Prepared for

Airservices Australia

Subject

Screening-level exposure and risk assessment of potential construction exposure to selected perfluorinated compounds

Author

Dr Christine Baduel

25 August 2015

UniQuest Project No: C02300

entox Innovations

A trading name of UniQuest Pty Ltd
(A.B.N 19 010 529 898)

The main commercialisation company of The University of Queensland Australia

UNIQUEST

Title

Screening-level exposure and risk assessment of potential construction exposure to selected perfluorinated compounds

Disclaimer

UniQuest has prepared this document for the purposes expressly stated in this document. UniQuest otherwise disclaims responsibility to any person other than Airservices Australia arising in connection with this report.

The work and opinions expressed in this report are those of the Author.

Project Team

Dr Christine Baduel
Jennifer Braeunig
Dr Lesa Aylward
Professor Jochen Mueller

EXECUTIVE SUMMARY

Perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) are man-made and persistent organic pollutants present in aqueous film-forming foam (AFFF). The historical use of AFFF led to the presence of these chemicals in soil, sediment, surface water and groundwater in the vicinity of AFFF impacted sites. Workers may come into contact with contaminated media during activities at sites contaminated with PFOS and PFOA due to AFFF use.

The objectives of this report are:

- To assess whether commonly measured concentrations of PFOA and PFOS in different environmental media around firefighting training grounds may potentially lead to exposures for workers in excess of recommended exposure limits for these compounds under anticipated working conditions during excavation and construction/demolition activities; and
- To provide preliminary recommendations for mitigation of exposure to workers/personnel.

Three occupational activities at AFFF impacted sites have been considered. For each scenario, the exposure pathways have been identified and screening level exposure as well as health risk assessment have been conducted based on calculated chemical intake and chemical concentrations obtained from previous onsite monitoring (provided by Airservices).

Overall, the main exposure pathways identified were incidental ingestion and inhalation. The estimated screening hazard index investigated for the three working activity scenarios did not exceed the relevant adopted acceptable value (<1) suggesting that the exposures and risks to workers would be considered acceptable. The screening hazard index exceeded one only in a single 'worst case' scenario based on relatively heavily contaminated soil and concrete (chemical concentrations > 200 mg/kg) and with an exposure frequency longer than 45 days assuming no mitigation strategies have been used (wetting soil/wearing mask).

We recommend that the personnel working on contaminated sites covered by the scenarios investigated here should be conscious of the presence of these chemicals in the different media and aware of the exposure routes and the notion of persistence. The proper use of personal protective equipment (PPE) must be explained to all current/new personnel and proper use of PPE must be enforced during worker activities. For personnel that are likely to

work extended periods with contaminated media or who otherwise are not covered in the scenarios described here (e.g. higher contamination level or additional exposure routes) a revision of these exposure estimations would be required.

ABBREVIATIONS

Acronym	Description
ABSr	Bioavailability or relative absorption of PFOS and PFOA from soils
AFFF	Aqueous Film Forming Foam
Airservices	Airservices Australia
$BMDL_{10}$	Benchmark dose for a 10% effect size
b.w.	Body weight
C	Adopted concentration value
D	Dust concentration in air
ED	Exposure duration
EF	Exposure frequency
FTG	Fire Training Ground
HQ	Hazard Quotient
HI	Hazard Index
InR	inhalation rate for construction workers
IR	Daily incidental soil ingestion construction
Kp	Penetration kinetics from aqueous vehicle
NOAEL	No observable adverse effect level
OSHA	US Occupational Safety and Health Administration
PFAS	Per and poly-fluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulphonate
PPE	Personal protective equipment
SA	Skin surface area
TDI	Tolerable Daily Intake
USEPA	United States Environmental Protection Agency
W	Working duration per day

TABLE OF CONTENTS

1. INTRODUCTION

Entox has undertaken a screening-level exposure and risk assessment on behalf of Airservices Australia (Airservices) to assess the potential for exposure of workers to selected perfluorinated chemicals, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), in soil, concrete from firefighting areas, groundwater, surface water and sediment that have been contaminated with these compounds at several locations in the vicinity of airports. In particular, exposure of workers conducting intrusive activities such as digging, demolition, and other construction activities is considered here. Work scenarios and adopted concentration levels have been provided by Airservices. This assessment presents an evaluation of the potential for exposure to these compounds using limited available data and assumptions regarding potential contact pathways that are conservative; that is, likely to over-estimate risk. The resulting exposure estimates are compared to existing assessments of tolerable daily intakes (TDIs) for PFOS and PFOA, which are estimates of long-term average exposure levels that are not likely to result in adverse health impacts.

1.1 Objectives and scope of work

The objectives were to:

- Assess potential exposure to individuals undertaking intrusive works resulting from their contact with soil, sediment, concrete, groundwater and surface water;
- Compare the estimated exposure levels to existing exposure guidance values in a screening-level risk assessment; and
- Provide practical guidance and recommendations to Airservices about how to mitigate any such risks to workers, including recommendations about any specific personal protective equipment (PPE) that should be worn and how such PPE should be handled after it is worn.

The scope of work undertaken to achieve the objectives was to:

- Identify and describe potential exposure sources and pathways specific to the occupational activities at AFFF contaminated sites described by Airservices;
- Discuss and interpret the identified exposure pathways using available literature concerning PFOS and PFOA absorption as well as TDIs;
- Calculate possible intake rates for workers and discuss these; and

- Discuss PPE used and advise on the proper handling of used PPE.

1.2 Perfluorinated Chemicals

Per- and poly-fluoroalkyl substances (PFASs) have been used extensively in aqueous film forming foams (AFFF) at various airport sites throughout Australia. Working with AFFF or working on sites contaminated with PFASs, including PFOS and PFOA, can lead to exposure of humans to these chemicals. PFASs are persistent, with human elimination half-lives for PFOS and PFOA of 5.4 years and 3.8 years, respectively (Olsen et al. 2007). In animals, PFOS and PFOA have been shown to disrupt normal endocrine activity, to be peroxisome proliferators, hepatotoxic and potentially carcinogenic (Kennedy et al. 2004, OECD, 2002, White et al. 2011). To date, epidemiological studies linking adverse health outcomes to increased PFOS/PFOA concentrations are sparse. Increased PFOA serum levels in humans have so far been linked with increased serum lipids and uric acid levels; and positive associations have been described between PFOS serum concentrations and total cholesterol, triglycerides and uric acid in the general population (for an overview, see Khalil et al. 2015). However, additional research in animals and humans is needed to better understand potential adverse health effects associated with exposure to PFASs.

1.3 Personal protective equipment (PPE)

Information on current PPE practices at the Airservices sites was provided by Airservices. According to this information, PPE used by intrusive workers contracted by Airservices includes heavy-duty gloves, masks, hats, and long sleeved shirts.

The exposure assessment carried out in this document did not consider protection from exposure to PFASs by the PPE.

2. TOLERABLE DAILY INTAKE OF PFOS/PFOA

A TDI is an estimate of the amount of a chemical in air, food or drinking water expressed on a body weight (b.w.) basis, which can be taken in daily over the lifetime of a human without appreciable health risk. TDIs are usually calculated on the basis of animal studies to which uncertainty factors are applied to account for inter and intra-species differences and general uncertainty. The TDI is derived using the most sensitive endpoint in the most relevant study as described below:

$$TDI = \frac{\text{NOAEL or LOAEL}}{\text{UF}}$$

Where

NOAEL = no-observable-adverse-effect level
LOAEL= lowest-observable-adverse-effect level
UF = Uncertainty factor

The TDI is an estimated amount and is not so precise that it cannot be exceeded for short periods of time and short-term exposure to chemicals exceeding the TDI is usually not a cause for concern, provided the person's average long-term intake does not exceed the limit set.

The NOAEL is defined as the highest dose of a chemical in a single study, found to cause no detectable adverse health effects. Preferably the NOAEL should be based on a long-term study, however, if no other data is available short term studies may also be used. An alternative approach to using the NOAEL for the derivation of the TDI is using the benchmark dose (BMD).

TDI PFOS: 150 ng/kg body weight per day

The TDI for PFOS was derived by the European Food Safety Authority (EFSA, 2008) from the NOAEL of 0.03 mg/kg b.w. per day derived from a subchronic study with Cynomolgus monkeys (Seacat et al. 2002) showing changes in lipids and thyroid hormones at the next higher dose of 0.15 mg/kg b.w. per day. An overall uncertainty factor of 200 was applied to the NOAEL to derive the TDI:

0.03 mg/kg b.w. per day / 200 (safety factor) = 0.00015 mg/kg b.w. per day = 150 ng/kg b.w. per day

The uncertainty factor of 200 is comprised of an uncertainty factor of 100 which was applied for inter and intra-species differences and an additional UF of 2 to compensate for uncertainties in connection to the relatively short duration of the key study and the internal dose kinetics.

TDI PFOA: 1500 ng/kg b.w. per day

The TDI for PFOA was derived by EFSA (EFSA, 2008) from the $BMDL_{10}$ (Benchmark dose for a 10% effect size) of increased absolute liver weight in male rats (Perkins et al. 2004, Palazzolo et al. 1993). Uncertainty factors were applied: 100 for inter and intra-species differences and 2 to compensate for uncertainties relating to the internal dose kinetics.

Both the PFOS and the PFOA TDIs derived by the EFSA are based on data from subchronic studies. TDIs based on long-term studies would be preferable and give more reliable TDIs. Therefore, the TDIs should be used and applied with caution.

The TDIs presented here are applicable to PFOS and PFOA only. While these chemicals are also the main contaminants at the respective working areas, other PFCs have been used in the AFFF foams and may contribute to the contamination. However, we did not identify any formal assessments of TDIs for other PFCs.

Table 1 Tolerable daily intakes (TDI) derived by the European Food Safety Authority (EFSA)

	PFOS	**PFOA**
TDI EFSA	150 ng/kg b.w.	1500 ng/kg b.w.

3. EXPOSURE ASSESSMENT

The purpose of the exposure assessment is to estimate the potential levels of exposure and absorption of PFOS and PFOA among the exposed individuals. The levels of exposure are estimated based on assumptions regarding contact rates with various media as well as assumptions regarding frequency and duration of exposure and concentrations of the contaminants in the media. The specific media considered here include soils, sediment, cement pad debris, groundwater, surface water, and inhaled dust.

3.1 Exposure pathways

Individuals may come into contact with contaminated soil, dust, concrete, groundwater and associated wastes (e.g. spoil, extracted groundwater) when undertaking works on Airservices sites. The nature of works by such individuals may involve construction and maintenance activities such as trenching for cables, cutting up concrete, modifications or extensions to fire stations and replacements of underground assets.

Based on the information provided by Airservices, the majority of excavation and intrusive works undertaken by construction workers do not result in long term exposure to PFASs for reasons including:

- Trenches and other excavations (such as construction of footings in new constructions) are only open for the minimum time necessary to do works, usually no more than three days and often for a day;
- Most excavations are performed mechanically (e.g. with a ditch digger) so direct exposure to soils during excavation works is limited; and
- Most excavation(s) and construction activities are shallow so that while interactions with groundwater do occur they are minimal.

Construction workers conduct intrusive works other than excavations, including the establishment of footings and the laying of concrete foundations. However, as with excavations works, these other intrusive construction works are ongoing for the minimum time necessary, thus limiting the direct exposure time. The single difference between construction activities and trenching works is the expanse of impacted soils that may be exposed and hence subject to the creation of dust.

Demolition works largely do not involve subsurface activities, but where these do occur such activities resemble excavation/construction works and so are considered covered by these. The only significant difference is that demolition activities tend to generate more dust and debris over a greater time period than excavation and construction works.

The significant exposure scenarios and the exposure pathways that may occur are considered to be the following:

- **Scenario 1** Construction/demolition workers digging in soil: Incidental ingestion of soil, dust inhalation, dermal exposure to groundwater;
- **Scenario 2** Direct contact with sediment and contaminated surface water: Incidental ingestion of sediment and dermal exposure to contaminated water; and
- **Scenario 3** Demolition of infrastructure of highly contaminated area such as firefighting training ground: incidental ingestion of concrete debris and dust inhalation.

These exposure scenarios and pathways are summarized in Table 2.

Table 2 Exposure scenarios and the pathways of exposure included in the exposure estimation

Scenario	Soil Ingestion	Concrete Debris Ingestion	Sediment Ingestion	Dust Inhalation	Surface Water Dermal Exposure	Groundwater Dermal Exposure
1) Workers digging in soil	X			X		X
2) Contact with sediment and surface water			X		X	
3) Workers demolishing infrastructure		X		X		

3.2 Exposure parameters

Human exposure parameters adopted in the following estimations were obtained from different sources. These parameters are used in risk assessment contexts and tend to be conservative (i.e., likely to over-estimate exposures). The assumed exposure parameters are summarised in Table 3.

Table 3 Exposure parameters adopted

Parameter/definition (unit)	**Adopted value**	**Symbol**	**Source**
Exposure frequency (days/year)	3 and 90	EF	Information provided by Airservices
Exposure duration (years)	1	ED	Information provided by Airservices
Working duration per day (h)	8	WD	Airservices
Adopted concentration value	See Table 4	C	Airservices
Body Weight (kg)	80	BW	
Skin surface (half a body) (cm^2)	10,000	SA	EPA Exposure Factors Handbook (EPA 2011)
Penetration kinetics from aqueous vehicle (cm/h)	9.49 E^{-07}	Kp	Fasano et al., 2005[a]
Dust concentration in air (mg/m^3)	10	D	Australian nuisance dust standard[b]
Inhalation rate for construction workers (m^3/hour)	1.44	InR	EPA Exposure Factors Handbook (EPA 2011)
Daily incidental soil ingestion construction (mg/d)	300	IR	EPA Exposure Factors Handbook (EPA 2011)
Bioavailability or relative absorption of PFOS and PFOA from soils (unitless):	1	ABSr	No available data. Conservative assumption assumes complete bioavailability from soils.

[a] Dermal penetration coefficient for PFOA determined for human skin and applied here to PFOS.
[b] Guidance on the interpretation of workplace exposure standards for airborne contaminants. Safe work Australia. 2012

3.3 Exposure concentrations in media

Airservices provided a range of concentrations for PFOS and PFOA in various media. The information presented in Table 4 is based on data from Sydney and Brisbane sites. The exposure concentrations adopted in the estimation for PFOS and PFOA in groundwater, surface and sediment are considered as the highest screening concentration rather than average. The adopted concentration of PFOA in soil is the arithmetic mean from the two given values. Due to the wide range of concentration of PFOS in soil provided by Airservices, two different soil concentrations (C1 and C2) are investigated where the adopted exposure values are as follows:

- C1: The arithmetic mean calculated from the minimum and maximum reported concentrations C1 = 230 mg/kg.
- C2: The median of a log normal distribution (Gaussian distribution) from the maximum and minimum is 3.7 mg/kg; a recent evaluation of homogenised soils from Hobart site led to a similar value of 2.5 mg/kg. Based on this we chose an intermediate value of 3

mg/kg to represent a PFC concentration in soil around areas where the AFFF were used (for example, during regular training exercises).

Table 4 PFOS and PFOA exposure concentrations assumed in different media

Media	PFOS concentration range	PFOA concentration range	Adopted concentration for PFOS	Adopted concentration for PFOA	References
Soil	0.03 – 460 mg/kg	0.001–3 mg/kg	C 1: 230 mg/kg C 2: 3 mg/kg	1.5 mg/kg	Airservices
Sediment	0.03 – 1 mg/kg	0.01 mg/kg	1 mg/kg	0.01 mg/kg	Airservices
Groundwater	0.1 - 2100 µg/L	0.04 – 260 µg/L	2100 µg/L	260 µg/L	Airservices
Surface Water	0.03 – 160 µg/L	0.03 – 9 µg/L	160 µg/L	9 µg/L	Airservices
FTG Concrete	0.07–250 mg/kg	0.08–1.5 mg/kg	10 mg/kg	0.7 mg/kg	Baduel et al., 2015

3.4 Estimation of chemical intakes via different pathways

3.4.1 Methods

Estimation of chemical intake requires the adoption of several assumptions in order to calculate potential human exposure. The assumptions used are conservative and are likely to over rather than under-estimate potential exposures. Exposure estimates for each exposure pathway (dermal, inhalation, and ingestion) were calculated using the following equations. The symbol definitions and values adopted are listed previously in Table 3.

$$dermal\ absorption = \frac{Kp\ \times\ SA\ \times C\ \times WD}{BW}$$

$$inhalation\ intake = \frac{InR\ \times C \times D \times WD}{BW}$$

$$incidental\ ingestion = \frac{C\ \times IR \times ABSr}{BW}$$

3.4.2 Results

The exposure calculations have been done based on several assumptions. For the dermal contact, it is assumed that contact with the surface water and groundwater results in wetted clothing and a skin exposure for 10,000 cm^2 exposed surface area (half body) for eight hours per day.

To estimate absorption level through inhalation, we assumed 10 mg/m^3 of dust in air, corresponding to the Australian nuisance dust standard provided by the Australian Government statutory agency. Depending on the scenario, this dust was assumed to arise from the contaminated soil, or from the contaminated concrete debris, and that no dust suppression techniques were used (e.g. wetting soil or debris). The inhalation rate was assumed to be 1.44 m^3/hour, a value recommended for estimating inhalation rates for construction workers, over eight hours (approx. 12 m^3/working day) per the EPA Exposure Factors Handbook (EPA 2011). All of the inhaled dust was assumed to result in 100% systemic absorption of the contaminants, either through desorption of the contaminants from respirable particles in the lung, or from swallowing of dust after mucociliary clearance from the respiratory tract.

To estimate the exposure level via incidental ingestion, we assumed daily incidental soil ingestion at the construction site of 300 mg (EPA 2011).

3.4.2.1 PFOS exposure estimation:

The calculations of the intake of PFOS for the three investigated scenarios are presented in Table 5.

- **Scenario 1** Construction/demolition workers digging in soil: Incidental ingestion of soil, dust inhalation, dermal exposure to groundwater. The estimated daily intake is 1209 ng/kg-d of PFOS when the soil concentration of PFOS is set at 230 mg/kg and, in that case, the intake exceeds substantially the TDI value (806 % TDI). The estimated daily intake drops to 17.7 ng/kg-d when the soil concentration of PFOS is set at 3 mg/kg-d, which corresponds to 12% of the TDI.
- **Scenario 2** Direct contact with sediment and contaminated surface water: Incidental ingestion of sediment and dermal exposure to contaminated water. In this scenario the total daily intake is estimated at 3.9 ng/kg-d, which represents 2.6 % of the TDI.
- **Scenario 3** Demolition of infrastructures of highly contaminated areas such as firefighting training grounds: incidental ingestion of concrete debris and dust inhalation. The total daily intake is estimated at 52.5 ng/kg-d, which is 35% of the TDI.

Table 5 Calculated daily intake of PFOS for the different scenarios

Expsoure to PFOS	Scenario 1a*	Scenario 1b*	Scenario 2	Scenario 3
Dermal from aqueous vehicle	**Groundwater**	**Groundwater**	**Surface water**	
Kp, cm/hr:	9.49E-07	9.49E-07	9.49E-07	
Surface area, cm2:	10000	10000	10000	
Concentration, mg/mL:	0.0021	0.0021	0.00016	
Time, hr:	8	8	8	
Quantity absorbed, mg:	1.59E-04	1.59E-04	1.21E-05	
Bodyweight, kg:	80	80	80	
Dose/8 hr, mg/kg:	1.99E-06	1.99E-06	1.52E-07	
Conversion factor, ng/mg:	1.00E+06	1.00E+06	1.00E+06	
Dose/8 hr, ng/kg:	1.99	1.99	0.15	
% TDI	1.3	1.3	0.1	
Inhalation	**Soil (C1)**	**Soil (C2)**		**Concrete**
Soil concentration of PFOS, mg/kg:	230	3		10
Dust concentration in air (mg/m3):	10	10		10
Conversion factor, mg/kg:	1.00E+06	1.00E+06		1.00E+06
PFOS concentration in air, mg/m3:	2.30E-03	3.00E-05		1.00E-04
8 hour air volume, Construction worker, m3:	12	12		12
Bodyweight, kg:	80	80		80
Daily inhaled dose, mg/kg-d:	3.45E-04	4.50E-06		1.50E-05
Conversion factor, ng/mg:	1.00E+06	1.00E+06		1.00E+06
Daily inhaled dose, ng/kg-d:	345	4.5		15.00
% TDI	230.0	3.0		10.0
Incidental ingestion	**Soil (C1)**	**Soil (C2)**	**Sediment**	**Concrete**
PFOS in soil, mg/kg:	230	3	1	10
Daily incidental soil ingestion construction, mg:	300	300	300	300
Relative absorption rate, fraction:	1	1	1	1
Bodyweight	80	80	80	80
Conversion factor, ng/mg	1.00E+06	1.00E+06	1.00E+06	1.00E+06
Conversion factor, mg/kg:	1.00E+06	1.00E+06	1.00E+06	1.00E+06
Daily incidental PFOS ingestion, ng/kg-d:	862.5	11.25	3.75	37.50
% TDI	575.00	7.50	2.50	25.00
Total daily dose ng/kg-d	1209.5	17.7	3.9	52.5
%TDI total	806.3	11.8	2.6	35.0

*Scenario 1a refers to the case where the soil concentration is 230 mg/kg, and Scenario 1b refers to a soil concentration of 3 mg/kg.

3.4.2.2 PFOA exposure estimation:

The estimation of PFOA intakes for the three investigated scenarios is presented in Table 6.

- **Scenario 1** Construction/demolition workers digging in soil: Incidental ingestion of soil, dust inhalation, dermal exposure to groundwater. The estimated daily intake is 8.1 ng/kg-d of PFOA which is <1% of the TDI.
- **Scenario 2** Direct contact with sediment and contaminated surface water: Incidental ingestion of sediment and dermal exposure to contaminated water. In this scenario the daily intake of PFOA is estimated at 0.05 ng/kg-d which is <1% of the TDI.

- **Scenario 3** Demolition of infrastructures of highly contaminated areas such as firefighting training grounds: incidental ingestion of concrete debris and dust inhalation. The total daily intake is estimated at 3.7 ng/kg-d (<1% of the TDI).

Table 6 Calculated daily intake of PFOA for three different scenarios

Expsoure to PFOA	Scenario 1	Scenario 2	Scenario 3
Dermal from aqueous vehicle	**Groundwater**	**Surface water**	
Kp, cm/hr:	9.49E-07	9.49E-07	
Surface area, cm2:	10000	10000	
Concentration, mg/mL:	0.00026	0.000009	
Time, hr:	8	8	
Quantity absorbed, mg:	1.97E-05	6.83E-07	
Bodyweight, kg:	80	80	
Dose/8 hr, mg/kg:	2.47E-07	8.54E-09	
Conversion factor, ng/mg:	1.00E+06	1.00E+06	
Dose/8 hr, ng/kg:	0.25	0.01	
% TDI	0.016	0.001	
Inhalation	**Soil**		**Concrete**
Soil concentration of PFOA, mg/kg:	1.5		0.7
Dust concentration in air (mg/m3):	10		10
Conversion factor, mg/kg:	1.00E+06		1.00E+06
PFOA concentration in air, mg/m3:	1.50E-05		7.00E-06
8 hour air volume, Construction worker, m3:	12		12
Bodyweight, kg:	80		80
Daily inhaled dose, mg/kg-d:	2.25E-06		1.05E-06
Conversion factor, ng/mg:	1.00E+06		1.00E+06
Daily inhaled dose, ng/kg-d:	2.25		1.05
% TDI	0.15		0.07
Incidental ingestion	**Soil**	**Sediment**	**Concrete**
PFOA in soil, mg/kg:	1.5	0.01	0.7
Daily incidental soil ingestion construction, mg:	300	300	300
Relative absorption rate, fraction:	1	1	1
Bodyweight	80	80	80
Conversion factor, ng/mg	1.00E+06	1.00E+06	1.00E+06
Conversion factor, mg/kg:	1.00E+06	1.00E+06	1.00E+06
Daily incidental PFOA ingestion, ng/kg-d:	5.625	0.0375	2.63
% TDI	0.38	0.003	0.18
Total daily dose ng/kg-d	8.1	0.05	3.68
%TDI total	0.54	0.003	0.25

3.4.2.3 Risk estimation

TDIs are established by selecting a point of departure (usually a no-effect level in an animal toxicity study) and application of a series of uncertainty factors designed to account for potential uncertainties in the extrapolation to human tolerable exposure levels (see Section 4 for information on the TDIs established for PFOS and PFOA). It assumes that there is an average level of chronic exposure below which it is unlikely for a population to experience adverse health outcomes, and TDIs are usually used to assess longer-term average exposure rates, rather than short-term exposure levels, which may be intermittently higher. The hazard quotient (HQ) is the ratio of the potential exposure dose to the chemical and the TDI.

It can be expressed as follows:

$$Hazard\ Quotient = \frac{Daily\ estimated\ exposure\ level\ \times Exposure\ frequency\ (/y)}{TDI * 365\ (\frac{d}{y})}$$

The hazard index is equal to the sum of the hazard quotients from different exposure pathways where the exposure is defined for the same exposure period. When the hazard index exceeds 1, the margin between the no-effect level in the animal study and the exposure level experienced is eroded, and there may be concern for potential health effects.

$$Hazard\ index = HQ1 + HQ2 + \cdots + HQn$$

The information provided by Airservices stipulates that the workers were on site no more than three days per year and often for only one day to perform the work. Table 7 presents the derived hazard index based on an exposure frequency of three days per year. A hypothetical extended exposure time period (perhaps due to a major construction project) of 90 days per year was also considered, and the results are presented in Table 8.

Table 7 Hazard Quotient and Hazard index for PFOA and PFOS and an exposure frequency of 3 days per year

PFOA	**Scenario 1**	**Scenario 2**	**Scenario 3**
HQ compared to TDI, dermal:	0.000001	0.00000005	
HQ compared to TDI, inhalation:	0.00001		0.00001
HQ compared to TDI, ingestion:	0.00003	0.0000002	0.00001
Hazard index	0.00004	0.0000003	0.00002

PFOS	**Scenario 1a**	**Scenario 1b**	**Scenario 2**	**Scenario 3**
HQ compared to TDI, dermal:	0.0001	0.0001	0.00001	
HQ compared to TDI, inhalation:	0.02	0.0002		0.0008
HQ compared to TDI, ingestion:	0.05	0.001	0.0002	0.002
Hazard index	0.07	0.001	0.0002	0.003

Table 8 Hazard Quotient and Hazard index for PFOA and PFOS and an extended exposure time period of 90 days per year

PFOA	Scenario 1	Scenario 2	Scenario 3
HQ compared to TDI, dermal:	0.00004	0.000001	
HQ compared to TDI, inhalation:	0.0004		0.0002
HQ compared to TDI, ingestion:	0.0009	0.000006	0.0004
Hazard index	0.001	0.000008	0.0006

PFOS	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
HQ compared to TDI, dermal:	0.003	0.003	0.0002	
HQ compared to TDI, inhalation:	0.6	0.007		0.02
HQ compared to TDI, ingestion:	1.4	0.02	0.006	0.06
Hazard index	2.0	0.03	0.006	0.09

The hazard index exceeds 1 in the case of scenario 1a for PFOS with an exposure frequency of 90 days per year (the hazard index exceeds 1 when the exposure frequency is longer than 45 days). This estimation may overestimate the risk due to the high level of PFOS concentration used in this specific scenario and a relatively long working period in such high contaminated soils which is unlikely unless work concentrates on particular areas such as fire-fighting training grounds.

Overall, the above risk estimates suggest that no unacceptable risk is posed to workers from the proposed working activities.

4. RECOMMENDATIONS INCLUDING MEASURES TO MINIMISE EXPOSURE

Contractors working on construction sites should in general wear personal protective equipment, including, for example, long sleeves, pants, boots and gloves, and it is stipulated that this is general practice at Airservices regardless of whether contamination is present or not.

Appropriate levels of PPE should be based on

- The amount of contamination at the site;
- The time spent working on the site;
- The nature of the work;
- Expected or potential exposure levels; and
- Route of entry of the contaminant into the body.

The exposure assessment presented here revealed dust and soil as the main source of PFOS/PFOA that may be taken up through primarily inhalation, or incidental ingestion such as hand to mouth contact. To control and minimise the potential of exposure of workers for the scenarios identified here, we therefore propose the use of PPE as listed in Table 9. PPE should be worn at all times to protect workers, if it does not lead to other dangers such as heat stress, restricted view, or restricted mobility or control of machinery. Proper use of appropriate PPE, especially for Scenario 1a), will reduce the potential for exposure to PFOS/PFOA; for example, Australian Standard 1715:2009 details the protection factors afforded by different types of respirator masks.

Table 9 Proposed use of PPE for the identified scenarios.

Scenario	Heavy duty gloves	Hat	Long sleeved shirt	Mask
1a and b)* Workers digging in soil	X	X	X	X
2) Contact with sediment and surface water	X		optional	
3) Workers demolishing infrastructure	X	optional	optional	X

*Scenario 1a refers at the case where the soil concentration is 230 mg/kg, and Scenario 1b refers at a soil concentration of 3 mg/kg.

Furthermore, general measures to be communicated to workers should include:

- Education about the basic exposure routes for the chemicals and the notion of persistence of the chemicals;
- Workers should be trained and instructed on the proper use of PPE. They should be made aware of dust/particles around the edges of PPE and lodged within the fabric (no shaking out of clothes in closed rooms);
- Direct contact with the material should be avoided (i.e. materials as well as working equipment have to be in the back of the working ute and not in the cabin of the vehicle);
- Hands should be thoroughly washed before any break (food consumption, cigarette);
- Control measures to avoid contamination of food and other related intake such as contaminated cigarettes and hand to mouth contact;
- No breaks should be taken directly at the contaminated site; and
- Contaminated containers should be appropriately marked and not be recycled for other purposes but disposed of correctly.

General measures to reduce the formation of dust, which was identified as the main exposure route, should include:

- Minimising the amount of time contaminated soils are exposed to the elements, including covering contaminated soils where feasible when the works necessitate uncovered ground for lengthy periods of time;
- Wetting of soil before excavation or surface works to minimise dust and thus exposure to dust and dirt (whilst not creating potential runoff or an airborne mist exposure route); and
- Taking into consideration weather conditions (high winds, dry weather, etc.) when working on contaminated sites.

To reduce the risk of workers coming into contact with PFC contaminated clothing/PPE after leaving the working area and to prevent outside people from being exposed to PFCs the working clothes/PPE should be laundered at the facility and not be taken home or used at other non-contaminated sites.

For personnel who are likely to work extended periods on contaminated sites or that otherwise are not covered in the scenarios described here (e.g. higher contamination level, additional exposure routes, or longer durations) we recommend that the exposure estimate be revised accordingly to incorporate the different conditions. Furthermore, depending on the expected period and level of exposure, for staff exposed for a lengthy period to a contaminated site or for those who routinely work in contaminated sites as part of their job, consideration should be given to collection and archiving of blood samples for monitoring of PFC exposure. Future analysis of PFCs in such archived samples and comparison with newly collected samples from the same individuals can provide valuable information on person specific exposure during the period between sample collections.

5. CONCLUSIONS

In this report we assessed potential exposure to PFOS and PFOA related to intrusive work at potentially contaminated sites. The aim was to assess different pathways, estimate exposure scenarios and provide some practical guidance to limit exposure. The scenarios used for the exposure assessments did not consider the extent of protection provided through the correct use of PPE.

The main exposure pathways identified are incidental ingestion and inhalation, while absorption following dermal contact was estimated as relatively small in comparison. The estimated screening hazard index investigated for the three provided working activities did not exceed the relevant adopted acceptable value suggesting that the risk to workers would be considered acceptable. The screening hazard index exceeded 1 when considering relatively heavily contaminated soil and concrete (chemical concentrations > 200 mg/kg) and an exposure frequency longer than 45 days. This estimation did not cover mitigation measures such as the use of a mask or wetting the soil to limit the exposure to projected dust particles. Consequently, it is considered that this assessment is likely to overestimate the exposure and is therefore representative of a ‘worst case’ scenario.

We recommend that the workers must be aware of the potential of exposure when working on site. In addition, the proper use of PPE must be explained to all personnel, as well as enforced during work activities. In accordance with other WH&S measures, standard work health and safety procedures for work conducted on contaminated sites should be followed by workers (as well as the use of appropriate PPE).

References

Australian Standard AS/NZS 1715:2009. Selection, use and maintenance of respiratory protective equipment. Standards Australia 2009.

Baduel C, Paxman CJ, Mueller JF, Perfluoroalkyl substances in a firefighting training ground (FTG), distribution and potential future release, *J. Hazard. Mater.* 2015, 296 46-53.

European Food Safety Authority (EFSA). Opinion of the Scientific Panel on Contaminants in the Food chain on Perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and their salts, *The EFSA Journal* (2008) Journal number, 653, 1-131.

Fasano WJ, Kennedy GL, Szostek B, Farrar DG, Ward RJ, Haroun L, Hinderliter PM. Penetration of ammonium perfluorooctanoate through rat and human skin in vitro. *Drug and Chemical Toxicology* (2005), 28:1, 79-90.

Kennedy Jr GL, Butenhoff JL, Olsen GW, O'Connor J, Seacat AM, Perkins RG, Biegel LB, Murphy SR, Farrar DG. The toxicology of perfluorooctanoate. *Crit Rev Toxicol* (2004);34:351–84.

Khalil N, Lee M, and Steenland K. Epidemiological Findings. *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances*. Springer International Publishing, (2015). 305-335.

OECD. Co-operation on existing chemicals: hazard assessment of perfluorooctane sulfonate (PFOS) and its salts. OECD; 2002.

Olsen GW, Burris JM, Ehresman DJ, Froelich JW, Seacat AM, Butenhoff JL, Zobel LR. Halflife of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorochemical production workers. *Environ Health Perspect* (2007);115:1298–305.

Perkins RG, Butenhoff JL, Kennedy GL and Palazzolo M. 13-week dietary toxicity study of ammonium perfluorooctanoate (APFO) in male rats. *Drug Chem Toxicol* (2004) 27, 361-378.

Palazzolo MJ. 13-Week toxicity study with T-5180, ammonium perfluorooctanoate in male rats. Report No. HWI 6329- 100, Hazleton Wisconsin, Madison, WI. USEPA Public Docket (1993) AR-226-0449 and AR-226-0450.

Safe Work Australia: Guidance on the interpretation of workplace exposure standards for airborne contaminants, 2012.

Seacat AM, Thomford PJ, Hansen KJ, Olsen GW, Case MT and Butenhoff JL. Subchronic toxicity studies on perfluoroctanesulfonate potassium salt in cynomolgus monkeys. *Toxicol Sci* (2002). 68, 249-264.

U.S. Environmental Protection Agency (EPA). (2011) Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Washington, DC;EPA/600/R-09/052F.

White SS, Fenton SE, Hines EP. Endocrine disrupting properties of perfluorooctanoic acid. *J Steroid Biochem Mol Biol* (2011)127(1-2):16-26.