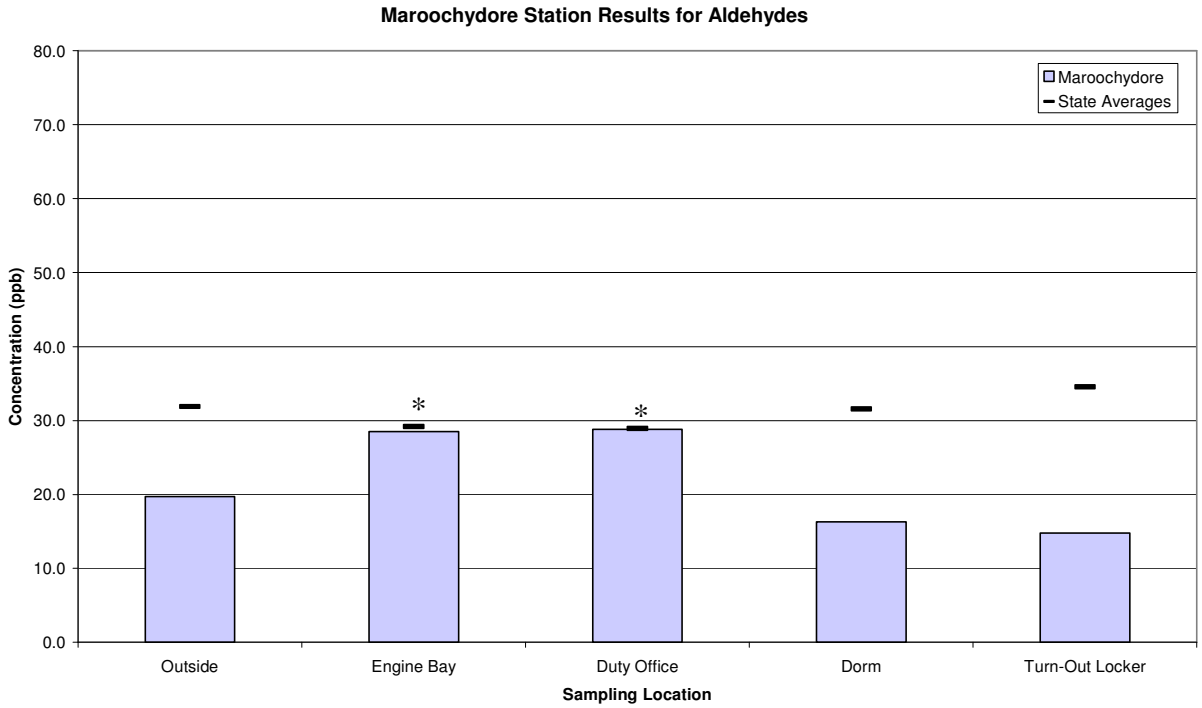
Atmospheric Contaminants – aldehydes

Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes.

Figure 3.67 shows the total aldehyde concentration is obtained from the summation of the concentrations of the following aldehydes: valeraldehyde, benzaldehyde, acrolein, formaldehyde.

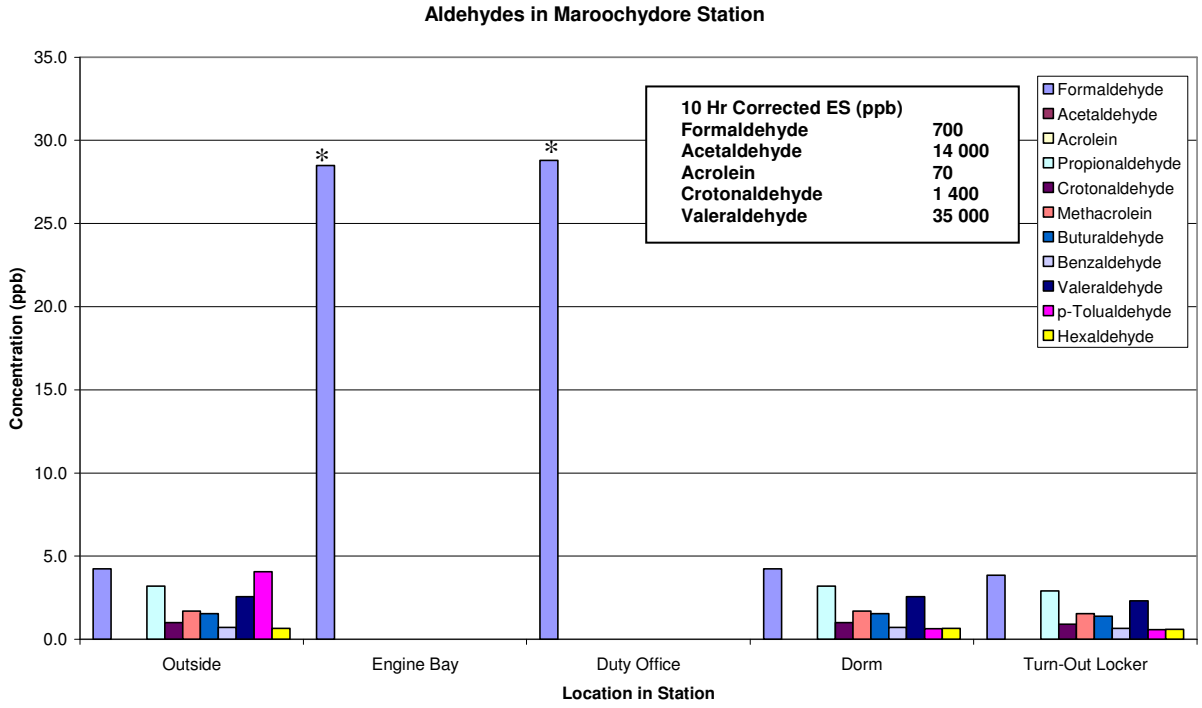
The total aldehyde results show that all station areas, except the engine bay (28.5 ppb) and PPE locker (28.8 ppb), background concentration of 20 ppb. However, all station areas are below the outside state average (32 ppb) and their respective state averages.

The total aldehyde concentration (Figure 3.68) within the engine bay and duty office was 29 ppb for both areas, which is similar to the state average concentrations (28.5 ppb and 29.2 ppb). However, these latter results were obtained on passive diffusion badges and only formaldehyde was reported. The highest concentration is more than 23 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. All acrolein measurements were at or below the R.L, which is more than 70 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}) of 70 ppb.



* Results from passive badges

Figure 3.67
Total aldehyde concentrations in areas of interest for a 10 Hr day shift at Maroochydore fire station.



* Results from passive badges

Figure 3.68
Aldehydes detected for a 10 Hr day shift at Maroochydore fire station.

Atmospheric Contaminants – Particulate Matter

Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

Polyaromatic Hydrocarbons

The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 and time adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard for PAH. Some individual PAH have established ES such as naphthalene - (52 mg/m^3 or 52 000 µg/m^3) and a 10 Hr time corrected ES_{10} (36.4 mg/m^3 or 36 400 µg/m^3). If the result obtained was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case concentration.

	Maroochydore Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	**10100**	**5800**	**6100**
Fluoranthene	<RL	**7000**	**3600**	<RL
Anthracene	<RL	**6700**	**4200**	<RL
Phenanthrene	**15400**	**58300**	**41700**	**19400**
Fluorene	**6500**	**40800**	**43500**	**14400**
Acenaphthene	<RL	**5900**	**5400**	<RL
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	49000	360000	110000	180000
Reporting Limit	4300	3000	3100	3500
Total PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.02	0.13	0.10	0.04
Total with Naphthalene (µg/m^3)	0.07	0.49	0.21	0.22
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from (pg/m^3) to (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.07	0.15	0.13	0.08
Total with Naphthalene (µg/m^3)	**0.12**	**0.51**	**0.24**	**0.26**
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.20

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Maroochydore fire station.

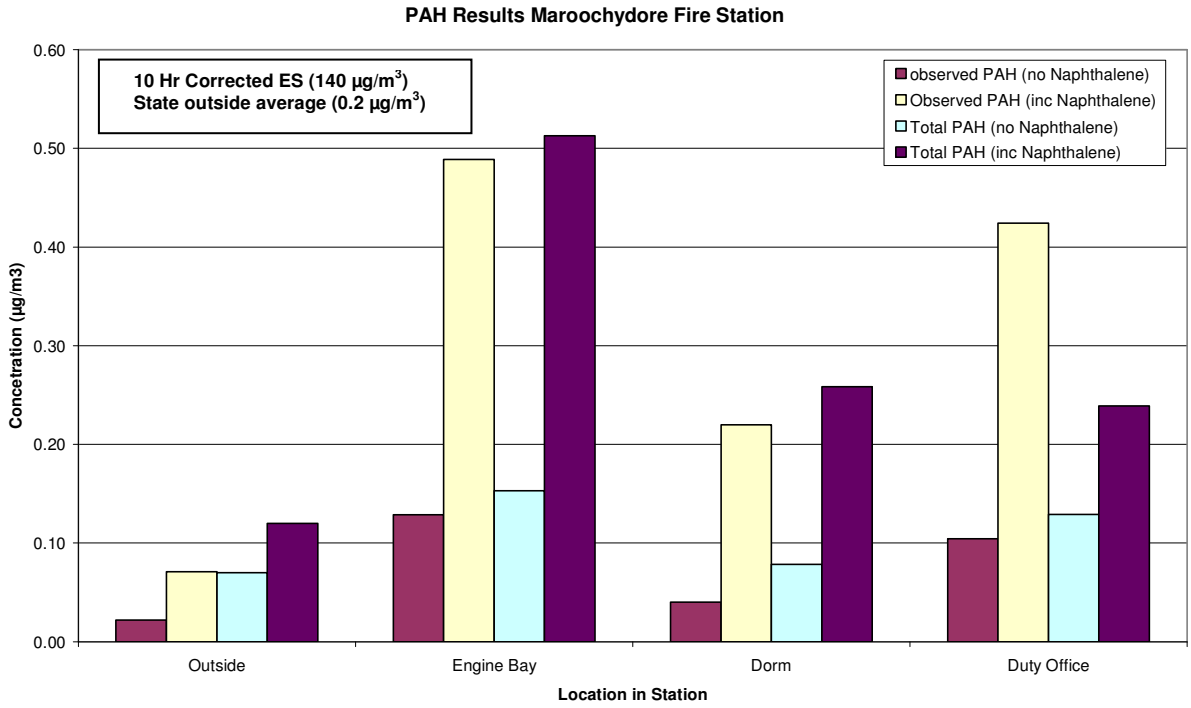
Outside Station (Background)

Figure 3.69 shows the PAH background concentration (0.12 µg/m^3) was greater than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs; phenanthrene, fluorene and naphthalene were detected outside Maroochydore fire station. Care should be shown with these total results as they are derived from the addition of mostly reporting limit concentrations.

Inside Station (10 Hr monitoring)

The PAH concentration within the station areas were less than the average PAH concentrations obtained across the state, except the dormitory average concentration (0.3 µg/m^3). The highest PAH concentration obtained was in the engine bay (0.5 µg/m^3), which was more than 270 times less than the ES_{10} 140 µg/m^3.

The PAHs; pyrene, fluoranthene, phenanthrene, anthracene, acenaphthene, fluorene and naphthalene, classified as non-carcinogenic by the US EPA, were detected in the various areas within the station. Naphthalene contributes most to the total PAH concentration, which is a consistent trend across all areas of the fire station. The highest naphthalene concentration in any area is more than 20,000 times below the established ES_{10} 36 400 µg/m^3 and more than 350 times below the odour threshold (200 µg/m^3).



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.69
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Maroochydore fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

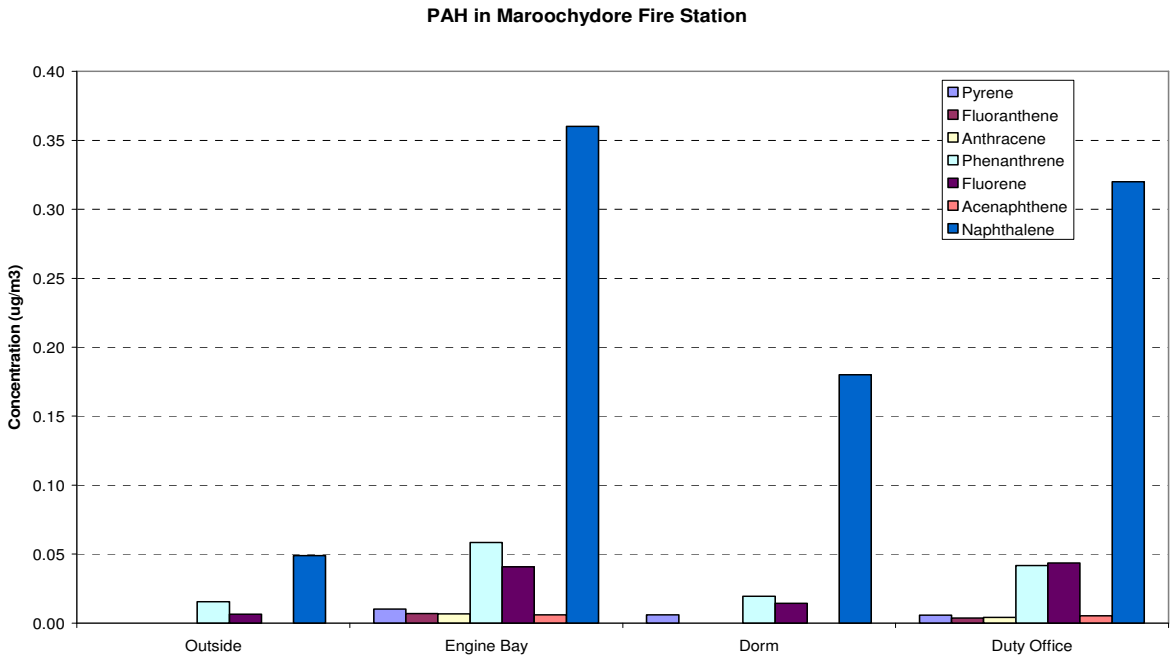


Figure 3.70
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Maroochydore fire station.

Diesel Particulate Matter

Diesel particulate matter (DPM) has been described extensively in chapter one. Although there is no established ES, a level of concern (LOC) of 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L), the R.L value was used. A recent review[33] reported that US fire fighter DPM exposure to DPM is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

Outside Station (Background)
The DPM background concentration was at or below the reporting limit (R.L – 0.001 mg/m^3 EC), which is less than the average background DPM concentration across the state (0.002 mg/m^3 EC), and the QFRS LOC (0.1 mg/m^3 EC). The average concentrations in all areas within the station, except the engine bay (0.003 mg/m^3) were also or below the R.L. (0.001 mg/m^3 EC), which is more than 30 times below the level of concern (0.1 mg/m^3 EC).

Start if Shift, Turn-out and Return Trials
The DPM concentration for the start of shift check (17 minutes, 0.06 mg/m^3 EC) is higher than the average start of shift concentration (0.044 mg/m^3 EC – including the Firepac 3000 Mk 3 measurement) across the state. However, it is *ca*. 1.5 times less than the QFRS LOC (0.1 mg/m^3 EC). The DPM concentration for the turnout simulation (0.01 mg/m^3 EC) was greater than the turn-out state average (0.009 mg/m^3), while the return simulation (0.01 mg/m^3 EC) was less than the return state average (0.013 mg/m^3). There are several factors that may affect these results, including the engine bay design, ventilation and appliance performance. These concentrations are more than 10 times less than the level of concern (0.1 mg/m^3 EC). However, the start of shift measurement was similar to the US fire fighter DOM exposure[33] concentration of 0.05 mg/m^3 EC.

The results demonstrate that the exposure of fire fighters whilst working at this station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern. In many instances there is no significant difference compared with the background measurements and the averages across Queensland.

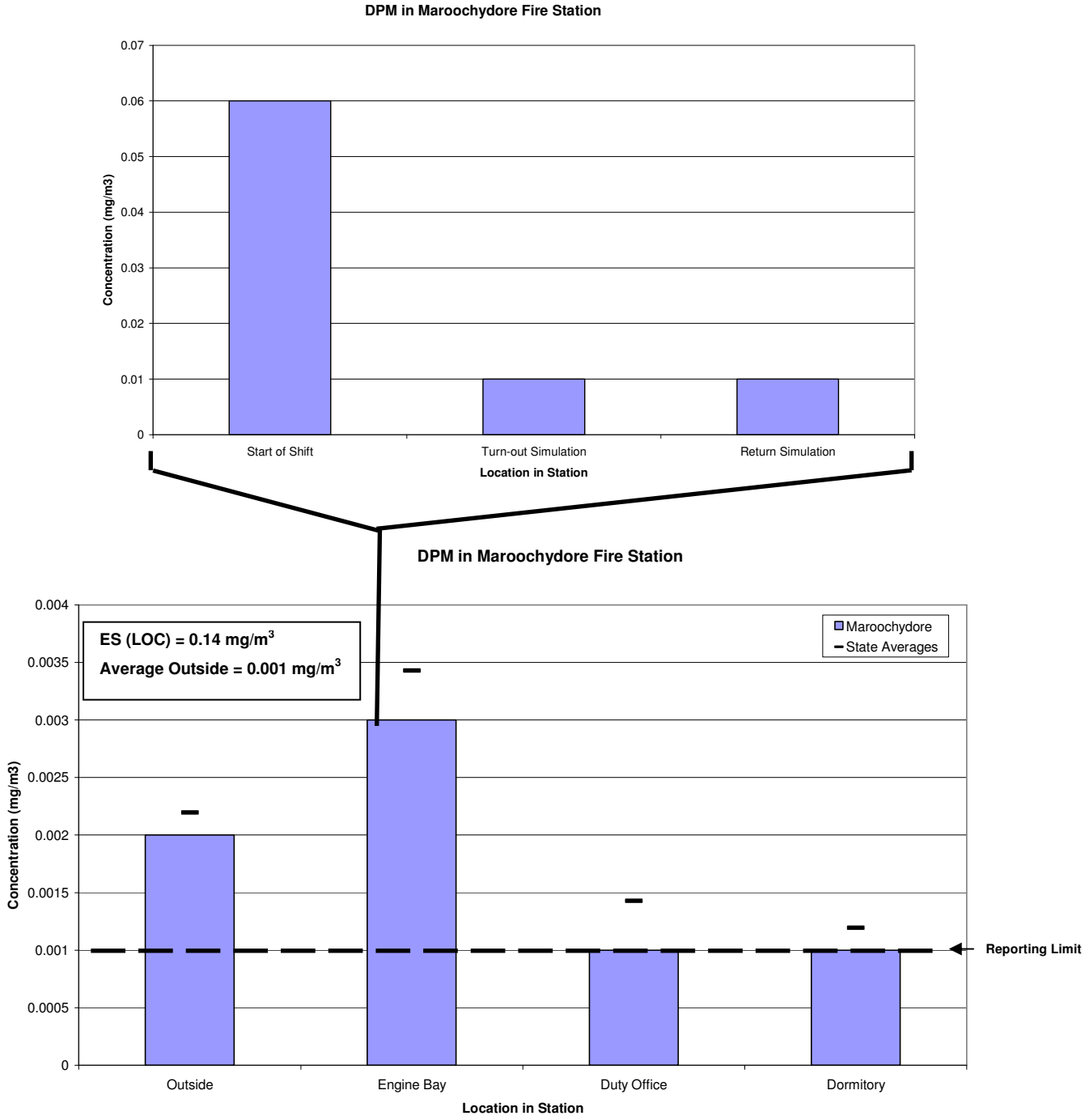


Figure 3.71

DPM concentrations for Maroochydore station was based on 10 Hr shift (dorm, Eng. Bay, duty office and outside) and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Maroochydore Results

The Maroochydore station trials showed that no stations activity exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.12	0.002	1	3	<2.5	<1	<19.7	<0.5	<0.5	0.4	0.1	0.0
Engine Bay	0.51	0.003	4.7	4.1	<2.9	<1	<28.5			1.0	0.1	0.0
Start of Shift		0.06	16.3	66.3	48.4	102	<247	<0.5	<0.5			
Turnout		0.01	<4.4*	5.6	<3.2	4.0	<208	<0.5	<0.5			
Return		0.01	<5.3*	5.0	<3.9	<4.8	<214	<0.5	<0.5			
Duty Office	0.24	0.001	1	1	<2	-	<28.8	<0.5	<0.5	0.9	0.1	0.0
Dormitory	0.26	0.001	1	1.5	<2	<1	<16.3	<0.5	<0.5	0.05	0.0	0.1
Mess/Lounge			1	1.5	<2	<1	<29.4	<0.5	<0.5			
PPE Locker			<2.6	<4.1	<2.6	<2.4	<14.8	<0.5	<0.5	0.5	0.0	0.0

The greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

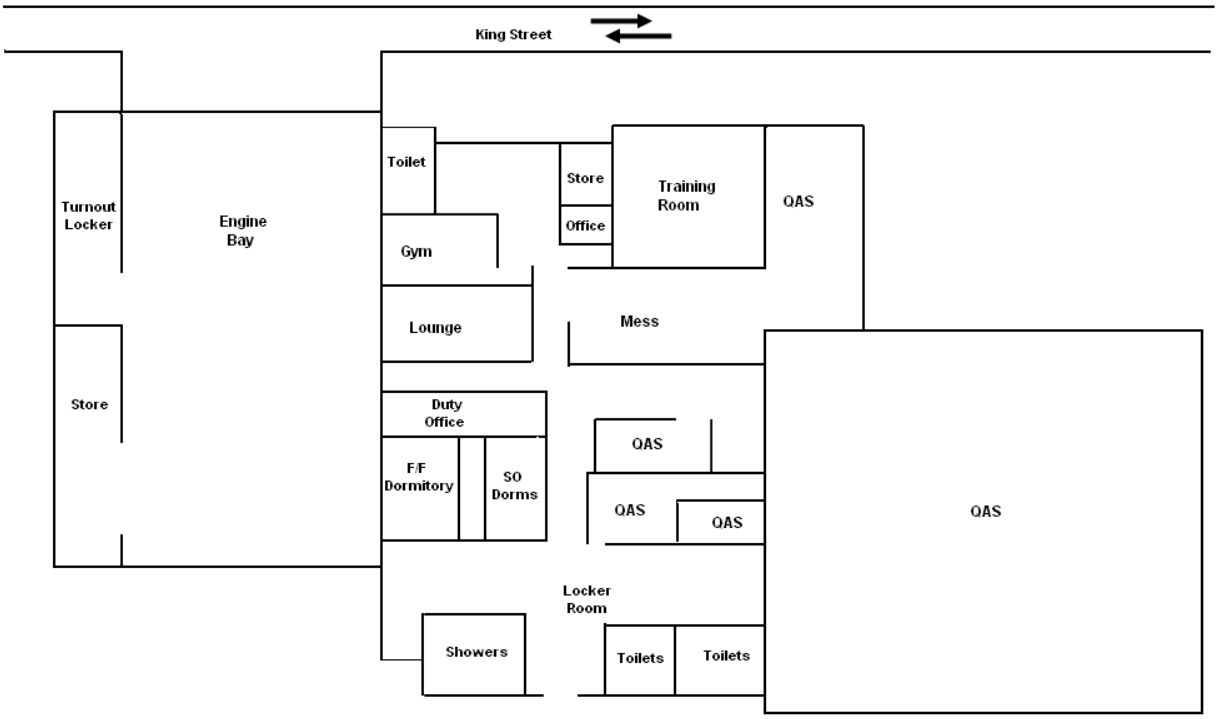
Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Review of QFRS Fire Station Data

Brisbane Region

Caboolture Fire Station

The Caboolture fire station is a newer style station built after to 1995. It is last permanent station on the northern extremity of the Brisbane region. It is the major station, with two engine bays housing three fire fighting, one rescue and one water tanker appliances. The station is crewed by six permanent fire fighters and auxiliary fighters, who are directly impacted on by the engine room activities. In 2007 there were 1758 reported responses.



Fire fighter exposures in the Caboolture Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide and nitrogen dioxide concentrations were measured during the station activities: start of shift checks, turn out and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results of all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Rockhampton – NO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Rockhampton – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.21

Concentration of airborne nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

The airborne concentration of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were below the limit of detection (0.5 ppm) for all activities. The ambient airborne concentrations of each in South East Qld[46] and Brisbane[48] are (NO_2 6 ppb and SO_2 1 ppb) and (NO_2 1.5 ppb and SO_2 8.2 ppb) respectively.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift. The measurements are reported as peak concentrations over 1 minute averaging periods.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**		**Multi Rae four gas detector**			
	Total VOC (ppm)		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing			
			Hydrogen sulphide (ppm)		Carbon monoxide (ppm)	
	Caboolture Station	State Average	Caboolture Station	State Average	Caboolture Station	State Average
Outside	0	0.5	0.04	0.1	0.1	0.7
Engine Bay	0.1	0.1	0.01	0.1	1.3	1.3
Duty Office	0.2	0.1	0.05	0.2	0.04	1
Dormitory	0.1	0.1	0.1	0.1	0.1	0.6
Mess / Lounge	0	n/a	0.04	-	-	-
L2 PPE Locker	0	0.2	0.01	0.1	2	1.4

Table 3.22

Time averaged concentrations for the air-borne contaminants, total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO) monitored over the 10 Hr day shift period.

Carbon Monoxide - total average concentrations

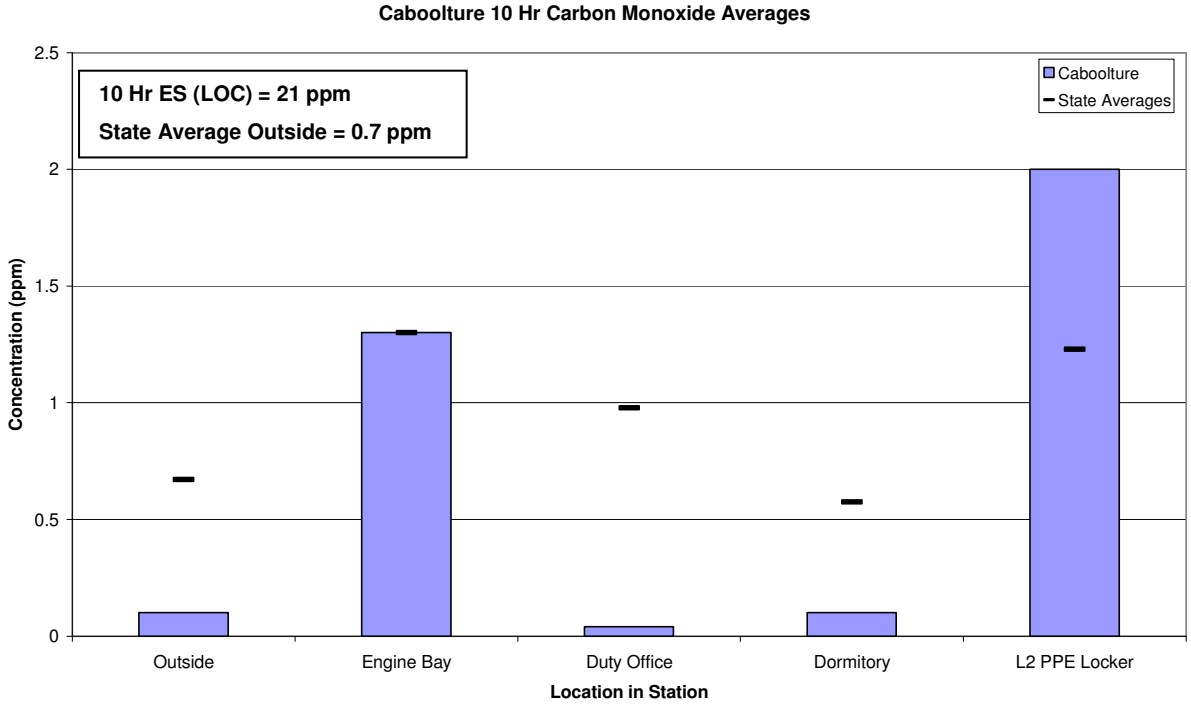


Figure 3.72
Time averaged carbon monoxide concentrations for a day shift at Caboolture fire station.

Outside Station (Background)
The background carbon monoxide concentration (0.1 ppm) was less than the average outside concentration (0.7 ppm) across the state, and the average South East Qld[46] airborne concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station, except the engine bay (1.3 ppm) and PPE locker (2.0 ppm), were equal to or less than the average background concentration. The highest concentration was the PPE locker (2.0 ppm), which is ca. 10 times less than the ES_{10} of 21 ppm and *ca*. 4 times less than the NEPM concentration (9 ppm).

Carbon Monoxide - 10 Hr continuous monitoring
Figure 3.73 below illustrates there were three activities where carbon monoxide excursions were observed. These excursions corresponded to activities such as start of shift checks and appliances leaving and returning to station. In general, carbon monoxide excursions occurring during emergency response were measured only in the engine bay. The only non-engine bay excursion occurred in the PPE, which is an enclosed room open to the engine bay.

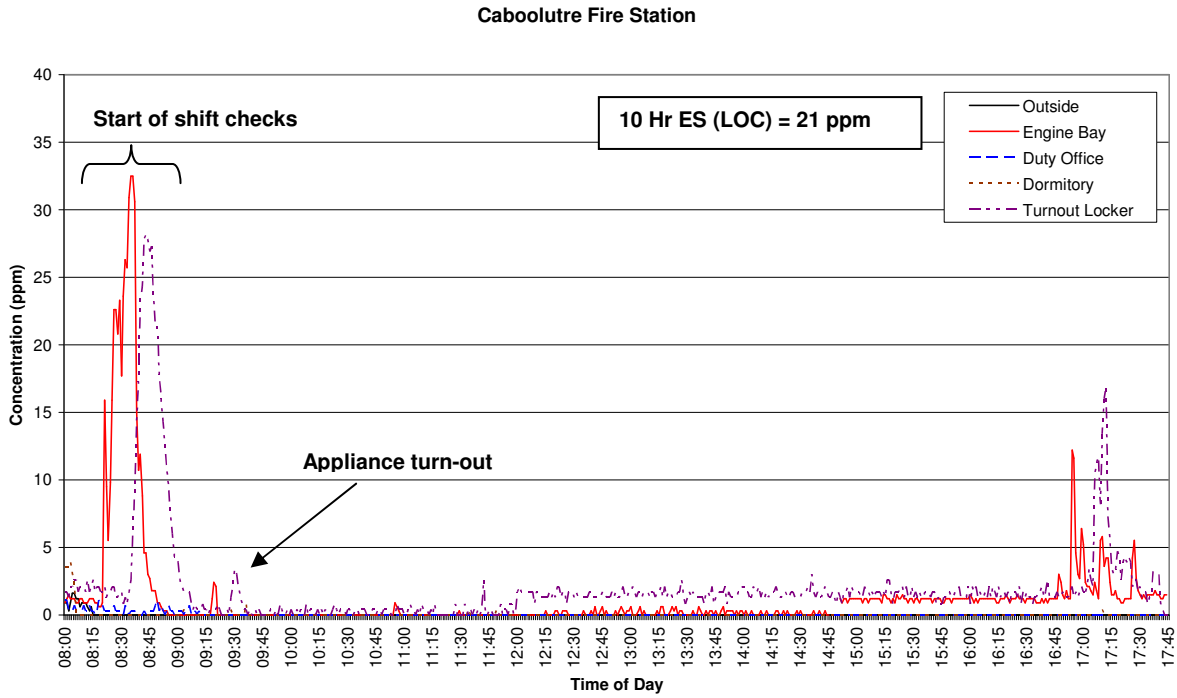


Figure 3.73
Carbon monoxide readings for a 10 Hr day shift at Caboolture fire station.

The highest carbon monoxide (CO) concentrations were obtained during the start of shift checks (16 minutes) in the engine bay (32.5 ppm) and PPE locker (28.2 ppm). All were above the CO sensor LOD of 1 ppm. This is consistent with the position of the appliances and the PPE locker being open to the engine bay and immediately adjacent to the nearest appliance exhaust. The concentration within the engine bay exceeds the ES_{10} (21 ppm), however, it did not exceed the *NOHSC:* [45] *Guidelines for the control of short-term excursions for Carbon Monoxide* 30 minute limit of 100 ppm or the 15 minute limit of 200 ppm.

Hydrogen Sulfide - total average concentrations
All monitoring was performed over one minute averaging periods for the length of the data collection with the peak concentrations within these periods plotted against the time of day. The outside reading was taken external to the station for a background sample and was adjacent to the entry of the front yard, adjacent to King Street.

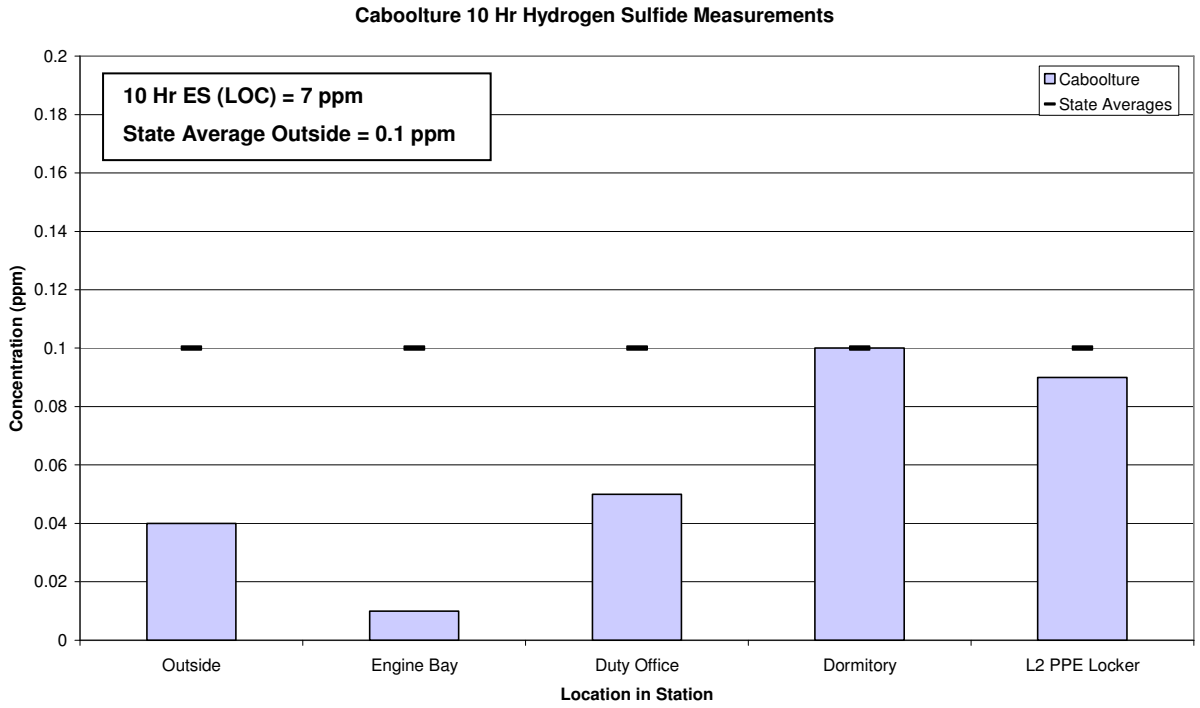


Figure 3.74
Time averaged hydrogen sulfide concentrations for a day shift at Caboolture fire station.

Outside Station (Background)
The background hydrogen sulfide concentration (0.04 ppm) is significantly less than the average outside concentration (0.1 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
The highest reading was observed in the dormitory (0.1 ppm), which was at the average dormitory concentration (0.1 ppm) for all fire stations, and *ca* 70 times below the ES_{10} (7 ppm) concentration.

Hydrogen Sulfide - 10 Hr continuous monitoring

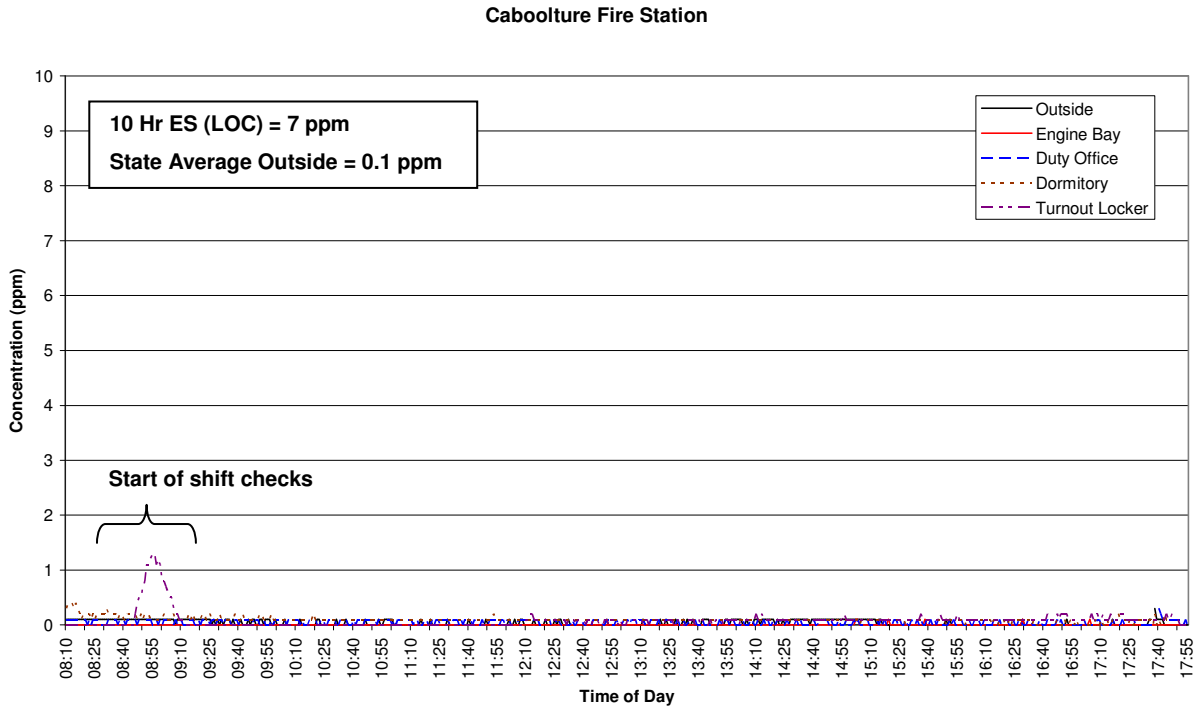


Figure 3.75
Hydrogen Sulfide concentrations for a 10 Hr day shift at Caboolture fire station.

The only H_2S excursions (1.3 ppm) occurred during the start of shift check (12 minutes) within the engine bay. The concentration does not exceed the ES_{10} of 7 ppm, but may explain odours detected by fire fighters.

Atmospheric Contaminants – total volatile organic compounds of concern
The total volatile organic compounds (tvoc's) results used for Caboolture station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. The tvoc's were measured for as close as practicable to 10 Hr over a standard day. All measurements were continuously recorded on instruments that logged peak concentrations over 1 minute averaging periods to ensure any potential contamination by fire appliances was highlighted.

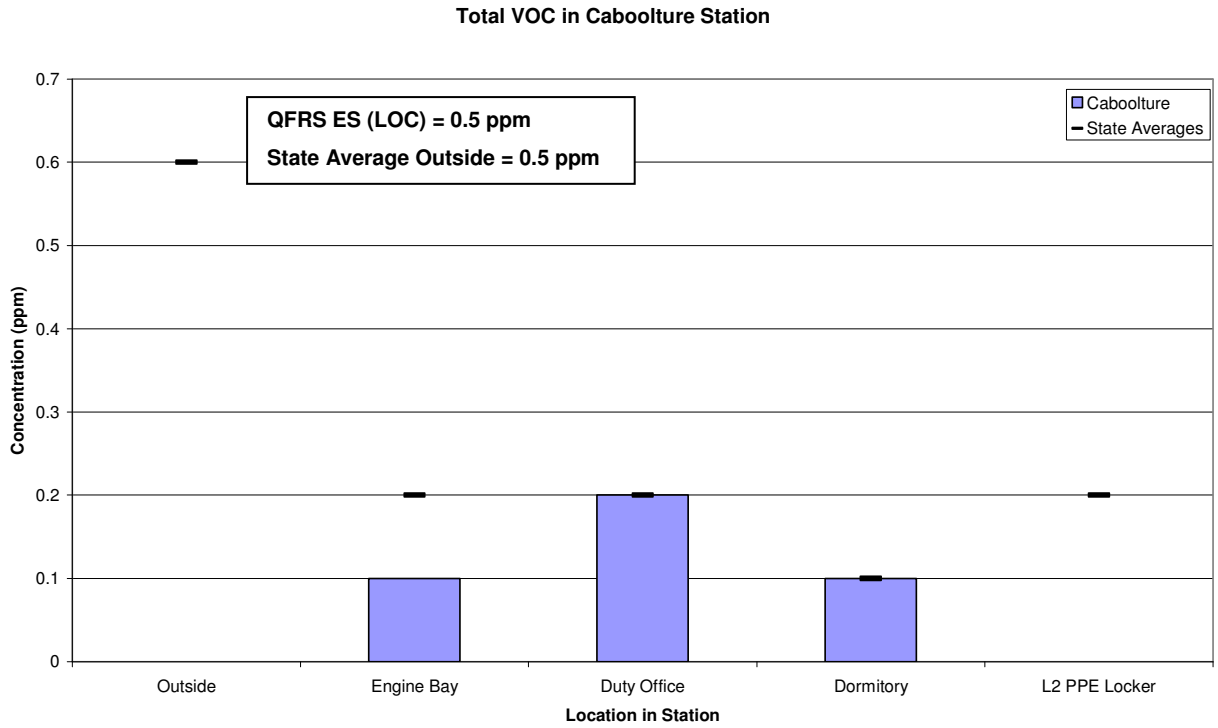


Figure 3.76
Volatile organic compounds concentrations for a 10 Hr day shift at Caboolture fire station.

Outside Station (Background)
The Caboolture average background concentration (< 0.1 ppm) was significantly less than the average outside concentration (0.5 ppm) obtained across the state and the QFRS established level of concern (0.5 ppm).

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station were similar to the background concentration except in the case of the duty office (0.2 ppm), which is higher than duty office average state (0.1ppm), but significantly less than the outside state average and the QFRS established level of concern (0.5 ppm). The engine bay (0.1ppm), duty office (0.2 ppm) and PPE locker (0.1ppm), were all above the outside measurement, but below the state outside average (0.5 ppm) and the QFRS tvoc exposure standard (0.5 ppm). The duty office was the only area above the comparable duty office state average (0.1 ppm). However, the duty office was 2.5 times lower than the outside state average (0.5 ppm) and the QFRS tvoc exposure standard (0.5 ppm).

Volatile organic compounds - 10 Hr continuous monitoring

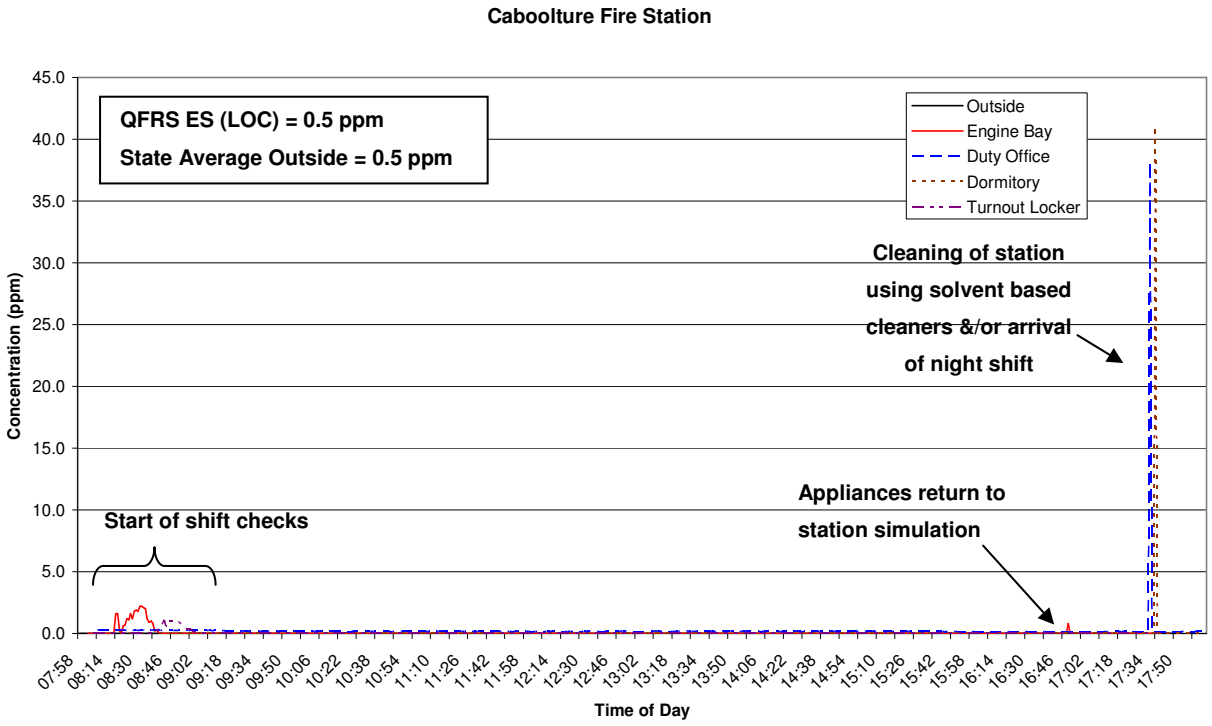


Figure 3.77
Total volatile organic compounds readings for a 10 Hr day shift at Caboolture fire station.

All monitoring results displayed peak concentrations (over one minute averaging periods) for the length of the data collection. The time averaged total volatile organic compounds (tvoc) results showed that the engine bay, duty office and PPE locker were the only areas with significant tvoc's levels measured.

The Caboolture station tvoc results show the only significant measurements occurred in the engine bay (2.1 ppm) and PPE locker (1.1 ppm) during the start of shift checks, and latter in the afternoon in the duty office (38.1 ppm) and the dormitory (41.0 ppm).

The engine bay and PPE locker concentrations during the start of shift checks did not exceed the QFRS exposure standard LOC 0.5 ppm or the state outside average (0.5 ppm). However, the duty office and dormitory results both exceeded the QFRS exposure standard LOC 0.5 ppm and the state outside average (0.5 ppm), and may have been due to increased traffic activity within the station by the arrival of night shift staff and the cleaning activates of day shift staff.

A peak detected late afternoon in the engine bay (1.0 ppm) coincided with the return of vehicles to the station.

Atmospheric Contaminants – hexane, benzene, toluene and xylene

Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A Mixture of evacuated canisters, active and passive sorbent techniques was used. The result for the dormitory is based on five hours and not tens hours due to equipment failure. Instantaneous measurements of benzene generated during the station activities were also obtained. If the result obtained was less than the reporting limit (<R.L) the R.L was used to illustrate the worst case concentration for a specific location.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<6.3*	1	-	<5.3*	1.8	-	<4.6*	<2	-	6.2	<1	-	<17.0*	<29.1*
Engine Bay			1.3	-		5.4	-		3.4	-		1.0	-		<29.3*
Start of Shift	<0.5	31			101			83			272			<209*	
Turnout	<0.5	<3.1*			6.1			5.8			6.2			<211*	
Return	<0.5	<3.1*			4.5			4.1			9.4			<344*	
Duty Office	<0.5		1	-		1.0	-		<2	-		<1	-		<28.8*
Dormitory	<0.5	<6.3*	1	-	8.2	1.3	-	<4.6*	<2	-	8.8	<1	-	<17.2*	<29.2*
Mess area	<0.5		1	-		1.9	-		<2	-		<1	-		<28.4*
PPE Locker	<0.5	<6.3*			14.1			9.4			26.1			<20.0*	

Table 3.23

Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Caboolture fire station over a day shift.

Atmospheric Contaminants – hexane

Outside Station (Background)

The hexane background concentration outside Caboolture fire station was at or below the R.L (<1.0 ppb) and was less than the average background concentration (1.1 ppb) across the state. This is significantly lower than the average hexane airborne concentration (18.6 ppb) in Brisbane.[48]

The average concentrations in all areas within the station were at or below the R.L (<1.0 ppb), which is more than 14000 times less than the ES_{10} of 14 000 ppb. The hexane odour threshold is 65 000 ppb.

The hexane concentration obtained after the start of shift check, turnout simulation, and return simulation were 162 ppb, <R.L (3.4 ppb) and <R.L (7.8 ppb) respectively. These concentrations are higher than the hexane background concentration. The start of shift concentration is greater than the average start of shift concentration (92 ppb) across the state, but the turn-out and return simulations were significantly less than their respective average concentrations 4.9 ppb, and 14.5 ppb from across the state. The start of shift result is *ca*. 86 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.

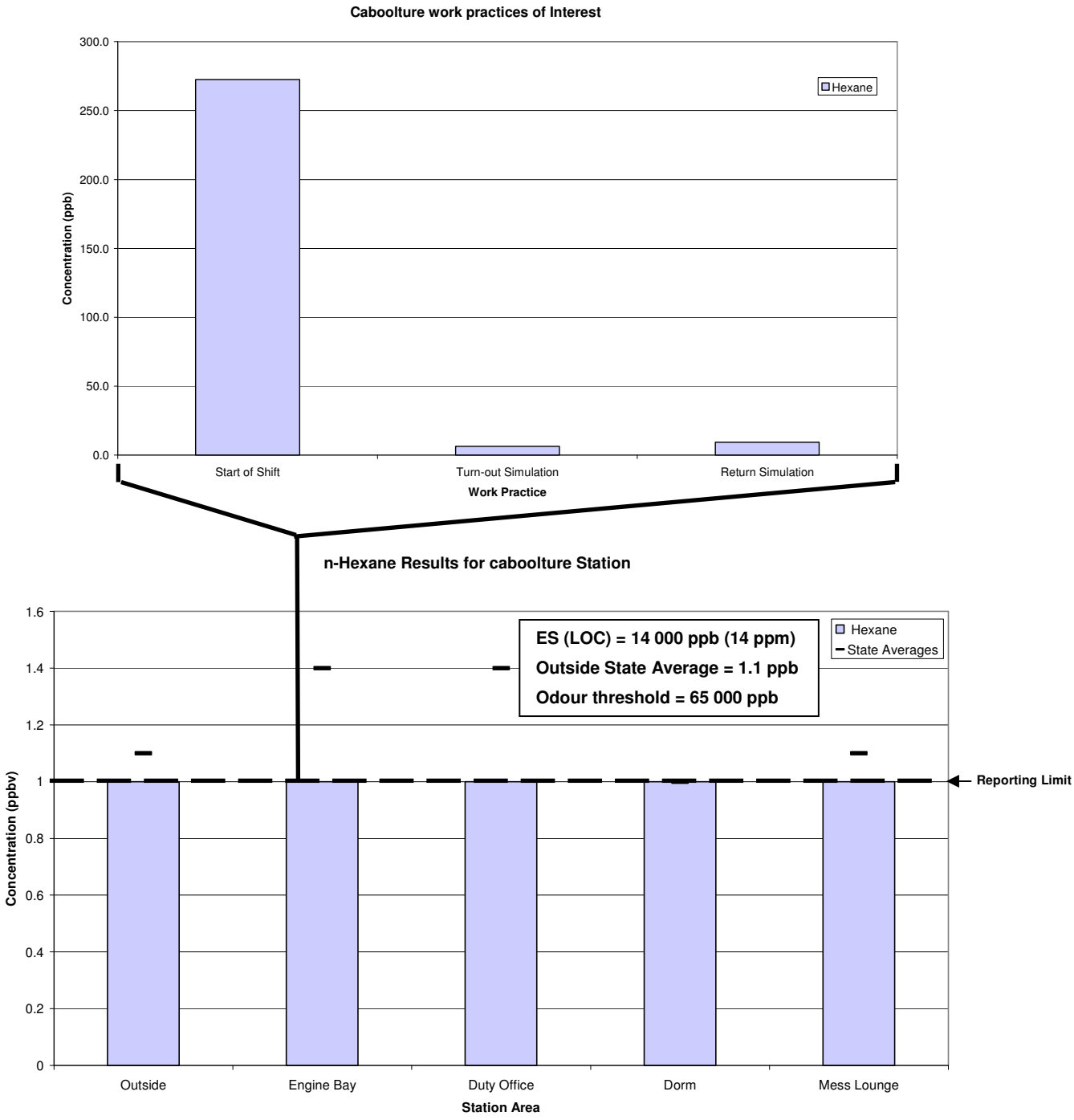


Figure 3.78
Hexane concentrations from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

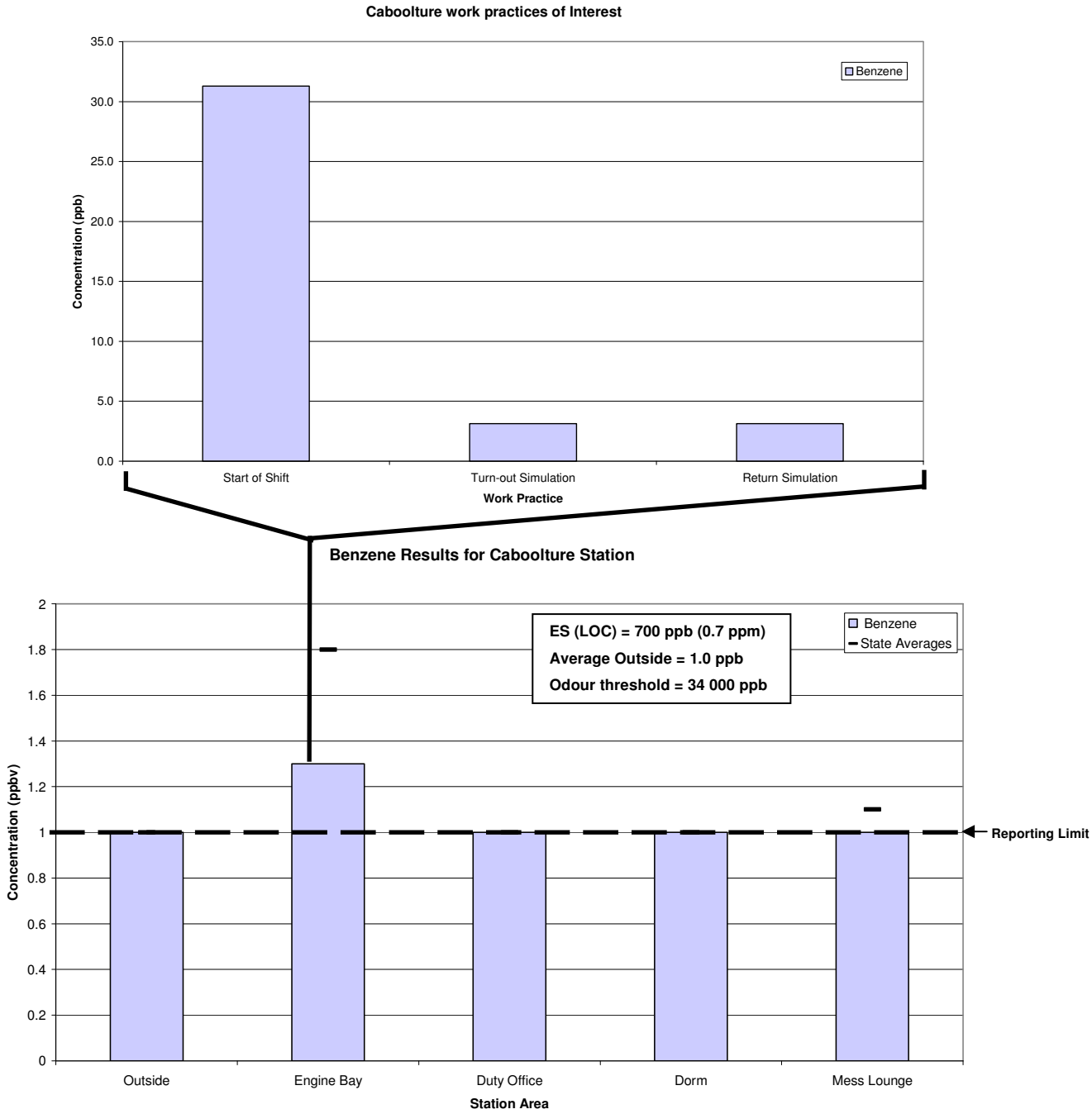


Figure 3.79
Benzene readings from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Outside Station (Background)
The background benzene concentration outside Caboolture fire station was at or below the R.L (1.0 ppb) and the average background concentration across the state (1.0 ppb). The average concentrations in all areas within the station, except the engine bay (1.3 ppb), were at or below the R.L. The engine bay result is *ca*. 650 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. The average airborne benzene concentrations in South

East Qld[46] and Brisbane[48] are 0.8 ppb (range: 0.4 to 1.5 ppb) and 3.3 ppb (range: 0.43 to 10.33 ppb) respectively. The benzene odour threshold is 34 000 ppb.

The benzene concentration observed after the start of shift check (12 minutes), turnout simulation, and return simulation were 31.3 ppb, <3.1 ppb and <3.1 ppb respectively. These concentrations are higher than the Caboolture background concentration; with the start of shift concentration *ca*. 22 times less than the ES_{10} of 700 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – toluene

Outside Station (Background)
The toluene background concentration outside Caboolture fire station (1.9 ppb) was below the average background (2.1 ppb) concentration across the state. The average concentrations in all areas within the station were below their respective average concentrations in station areas across the state. The highest concentration was obtained in the engine bay (5.4 ppb), which is *ca*. 6000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb. This background result is similar to the average toluene airborne concentrations in South East Qld[46] and Brisbane[48], 1.6 ppb (range: 0.7 to 4.9 ppb) and 10.6 ppb (range: 1.8 to 83 ppb) respectively.

The toluene concentration observed after the start of shift check (12 minutes), turnout simulation, and return simulation (101 ppb, <6.1 ppb and <4.5 respectively) are higher than the Caboolture background concentration. The start of shift checks and the turnout simulation concentrations are higher than their respective average concentrations obtained across the state (83.6 ppb and 4.5 ppb 6). The highest result within Caboolture was the start of shift, which is *ca*. 340 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

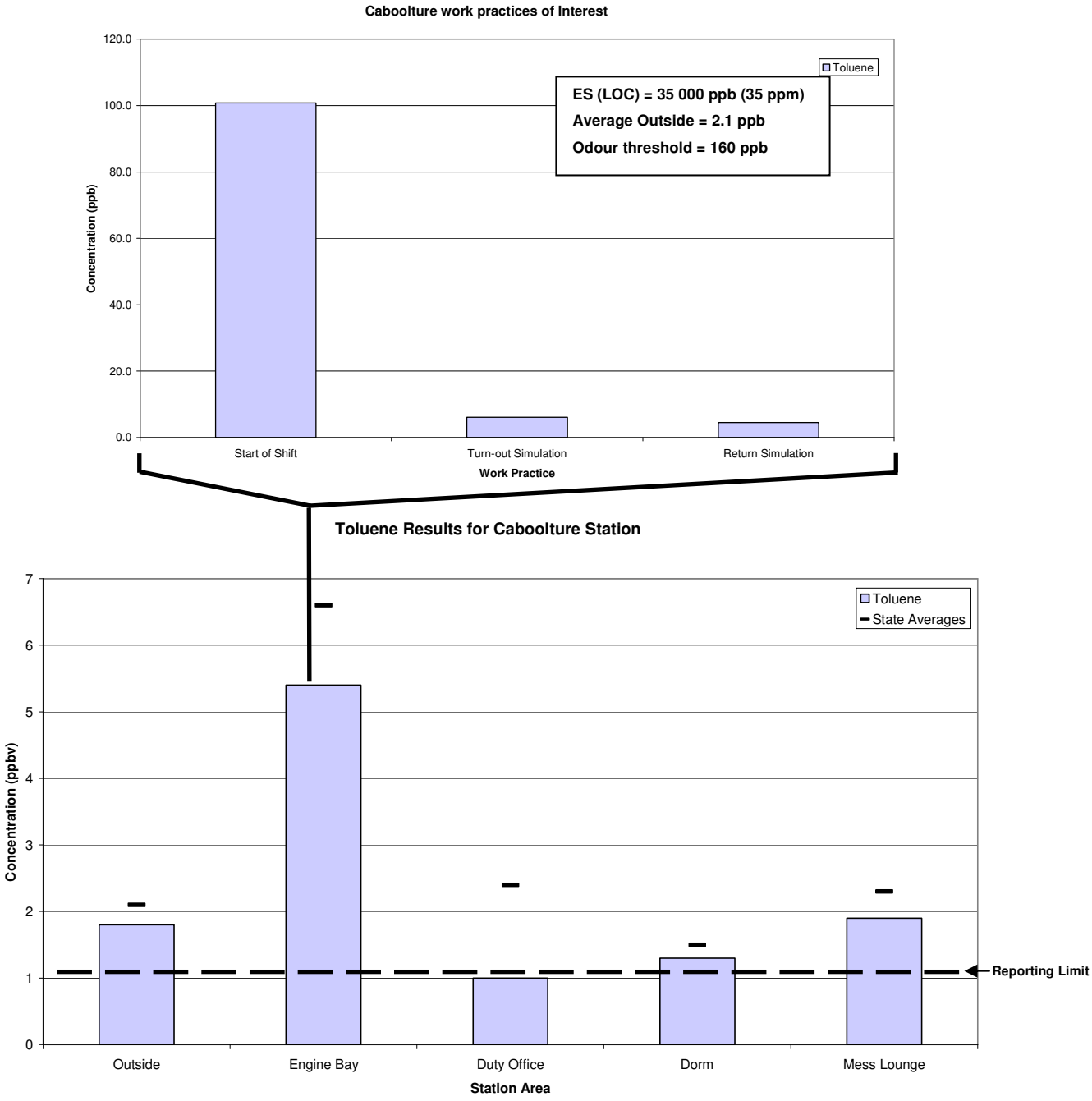


Figure 3.80
Toluene readings from evacuated canisters controlled by 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – xylene

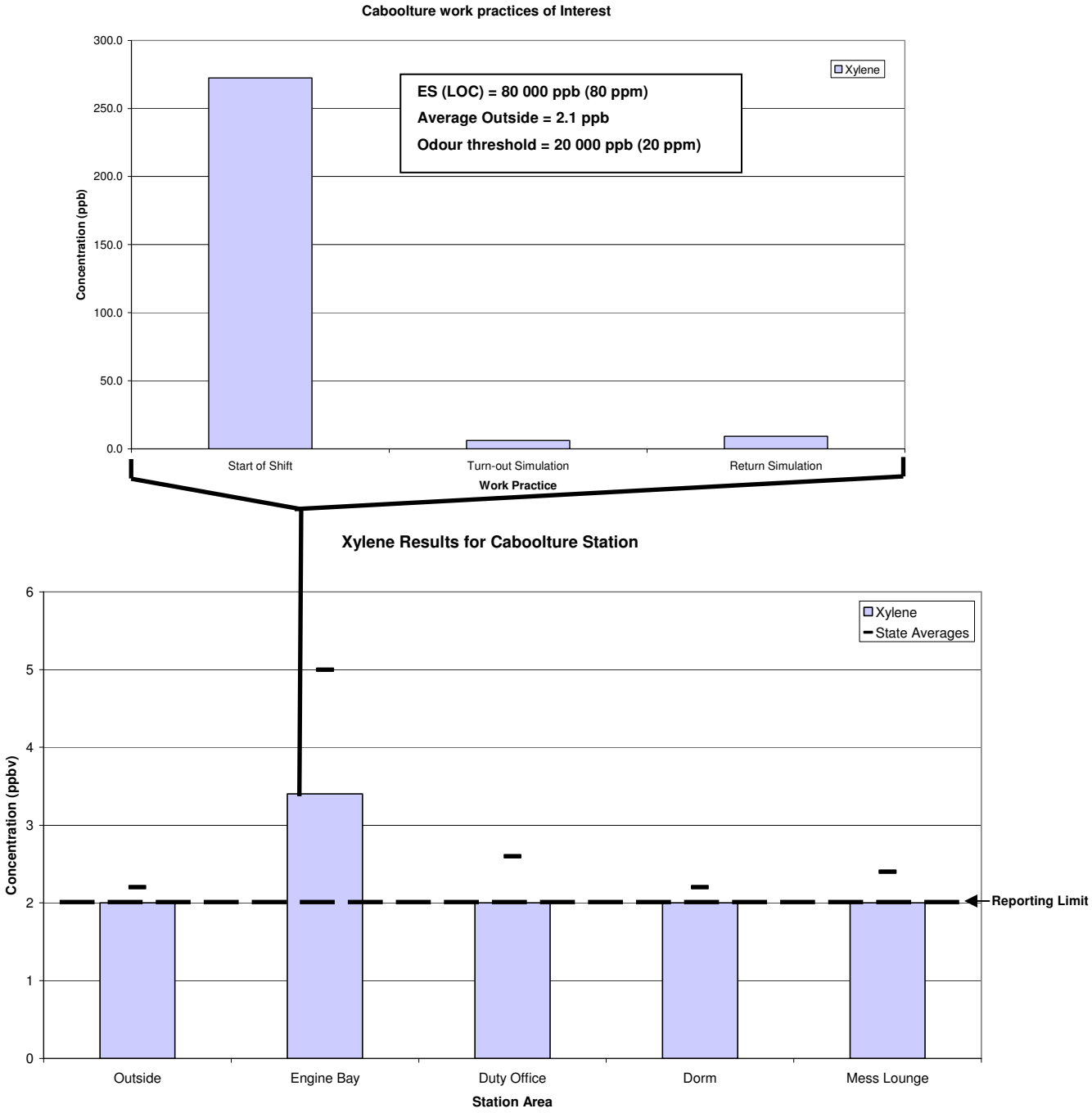


Figure 3.81
Xylene concentrations using evacuated canister controlled by a flow valve for a 10 Hr day shift. South west region concentrations are based on Tenax tubes and passive badges.

The xylene background concentration outside Caboolture fire station (2 ppb) was below the average background (2.2 ppb) concentration across the state. This background result is significantly less than the xylene airborne concentrations in South East Qld[46] - 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] -3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as p-xylene data, but calculated as total xylene based on p-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the *m-&p*-xylene with the *o*-xylene.

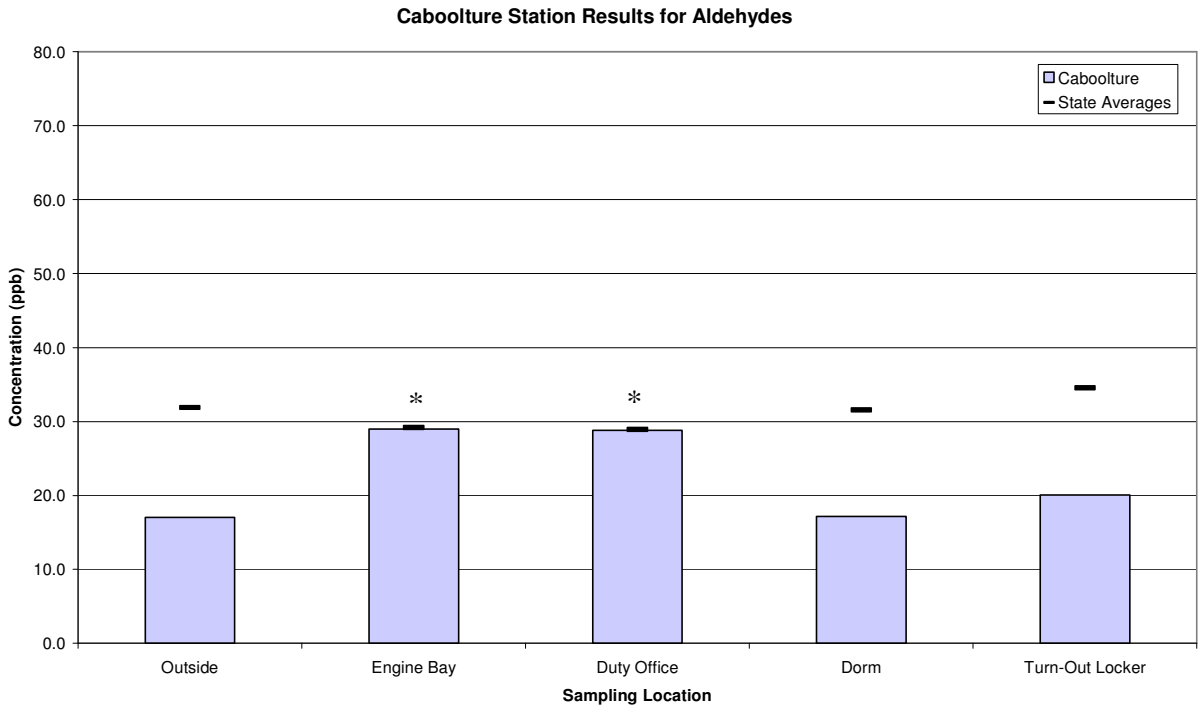
The average concentrations in all areas within the station were below the state average concentrations. The highest concentration obtained was in the engine bay (3.4 ppb), which is more than 16400 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 56 000 ppb. The xylene odour threshold is 20 000 ppb.

The xylene concentration observed after the start of shift check (12 minutes), turnout simulation, and return simulation were 272 ppb, <6.2 ppb and <9.4 ppb respectively. These concentrations are higher than the background concentration of xylene and average xylene concentrations obtained across the state. The highest of these concentrations (start of shift 105 ppb) is *ca*. 200 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – aldehydes

Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes. These voc's are important due to their presence in diesel exhaust and their potential as respiratory and eye irritants. Aldehydes are typically formed in combustion processes and so may form from diesel exhaust, fires where PPE is worn and potentially transported back to station and numerous industrial processes in nearby premises to stations.

The total aldehyde concentrations are obtained from the summation of the concentrations of the following aldehydes: hexaldehyde, *p*-tolualdehyde, valeraldehyde, benzaldehyde, buturaldehyde, methacrolein, crotonaldehyde, propionaldehyde, acrolein, acetaldehyde and formaldehyde.



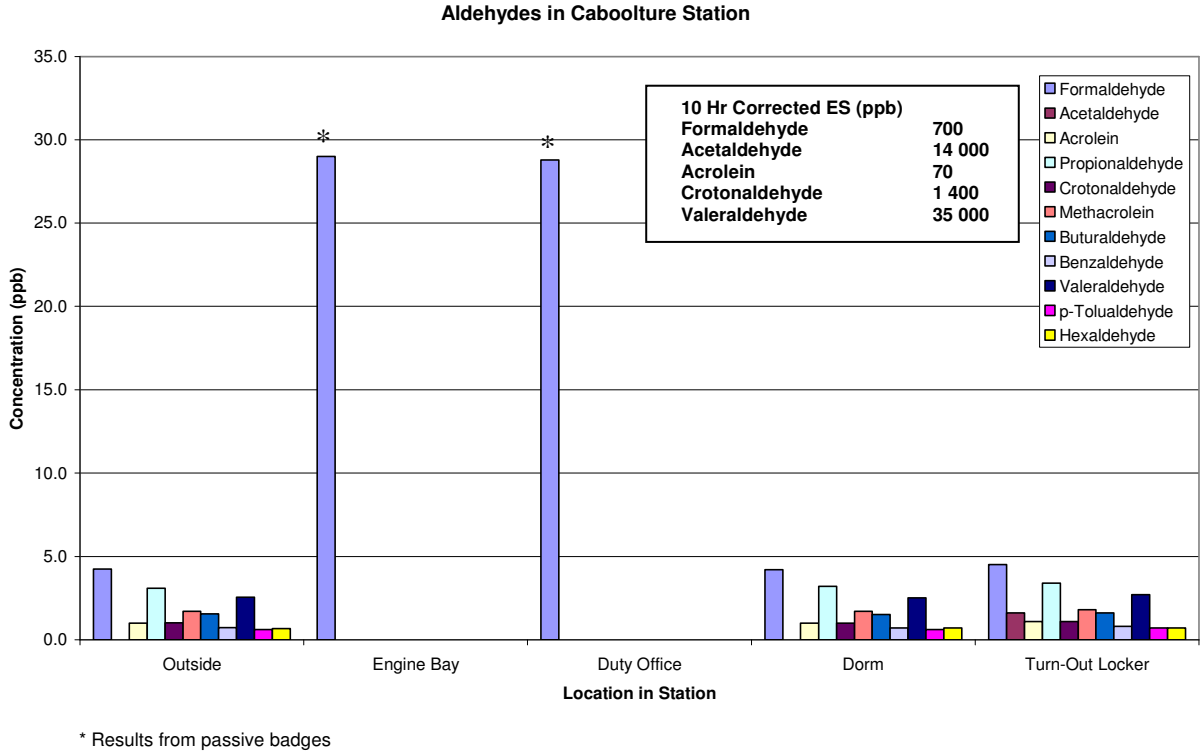
* Results from passive badges

Figure 3.82

Total aldehydes in areas of interest for a 10 Hr day shift at Caboolture fire station.

The total aldehyde results show that all station areas are above the outside (17.0 ppb) measurement, but at or below their respective state averages. The highest concentrations

were in the engine bay and duty office which were both 29 ppb, which are similar to the state average concentrations (29.2 ppb and 28.9 ppb). However, these latter results were obtained on passive diffusion badges and only formaldehyde was reported from the laboratory. The highest concentration is more than 23 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. All acrolein concentrations were at or below the R.L, which is more than 70 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}) of 70 ppb.



* Results from passive badges

Figure 3.83
Aldehyde concentrations for a 10 Hr day shift at Caboolture fire station.

Atmospheric Contaminants – Particulate Matter

Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

Polyaromatic Hydrocarbons

The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 and time adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard for PAH. Some individual PAH have established ES such as naphthalene - (15 mg/m^3). If the result obtained was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case concentration for a specific location.

Outside Station (Background)

The PAH background concentration (0.17 µg/m^3) was greater than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs: fluorene, pyrene, phenanthrene and naphthalene were detected outside the station.

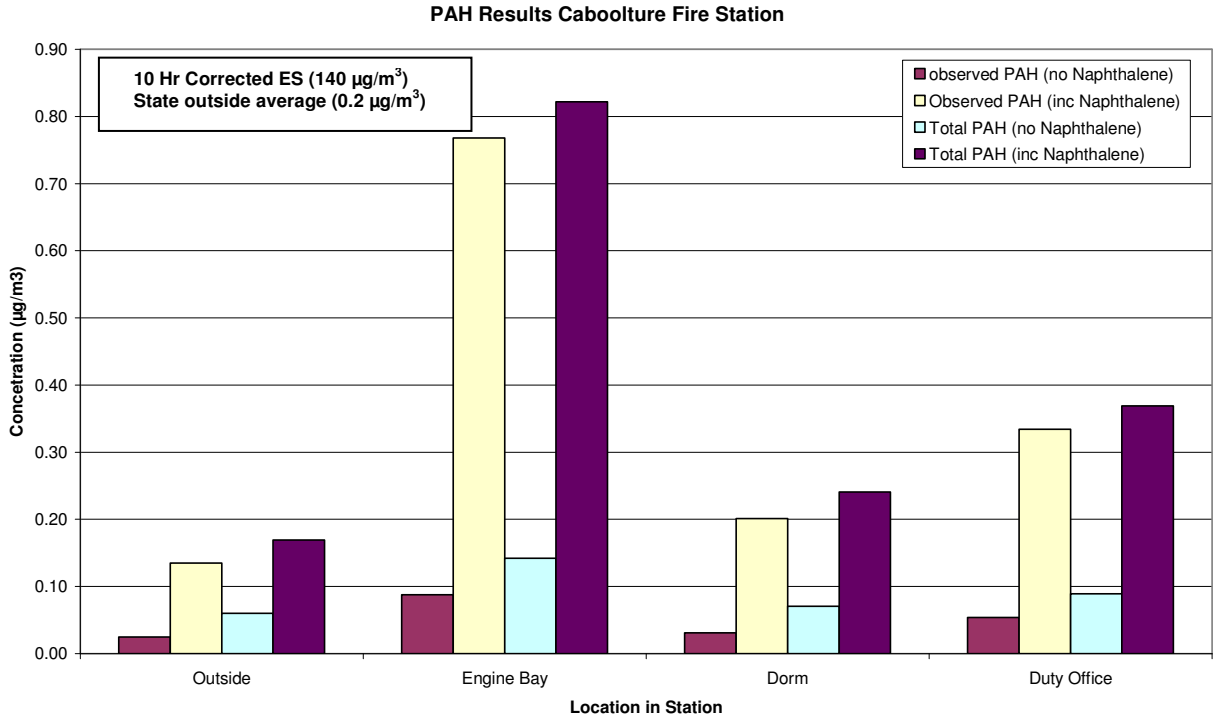
Inside Station (10 Hr monitoring)
The PAH concentrations within all fire station areas were greater then the PAH background concentration and their respective average PAH concentrations obtained across the state. The highest PAH concentration was in the engine bay, which is more than 160 times less than the ES_{10} 140 µg/m^3. The non-carcinogenic PAHs, pyrene, fluoranthene, phenanthrene, fluorene and naphthalene, were detected in the various areas in the station.

	Caboolture Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	4400	15100	5700	4000
Fluoranthene	<RL	7900	<RL	<RL
Anthracene	<RL	<RL	<RL	<RL
Phenanthrene	11800	37000	26300	16300
Fluorene	8400	27800	22000	10900
Acenaphthene	<RL	<RL	<RL	<RL
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	110000	680000	280000	170000
Reporting Limit	3100	5400	3200	3600
Total PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.02	0.09	0.05	0.03
Total with Naphthalene (µg/m^3)	0.13	0.77	0.33	0.20
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3) to better reflect a measurable quantity				
Total without Naphthalene (µg/m^3)	0.06	0.14	0.09	0.07
Total with Naphthalene (µg/m^3)	0.17	0.82	0.37	0.24
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.24
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Caboolture fire station.

The figures below demonstrate naphthalene is the most significant contributing PAH to the total concentration. This trend is consistent across all areas of the fire station and few if any other PAHs are detected.

The highest estimated naphthalene concentration in any area is more than 20,000 times below the established ES_{10} 10 500 µg/m^3 and more than 290 times below the naphthalene odour threshold (200 µg/m^3).



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.84

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Caboolture fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

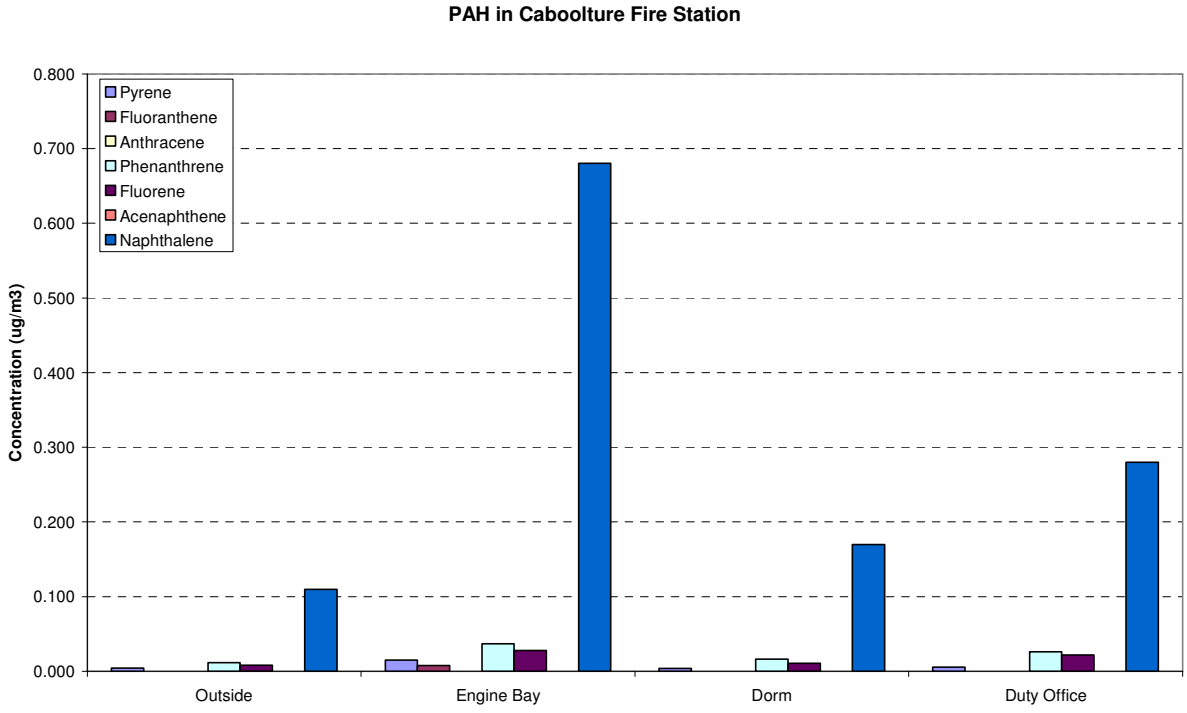


Figure 3.85

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Caboolture fire station.

Diesel Particulate Matter
The diesel particulate matter (DPM) has been described extensively in chapter one. There is no established ES for DPM and a level of concern 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L) the R.L was used to illustrate the worst case concentration for a specific location. The US fire fighter[33] DPM exposure is typically ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

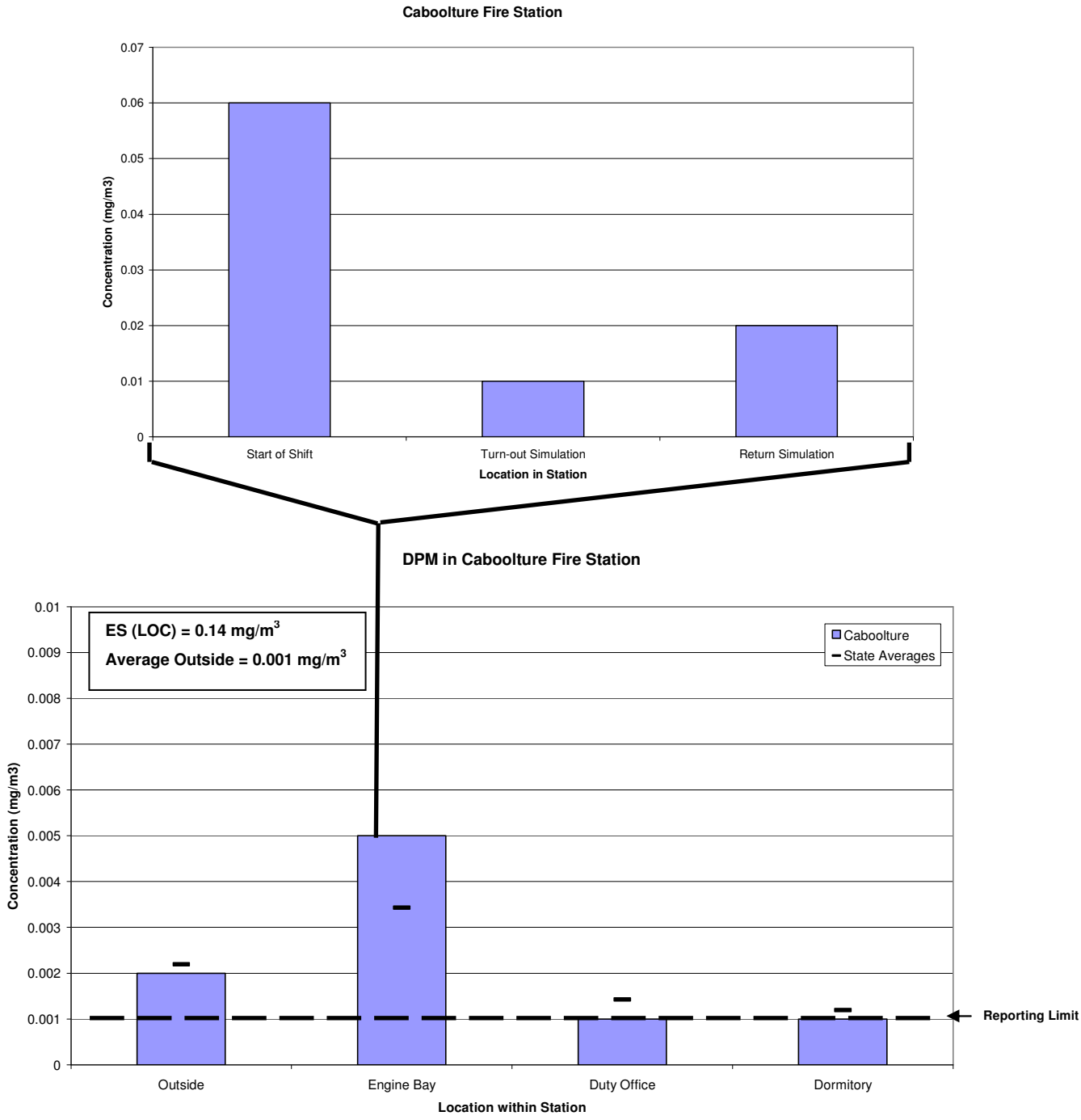
10 Hr monitoring Station
The DPM background concentration (0.002 mg/m^3) is same as the average background DPM concentration across the state (0.002 mg/m^3). The average concentrations in all areas within the station were at or below the R.L and less than the average concentrations obtained across the state except the engine bay (0.005 mg/m^3). This concentration is greater to the state average concentration. The result for the dormitory was obtained after only five hours sampling as a result of equipment failure.

Station Activity monitoring
The DPM concentration observed after the start of shift check (12 minutes) was (0.06 mg/m^3 EC), which is higher than the average start of shift concentration (0.044 mg/m^3 EC – including the Firepac 3000 Mk 3 measurement) across the state. This concentration is more than 30 times less than the established LOC of 0.1 mg/m^3 EC, when the all engine bay doors are closed and no deliberate ventilation applied to remove exhaust emissions.

The DPM concentrations for the turnout simulation, and return simulation were both 0.01 mg/m^3, which is higher than the state turn-out average (0.009 mg/m^3) and less than the state return average (0.013 mg/m^3). Several explanations account for these results, including the engine bay design, ventilation and appliance performance. These concentrations are more than 10 times less than the level of concern (0.1 mg/m^3 EC).

These Caboolture station results show that only the start of shift checks was the only measurement that exceeded the typical US fire fighter exposure[33] concentration of 0.05 mg/m^3 EC, during the 10 Hr day shift or any activity of interest.

The results demonstrate that the exposure of fire fighters whilst working at this station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern. In many instances there is no significant difference compared with the background concentrations and the averages across Queensland.



* Due to instrument failure, the dormitory concentration relates to five (5) hours only.

Figure 3.86
DPM concentrations for Caboolture station based on 10 Hr shift and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Caboolture Results

The Caboolture station trials showed that no station activity exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.17	0.002	1	1.8	<2	<1	<17.0	<0.5	<0.5	0.1	0.04	0.0
Engine Bay	0.82	0.005	1.3	5.4	3.4	<1	<29.3			1.3	0.01	0.1
Start of Shift		0.06	31	101	83	272	<209	<0.5	<0.5			
Turnout		0.01	<3.1	6.1	5.8	6.2	<211	<0.5	<0.5			
Return		0.02	<3.1	4.5	4.1	9.4	<344	<0.5	<0.5			
Duty Office	0.37	0.001	1	1.0	<2	<1	<28.8	<0.5	<0.5	0.04	0.05	0.2
Dormitory	0.24	0.001	1	1.3	<2	8.8	<17.2	<0.5	<0.5	0.1	0.1	0.1
Mess/Lounge			1	1.9	<2	<1	<28.4	<0.5	<0.5			
PPE Locker			<6.3	14.1	9.4	26.1	<20.0*	<0.5	<0.5	2.0	0.09	0.0

The greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

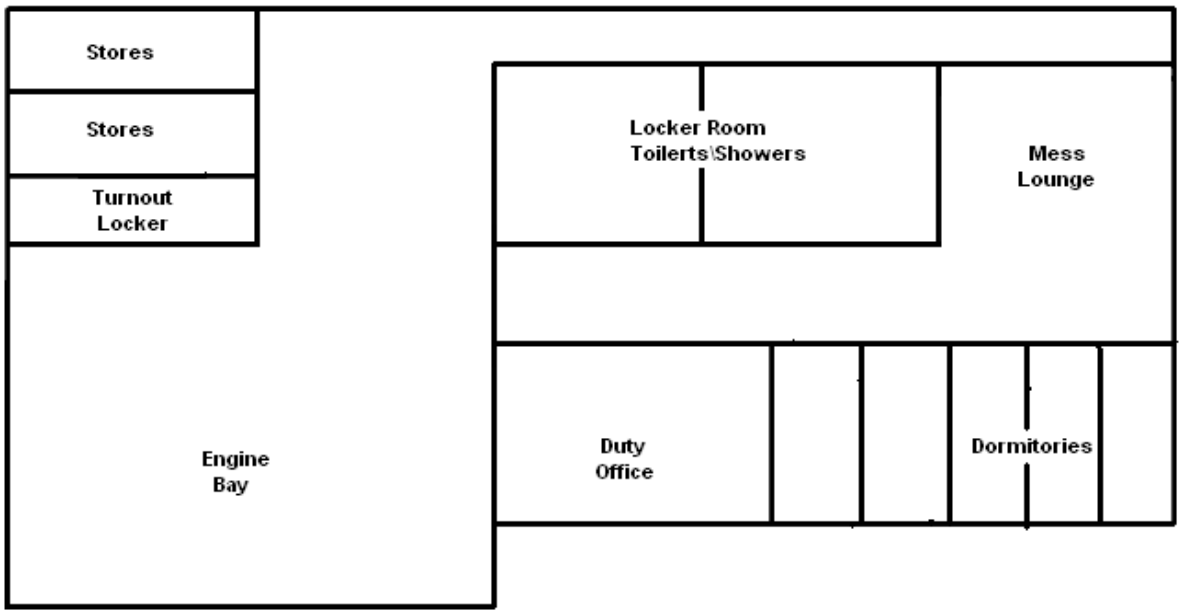
Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Review of QFRS Fire Station Data

South Eastern Region

Loganlea Fire Station

The Loganlea fire station is an older style station built prior to 1970. It is the major station in the Logan City area (Northern section of the South Eastern region), with three engine bays housing three fire fighting, one rescue and one appliances. The station is staffed by six fire fighters. In 2007 there were 1302 reported responses.



Fire fighter exposures in the Loganlea Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide and nitrogen dioxide concentrations were measured during the station activities: start of shift checks; turn out; and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results for all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Loganlea – NO_2 (ppm)	n.d	0.75 ss	n.d	n.d	n.d	n.d
Loganlea – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.25 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.25
Peak concentrations of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) air-borne contaminants in Loganlea Fire Station.

The airborne concentration of sulfur dioxide was below the limit of detection (0.5 ppm) for all activities. These concentrations are at or below the average concentration obtained for all fire stations. The airborne concentration of nitrogen dioxide was below the LOD for all activities except the start of shift check (0.75 ppm), which was the highest result obtained for all fire stations, but below the 10 Hr corrected exposure ES_{10} of 2 ppm. All concentrations were below the South East Qld[46] and Brisbane[48] average airborne concentrations.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**		**Multi Rae four gas detector**			
	Total VOC (ppm)		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing			
			Hydrogen sulphide (ppm)		Carbon monoxide (ppm)	
	Loganlea Station	State Average	Loganlea Station	State Average	Loganlea Station	State Average
Outside	0.1	0.5	0.1	0.1	1.3	0.7
Engine Bay	0.1	0.1	0.1	0.1	2.1	1.3
Duty Office	n/a	0.1	0.1	0.2	0.8	1
Dormitory	0.01	0.1	0.3	0.1	1.6	0.6
Mess / Lounge	n/a	n/a	0.1	-	0.5	-
L2 PPE Locker	0.6	0.2	0.1	0.1	1.3	1.4

Table 3.26
Averaged concentrations for total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO) monitored over the 10 Hr day shift period.

Carbon Monoxide - total average concentrations

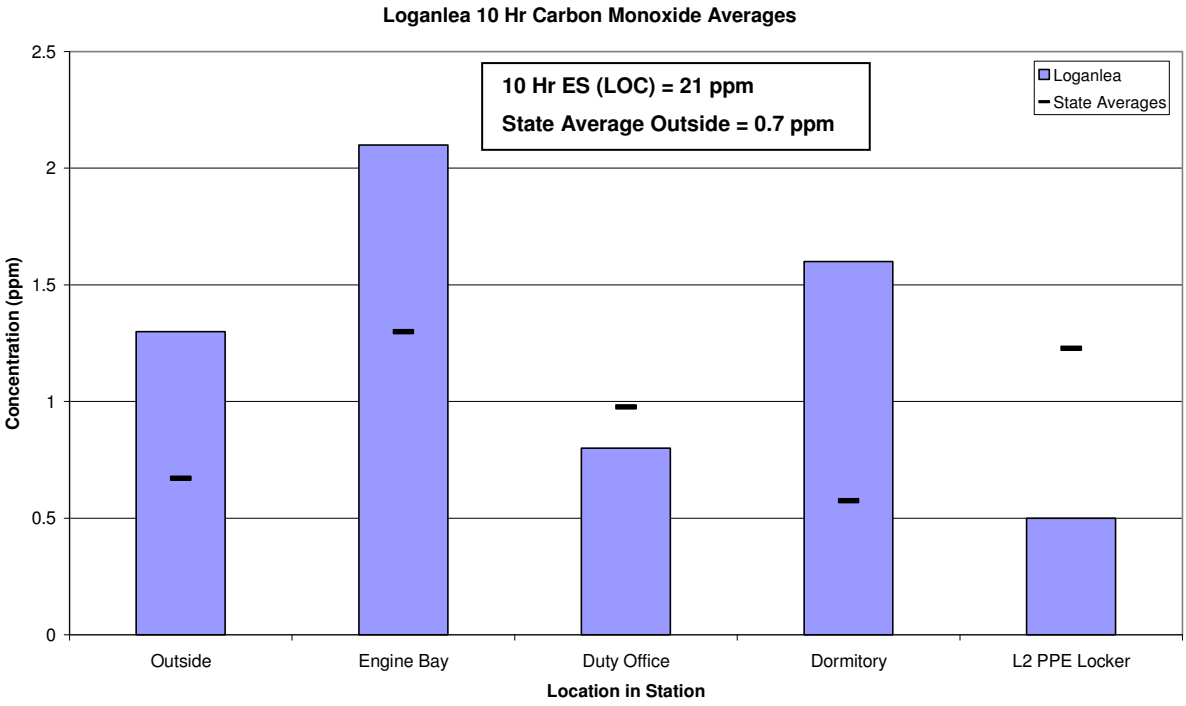


Figure 3.87
Carbon monoxide concentrations for a 10 Hr day shift at Loganlea fire station.

Outside Station (Background)
The background carbon monoxide concentration (1.3 ppm) was *ca*. 2 times higher than the average outside concentration (0.7 ppm) obtained across the state, but similar to the average South East Qld[46] airborne concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
All concentrations within the station exceed the average background concentration (0.7 ppm) across the state, but only the engine bay (2.1 ppm) and dormitory (1.6 ppm) exceed the Loganlea background concentration (1.3 ppm). The engine bay concentration (2.1 ppm) exceeded the average engine bay concentrations (1.3 ppm) for all fire stations. However, it was *ca*. 10 times less than the (ES_{10} – 21 ppm) and 4 times less than the NEPM ambient air quality standard (9 ppm). There are several possible explanations that may account for the discrepancy including location and office design and ventilation arrangements.

Carbon Monoxide - 10 Hr continuous monitoring
Figure 3.88 below shows two activities where carbon monoxide excursions were observed. These excursions corresponded to activities such as start of shift checks and appliances leaving and returning to station. In general, carbon monoxide excursions occurring during emergency response were measured only in the engine bay. The only non-engine bay excursions occurred outside the station during peak hour traffic. A turn-out occurred during this time, when all engine bay doors had been opened. The highest concentration occurred in the engine bay (74.6 ppm) during the start of shift check (33 minutes). This concentration exceeded the ES_{10} - 21 ppm, however, it did not exceed the NOHSC:[45] *Guidelines for the control of short-term excursions for Carbon Monoxide* limit of 100 ppm for 30 minutes.

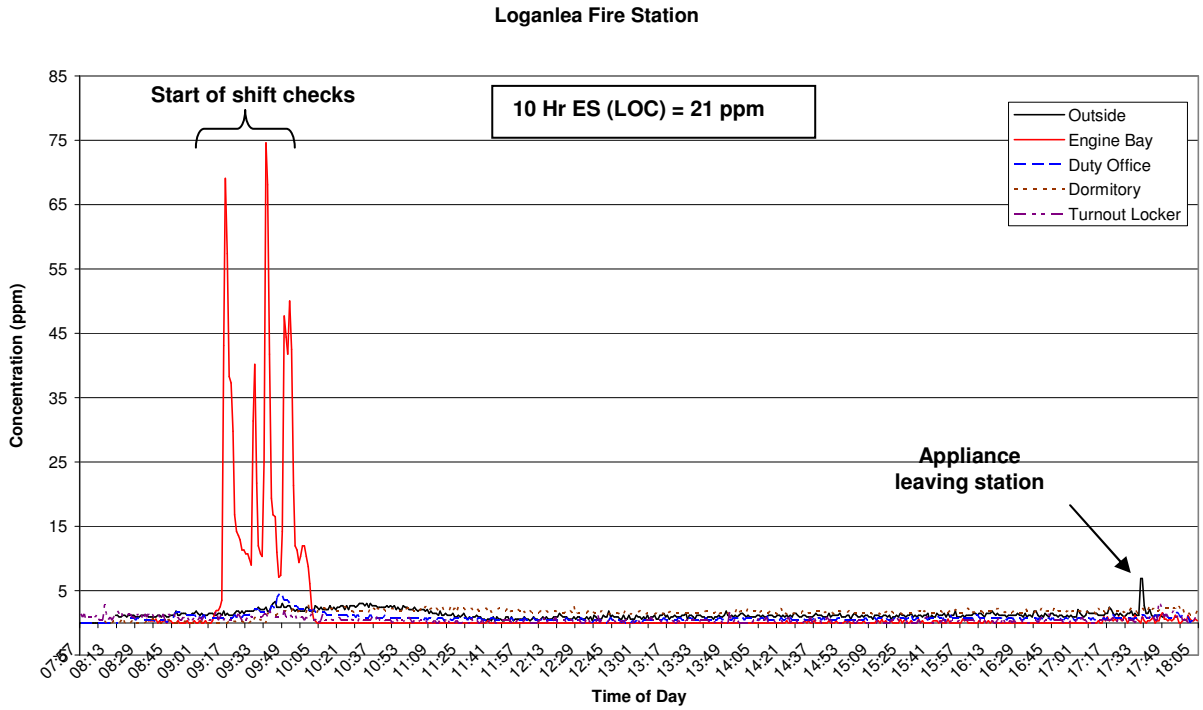


Figure 3.88
Carbon monoxide readings for a 10 Hr day shift at Loganlea fire station.

Hydrogen Sulfide - total average concentrations

Outside Station (Background)
Figure 3.89 (below), shows the Loganlea background hydrogen sulfide concentration (0.1 ppm) is the same as the average outside concentration (0.1 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station, except the dormitory (0.3 ppm), were less than the average background concentration 0.1 ppm). The highest reading was the dormitory, which was above the average dormitory concentration (0.1 ppm) for all fire stations, but below the 10 Hr corrected ES_{10} (7 ppm) concentration.

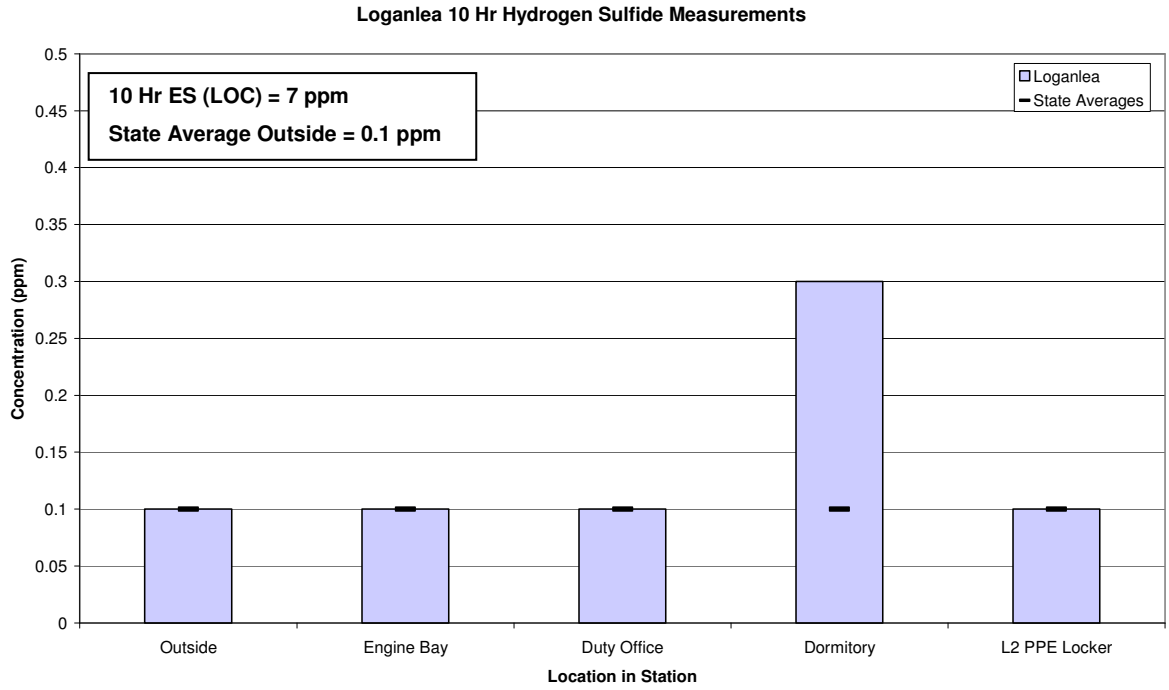


Figure 3.89
Time averaged hydrogen sulfide readings for a day shift at Loganlea fire station.

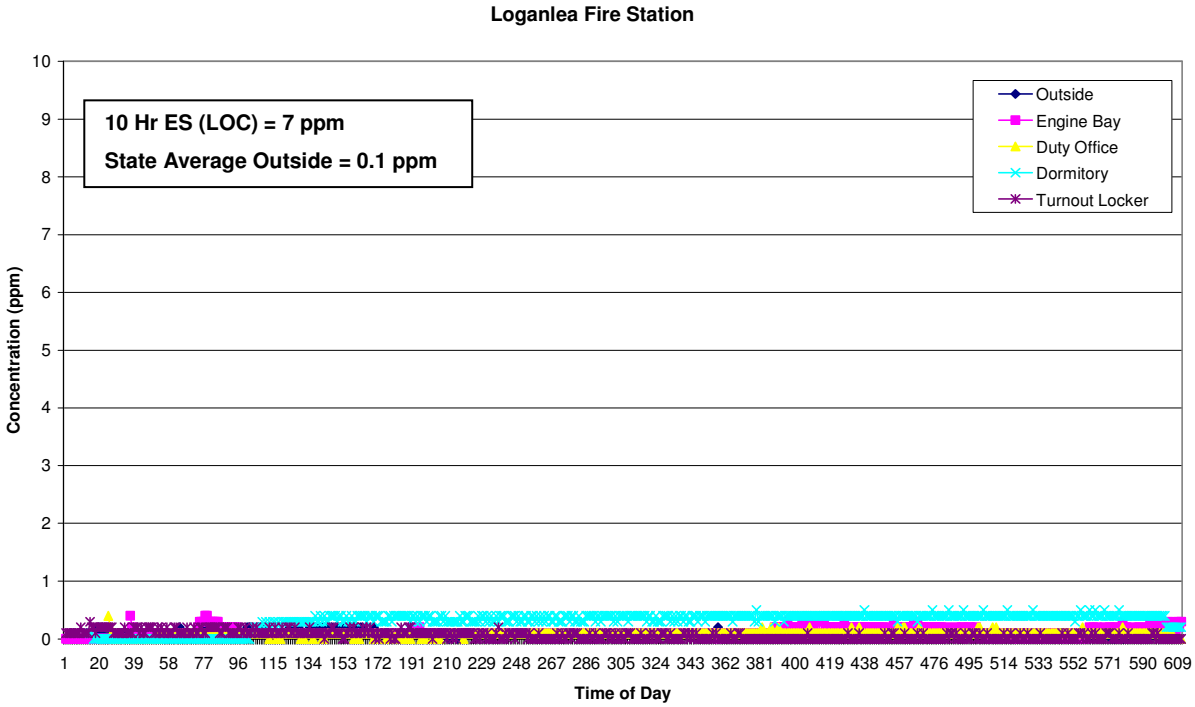


Figure 3.90
Hydrogen Sulfide readings for a 10 Hr day shift at Loganlea fire station.

All hydrogen sulfide (H_2S) concentrations were below the H_2S sensor LOD of 1 ppm, which is consistent with no 10 Hr average exceeding the ES_{10} (7 ppm).

Atmospheric Contaminants – total volatile organic compounds of concern
The total volatile organic compounds (tvoc's) results used for Loganlea station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. The tvoc's were monitored for as close as practicable to 10 Hr over a standard day. All concentrations were continuously recorded on instruments that logged peak concentrations over 1 minute averaging periods. Peak concentrations were used to ensure any potential contamination by fire appliances was highlighted.

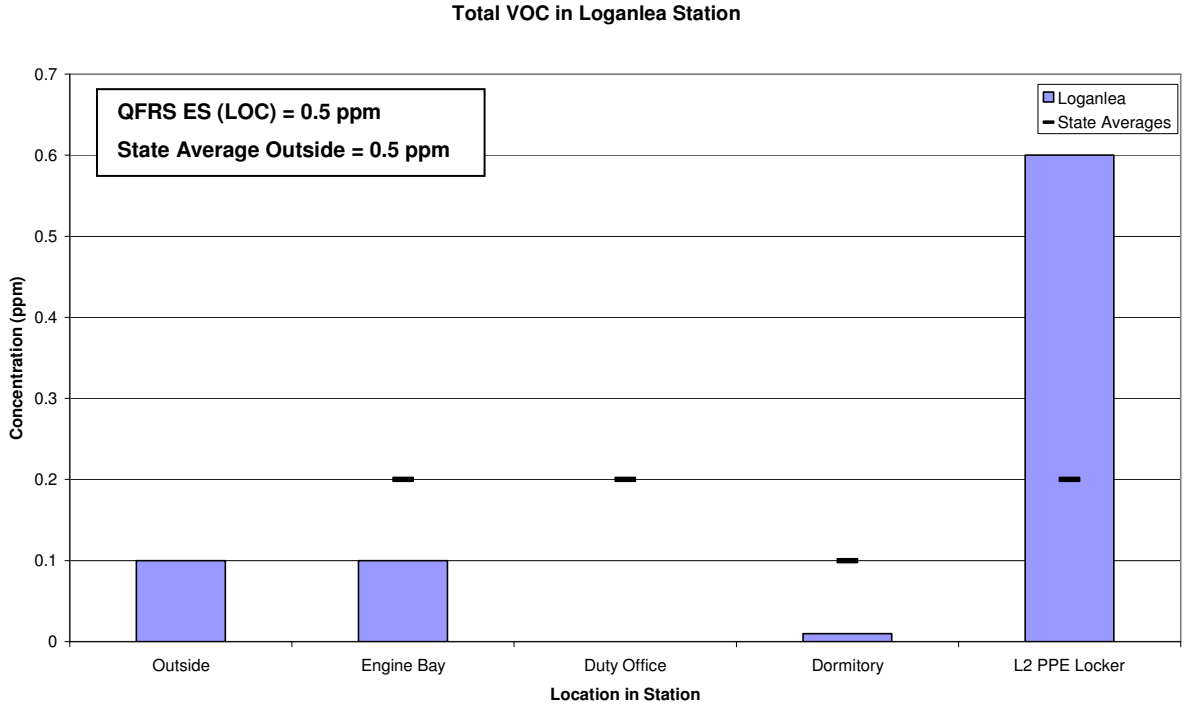


Figure 3.91
Total volatile organic compounds (tvocs) readings for a 10 Hr day shift at Loganlea fire station.

Outside Station (Background)
The average Loganlea background tvoc concentration (0.1 ppm) was significantly less than the average outside concentration (0.5 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
The average concentrations obtained within the station show that all areas, except the PPE locker (0.5 ppm), are at or below the Loganlea outside (0.1 ppm) and their respective state averages.

The PPE locker was above the Loganlea outside (0.1 ppm), the PPE locker state average (0.2 ppm), but equal to the QFRS LOC (0.5 ppm) and outside state average (0.5 ppm). The PPE locker graph indicated that the levels commenced at 0.1 ppm and continued to increase. This may have been due to a number of factors including build-up in an enclosed area due to an increase in daytime activities or humidity.

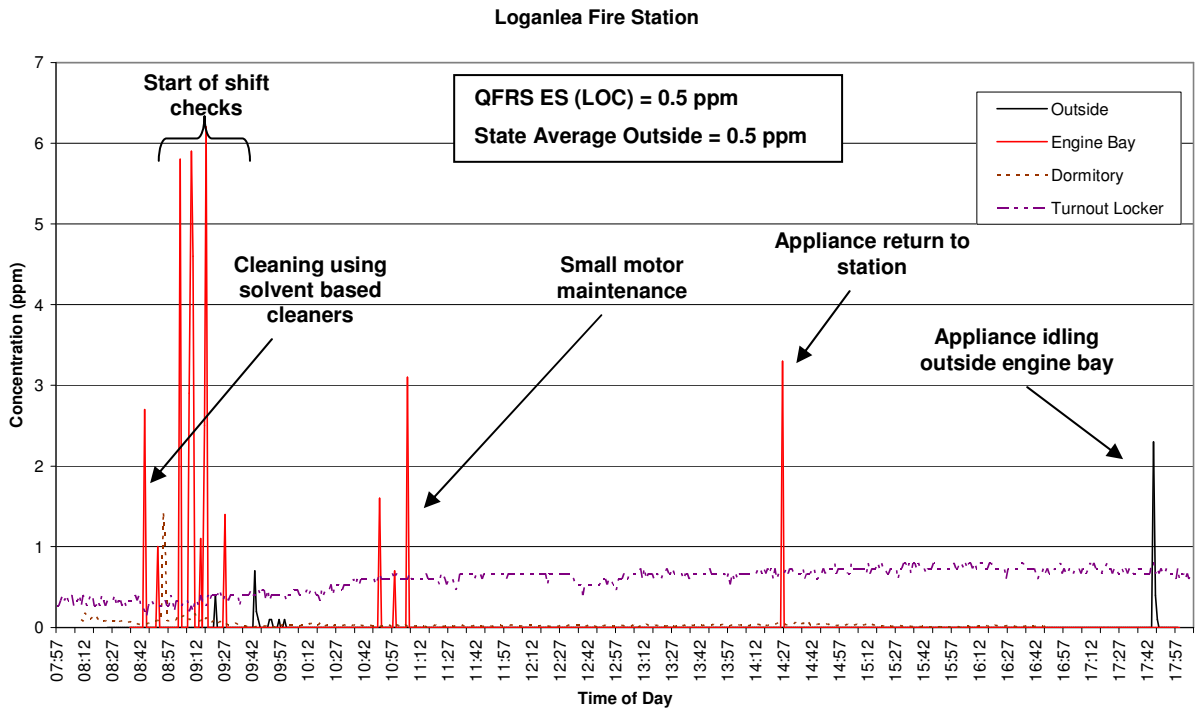


Figure 3.92
Total volatile organic compounds readings for a 10 Hr day shift at Loganlea fire station.

Volatile organic compounds - 10 Hr continuous monitoring
The Loganlea tvoc results show four occasions where excursions were observed. These excursions corresponded to activities such as start of shift check and emergency response and returns to station. The majority of peaks were located in the engine bay (6.2 ppm) and dormitory (1.4 ppm) and occurred during the start of shift checks and station cleaning activities.

All engine bay and dormitory concentrations during the start of shift checks exceeded the QFRS LOC (0.5 ppm) and the state outside average (0.5 ppm). However, once these tasks were performed and the engine bay doors opened, both areas quickly dropped to normal levels, i.e. less than the 0.5 ppm.

A peak in the latter afternoon was detected in the engine bay (1.0 ppm) area, which coincided with the appliance idling outside the station.

Atmospheric Contaminants – hexane, benzene, toluene and xylene

Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A mixture of evacuated canisters, active and passive sorbent techniques was used. Instantaneous concentrations of benzene generated during the station activities were also obtained. If the result obtained was less than the reporting limit (<R.L) the R.L was used to illustrate the worst case concentration for a specific location.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	<1.6*	1	N.R	5.7	3.1	N.R	12.5	<3	N.R	<1.6*	<1	N.R	<44.3*	<29.9*
Engine Bay			1	N.R		17	N.R		13.5	N.R		<1	N.R		<29.9*
Start of Shift	<0.5	48			>204*			276			26			<156*	
Turnout	<0.5	<10*			<10*			<10*			<10*			<140*	
Return	<0.5	<18*			<18*			<18*			<18*			<133*	
Duty Office	<0.5		1	N.R		1	N.R		<2	N.R		<1	N.R		<27.7*
Dormitory	<0.5	<2.6*	1	N.R	<10*	1	N.R	13.2	<2	N.R	<2.5*	<1	N.R	<53.9*	<29.3*
Mess area	<0.5		1	N.R		2.5	N.R		<2	N.R		<1	N.R		<29.3*
PPE Locker	<0.5	<10*			<10*			<10*			<10*			<50.8*	

Table 3.27

Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Loganlea fire station over a day shift. The BTXh PPE locker results are based on a five Hr sample due to a lost sample by the testing laboratory.

Atmospheric Contaminants – hexane

Figure 3.93 (below) shows the hexane background concentration outside Loganlea fire station was at or below the R.L (1.0 ppb) and was less than the average background concentration (1.1 ppb) across the state. The average concentrations in all areas within the station were at or below the R.L, which is more than 14000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 14 000 ppb and significantly less than the average Brisbane[48] airborne concentration (18.6 ppb). The odour threshold for hexane is 65 000 ppb.

The hexane concentrations obtained after the start of shift check, turnout simulation, and return simulation (119 ppb, <2.8 ppb and <5.1 ppb respectively) where higher than the Loganlea background concentration. The start of shift concentration is greater than the average start of shift concentration (92 ppb) across the state, but the turn-out and return simulation results are less than the average concentrations (4.9 ppb, and 14.5 ppb respectively) across the state. The start of shift concentration is *ca*. 117 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.

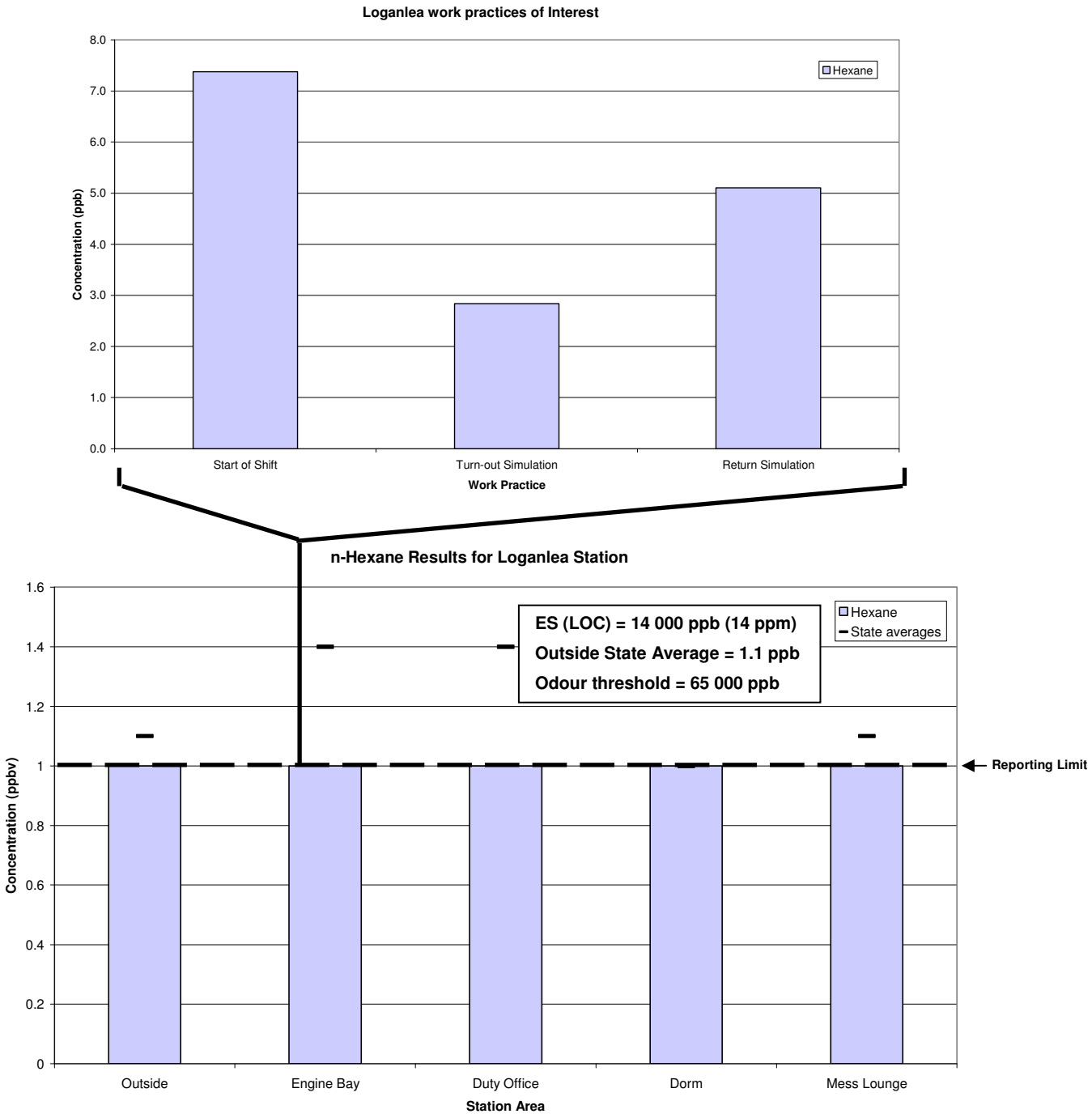


Figure 3.93
Hexane from evacuated canister controlled by a 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – benzene

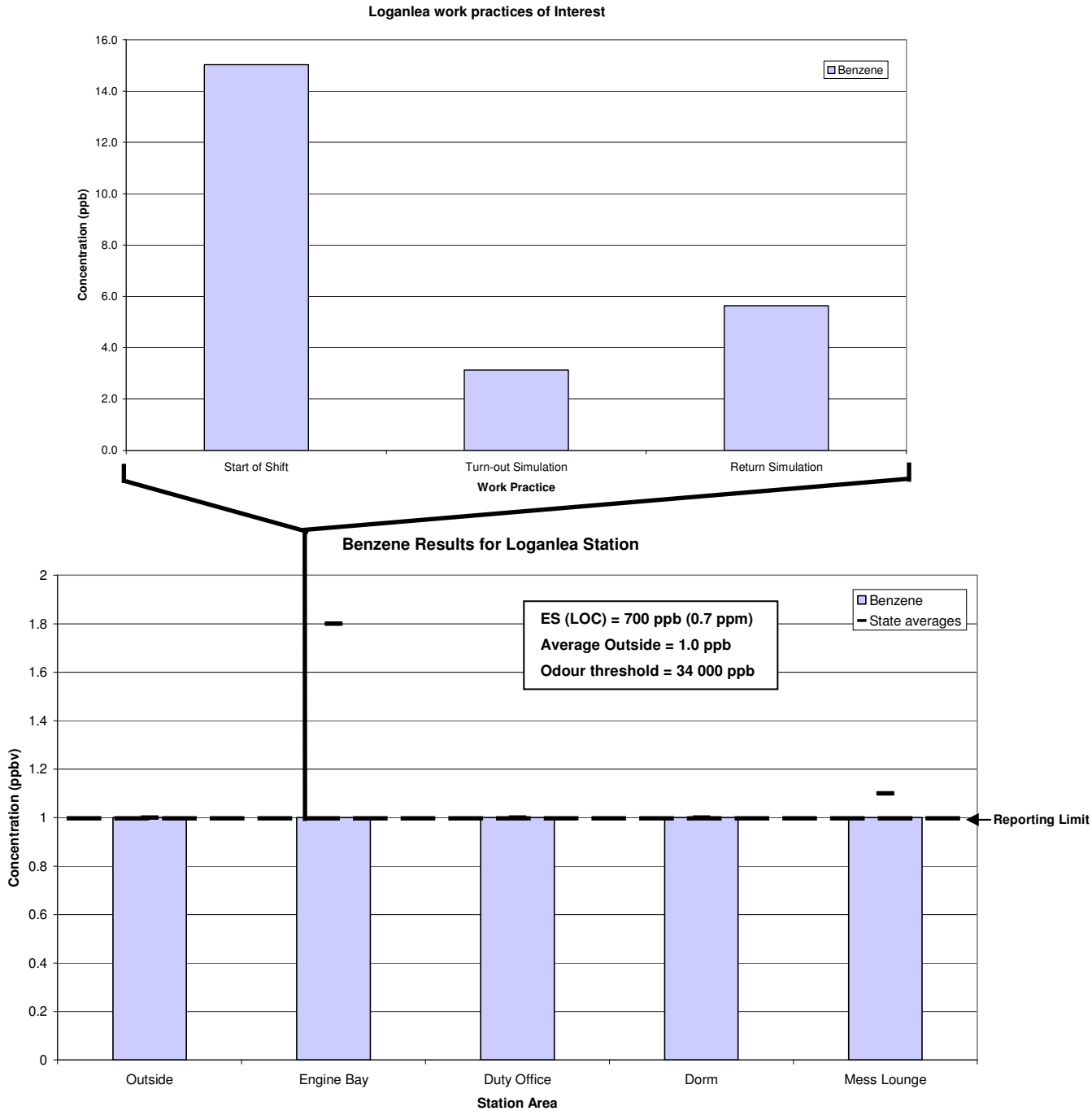


Figure 3.94
Benzene concentrations from evacuated canister controlled by a 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

The benzene background concentration outside Loganlea fire station was at or below the R.L (1.0 ppb) and the average background concentration across the state (1.0 ppb). The average concentrations in all areas within the station were at or below the R.L, which is *ca*. 700 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. This result is similar to the benzene airborne concentrations in South East Qld[46] - 0.8 ppb (range: 0.4 to 1.5 ppb)

and Brisbane[48] - 3.3 ppb (range: 0.43 to 10.33 ppb). The benzene odour threshold is 34 000 ppb.

The benzene concentrations obtained after the start of shift check (33 minutes), turnout and return simulations (15 ppb, <3.1 ppb and <5.6 ppb respectively) are higher than the background concentration of benzene, but less than the average concentrations (28 ppb, 5.3 and 16.5 ppb respectively) obtained across the state. The start of shift concentration is *ca*. 46 times less than the ES_{10} of 700 ppb. Common sources of benzene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – toluene

Outside Station (Background)
The toluene background concentration outside Loganlea fire station (3.1 ppb) was greater than the average background concentration across the state (2.1 ppb) and similar to the toluene airborne concentrations in South East Qld[46] - 1.6 ppb (range: 0.7 to 4.9 ppb) and Brisbane[48] 10.6 ppb (range: 1.8 to 83 ppb).

The average concentrations in all station areas, except the engine bay (17 ppb) and mess area (2.5 ppb) were less than the average station area concentrations obtained across the state. The engine bay result is *ca*. 2000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb. The toluene odour threshold (160 ppb)

The toluene concentration obtained after the start of shift check (33 minutes), turnout and return simulations (54 ppb, <2.7 ppb and <4.8 ppb respectively) are higher than the background concentration of toluene, but less than the average concentrations for these activities (83.6 ppb, 4.5 ppb and 6 ppb respectively) obtained across the state. The start of shift concentration is *ca*. 640 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

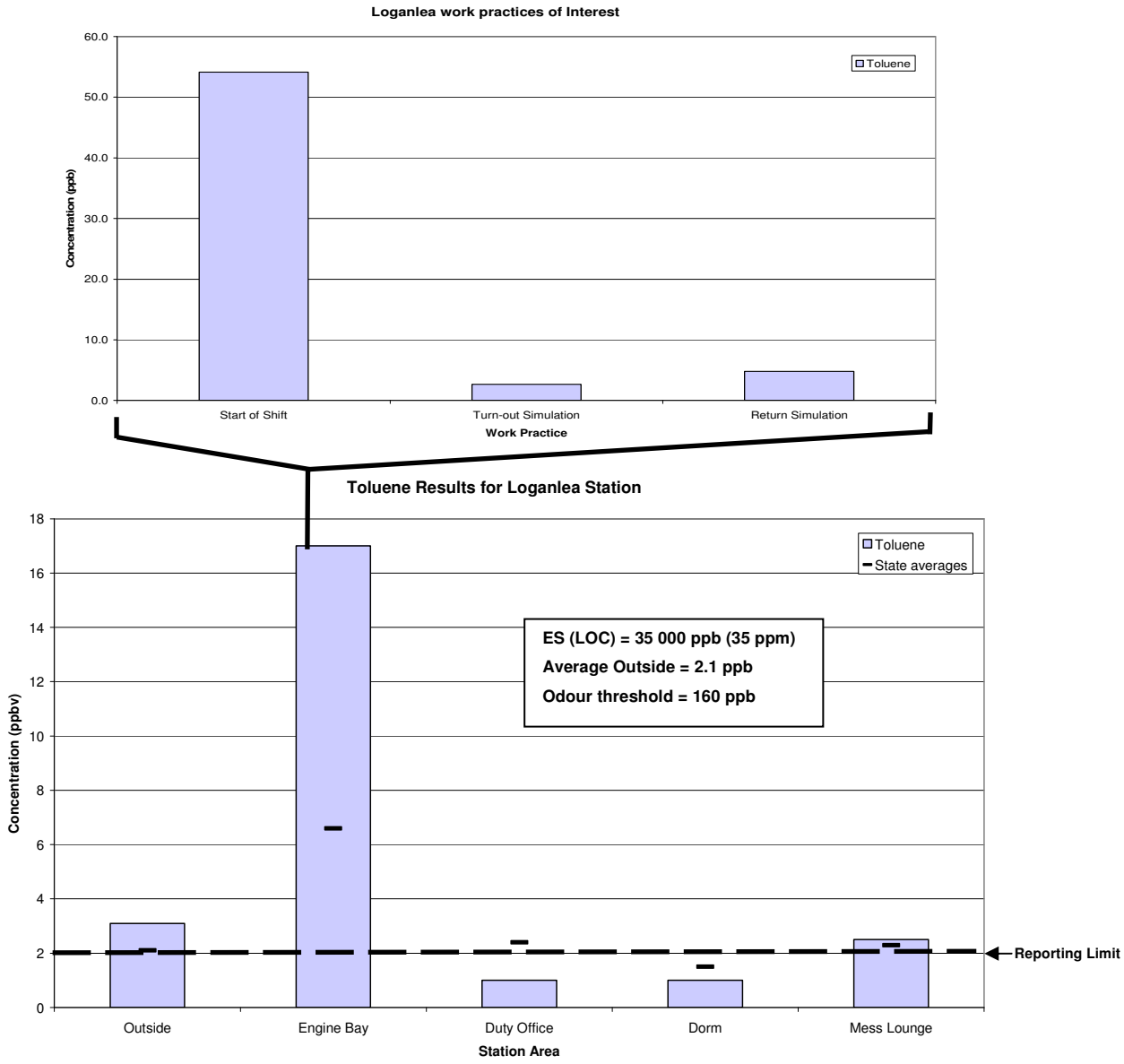


Figure 3.95
Toluene concentrations from evacuated canisters controlled by a 10 Hr flow regulators. The results for the activities of interest were collected using Tenax tubes.

Atmospheric Contaminants – xylene

Outside Station (Background)
Figure 3.96 below, shows the xylene background concentration outside Loganlea fire station (3 ppb) was greater than the average background concentration (2.2 ppb) across the state. This background result is similar to the average xylene airborne concentrations in South East Qld[46] - 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] - 3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as *p*-xylene data, but calculated as total xylene based on p-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the *m-&p*-xylene with the o-xylene. The xylene odour threshold is 20 000 ppb.

The average concentrations in all station areas, except the engine bay (13.5 ppb), were less than the average station area concentrations obtained across the state. The engine bay result

is more than 800 times below the 10 Hr time corrected exposure standard (ES_{10}) of 56 000 ppb. The average xylene airborne concentration in a Brisbane industrial area[48] was 3.4 ppb (average of two means for *o*-xylene and *m/p*-xylene).

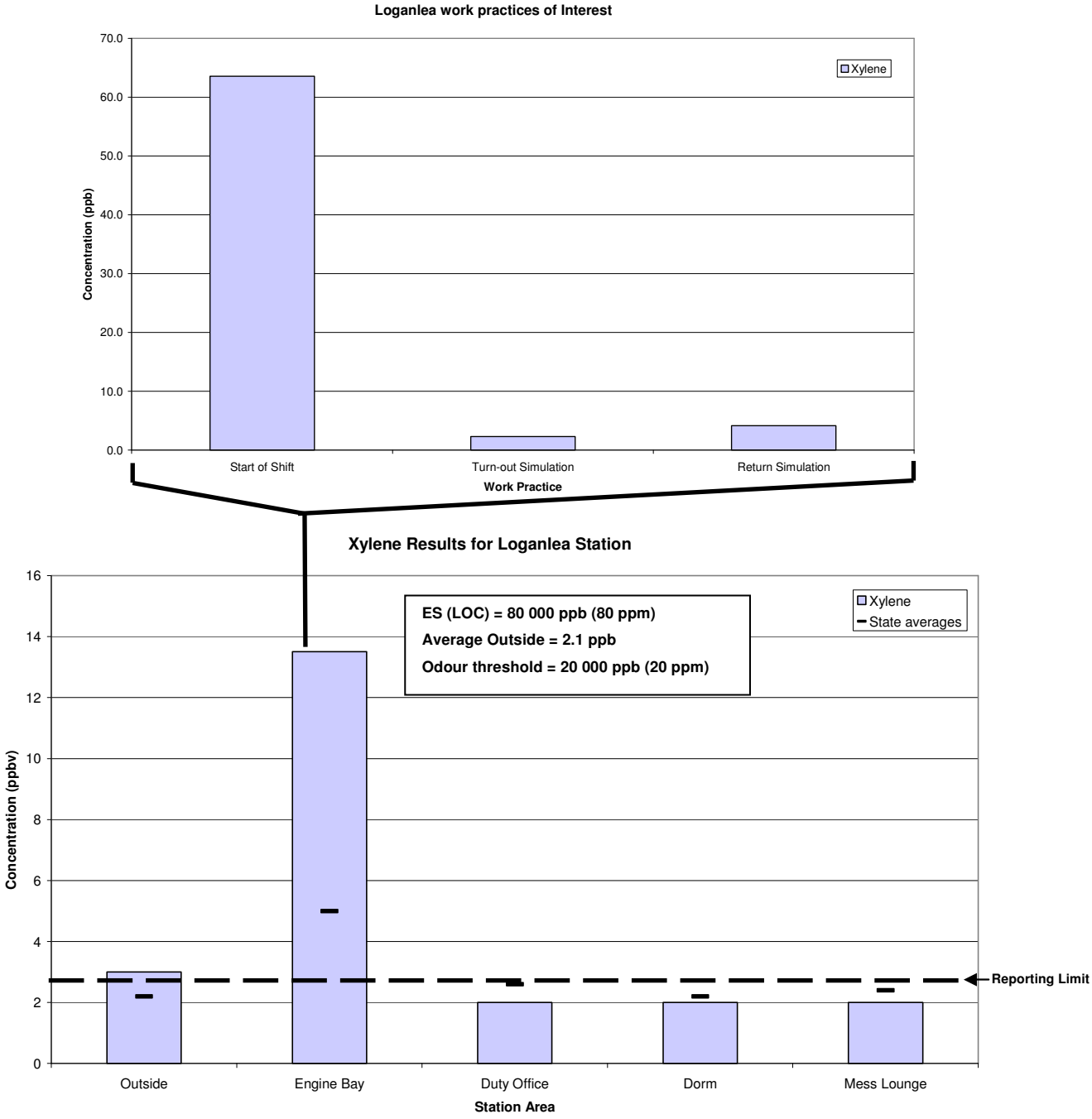


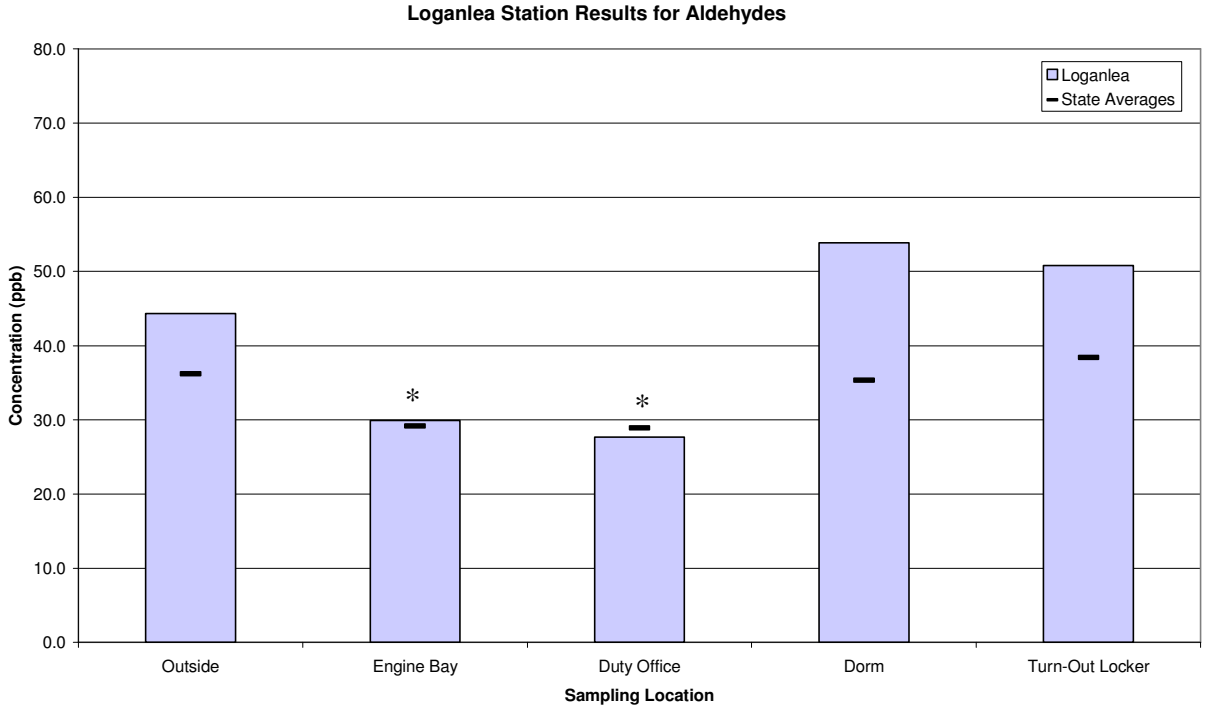
Figure 3.96
Xylene concentrations from evacuated canisters using 10 Hr flow regulators. Analyses for xylene were reported as the isomers *m-* / *p*-xylene and *o*-xylene.

The xylene concentrations obtained after the start of shift check (33 minutes), turnout and return simulations (64 ppb, <2.3 ppb and <4.1 ppb respectively) are higher than the background concentration of xylene, but less than the average concentrations for these activities (105 ppb, 5.3 ppb, and 12.5 ppb respectively) obtained across the state. The start of

shift concentration is *ca*. 800 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – aldehydes

Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes.

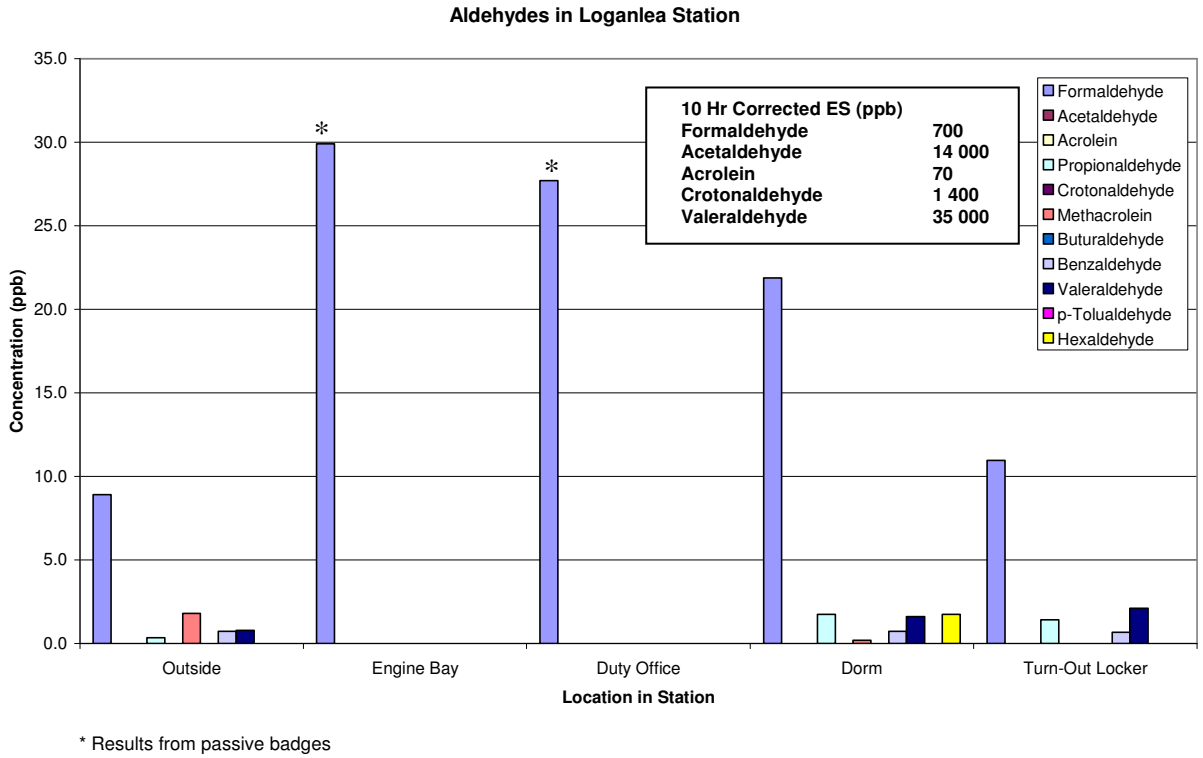


* Results from passive badges

Figure 3.97
Aldehydes concentrations for a 10 Hr day shift at Loganlea fire station.

The total aldehyde concentration is obtained from the summation of the concentrations of the following aldehydes: valeraldehyde, benzaldehyde, acrolein, formaldehyde. The total aldehyde background concentration outside Loganlea fire station was 44 ppb, which is above the average outside concentration (36.2 ppb) obtained across the state.

All station areas, except the engine bay (30 ppb) and duty office (28 ppb), are above the Loganlea fire station outside concentration (44 ppb) and their respective station area averages across the state. The dormitory, which was a spare storage area, recorded the highest concentration (54 ppb). The South East Qld average aldehyde airborne concentration[48], which incorporated three of the aldehydes measured in these trials (formaldehyde, acetaldehyde and propionaldehyde), is 1.7 ppb (range: of 2.0 to 7.2 ppb). The fire station results were typically below the reporting limits for most aldehydes.



* Results from passive badges

Figure 3.98
Aldehydes detected for a 10 Hr day shift at Loganlea fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

Figure 3.98 shows that of the standard sweep of aldehydes tested for in Loganlea fire station, only formaldehyde (700 ppb), acetaldehyde (14 000 ppb), acrolein (70 ppb), crotonaldehyde (1 400 ppb) and valeraldehyde (35 000 ppb) have Australian exposure standards. Of the aldehydes with an exposure standard, formaldehyde typically showed the highest limits, but one of the lowest exposure standards. The two highest aldehyde concentrations were in the engine bay (30 ppb) and duty office (29 ppb), which are similar to the state average concentrations (28.5 ppb and 29.2 ppb). However, these latter results were obtained on passive diffusion badges and only formaldehyde was reported. The highest concentration is more than 23 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb. The aldehyde with the lowest exposure standard, acrolein, was not detected.

Atmospheric Contaminants – Particulate Matter

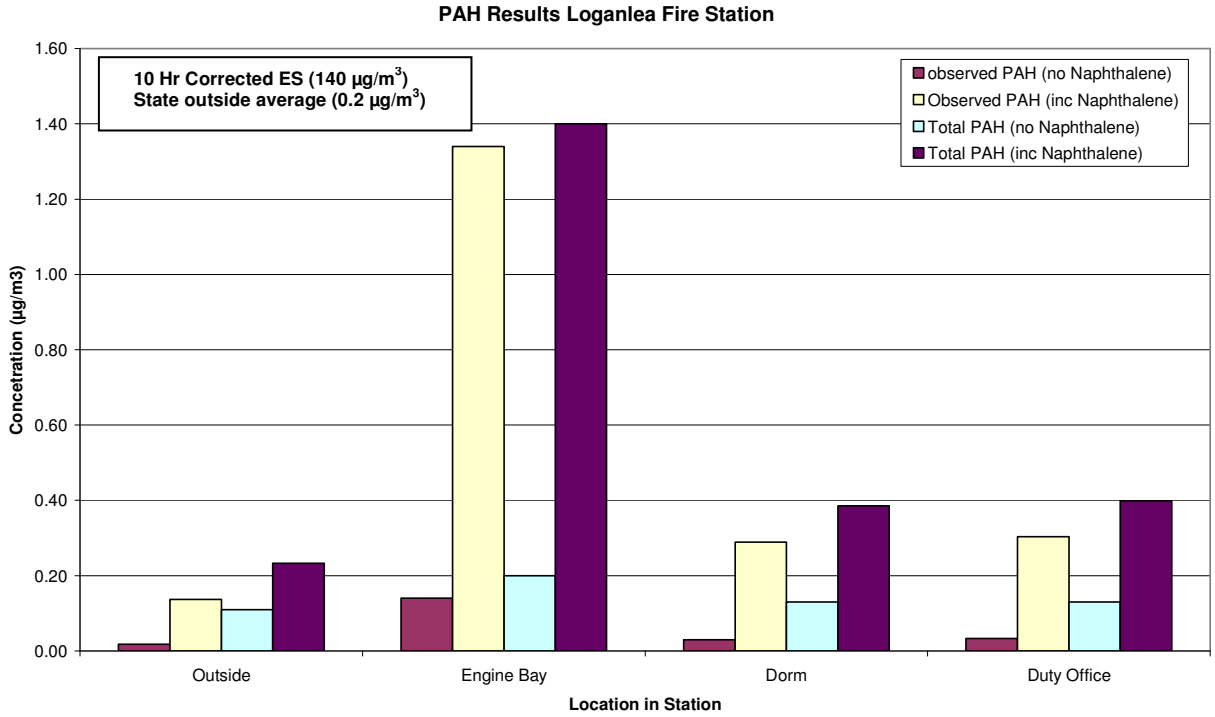
Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

Polyaromatic Hydrocarbons

The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 and time adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard for PAH. Some individual PAHs have established ES, *e.g.* naphthalene ES (15 mg/m^3). If the result obtained was less than the reporting limit (<R.L.) the R.L was used to illustrate the worst case concentration for a specific location.

	Loganlea Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	**20,000**	<RL	<RL
Fluoranthene	<RL	**14,000**	<RL	<RL
Anthracene	<RL	**9,300**	<RL	<RL
Phenanthrene	**8,200**	**43,000**	**21,000**	**16,000**
Fluorene	**9,000**	**39,000**	**12,000**	**13,000**
Acenaphthene	<RL	**15,000**	<RL	<RL
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	**120,000**	**1,200,000**	**270,000**	**260,000**
Reporting Limit	8000	8000	8000	8000
Total PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.02	0.14	0.03	0.03
Total with Naphthalene (µg/m^3)	0.14	1.34	0.30	0.29
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3) to better reflect a measurable quantity				
Total without Naphthalene (µg/m^3)	0.11	0.20	0.13	0.13
Total with Naphthalene (µg/m^3)	**0.23**	**1.40**	**0.40**	**0.39**
State Averages	**0.14**	**0.63**	**0.30**	**0.26**

Table 3.28
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Loganlea fire station.



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.99
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Loganlea fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

Outside Station
The PAH background concentration (0.23 µg/m^3) outside Loganlea station was greater than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs: fluorene, phenanthrene and naphthalene were detected outside the station.

Inside Station (10 Hr monitoring)
The PAH concentrations within the fire station areas were greater then the PAH background concentration and the average PAH concentrations within the station areas obtained across the state. The highest PAH concentration obtained was in the engine bay (1.4 µg/m^3), which is *ca*. 100 times less than the ES_{10} of 140 µg/m^3. The non-carcinogenic PAHs: pyrene, fluoranthene, phenanthrene, anthracene, acenaphthene, fluorene and naphthalene were detected in the various areas within the station.

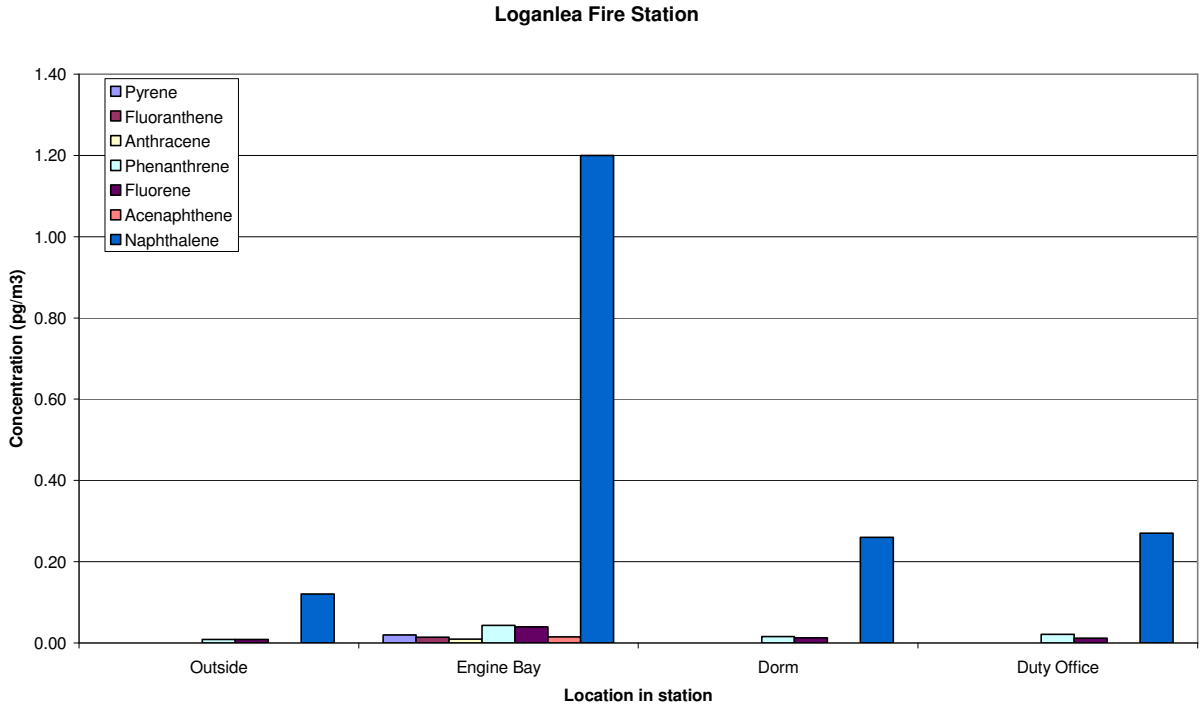


Figure 3.100
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Loganlea fire station.

Naphthalene is the most significant contributing PAH to the total PAH concentration. This trend is consistent across all areas of the fire station and few if any other PAHs are detected. The highest estimated naphthalene concentration in any area is more than 11,000 times below the established naphthalene ES_{10} 10 500 µg/m^3 and more than 160 times below the naphthalene odour threshold (200 µg/m^3).

Diesel Particulate Matter
The diesel particulate matter (DPM) has been described extensively in chapter one. There is no established NES for DPM and the level of concern 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L) the R.L was used to illustrate the worst case concentration for a specific location. The typical US fire fighter DPM exposure is ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC)[33].

10 Hr monitoring Station
The DPM background concentration was at or below the reporting limit (< 0.001 mg/m^3 EC) and is less than the average background DPM concentration across the state (0.002 mg/m^3 EC). The average concentrations in all station areas, except the engine bay (0.003 mg/m^3), were at or below the R.L. and less than the average concentrations obtained in all areas across the state.

Station Activity monitoring
The DPM concentration obtained after the start of shift check (33 minutes, 0.06 mg/m^3 EC), is above the average start of shift concentration (0.044 mg/m^3 EC - including the Firepac 3000 Mk 3 measurement) obtained across the state. However, this concentration is more than 30 times less than the established LOC of 0.1 mg/m^3 EC, when the engine bay doors are closed and no deliberate ventilation applied to remove exhaust emissions.

The DPM concentrations obtained after the turnout and return simulations were at or less than the reporting limit (0.001 mg/m^3), and below the average state turn-out and return concentrations (0.009 mg/m^3 and 0.013 mg/m^3 respectively). There are several explanations to account for these results, including the engine bay design, ventilation and appliance performance. These concentrations are more than 100 times less than the level of concern (0.1 mg/m^3 EC).

The results demonstrate that the exposure of fire fighters whilst working at this station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern. In many instances there is no significant difference compared with the background concentrations and the averages across Queensland.

These Loganlea station results show that the start of shift was the only measurement exceeded the typical US fire fighter exposure[34] concentration of 0.05 mg/m^3 EC, during the 10 Hr day shift or any activity of interest.

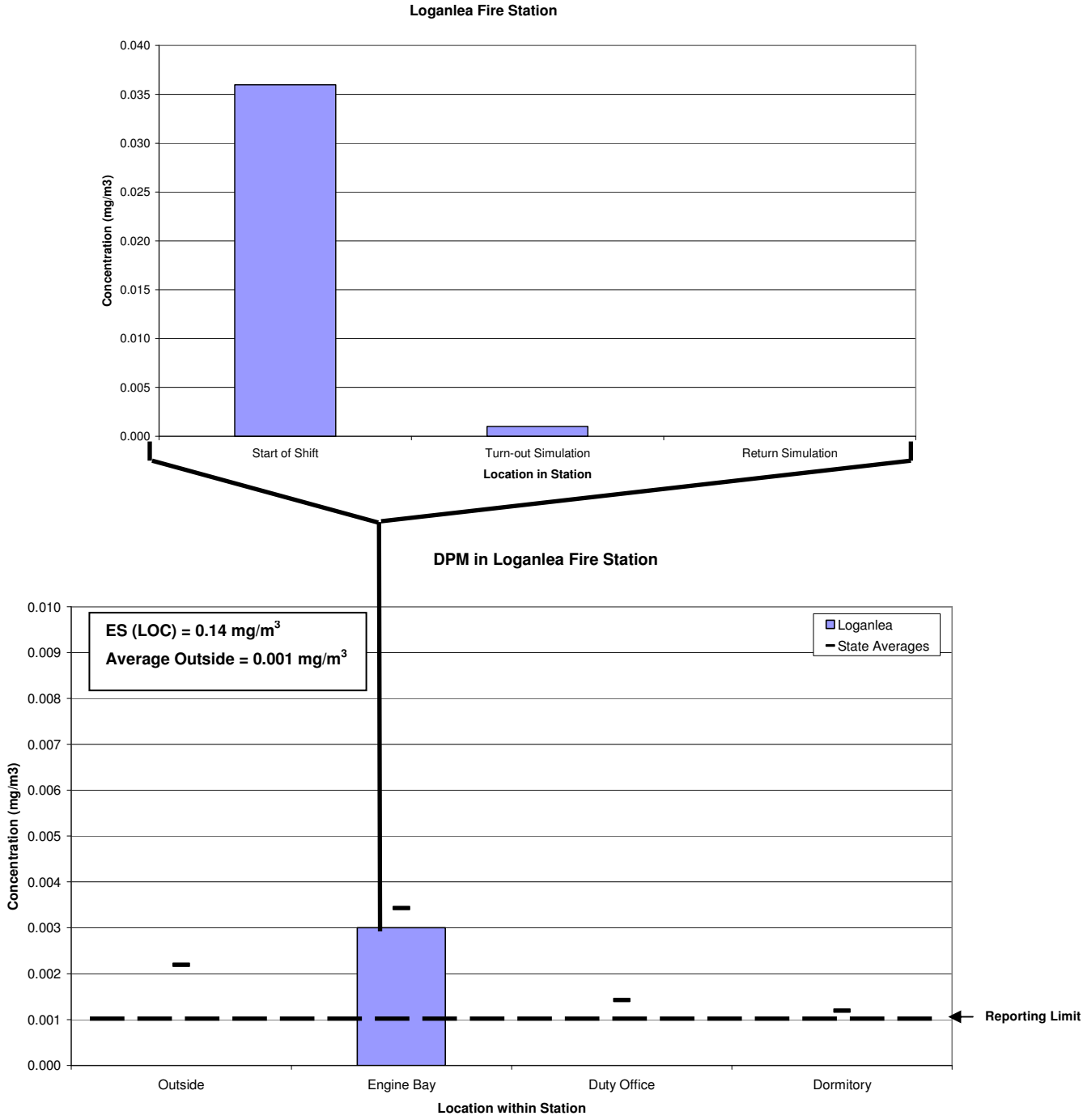


Figure 3.101
DPM results for Loganlea station was based on 10 Hr shift and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Loganlea Results

The Loganlea station trials showed that no stations activity exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.23	0.001	1	3.1	<3	<1	<44.3	<0.5	<0.5	1.3	0.1	0.01
Engine Bay	1.40	0.003	1	17	13.5	<1	<29.9			2.1	0.1	0.04
Start of Shift		0.036	48	>204	276	2	<156	<0.5	0.75			
Turnout		0.001	<10	<10	<10	<10*	<140	<0.5	<0.5			
Return		0.001	<18*	<18	<18*	<18	<133	<0.5	<0.5			
Duty Office	0.40	0.001	1	1	<2	<1	<27.7	<0.5	<0.5	0.8	0.1	0.08
Dormitory	0.39	0.001	1	1	<2	<1	<53.9	<0.5	<0.5	1.6	0.3	0.0
Mess/Lounge			1	2.5	<2	<1	<29.3	<0.5	<0.5			
PPE Locker			<10	<10	<10	<10	<50.8*	<0.5	<0.5	0.5	0.1	0.6

The greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

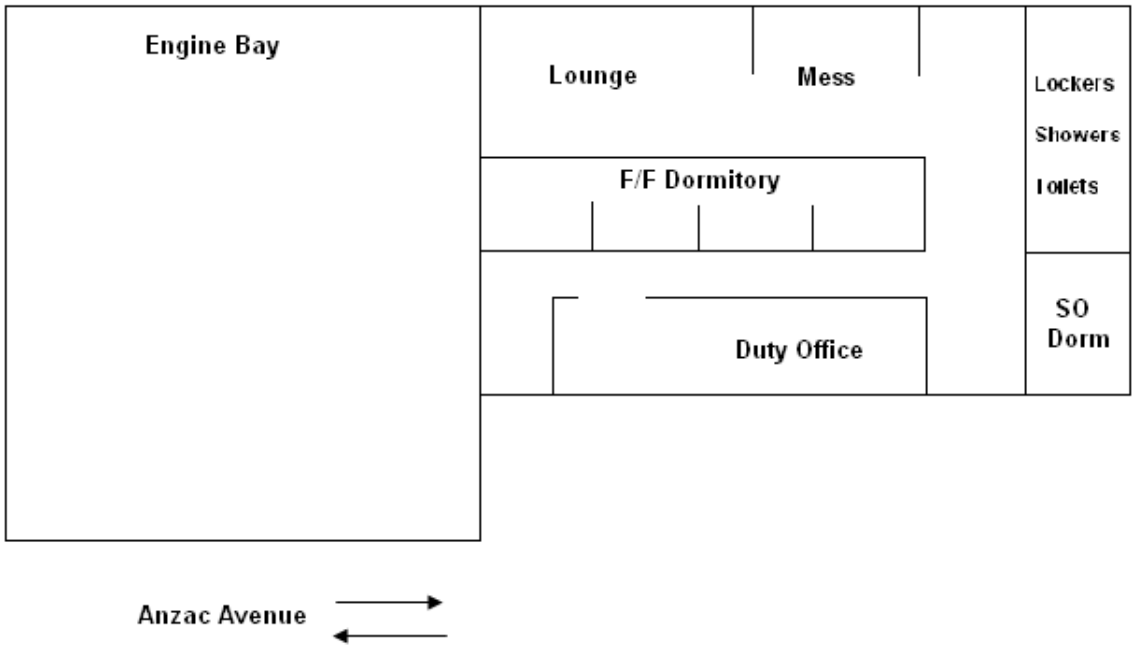
Review of QFRS Fire Station Data

South Western Region

Anzac Avenue Fire Station

The Anzac Avenue fire station is a mid range station built between 1970 and 1995. It is the second station in the Toowoomba area, housing two fire fighting appliances and four fire fighters. In 2007 there were 1062 reported responses. The regional training complex is next to the station.

The station is located on the Gore highway and is a major thoroughfare for Toowoomba and adjacent to stock yards that were operating that day.



Fire fighter exposures in the Anzac Avenue Fire Station to diesel and petrol exhausts generated from typical fire station activities are discussed as atmospheric contaminates, volatile organic compounds and exhaust particulates.

Atmospheric Contaminants – nitrogen dioxide and sulfur dioxide

The instantaneous airborne sulphur dioxide and nitrogen dioxide concentrations were measured during the station activities: start of shift checks; turn out; and return to station. Measurements were also obtained outside the station prior to the commencement of station activities. The table below describes the results obtained and average results for all stations.

Sampling Location	Outside	Engine Bay	Duty Office	Dormitory	Mess / Lounge	L2 PPE Locker
Anzac Avenue – NO_2 (ppm)	n.d	0.5 ss	n.d	n.d	n.d	n.d
Anzac Avenue – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
State Average – NO_2 (ppm)	n.d	0.2 ss	n.d	n.d	n.d	n.d
State Average – SO_2 (ppm)	n.d	n.d	n.d	n.d	n.d	n.d
Note No significant levels of the gases could be detected (n.d) for any of the trials. Where a concentration is listed, the actual the station activity that it was associated with is listed as: start of shift (ss), turnout (to) and return to station (rt).						

Table 3.29

Peak concentrations of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) air-borne contaminants in Anzac Avenue Fire Station.

The airborne concentration of nitrogen dioxide and sulfur dioxide were below the limit of detection (0.5 ppm) for all activities. The Loganlea station sulfur dioxide results are at or below the average concentration obtained for all fire stations and the airborne concentration of nitrogen dioxide was below the R.L. for all activities, except the start of shift check, which was above the average concentration obtained for all fire stations, but below the corrected ES_{10} of 2 ppm. All activities were below the South East Qld[46] NO_2 (6 ppb) and SO_2 (1 ppb) and Brisbane[37] NO_2 (1.5 ppb) and SO_2 (8.2 ppb) average airborne concentrations.

Atmospheric Contaminants – carbon monoxide and hydrogen sulfide

The airborne concentration of carbon monoxide and hydrogen sulphide were measured continuously during normal station activities for as close as practicable to the standard 10 Hr day shift.

Sampling site location	**Photo-ionisation detector (10.6 eV Lamp)**		**Multi Rae four gas detector**			
	Total VOC (ppm)		Note: LFL (0%) and oxygen (20.9%) were constant through-out testing			
			Hydrogen sulphide (ppm)		Carbon monoxide (ppm)	
	Anzac Av Station	State Average	Anzac Av Station	State Average	Anzac Av Station	State Average
Outside	3.6	0.5	0.2	0.1	1.1	0.7
Engine Bay	0.0	0.1	0.1	0.1	1.5	1.3
Duty Office	0.3**	0.1	0.1	0.2	1.1	1
Dormitory	0.2	0.1	0.1	0.1	n/a	0.6
Mess / Lounge	0.3	n/a	0.1	-	1.1	-
L2 PPE Locker	3.6	0.2	0.2	0.1	1.1	1.4

* note: The Cairns PPE locker was not present, but storage shelves within the engine bay

Table 3.30

Peak concentrations of total volatile organic compounds (tvoc), hydrogen sulphide (H_2S) and carbon monoxide (CO).

Carbon Monoxide - total average concentrations

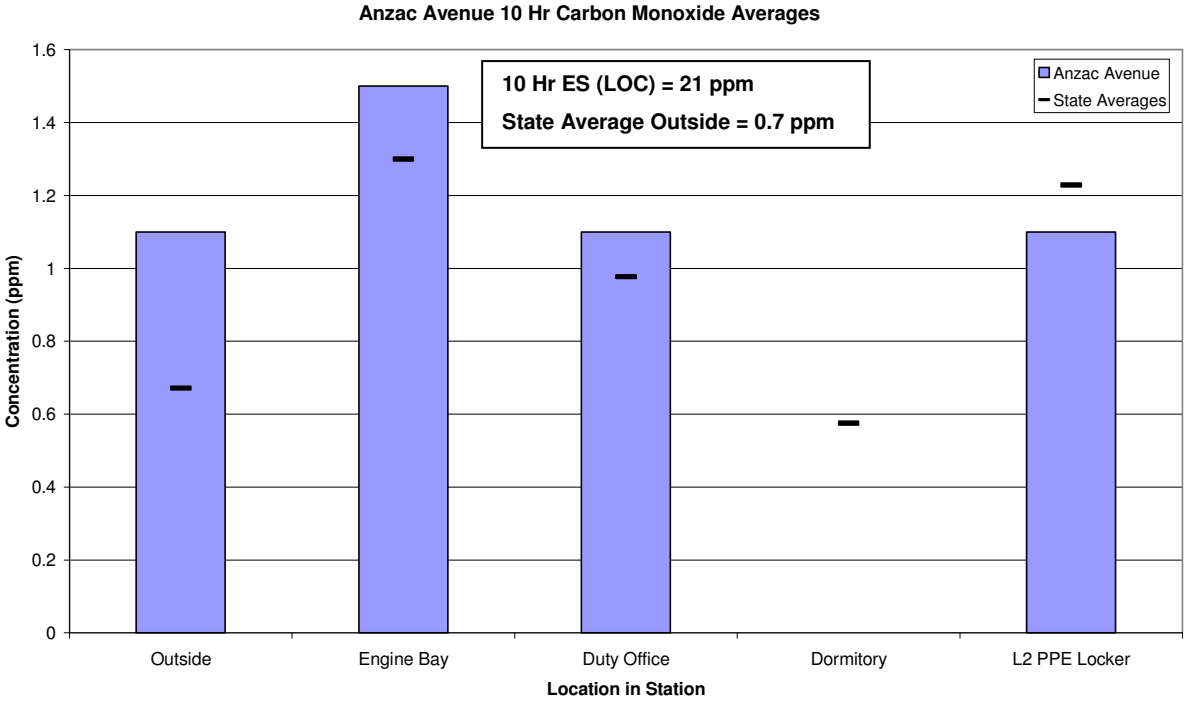


Figure 3.102
Carbon monoxide concentrations for a day shift at Anzac Avenue fire station.

Outside Station (Background)
The background carbon monoxide concentration (1.1 ppm) was higher than the average outside concentration (0.7 ppm) obtained across the state, but similar to the average South East Qld[46] airborne concentration of 1.7 ppm (range: 1.0 to 4.0 ppm).

Inside Station (10 Hr monitoring)
All average concentrations obtained within the station, except the dormitory, were above the average background concentration. The highest concentration was the engine bay (1.5 ppm), which is *ca*. 14 times less than the ES_{10} of 21 ppm, and 6 times less than the NEPM concentration (9 ppm). There are several reasonable explanations that may account for the observations including the high CO concentrations obtained during the start of shift check.

Carbon Monoxide - 10 Hr continuous monitoring

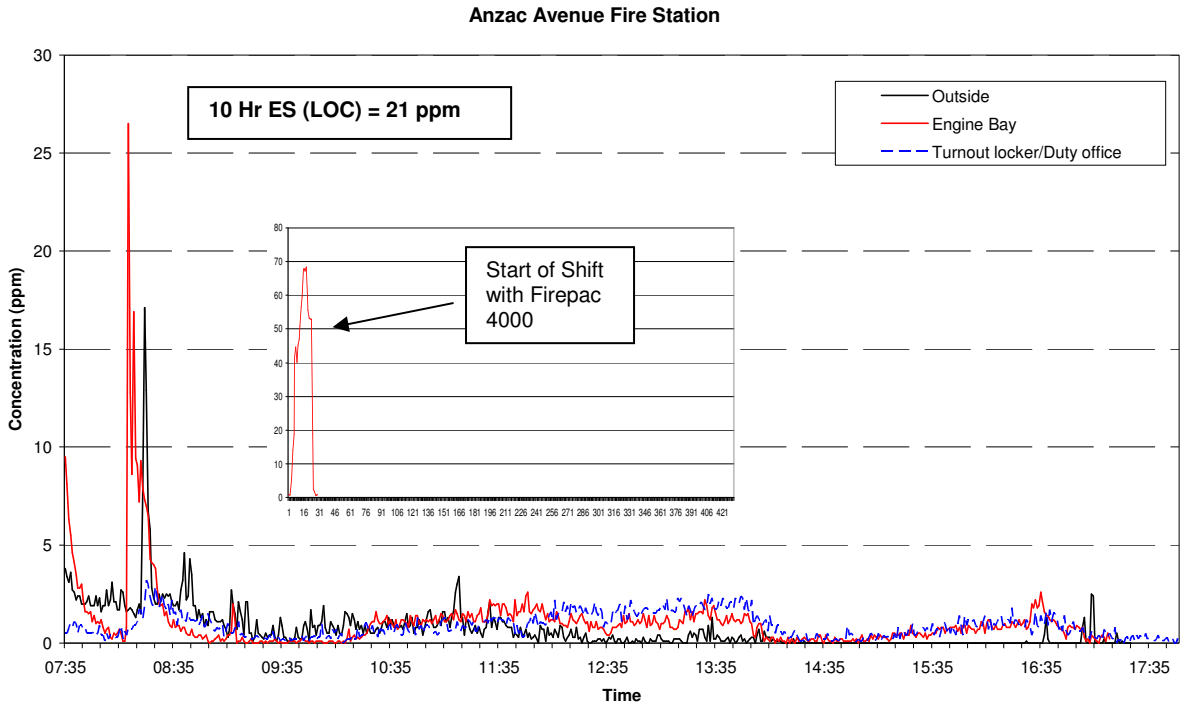


Figure 3.103
Carbon monoxide concentrations for a 10 Hr day shift at Anzac Avenue fire station. The inset shows the CO concentrations when the Firepac 3000 Mk 3 I used during the start of shift checks. The duty office and turnout locker measurement were combined due their locations.

The start of shift checks shows the one major activity where carbon monoxide excursions were observed. In general, carbon monoxide excursions occurring during emergency response were measured only in the engine bay.

The highest concentrations occur in the engine bay (26.5 ppm) during the start of shift check (20 minutes). This concentration exceeds the ES_{10} - 21 ppm, but not the *NOHSC:* [45] *Guidelines for the control of short-term excursions for Carbon Monoxide* 30 minute limit of 100 ppm or the 15 minute limit of 200 ppm.

Hydrogen Sulfide - total average concentrations
All monitoring was performed over one minute averaging periods for the length of the data collection with the peak concentrations within these periods plotted against the time of day. The outside reading was taken external to the station for a background sample and was adjacent to the entry of the front yard.

Outside Station (Background)
The background hydrogen sulfide concentration (0.2 ppm) is higher than the average outside concentration (0.1 ppm) obtained across the state.

Inside Station (10 Hr monitoring)
All measurements within the station areas were at or below the LOD (0.1 ppm) and equal to or less than the average station area concentrations (0.1 ppm) for all fire stations across the state. All station results were *ca* 70 times below the ES_{10} of 7 ppm.

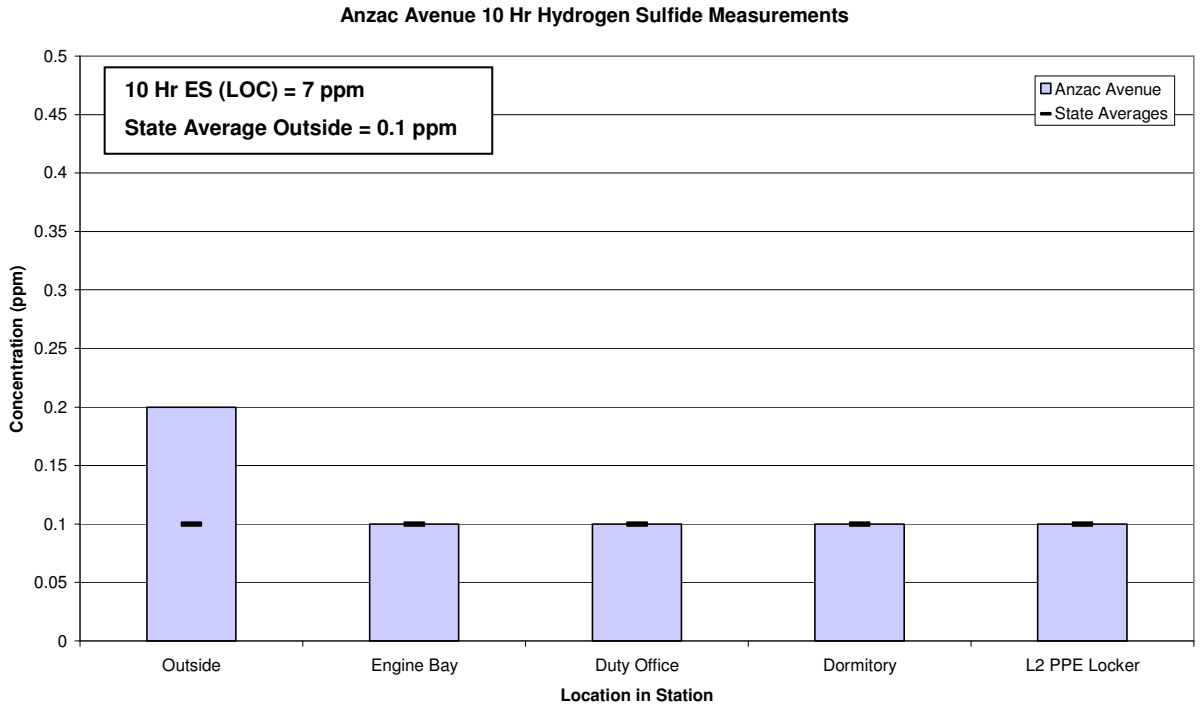


Figure 3.104
Hydrogen sulfide concentrations for a day shift at Anzac Avenue fire station.

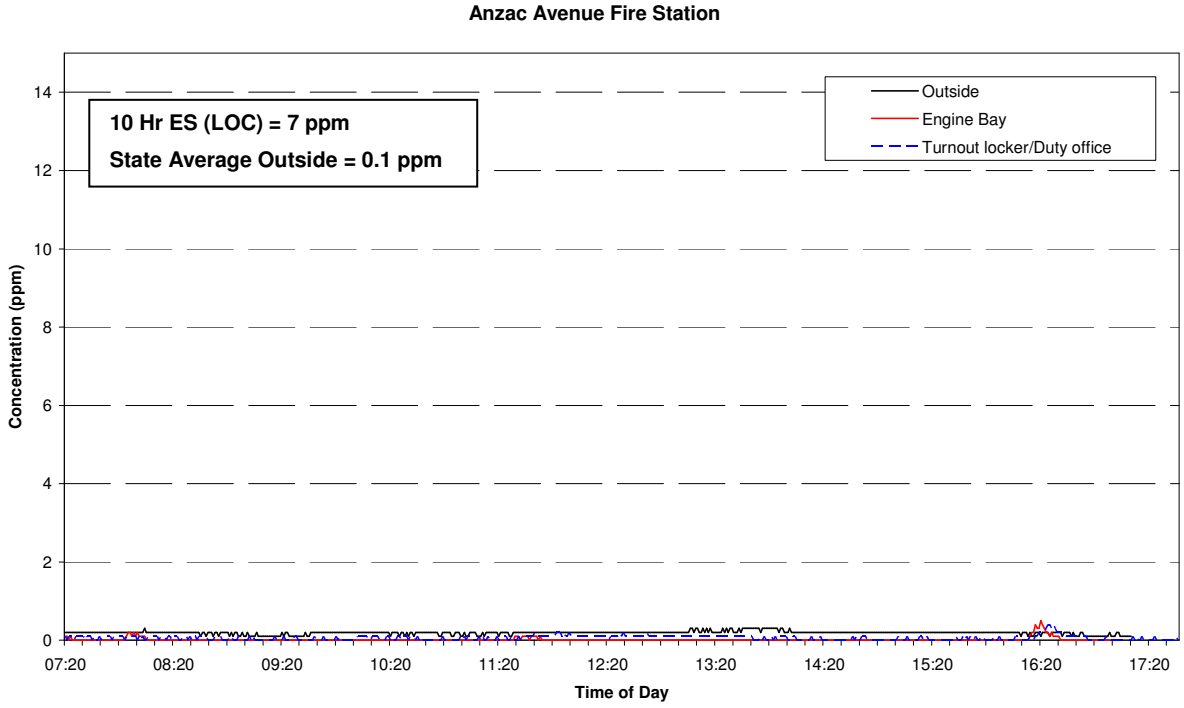


Figure 3.105
Hydrogen Sulfide concentrations for a 10 Hr day shift at Anzac Avenue fire station.

All hydrogen sulfide (H_2S) concentrations were below the H_2S sensor LOD, is consistent with no total 10 Hr average exceeding the ES_{10} (7 ppm).

Atmospheric Contaminants – total volatile organic compounds of concern

The total volatile organic compounds (tvoc's) results used for Anzac Avenue station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario. The tvoc's were monitored for as close as practicable to 10 Hr over a standard day. All concentrations were continuously recorded on instruments that logged peak concentrations over 1 minute averaging periods. Peak concentrations were used to ensure any potential contamination by fire appliances was highlighted.

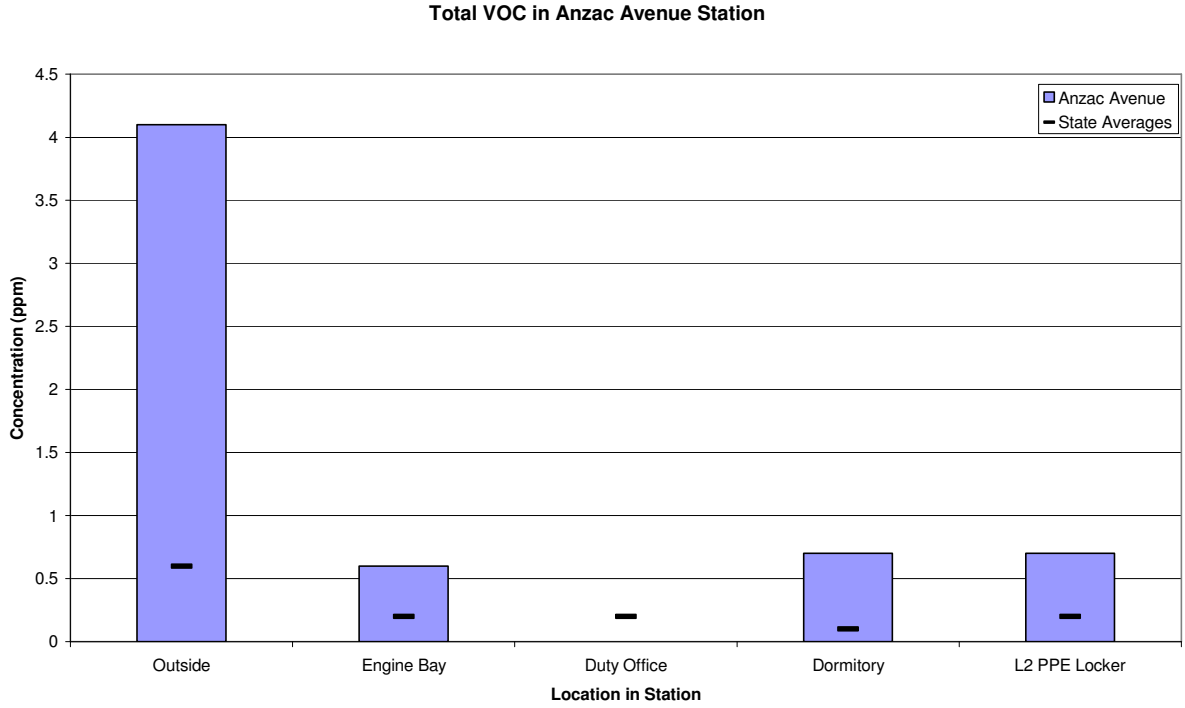


Figure 3.106
Volatile organic compounds (tvoc) concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Outside Station (Background)

The total average Anzac Avenue background tvoc concentration (4.1 ppm) was significantly higher than the average outside concentration (0.5 ppm) obtained across the state, and more than 4 times higher than the QFRS LOC of 0.5 ppm.

Inside Station (10 Hr monitoring)

The average concentrations obtained within the station were significantly lower than the background concentration, but higher than their respective state average concentrations. The highest concentration (0.7 ppm) was in the PPE locker and dormitory, which is higher than the average concentrations for areas across the state. It is also slightly higher than the QFRS LOC of 0.5 ppm and the average outside concentration (0.5 ppm).

Volatile organic compounds - 10 Hr continuous monitoring

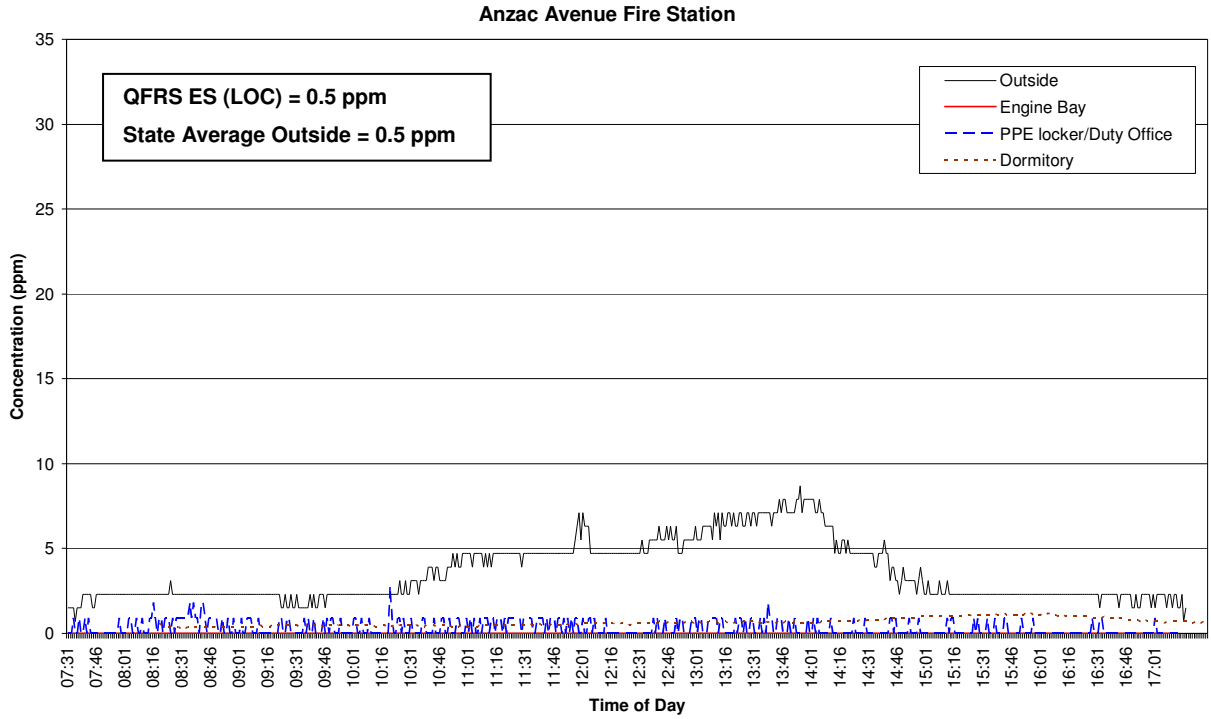


Figure 3.107
Total volatile organic compounds readings for a 10 Hr day shift at Anzac Avenue fire station.

All monitoring results displayed peak concentrations (over one minute averaging periods) for the length of the data collection. The average total volatile organic compounds (tvoc) results showed that no station areas exceeded the outside measurements.

There were no occasions where major excursions were observed. No station concentrations exceeded the QFRS exposure standard of 0.5 ppm and the state outside average (0.5 ppm). However, the Anzac Avenue outside measurement continued to build to a maximum throughout the day, before declining in the afternoon. The majority of the outside concentrations (peak: 8.7 ppm), PPE locker/duty office concentrations (peak: 0.9 ppm) and dormitory concentrations (peak: 1.1 ppm) exceeded the QFRS exposure standard (ES_{QFRS}) of 0.5 ppm and the state outside average (0.5 ppm). No significant engine bay concentrations were observed. The outside results roughly coincided with the cattle yard sales that occurred over the highway, up-wind from the station.

Atmospheric Contaminants – hexane, benzene, toluene and xylene

Samples were collected during the normal station activities for as close as practicable to the standard 10 Hr day shift and during specific activities. A mixture of active and passive sorbent techniques was used. Instantaneous concentrations of benzene generated during the station activities were also obtained. If the result obtained was less than the reporting limit (<R.L) the R.L was used.

Location with Station	Benzene (ppm)	Benzene (ppb)			Toluene (ppb)			Xylene (ppb)			Hexane (ppb)			Aldehydes (ppb)	
	Dräger Tube	ATD	Can	Passive	ATD	Can	passive	ATD	Can	passive	ATD	Can	passive	Active	Passive^
Outside	<0.5	0.5	N.A	<1.6*	3.7	N.A	<1.5*	2.0	N.A	<2.8*	17	N.A	<1.6*	<43.5*	<29.3*
Engine Bay			N.A	<1.6*		N.A	10.1		N.A	6.5		N.A	3.2		<29.3*
Start of Shift	<0.5	18.2			60.8			40.8			19			<197*	
Turnout	<0.5	14.1			151			10.4			13			<177*	
Return	<0.5	12.5			28.1			16.6			14			<167*	
Duty Office	<0.5		N.A	<1.6*		N.A	6.9		N.A	<4.5*		N.A	2.1		<29.3*
Dormitory	<0.5	1.3	N.A	<1.6*	10.3	N.A	2.*	5.8	N.A	<2.8*	1.0	N.A	<1.6*	<44.4*	<29.3*
Mess area	<0.5		N.A	<1.6*		N.A	2.4		N.A	<2.8*		N.A	<1.6*		<29.3*
PPE Locker	<0.5	0.4			3.2			1.8			3.4			<49.3*	

Table 3.31

Concentrations of the voc's of interest, aldehydes, hexane, benzene, toluene and xylene measured at the Anzac Avenue fire station over a 10 Hr day shift.

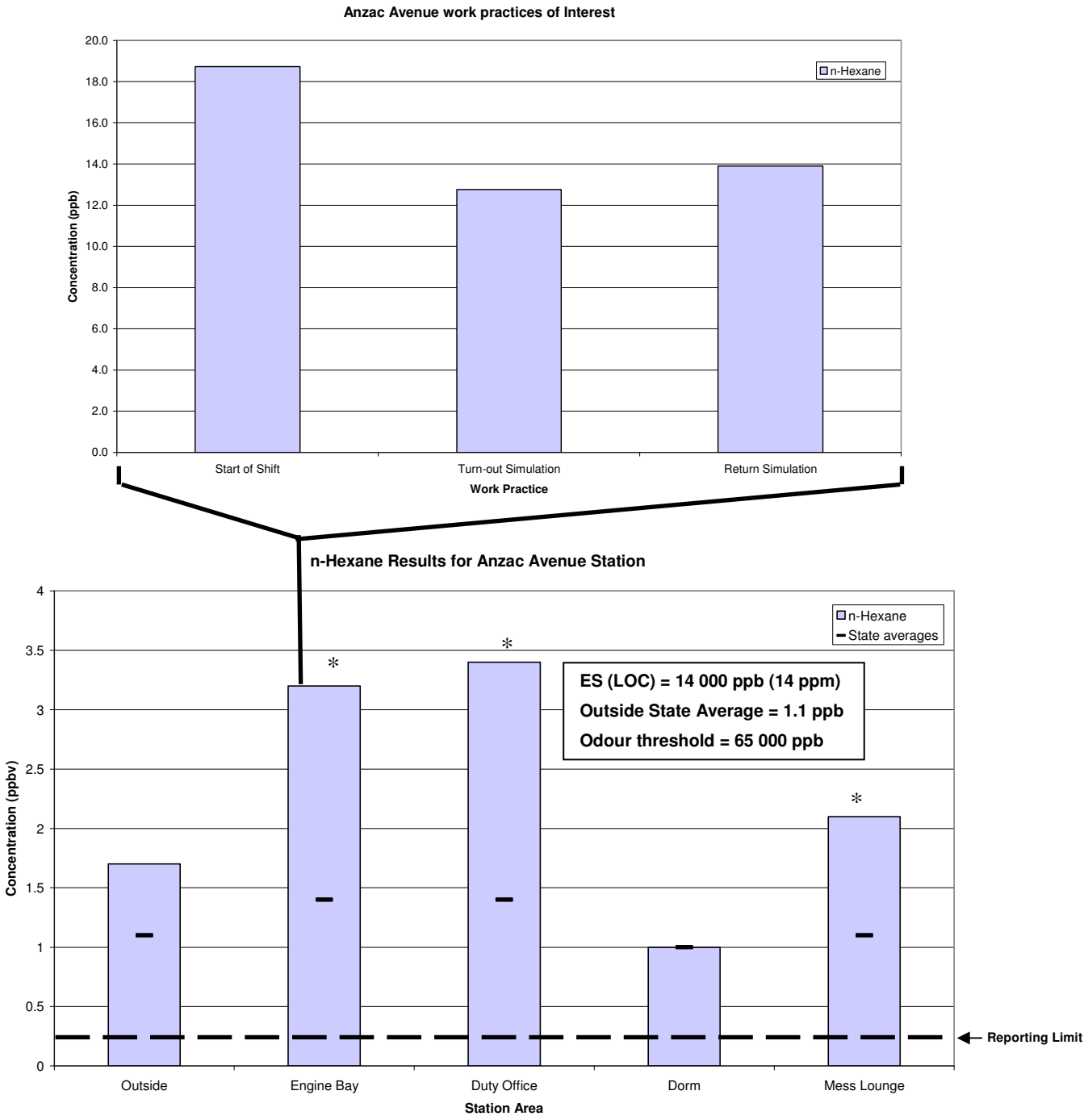
Atmospheric Contaminants – hexane

Outside Station (Background)

Figure 3.108 (below) shows the hexane background concentration (1.7 ppb) outside Anzac Avenue fire station was above the average background concentration (1.1 ppb) across the state. The hexane background concentration is significantly less than the average airborne hexane concentration (18.6 ppb) in Eagle Farm[48] (Brisbane). The hexane odour threshold is 65 000 ppb.

The average concentrations in all areas within the station, except the dormitory (1 ppb), were above the Anzac Avenue outside concentration, and above the average station area concentrations obtained across the state. The highest concentration was the duty office (3.4 ppb), which is *ca*. 4000 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 14 000 ppb.

The hexane concentration obtained after the start of shift checks, turnout simulation, and return simulation (18.7 ppb, <12.8 ppb and 13.9 ppb respectively) are higher than the hexane background concentration. The start of shift check is less than the average hexane concentration whilst the simulation results are greater than the average hexane concentration obtained for these activities (92 ppb, 4.9 ppb, and 14.5 ppb respectively). The highest concentration was the start of shift checks, which is *ca*. 750 times less than the ES_{10} of 14 000 ppb. Common sources of hexane are hydrocarbon fuels and petrol exhaust emissions.



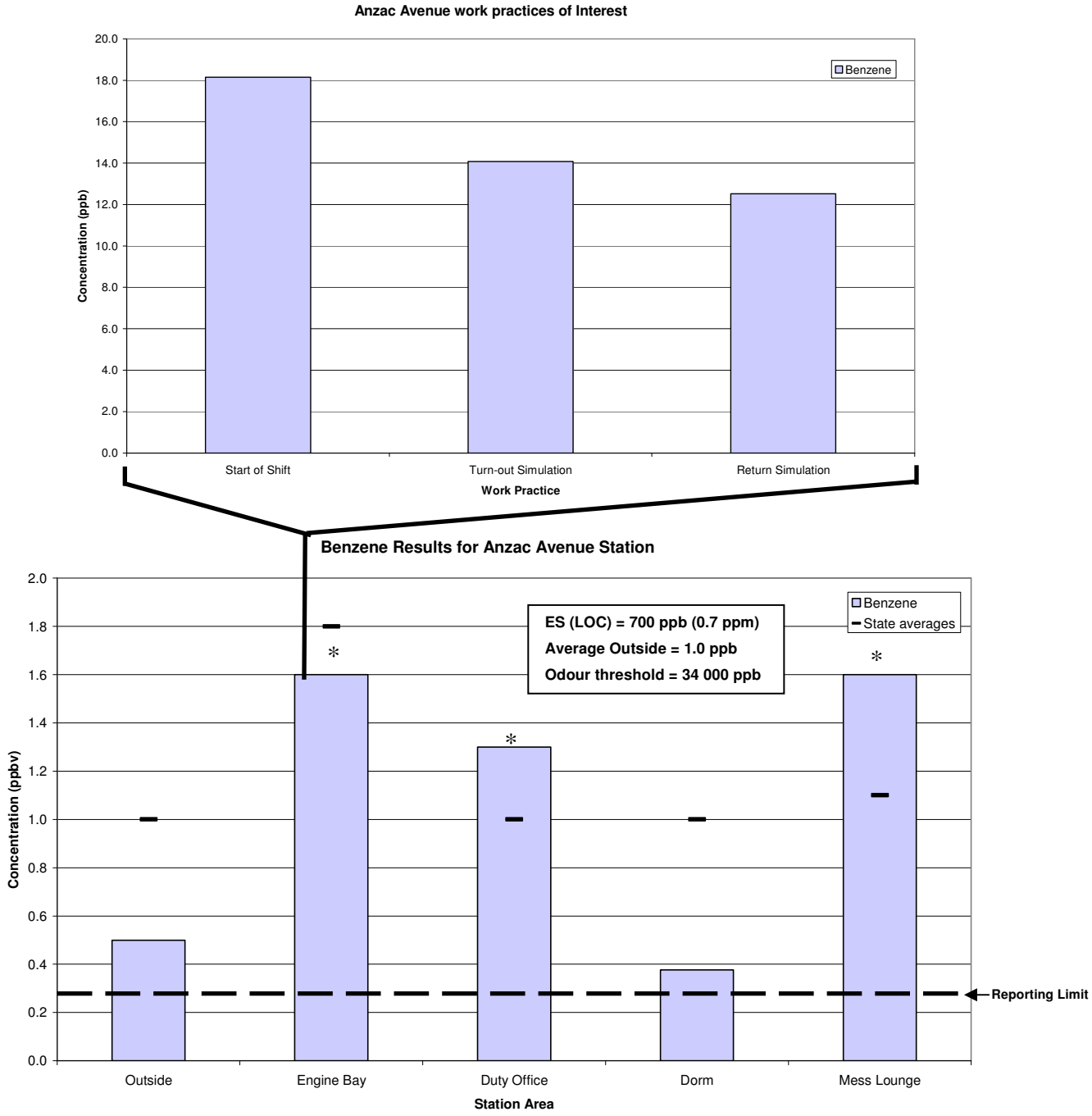
* passive badges

Figure 3.108
Hexane concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Atmospheric Contaminants – benzene

Outside Station (Background)
Figure 3.109 (below) shows the background benzene concentration (0.5 ppb) outside Anzac Avenue fire station was below the average background concentration across the state (1.0 ppb). This background result is similar to the average benzene airborne concentrations in South East Qld[46] of 0.8 ppb (range: 0.4 to 1.5 ppb) and Brisbane[48] of 3.3 ppb (range: 0.43 to 10.33 ppb). The average concentrations in all areas, except the engine bay (1.6 ppb), were

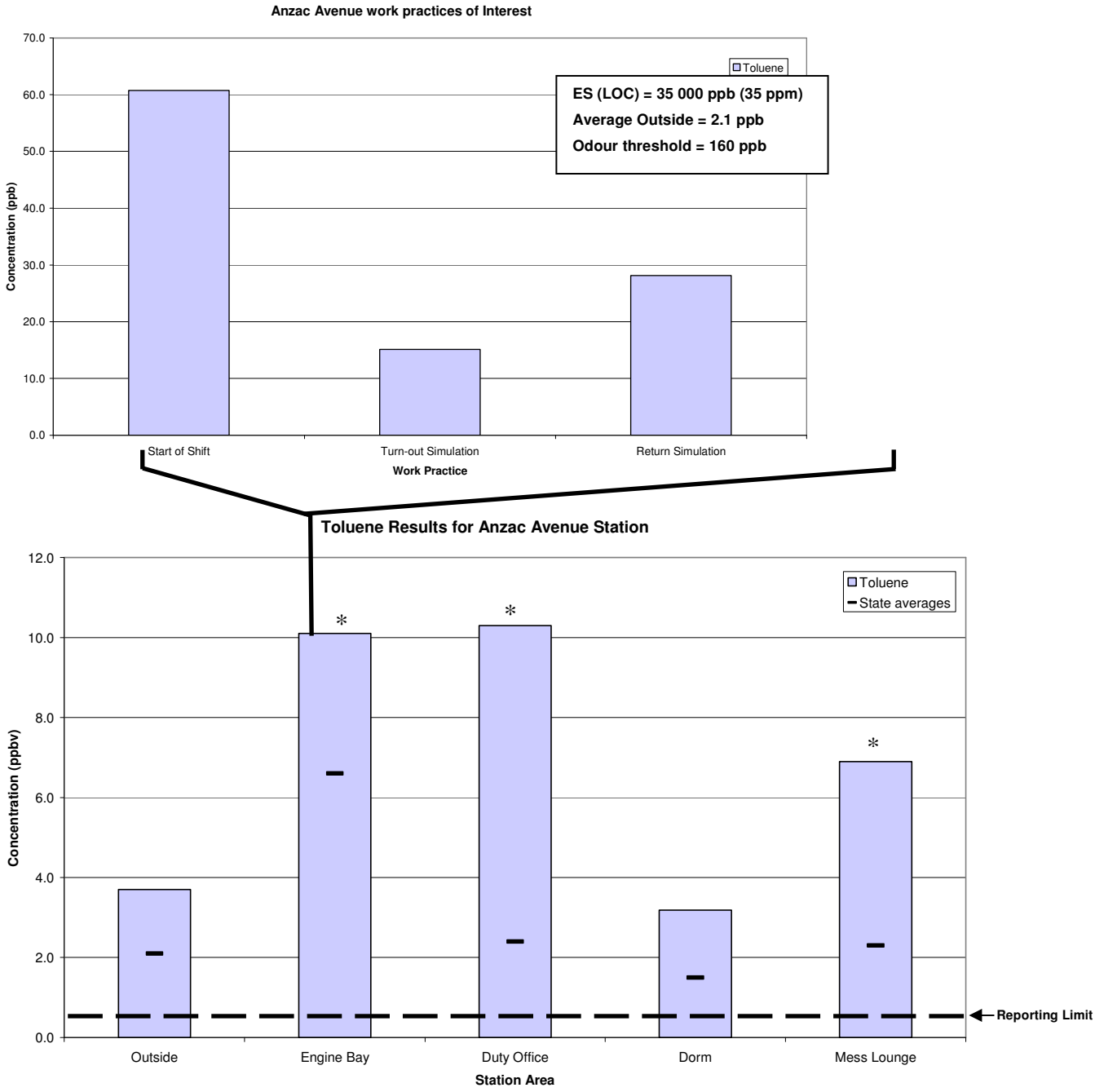
above the average station area concentrations across the state. The highest station area concentration was the engine bay, which is *ca*. 400 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 700 ppb and more than 21000 times below the odour threshold (34 000 ppb). However, the engine bay, duty office and PPE locker results are based on passive diffusion badges, and care should be used comparing to the active data previously reported.



* passive badges

Figure 3.109
Benzene concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Atmospheric Contaminants – toluene



* passive badges

Figure 3.110
Toluene concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Outside Station (Background)
The toluene background concentration outside Anzac Avenue fire station (3.7 ppb) was higher than the average background (2.1 ppb) concentration across the state. This background result is similar to the average toluene airborne concentrations in South East Qld[46] (of 1.6 ppb range: 0.7 to 4.9 ppb) and Brisbane[48] of 10.6 ppb (range: 1.8 to 83 ppb).

The average concentrations in all areas within the station were greater than the average station area concentrations obtained across the state. The highest concentration was in the

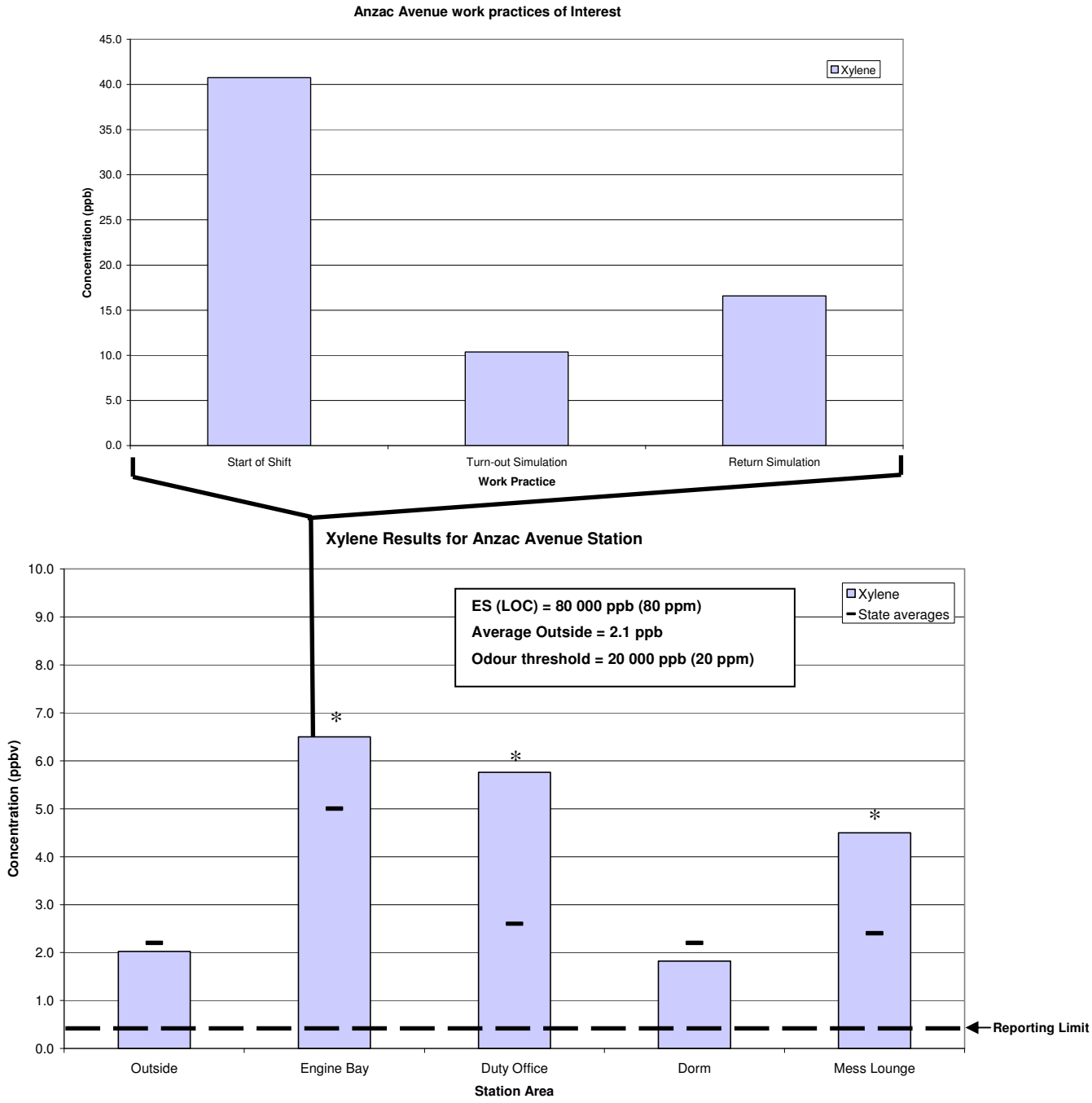
turnout PPE locker (10.3 ppb), which is *ca*. 3400 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 35 000 ppb and more than 15 times below the odour threshold (160 ppb).

The toluene concentrations obtained after the start of shift check (20 minutes), turnout simulation, and return simulation (61 ppb, <15.1 ppb and <28.1 ppb respectively) are higher than the background concentration of toluene. Although the start of shift concentration is less than the average start of shift concentration (83.6 ppb) across the state, the turn-out and return simulations were both higher than the average state simulation concentrations (4.5 ppb and 6 ppb respectively). The highest result was the start of shift checks, which is *ca*. 500 times less than the ES_{10} of 35000 ppb. Common sources of toluene are hydrocarbon fuels and diesel/petrol exhaust emissions.

Atmospheric Contaminants – xylene

Figure 3.111 (below) shows the xylene background concentration outside Anzac Avenue fire station was at or below the R.L (2.0 ppb) and was similar to the average background (2.2 ppb) concentration across the state. The average concentrations in all areas within the station, except the dormitory (1.8 ppb), were above the outside state average and average station areas state concentrations across the state. The highest concentration was the engine bay (6.5 ppb), which is *ca*. 8600 times less than the 10 Hr time corrected exposure standard (ES_{10}) of 56 000 ppb and more than 3000 times below the odour threshold (20 000 ppb). This background result is significantly less than the average xylene airborne concentrations in South East Qld[46] of 4.5 ppb (range: 2.5 to 8 ppb) and Brisbane[48] of 3.4 ppb (range: 0.2 to 28 ppb). The South East Qld results were reported as p-xylene data, but calculated as total xylene based on *p*-xylene being 20% of the total xylene concentration). The Brisbane data was based on the addition and averaging of the *m-&p*-xylene with the *o*-xylene.

The xylene concentration obtained after the start of shift check (20 minutes), turnout simulation, and return simulation (6.9 ppb, 2.3 ppb and 2.3 ppb respectively) are higher than the background concentration of xylene, but significantly less than the average xylene concentrations obtained across the state (105 ppb, 5.3 ppb, and 12.5 ppb respectively). The highest concentration is the start of shift results, which is *ca*. 1300 times less than the ES_{10} of 56 000 ppb. Common sources of xylene are hydrocarbon fuels and diesel/petrol exhaust emissions and these explanations readily account for the observations.



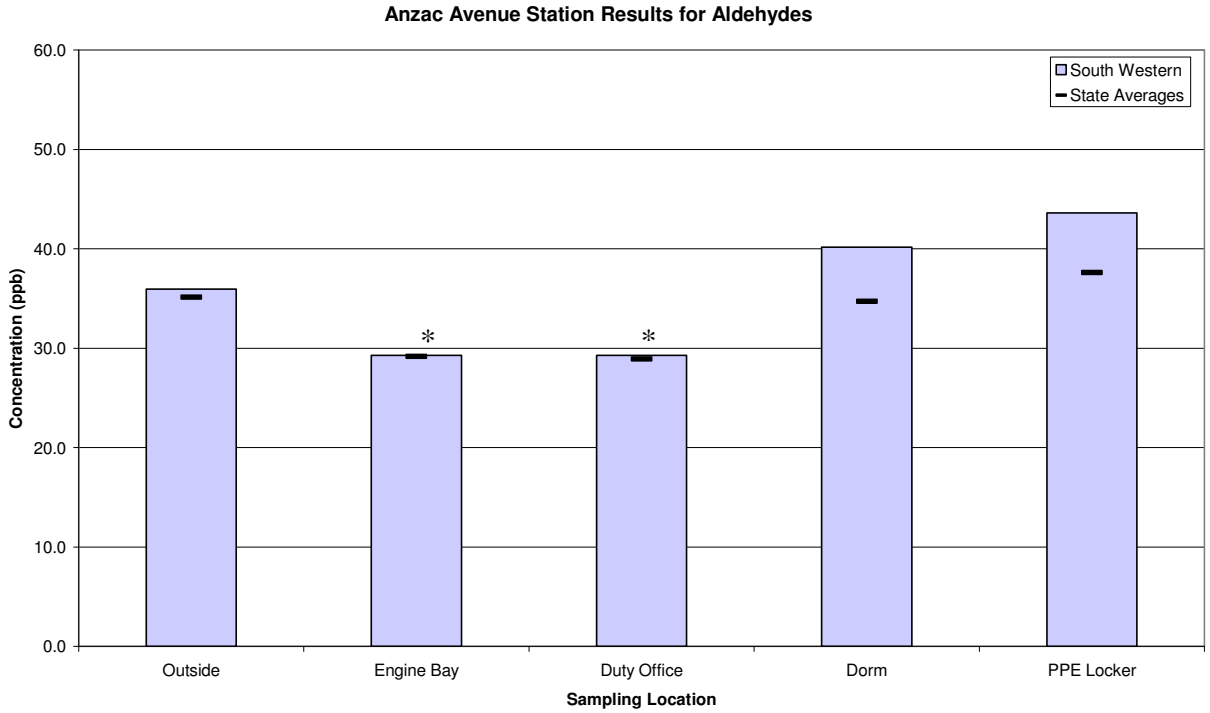
* passive badges

Figure 3.111

Xylene concentrations from evacuated canisters controlled by a 10 Hr flow regulators. Results for xylene were reported as the isomers *m-* / *p*-xylene and *o*-xylene.

Atmospheric Contaminants – aldehydes
Together with the hexane and BTX measurements, the aldehydes form part of the compounds of interest that form total volatile organic compounds. Samples were collected using absorbent tubes to measure for the specific aldehydes. The aldehyde results used for Anzac Avenue fire station included reporting limit concentrations where a result was recorded less than the reporting limit of the laboratory. This was done to provide the highest result and worst case scenario.

Of the standard sweep of aldehydes tested for at the Anzac Avenue station only formaldehyde (700 ppb), acetaldehyde (14 000 ppb), acrolein (70 ppb), crotonaldehyde (1 400 ppb) and valeraldehyde (35 000 ppb) have Australian exposure standards. One of the most common of these, formaldehyde, typically showed the highest limits, but one of the lowest exposure standards. The aldehyde with the lowest exposure standard, acrolein, was present in a number of areas.

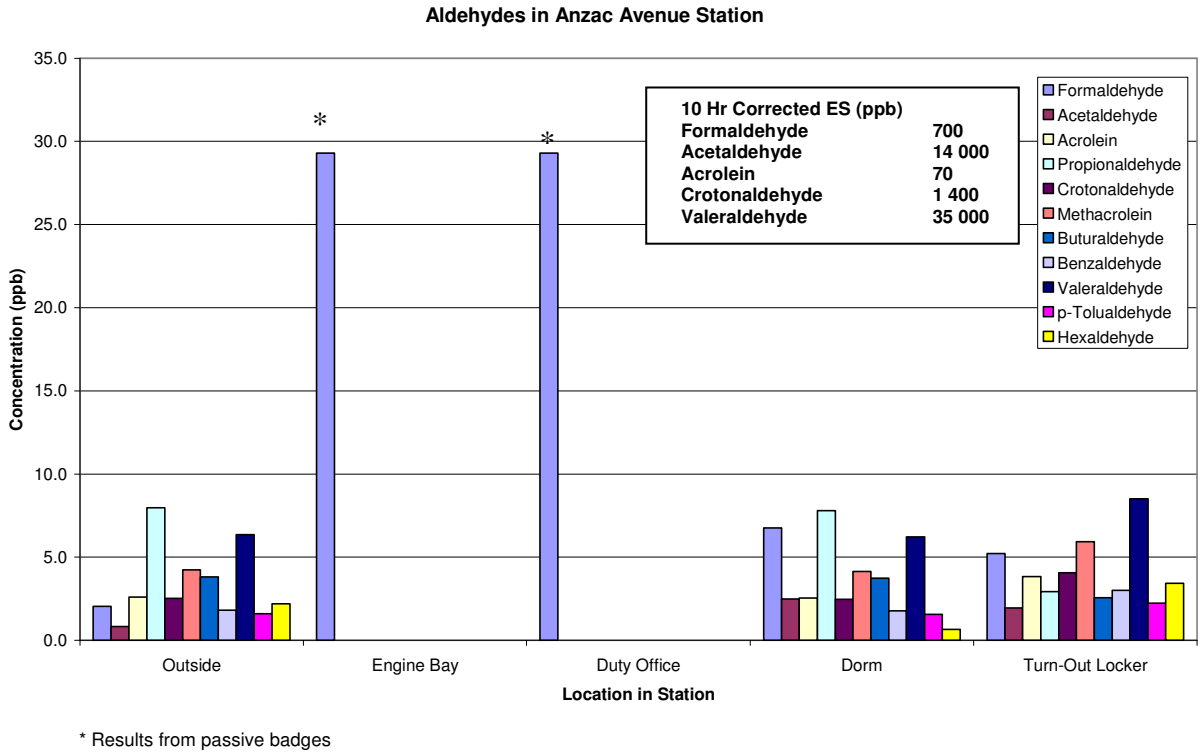


* Results from passive badges

Figure 3.112
Total aldehydes in areas of interest for a 10 Hr day shift at Anzac Avenue fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

The total aldehyde background concentration outside Anzac Avenue fire station was 36 ppb, which was similar to Loganlea, Townsville and Cairns fire stations outside results. The total aldehyde concentrations for the station areas show that the engine bay (29 ppb) and duty office (29 ppb) are below the outside (36 ppb), while the dormitory (40 ppb) and PPE locker (44 ppb) were higher. The engine bay and duty office were above their respective station area state averages. The highest Anzac Avenue measurement was the PPE locker.

The South East Qld average aldehyde airborne concentration[48], which incorporated three of the aldehydes measured in these trials (formaldehyde, acetaldehyde and propionaldehyde), is 1.7 ppb (range: of 2.0 to 7.2 ppb). The fire station results were typically below the reporting limits for most aldehydes.



* Results from passive badges

Figure 3.113

Aldehydes detected for a 10 Hr day shift at Anzac Avenue fire station. For this report when a result of <R.L occurred, the R.L concentration was used.

The outside results show 11 aldehydes, formaldehyde (8.9 ppb), acetaldehyde (0.8 ppb), acrolein (2.6 ppb), propionaldehyde (8.0 ppb), crotonaldehyde (2.5 ppb), methacrolein (4.2 ppb), buturaldehyde (3.8 ppb), benzaldehyde (1.8 ppb), valeraldehyde (6.3 ppb), p-tolualdehyde (1.6 ppb) and hexaldehyde (2.2 ppb). The formaldehyde measurement, was more than 78 times lower than the formaldehyde 10 Hr time corrected exposure standard (ES_{10}) and the acrolein measurement was 26 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}).

The highest formaldehyde measurement (passive badge 29 ppb) is more than 20 times lower than the formaldehyde 10 Hr time corrected exposure standard (ES_{10}). The aldehyde with the lowest exposure standard, acrolein, was detected in the outside (1.9 ppb), dormitory (1.9 ppb) and PPE locker (2.6 ppb) measurements. The highest of these was 26 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}).

The engine bay (30 ppb) and duty office (27.7 ppb) both only recorded formaldehyde since passive badges were only analysed by the laboratory for this aldehyde. The engine bay formaldehyde measurement was >23 time below the (ES_{10}) while the duty office acetaldehyde measurement was ca. 5600 times below the (ES_{10}).

The PPE locker showed the same sweep of 11 aldehydes, formaldehyde (5.2 ppb), acetaldehyde (1.9 ppb), acrolein (3.8 ppb), propionaldehyde (2.9 ppb), crotonaldehyde (4.1 ppb), methacrolein (5.9 ppb), buturaldehyde (2.6 ppb), benzaldehyde (3.0 ppb), valeraldehyde (8.5 ppb), p-tolualdehyde (2.2 ppb) and hexaldehyde (3.4 ppb) as the outside and dormitory measurements. Both the formaldehyde and acrolein were higher in the PPE locker than the outside measurements, however, the formaldehyde measurement, was >134 times lower than the formaldehyde 10 Hr time corrected exposure standard (ES_{10}) and the acrolein

measurement was >18 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}).

The dormitory showed a sweep of 11 aldehydes, formaldehyde (6.8 ppb), acetaldehyde (2.5 ppb), acrolein (2.5 ppb), propionaldehyde (7.8 ppb), crotonaldehyde (2.5 ppb), methacrolein (4.1 ppb), buturaldehyde (3.7 ppb), benzaldehyde (1.8 ppb), valeraldehyde (6.2 ppb), p-tolualdehyde (1.6 ppb) and hexaldehyde (0.7 ppb) as the outside and PPE locker measurements. Both the formaldehyde and acrolein were higher in the dormitory than the outside measurements, however, the formaldehyde measurement, was >100 times lower than the formaldehyde 10 Hr time corrected exposure standard (ES_{10}) and the acrolein measurement was >25 times below the acrolein 10 Hr time corrected exposure standard (ES_{10}).

Atmospheric Contaminants – Particulate Matter

Samples were collected during normal station activities for as close as practicable to the standard 10 hr day shift and during specific activities. The airborne concentration of polyaromatic hydrocarbons (PAH) and diesel particulate matter (DPM) were obtained.

Polyaromatic Hydrocarbons

The airborne polyaromatic hydrocarbons (PAH) of interest are described in chapter one. The US OSHA regulatory limit (0.2 mg/m^3 and time adjusted to a 10 hr exposure is 140 µg/m^3) was applied since there is no equivalent Australian Exposure standard for PAH. Some individual PAH have established ES such as naphthalene - ES (52 mg/m^3 or 52 000 µg/m^3) and a 10 Hr time corrected ES_{10} (36.4 mg/m^3 or 36 400 µg/m^3). . If the result obtained was less than the reporting limit (<R.L.) the R.L was used.

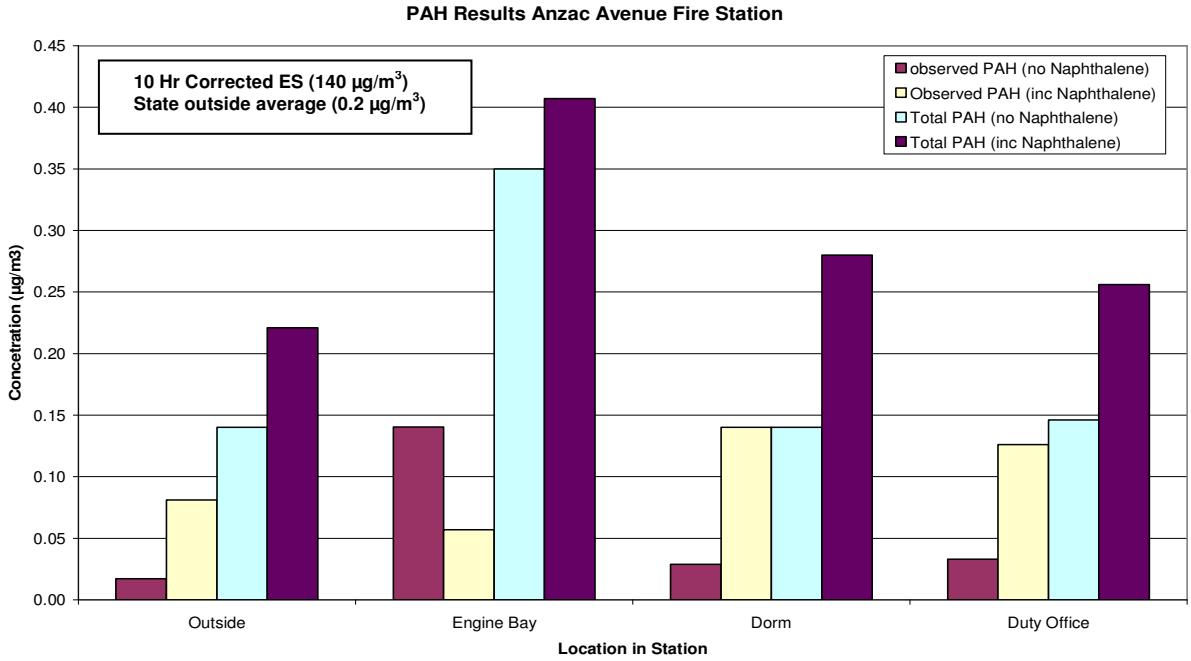
	Anzac Avenue Fire Station (pg/m^3)			
	Outside	Engine Bay	Duty Office	Dorm
Benzo[ghi]perylene	<RL	<RL	<RL	<RL
Dibenz[a,h]anthracene	<RL	<RL	<RL	<RL
Indeno[1,2,3-cd]pyrene	<RL	<RL	<RL	<RL
Benzo[a]pyrene	<RL	<RL	<RL	<RL
Benzo[b+k]fluoranthene	<RL	<RL	<RL	<RL
Chrysene	<RL	<RL	<RL	<RL
Benz[a]anthracene	<RL	<RL	<RL	<RL
Pyrene	<RL	<RL	<RL	<RL
Fluoranthene	<RL	<RL	<RL	<RL
Anthracene	<RL	<RL	<RL	<RL
Phenanthrene	<RL	<RL	**16000**	<RL
Fluorene	<RL	<RL	<RL	<RL
Acenaphthene	<RL	<RL	<RL	<RL
Acenaphthylene	<RL	<RL	<RL	<RL
Naphthalene	81,000	57,000	110,000	140,000
Reporting Limit	10000	25000	10000	10000
Total PAH concentrations excluding <RL data. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3).				
Total without Naphthalene (µg/m^3)	0.00	0.00	0.02	0.00
Total with Naphthalene (µg/m^3)	0.08	0.06	0.13	0.14
Total PAH concentrations including <RL data. Total PAH concentrations are the sum of actual concentrations and the RL concentrations. The totals below have been converted from picrgrams per cubic metre (pg/m^3) to micrograms per cubic metre (µg/m^3) to better reflect a measurable quantity				
Total without Naphthalene (µg/m^3)	0.14	0.35	0.15	0.14
Total with Naphthalene (µg/m^3)	0.22	0.41	0.26	0.28
State Averages	0.14	0.63	0.30	0.26

Table 3.32

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Outside Station (Background)
The PAH background concentration (0.22 µg/m^3) was greater than the average background PAH concentration (0.08 µg/m^3) across the state. The non-carcinogenic listed PAHs, fluorene, phenanthrene and naphthalene were detected outside the station.

Inside Station (10 Hr monitoring)
The PAH concentrations within the fire station were greater then the PAH background concentration. The concentrations were less than the average PAH concentrations obtained across the state, except the dormitory (0.24 µg/m^3). The highest PAH concentration obtained was in the engine bay (0.41 µg/m^3), which is more than 340 times less than the ES_{10} 140 µg/m^3. The non-carcinogenic PAHs, fluorene and naphthalene were detected in the various areas within the station.



Note: Concentrations with and without naphthalene were used due to the analysing laboratory caveats - Any result over approximately 100,000 pg/m^3 is outside of the calibration range and should be viewed with caution. The calibration may not be linear above this concentration. No dilution of the samples was performed.

Figure 3.114

Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Anzac Avenue fire station. The total data includes the observed data and the reporting limit (R.L) concentrations added.

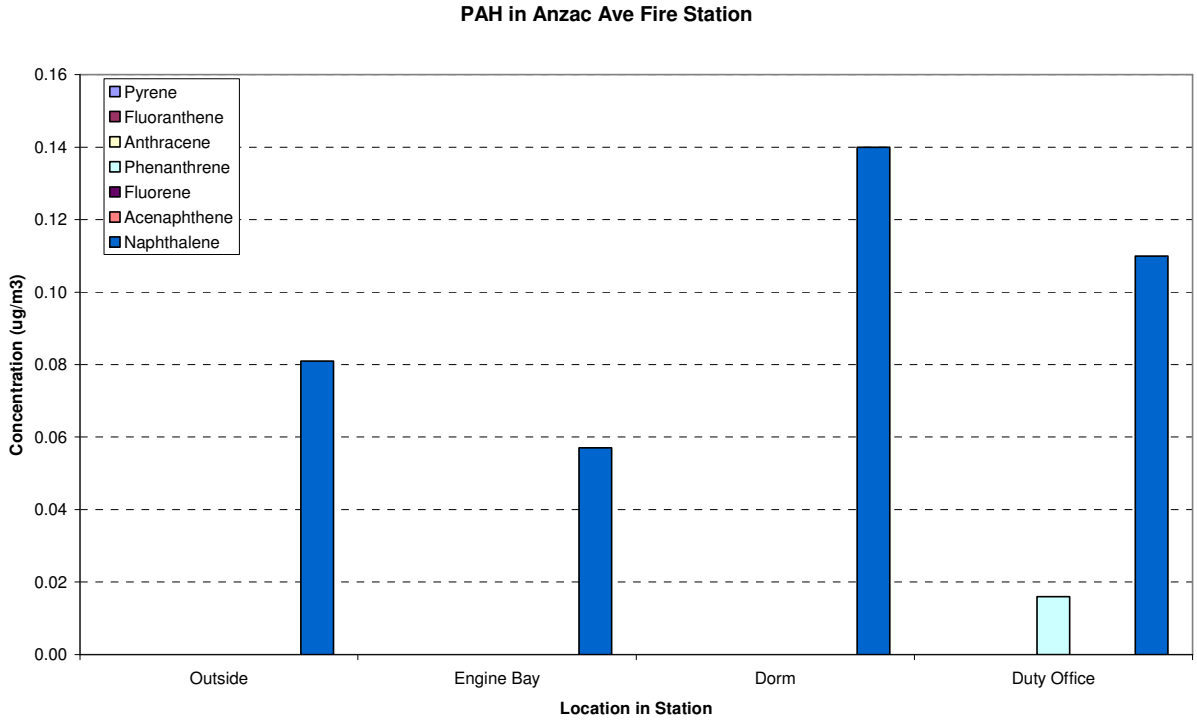


Figure 3.115
Polyaromatic hydrocarbon concentrations for a 10 Hr day shift at Anzac Avenue fire station.

Naphthalene is the most significant contributing PAH to the total PAH concentration. This trend is consistent across all areas of the fire station. The highest estimated naphthalene concentration in any area is more than 97,000 times below the naphthalene ES_{10} 10 500 µg/m^3 and more than 1400 times below the naphthalene odour threshold (200 µg/m^3).

Diesel Particulate Matter
The diesel particulate matter (DPM) has been described extensively in chapter one. There is no established NES for DPM and the level of concern 0.1 mg/m^3 EC has been applied. If the result obtained was less than the reporting limit (R.L) the R.L was used. A recent report has reported typical fire fighter exposure at <0.05 mg/m^3 EC. The typical US fire fighter[33] DPM exposure is ≤ 0.05 mg/m^3 EC (50 µg/m^3 EC).

10 Hr monitoring Station
The DPM background concentration (0.002 mg/m^3) for Anzac Avenue fire station is the same as the average background DPM concentration across the state (0.002 mg/m^3 EC). The average concentrations within the station were all greater than the average concentrations obtained across the state. The highest concentration was obtained in the engine bay (0.009 mg/m^3), which is more than 50 times less than the LOC.

The DPM concentration obtained after the start of shift check (16 minutes) was (0.08 mg/m^3 EC and is greater than the average start of shift concentration (0.044 mg/m^3 EC –including the Firepac 3000 Mk 3 measurement). This concentration is more than 1.25 times less than the established level of concern when the engine bay doors are closed.

The DPM concentration obtained when the Firepac 3000 Mk 3 was used during the start of shift check was 0.73 mg/m^3, which is more than 7 times the LOC. This is the only result that exceeded the LOC, and warrants further investigation where the engine bay doors are open

and/or ventilation is applied to determine whether the Firepac 3000 Mk 3 generated DPM concentration is greater than the LOC. Furthermore, determine if there are strategies to manage the emissions from the Firepac 3000 Mk 3 within the engine bay to minimise fire fighter exposure that can be successfully applied.

The DPM concentrations obtained after the turnout simulation, and return simulation were 0.01 mg/m^3 and 0.02 mg/m^3 respectively. These concentrations were greater than the state turn-out average (0.009 mg/m^3) and the state return average (0.013 mg/m^3).

There are several explanations to account for these results, including the engine bay design, ventilation and appliance performance. These concentrations are more than 5 times less than the level of concern (0.1 mg/m^3 EC).

The results demonstrate that exposure of fire fighters whilst working at the station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern except if start of shift check is undertaken with the Firepac 3000 Mk 3 appliance.

These Anzac Avenue station results show that the only measurement to exceed the typical US fire fighter exposure[33] concentration of 0.05 mg/m^3 EC was the start of shift.

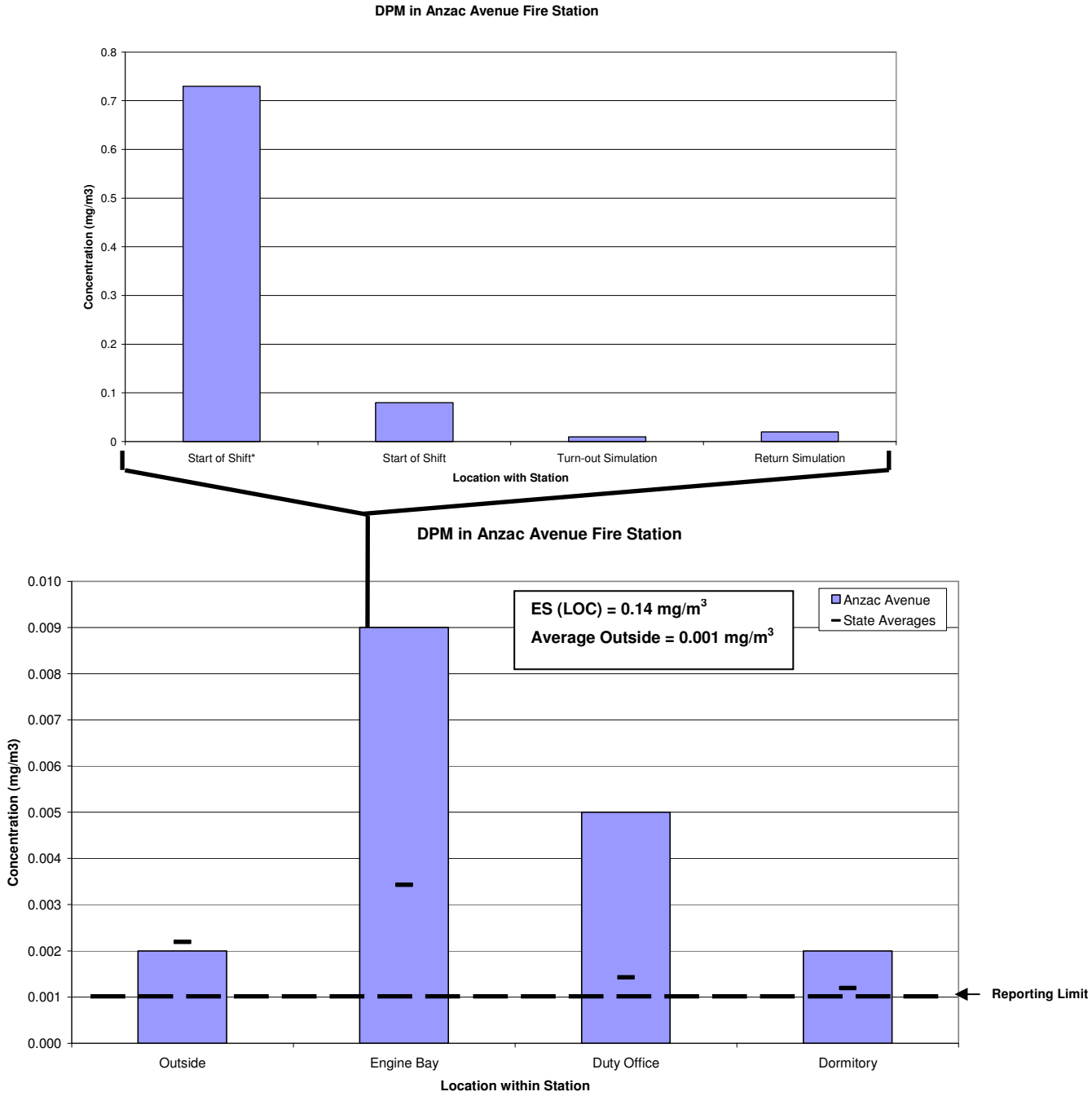


Figure 3.116

DPM results for Anzac Avenue station was based on 10 Hr shift (dorm, eng. Bay, duty office and outside) and actual or simulated activity times (start of shift, turn-out simulation and return simulation).

Summary of Anzac Avenue Results

The Anzac Avenue station trials showed that no stations activity, except the start of shift trial using a Firepac 3000 Mk 3 appliance, exceeded the established levels of concern, and typically measurements showed concentrations were below the reporting limits.

The results demonstrate that exposure of fire fighters whilst working at the station, undertaking start of shift checks and operational activities are significantly less than the established levels of concern except if start of shift check is undertaken with the Firepac 3000 Mk 3 appliance.

Further investigation needs to be performed to determine if DPM LOC is exceeded using the Firepac mark III 3000, if engine bay doors are open and/or ventilation is used.

Sampling Location	PAH	DPM	Benzene	Toluene	Xylene	Hexane	Aldehydes	SO_2	NO_2	CO	H_2S	Tvoc
	($\mu g/m^3$)	(mg/m^3)	Parts per billion (ppb)					Part per million (ppm)				
Outside	0.22	0.002	0.5	3.7	2.0	17	<43.5	<0.5	<0.5	1.1	0.2	3.6
Engine Bay	0.41	0.009	<1.6	10.1	6.5	<1.6	<29.3			1.5	0.1	0.6
Start of Shift		0.08	18.2	60.8	40.8	19	<197*	<0.5	0.5			
Start of Shift With Firepac		0.73										
Turnout		0.01	14.1	151	10.4	13	<177	<0.5	<0.5			
Return		0.02	12.5	28.1	16.6	14	<167	<0.5	<0.5			
Duty Office	0.26	0.005	<1.6	6.9	<4.5	2.1	<29.3	<0.5	<0.5	1.1	0.1	0.6
Dormitory	0.28	0.002	0.4	10.3	5.8	1.0	<44.4	<0.5	<0.5	-	-	0.7
Mess/Lounge			<1.6	2.4	<2.8	<1.6	<29.3	<0.5	<0.5			
PPE Locker			1.3	3.2	1.8	3.4	<49.3	<0.5	<0.5	1.1	0.1	0.6

In the trials without the Firepac mark III 3000, the greatest generation of diesel exhaust occurred during the start of shift checks.

Closing of doors that lead into the engine bay would reduce the transport of exhausts from the engine bay into station areas.

Keeping engine bay doors open during start of shift checks and/or perform checks outside of engine bay would reduce the build-up of exhaust within the engine bay confines.

Conclusions and Recommendations

Conclusions and Recommendations

This section is separated into five parts. They are:

- General conclusion;
- Recommendations about stations in the study;
- General recommendations to consider for current QFRS fire stations;
- General recommendations to consider for future QFRS fire stations; and
- Review the purpose of start of shift check.

General Conclusion

The emissions of diesel exhaust gases and particulates at seven stations (Cairns, Townsville, Rockhampton, Maroochydore, Caboolture, Loganlea and Anzac Avenue) over a 10 hr working day and specific activities were characterised and described in this report. The emissions included:

- Simple inorganic compounds like carbon monoxide;
- Volatile organic compounds like benzene and formaldehyde;
- Polyaromatic hydrocarbons; and
- Diesel particulate matter.

The results shows the data about the airborne contaminants obtained over 10 hours within various station areas and immediately adjacent to the station are significantly below the established levels of concern. The data is similar to the typical urban air shed concentrations for South East Queensland where known and is consistent across the stations.

Data was also obtained for the specific activities. These were appliance response; appliance return to station and start of shift check. The start of shift check trials were conducted with engine bay doors closed and any mechanical ventilation off to simulate the worst possible case. The results show the data about the airborne contaminants were less than the established levels of concern. These concentrations are likely to be significantly lower when the doors are opened enhancing natural ventilation. The exception to this conclusion is the diesel particulate matter (dpm) concentration measured when a Firepac 3000 Mk 3 was used during a start of shift check. The emissions from this appliance exceeded the established level of concern.

It is recommended the engine bay doors remain open during start of shift checks and consideration be given to performing the checks outside of engine bay. This approach will likely further reduce the concentration of any diesel exhaust within the engine bay confines.

It is recommended the QFRS provide information about the study, its findings, meaning to fire fighters and future activities the QFRS is considering.

It is recommended the Firepac 3000 Mk 3 be subjected to a further investigation that includes a start of shift check that includes but is not limited to engine bay doors closed; and engine bay doors open so that fire fighter exposure is reduced.

Recommendations about stations in the study

In the course of the investigation, the investigators observed a number of station management practices and station design practices could be improved to further reduce fire fighter exposures.

The start of shift check should be conducted with the engine bay doors opened to ensure there is natural ventilation within the engine bay. This approach will further reduce fire fighter

exposures. The engine bay doors should remain open for a few minutes after the appliance has departed and returned to assist the dispersal of any emissions.

In general, it was observed doors and windows opening directly to the engine bay are often left open allowing air to easily move from the engine bay into the station proper. It is recommended where possible these doors and windows should remain closed.

The door and window mechanical designs should be reviewed and if necessary the door replaced and self closing mechanisms be incorporated. The station administrative arrangements should be reviewed and if necessary modified to ensure the doors and windows remain closed. The fire fighters should be encouraged to adopt these improved practices and thus reduce their exposure. The combination of these two approaches will likely significantly address the fire fighter concerns raised in the survey about their exposures within the station.

It was observed at Rockhampton fire station there was a large hole in the wall separating the engine bay and the PPE locker room. This hole allows exhaust gases to readily move into the PPE locker from the engine bay. A fan, used to extract air from the PPE locker to outside the station generates a negative pressure in the room with respect to the adjoining engine bay drawing further air into the room. It is recommended the hole be repaired. The door seal to the engine bay should also be reviewed and upgraded if necessary to prevent air movement into the room. If the fan is to be maintained to keep a negative pressure within the PPE locker, a second opening to the outside environment be installed to enable fresh air rather than the air from the engine bay enter the room. It was also observed the door was constructed of flexible plastic and consideration should be given to replacing and upgrading the door.

It was observed at Townsville and Caboolture fire stations have PPE locker rooms that cannot be directly isolated from the engine bay. The current arrangement gives rise to concerns about the deposition of particulate matter onto the clothing. It is recommended this arrangement be reviewed and doors installed to prevent air movement from the engine bay into these rooms. This action will likely significantly address the fire fighter concerns about the deposition of particulate matter.

It was observed at Cairns fire station the PPE was stored directly adjacent to the appliances. The current arrangement should be reviewed and the storage arrangement improved. The improvement may range from an individual locker in the current position to a dedicated room that is readily assessable and sealed from the engine bay. This action will likely significantly address the fire fighter concerns about the deposition of particulate matter

It was observed at Anzac avenue fire station the PPE was stored in a corridor adjacent to the duty office. The current arrangement should be reviewed and the storage arrangement improved. The improvement may range from an individual locker in alternative location to a dedicated room that is readily assessable and sealed from the engine bay. This action will likely significantly address the fire fighter concerns about odours arising from the PPE within the station.

General recommendations to consider for current QFRS fire stations

The QFRS has a variety of fire station designs and general business rules for the day to day management of fire stations. Nonetheless, many fire stations have developed local management arrangements to suit their particular needs. It would seem apparent from observing the practices and arrangements at the seven stations many can be reviewed and there are opportunities for improvements across all QFRS fire stations to further reduce fire fighter exposures. Any review of existing practices and arrangements should consider several factors including:

- Operational requirements and station activity;
- Location and station design;
- Current and future appliance design;
- Current practices; and
- Changes demonstrate improvement.

These improvements range from enhancing administrative arrangements to enhancing engineering controls. However, the enhancement of engineering controls requires a risk based set of criteria to be established.

In general, the station administrative arrangements concerning whether doors and windows opening directly into the engine bay remain closed should be reviewed and if necessary modified to ensure the doors and windows remain closed. The fire fighters should be encouraged to adopt these improved practices and thus reduce their exposure. Information should be provided to fire fighters to remind of the benefits of such actions. The combination of these two approaches will likely significantly address the fire fighter concerns raised in the survey about their exposures within the station

The four most obvious functional arrangements to consider include:

- Doors from the engine bay to the station proper- construction and operation;
- Ventilation within the engine bay – natural ventilation through grilled doors;
- Storage of PPE-, location, storage and ventilation; and
- Engine performance.

The QFRS should consider developing a risk based tool to assess the four arrangements above. The tool will take into account factors such as those listed above. The results will assist determine priority items to improve when refurbishing fire stations across Queensland. In the specific case of engine performance QFRS Technical Services should consider the information about identifying vehicles outside the scope of current regulatory framework for diesel emissions and consider the benefit of retro-fitting ceramic disks to the exhaust systems. It has been shown ceramic disks can reduce particulate emissions by more than 95%.

General recommendations to consider for future QFRS fire stations

The design of new fire stations provides an opportunity to incorporate several performance requirements to address the following issues:

- Air movement between the engine bay and station proper- construction and operation of doors and windows;
- Ventilation within the engine bay – natural ventilation through grilled doors; and
- Storage of PPE-, location, storage and ventilation.

In the context of the risk control hierarchy it is likely engineering controls are the most reasonable element to apply. There are many factors to also consider as outlined above and perhaps the greatest is the future appliance fleet as it changes to match the evolving emissions regulatory environment.

The design should consider improvements to minimise air movement from the engine bay to the station proper without hindering the movement of fire fighters. Approaches may include:

- automatic opening/closing and/or self-closing doors between the engine bay and work areas;
- open air passageways and/or positive pressure airlock between the engine bay and station proper with self closing doors either side;
- positive pressure within the station proper *c.f* the engine bay;

- air conditioning/station exhausting to comply with AS1668; and
- air conditioning inlets away from the engine bay and station proper,

The design should consider improvements to ensure natural ventilation occurs within the engine bay and enhances the dispersal of engine emissions. Approaches may include:

- engine bays doors with grills encompassing the lower third of the door-back and front; and
- time delays closing of doors after appliances return and leave.

The design should consider improvements to better manage PPE storage and ventilation. Approaches may include:

- dedicated storage room and individual lockers for PPE that is separate from the engine bay or closed off from the engine bay;
- negative pressure air movement within the room and the air introduced is from outside the fire station; and
- continuous air movement within the lockers and is exhausted directly to the outside of the fire station

Review the purpose of start of shift check.

The diesel emission study has also revealed another activity to consider. That is the start of shift check; since it is the source of the greatest exposures of exhaust emissions to fire fighters, it is reasonable to investigate the activity further. In terms of the risk control hierarchy, it is also the most obvious since it addresses eliminating the emissions and hence exposures. It is recommended the start of shift check be reviewed since the potential benefits are significant. Reducing the start of shift check-starting the appliance to once a day will immediately reduce the fire fighter exposure by 50 %.

The “start of shift check” is an activity undertaken by the operational crew at the commencement of their shift. The purpose of the check is to ensure:

- Operational equipment on the vehicle is present and serviceable;
- Emergency response vehicle is serviceable; and
- Portable motorised equipment is serviceable.

Depending on the nature of the resources on the vehicle, the check typically is completed in less than 30 minutes. At several stations where extra emergency response vehicles are located, the activity takes significantly longer.

The “start of shift check” has apparently been a regular activity since the formation of fire brigades and horses were utilised. A common perception is in the early days of motorised vehicles, breakdowns were frequent and the start of shift checks identified many faults. In the last 30 years, the nature of the vehicles and the equipment carried on the vehicles has changed significantly in the past thirty years. Equipment and vehicle reliability is significantly greater than in years past and the failure rate referred to as the mean time between failures (MTBF). It is not clear there is any evidence the activity has been recently challenged and where appropriate modified to ensure it meets the objectives. Moreover, what are the performance measures to assess how well the activity is undertaken or it takes a similar time irrespective of the location of the station. Questions include:

- What is the purpose of the start of shift check?
- What is the rationale for checking equipment? And
- Can the process be improved so it is more efficient and potential exposures of fire fighters to exhaust emissions reduced?

A pathway forward

There are many potential approaches to review the start of shift activities that can be applied. Such a process might include:

- Review the purpose of the start of shift check;
- Review and identify the equipment on the vehicles;
- Obtain information about the MTBF and likely causes of failure of each piece of equipment;
- Rank each piece of equipment according to operational criticality;
- Develop a matrix using a combination of the operational criticality and MTBF to determine the testing/inspection frequency for each piece of equipment;
- Develop a revised start of shift check and trial the activity;
- Review the success of the activity and modify where necessary;
- Develop a change management strategy and revised start of shift check activity; and
- Implement change management strategy and revised start of shift activity across the QFRS.

The supplier of the equipment particularly motorised and portable equipment should provide information to the QFRS about the most frequent causes of failure and the MTBF. If the information has not been provided it should be sought. Alternatively, the QFRS should review the maintenance records for the equipment so the appropriate information obtained and assessed.

To illustrate an example of applying the MTBF to assist the QFRS determine a testing regime lets consider a fire appliance not starting at a station where there are four vehicles and responds to in excess of 4500 calls per year. It is reasonable to expect the station operates the vehicles in excess of 100,000 times per year when activities like inspections, exercises, and start of shift checks are included. In the last ten years, how many times has a vehicle failed to start during a start of shift check? The MTBF is less than one in a million. A similar comparison across the QFRS for all QFRS appliances is likely to indicate the MTBF is greater than one in ten million. Therefore, what is the justification for starting and running the fire appliance twice a day at the start of shift when the MTBF is so low? Moreover, would a start of shift check reasonably identify a fire appliance failing to start?

What would happen if the appliance was started once a day during the start of shift check?

The immediate and greatest benefit is fire fighter exposures to diesel exhaust emissions will

be immediately reduced by 50%.

An essential component of any review of the start of shift check is to ensure fire fighters do not lose any confidence about the operational equipment. Any review should be undertaken as a trial to ensure the benefits are demonstrable. A trial may include:

- Education program;
- Procedure;
- Fire fighter feedback about the revised start of shift check;
- Technical services feedback regarding whether there has been any reduction of the MTBF or changes in the associated on-going costs; and
- Performance measures to assess whether the changes are successful.

A further advantage of reducing the frequency of the start of shift check is reduced fuel usage. It is estimated an appliance idling for 30 minutes uses approximately 1 litre of diesel. Across the urban fleet within the QFRS, this amounts to a significant volume of fuel. If the start of shift check reduces this requirement by 30 minutes each day at current fuel prices the saving is likely to exceed $100,000 a year if not more than double that amount.

It is recommended the QFRS consider reviewing the start of shift check to determine if it can be improved and fire fighter exposure reduced.

Appendix 1 – Australian Exposure Standards for air contaminants in diesel exhaust

Contaminant	Det^{n} Method	National Occupational Health and Safety Council Exposure Standard (TWA)[1]	Corrected[3] TWA for 10 Hr shift	Corrected[3] TWA for 14 Hr shift
Carbon monoxide	MultiRae	30 ppm	21 ppm	10 ppm
Diesel particulate matter (DPM)	SKC - DPM	No Australian or Queensland exposure standard NSW Mineral Council - 0.2 mg/m^3 sub micron DPM i.e. ~ 0.17 mg/m^3 Total Carbon or 0.1 mg/m^3 EC measured as sub micron fraction		
Acrolein	SKC - DNPH	0.1 ppm	0.07 ppm	0.03 ppm
Formaldehyde	SKC - DNPH	1 ppm	0.7 ppm	0.3 ppm
Total volatile organic compounds - VOC_t	SKC – Tenax	No exposure standard		
	PID	QFRS std 0.5ppm (peak)		
PAH[2] (Polycyclic aromatic hydrocarbons)	SKC – high flow	No exposure standard		
Benzene	Dräger Tube	1 ppm	0.7 ppm	0.3 ppm
Nitrogen dioxide (NO_2)	Dräger Tube	3 ppm	2 ppm	1 ppm
Sulfur dioxide (SO_2)	Dräger Tube	2 ppm	1.4	0.7 ppm

1. TWA = NOHSC Time weighted average exposure standard, based on 8 hour working day at moderate working intensity
2. PAH represent the combination of a wide range of aromatic hydrocarbons and numerous exposure standards.
3. Guidance Note on the Interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment NOHSC 3008(1995) 3rd Edition recommends that to modify the exposure standards from a non-standard 8 Hr work day the following equation is used.

$$\text{Adjusted exposure standard (TWA)} = \frac{8 \times (24 - \text{hours of shift}) \times \text{Exposure Standard (8-hour TWA)}}{16 \times \text{hours of shift}}$$

Note: all adjusted exposure standards were rounded down to the nearest hour to account for significant figure errors.

Appendix 2

Diesel Exhaust Emission Exhaust Questionnaire for Fire Station Personnel

1. Do you think your station has a problem with diesel exhaust emissions:
    a. yes
    b. no

2. If you think your station has a problem with diesel exhaust emissions what are they:

_____

_____

_____

_____

3. Rank the following locations in your order of priority for air quality:

☐	Engine bay	1 = most important
☐	Duty office	5 = least important
☐	Dorm	
☐	Turnout gear locker	
☐	Mess/lounge	

4. How many appliances are there in your station:
    a. 1 appliance
    b. 2 appliances
    c. 3 appliances
    d. More than 3 appliances

5. How many appliances in your station are crewed under normal staffing arrangements:
    a. 1 appliance
    b. 2 appliances
    c. 3 appliances
    d. More than 3 appliances

6. Is your station permanent or auxiliary:
    a. Permanent
    b. Auxiliary
    c. Auxiliary staffed by a permanent day work Station Officer

7. How is your Engine Bay vented (circle all that apply):
    a. Leave both front and back roller doors open
    b. Leave only front or rear roller door open
    c. Automated mechanical venting on turn-out signal
    d. Manual starting of mechanical ventilation system
    e. No mechanical venting system

8. Are the doors leading from your engine bay to other work areas in the station left open or during day/night shifts (circle either open or closed for each area):

	Day Shift	Night Shift
Duty Office	Open / Closed	Open / Closed
Dorm	Open / Closed	Open / Closed
Turn-out gear locker	Open / Closed	Open / Closed
Mess/lounge	Open / Closed	Open / Closed

9. How do you store your turn-out gear:
    a. Next to appliance in engine bay
    b. In a dedicated turn-out gear room
    c. In engine bay away from appliance

10. Do you do shift checks outside engine bay confines?
    a. yes
    b. no