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Characterisation of CS Aerosol used in Mask Test Facilities

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Defence Science and Technology Organisation

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ABSTRACT

CS aerosol (o-chlorobenzylidene malonitrile) is a low to moderate toxicity irritant used by Australian Defence Force for respiratory protection training. It is classified as a hazardous substance with an occupational exposure limit of 0.39 mg / m^3 (STEL-C). Currently the ADF has no means of measuring the concentration of CS aerosol used within the Mask Test Facilities (MTF) during CBRN training. Driven by the health concern associated with CS exposure to personnel in MTF, this study aimed to: (i) characterise the physico-chemical properties of CS aerosol; (ii) validate the use of a commercial off-the-shelf equipment to monitor CS aerosol concentrations, and (iii) quantify CS levels in MTF.

The CS aerosol was identified as a poly-disperse, uni-modal aerosol with a dominant peak at 0.26 micrometers. The COTS optical photometer DustTrak, (TSI Inc Model 8520) was validated to accurately measure CS aerosol concentration. As anticipated, the CS levels in the MTF exceeded the concentrations that unprotected individuals could safely operate in by a factor of up to 40. However, protected individuals wearing a correctly fitted full face respirator are in compliance with the OH&S standards for respiratory protection.

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Executive Summary

CS aerosol (o-chlorobenzylidene malonitrile) is a low to moderate toxicity irritant used by Australian Defence Force (ADF) and other agencies for respiratory protection training. It is classified as a hazardous substance with an occupational exposure limit of 0.39 mg/m^3 (short term expsoure limit-ceiling (STEL-C)). Currently, the ADF has no means of measuring the concentration of CS aerosol used within the Mask Test Facilities (MTF). Driven by the health concern associated with CS exposure to personnel conducting respiratory protection training this study aimed to:

1. characterise the physico-chemical properties of CS aerosol
2. validate the use of a commercial off-the-shelf (COTS) equipment to monitor CS aerosol concentrations
3. quantify CS aerosol concentrations in the MTF during personnel training.

The study investigated CS aerosols under both laboratory and field conditions. Field trials were conducted at HMAS Cerberus, School of Ships Safety and Survivability.

The CS aerosols generated within an MTF showed broad poly-disperse, uni-modal size distribution with a dominant peak at 0.26 µm. Approximately, 93% of the CS aerosols mass was attributed to particles smaller than 2.5 µm and close to 99.9% aerosol number to particles smaller than 2.5 µm.

A COTS optical photometer (DustTrak, TSI Inc, Model 8520) was identified as a suitable instrument for measurements of CS concentration. The instrument's response was validated against data measured by gravimetric method. DustTrak is a simple, portable, battery operated and user friendly device providing means by which the ADF can accurately monitor CS concentrations within MTF during CBRN training.

The average PM_{10} (particulate matter smaller than 10 µm) mass concentrations of CS aerosol measured during the two CBRN training sessions were 5.8±0.6 mg/m^3 and 5.3±0.7 mg/m^3 (±standard error) with peak concentrations of approximately 15 mg/m^3. The average and peak concentrations were on average 14 times and up to 40 times greater than the occupational exposure limit of 0.39 mg/m^3, respectively. Unprotected individuals operating in this environment are in breach of the OH&S standards for respiratory protection. However, protected individuals operating in this environment (wearing a correctly fitted full face respirator with an assigned protection factor of 50) are in compliance with the OH&S standards for respiratory protection.

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Dr Jamriska is a Senior Research Scientist with 15 years of academia experience in aerosol physics. He has published more than thirty research papers in peer reviewed scientific journals and attracted research funding totalling close to one million dollars. Dr Jamriska joined DSTO in 2005 to establish and support CBRN aerosol R&D capabilities. His current work is focused on the characterisation of protective barrier fabrics and respirators against airborne CBRN threats and development of new IPE materials. Other areas of his research include T&E and R&D of aerosol sampling devices and development of new detection methods for aerosols of biological and non-biological origin.

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Mr Scanlan is a scientist with 10 years of research experience in the field of Chemical Biological Radiological (CBR) protective clothing and equipment. He is currently seconded to the Attorney-General's Department Protective Security Coordination Centre (PSCC) as a Science & Technology Advisor in support of the civilian counter terrorism community. Mr Scanlan graduated from the University of Adelaide with a Bachelor of Science (Hons) in 1997. His research focus is on providing tangible solutions to meet the needs of the end user.

Contents

Glossary

ADF	Australian Defence Force
Aerosol	Suspension of solid or liquid particles in the air
ACGIH	American Conference of Governmental Industrial Hygienists
APS	Aerodynamic Particle Sizer
CMD	Count Median Diameter
CS Aerosol	Aerosols emitted from CS pellet combustion
Ct50	Concentrations at which 50% of any group react or show signs of exposure to CWAs
CWA	Chemical Warfare Agent
IPE	Individual Protective Equipment
HEPA	High Efficiency Particulate Air Filter
LCt50	Product of concentration and exposure time that is lethal to 50% of exposed individuals
MOPP	Mission Oriented Protective Posture
MTF	Mask Test Facility
N_1, $N_{2.5}$, N_{20}	Number concentration of particles smaller than 1, 2.5 and 20 μm, respectively
CBRN	Chemical, Biological Radiological and Nuclear (environment)
NOHSC	National Occupational Health & Safety Commission
PCE	Pellet Combustion Efficiency (weight fraction of pellet material emitted as aerosol)
PM	Particulate Matter
PM_1, $PM_{2.5}$, PM_{10}	Particulate Matter smaller than 1, 2.5 and 10 μm, respectively
PSD	Particle Size Distribution
SOP	Standard Operating Procedure
SMPS	Scanning Mobility Particle Sizer
STD	Standard Deviation
STEL-C	Short Term Exposure Limit - Ceiling
STD	Standard Deviation
Std. Error	Standard Error defined as the ratio of (STD / Mean) × 100 %
Submicrometer	Smaller than one micrometer
Supermicrometer	Larger than one micrometer
TLV	Threshold Limit Value
TSP	Total Suspended Particulates
WEA	Weight of Emitted Aerosols
WOP	Weight Of Pellet

1. Introduction

CS aerosol, commonly known as tear gas, is an irritant agent used by law-enforcement agencies for riot control and military forces for training and combat. It produces transient discomfort and eye closure to render the recipient temporarily incapable of fighting or resisting [1]. Its effects: burning and pain on exposed mucous membranes and skin; eye pain and tearing; and respiratory discomfort, occur within seconds of exposure and seldom persist for more than a few minutes after the exposure has ended. CS has high LCt50 and a low effective Ct50 resulting in a high safety ratio and is considered relatively safe when used outdoors where the aerosols are rapidly dissipated by a wind induced dispersion [2]. Application of the CS in confined spaces (indoors) with limited or no air ventilation may result in extremely high and potentially life threatening exposure levels to unprotected personnel [3].

The American Conference of Governmental Industrial Hygienists (ACGIH) and National Occupational Health & Safety Commission (NOHSC) consider the CS as a hazardous substance with the STEL-C (ceiling) exposure standard 0.05 ppm or 0.39 mg/m^3 [4].

CS aerosol is used extensively by the ADF for CBRN training, both as a confidence builder in the ability of the face mask to perform its role and in the mask fit testing of individuals. The training is conducted in either a designated Mask Test Facilities (MTF) or a tent (11”×11”) according to SOP LWP(G)-7-2-5 [5]. The procedure describes application of the CS pellets (i.e. number and frequency, based on the number of participants and training serials), however the exact CS concentration and exposure levels are unknown and only limited data allowing reliable estimation of the concentration levels in MTF is available.

An accurate assessment of personnel exposure and health effects associated with the use of CS aerosols in MTF requires information about their physico-chemical characteristics and concentration levels present. The information is critical for the development of optimised SOP to minimise personnel exposure. The presented study aimed to address some these issues through a set of field trials at HMAS Cerberus MTF, and laboratory based experimentation.

The specific objectives of the study were as follows:

- Development and validation of a real-time monitoring system and measuring methodology for CS aerosols characterisation;
- Quantification of CS aerosols concentration and potential exposure to personnel in the MTF during training and comparison with existing OH&S standards;
- Determination of physico-chemical characteristics of CS aerosols including: (a) size distribution; (b) fraction of Particulate Mater (PM); (c) CS pellets combustion efficiency, and (d) chemical analyses of the emitted aerosols.

The presented work provided a foundation for a follow-up study [6] focused on assessment of the relationship between physiological response of a personnel conducting CBRN training in MTF and CS exposure levels.

2. Materials and Methods

2.1 CS

CS or o- chlorobenzylidene malonitrile (C10-H5-Cl-N2, CAS No. 2698-41-1) is a low to moderate toxicity irritant affecting the eyes, skin and respiratory tract. Dispersed as fine aerosols the STEL-C (ceiling) standard value is 0.05 ppm or 0.39 mg / m^3 and the immediately dangerous to life or health (IDLH) value 2 mg / m^3 [4], [7]. Under normal conditions CS is a white solid with a pepper odour, low vapour pressure (<1 mm of Hg), molecular weight of 189 amu and Boiling Point of 317–326°C. More information about CS pellets physico-chemical characteristics is presented in Appendix A.

2.2 CS aerosolisation

CS aerosols were generated by combusting CS respirator test kit pellets (Pains-Wessex, Australia). Two batches of pellets were tested (batch A and B) provided by the DSTO and RAN (training centre at HMAS, Cerberus), respectively. The batches differed in pellet's weight (approximately 1.0 g for batch A and 0.7 g for batch B) and age (5 years and 1 year). The pellets were placed on a metal tray, ignited by a lighter and flames quenched immediately after the ignition. This resulted in a smouldering process lasting for approximately 10–30 seconds until the pellet was completely consumed. During this time the instructor carried the tray throughout the room to achieve a homogeneous dispersion of the aerosols within the MTF. The process is depicted in Figures 1 and 2.

Figure 1: CS pellet before ignition

Figure 2: Smouldering CS pellet

2.3 Laboratory studies

Preliminary assessment of the measuring system and sampling procedures were conducted in the laboratory under controlled environmental conditions at DSTO prior to the field studies. CS aerosols were generated inside of a small experimental chamber (made of Perspex; volume 0.125 m^3) located in a fume hood. Half of a CS pellet was ignited and then quenched using the same procedure as used in MTF. The air in the chamber was mixed by a small fan and aerosol sample delivered to the measuring equipment sitting next to the chamber via conductive sampling lines (length ~50 cm, ID ~0.6 cm). The experimental setup used in laboratory is presented in Figure 3.

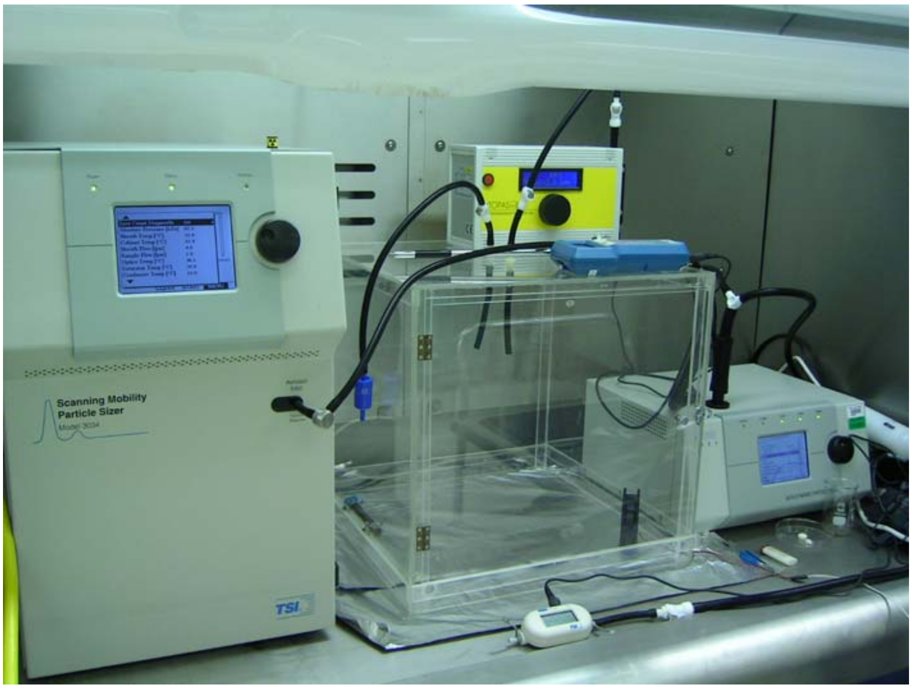

Figure 3: Laboratory setup for the measurements of CS aerosols characteristics. On the left Scanning Mobility Particle Sizer (SMPS); on the right Aerodynamic Particle Sizer (APS).

2.4 Mask test facility

The field trials were conducted in the MTF located at the RAN HMAS Cerberus. The MTF contains three compartments: the main room and two smaller, at the entrance and exit. The volume of the main area is approximately 76 m^3. The building is equipped with an air filtration system with HEPA filters installed at the exhaust allowing for rapid ventilation of MTF with ambient air. The site was selected on the basis of its proximity to DSTO, availability and active training program that allowed measurements during mask training conducted by RAN personnel. The outside of the MTF is presented in Figure 4.

2.5 Measured characteristics and instrumentation

The measured characteristics of CS aerosols included: (i) Particulate Matter (PM) mass concentration; (ii) PM size fraction (PM_{10}, $PM_{2.5}$ and PM_1 ~PM smaller than 10; 2.5 and 1 µm, respectively); (iii) number concentration; (iv) size distribution; and (v) combustion efficiency of CS pellets. The measurements were conducted across the aerosol size range of 0.01–20 µm using several measuring techniques including: optical, gravimetric, time-of-flight and electrical mobility. The terms particle and aerosol are used in this study interchangeably.

Figure 4: Mask Test Facility (MTF) at the RAN HMAS Cerberus

The following instruments were used in the study:

Ecotech MicroVol 1100 – low flow rate air sampler for collection of PM_{10}, $PM_{2.5}$ size fractions or TSP (Total Suspended Particulate). The sampled air is drawn through a high efficiency air filter (ID=47 mm) at a constant volumetric flow rate 3 L / min. The collected material was later weighted using an analytical balance (Mettler Toledo AB265-S) to determine PM mass.

DustTrak TSI Model 8520 – laser photometer providing real-time readout of aerosols mass concentration. Two units were used in parallel for (i) $PM_{2.5}$ and (ii) PM_1 or PM_{10} measurements. The instruments were factory-calibrated (new units), operated at the airflow 1.7 L / min and data were recorded every second.

Aerodynamic Particle Sizer (APS) TSI Model 3321 – time-of-flight instrument measuring number concentration and size distribution of particles in 0.5–20 µm size range. Data was measured every minute.

Portacount TSI Model 8020 – condensation particle counter allowing measurements of total number concentration for particles larger than 0.02 µm.

Scanning Mobility Particle Sizer (SMPS) TSI Model 3340 – electrical mobility spectrometer measuring the number concentration and size distribution of particles in 0.01–0.5 µm size range. The instrument operated at 1 L / min flow rate with one minute time resolution. Due to its availability, the SMPS was used only in laboratory studies.

An overview of the instrumentation used; operational parameters and measured characteristics is presented in Table 1. The experimental setup in the MTF is presented in Figure 5.

Table 1: Summary of the instrumentation, operational parameters and measured characteristics

Instrument	Flowrate (L/min)	Sampling interval (sec)	Parameters measured	Aerosol size range (micrometer)
MicroVol	3	Continuous	Air sampler (collection of particles on a filter)	$PM_{2.5}$; PM_{10}; TSP
DustTrak	1.7	1	Particle mass concentration	PM_1; $PM_{2.5}$; PM_{10}
APS	5	60	Number concentration and particle size distribution	0.5–20
PortaCount	0.7	2	Number concentration	0.02–10
SMPS	1	60	Number concentration and particle size distribution	0.01–0.5

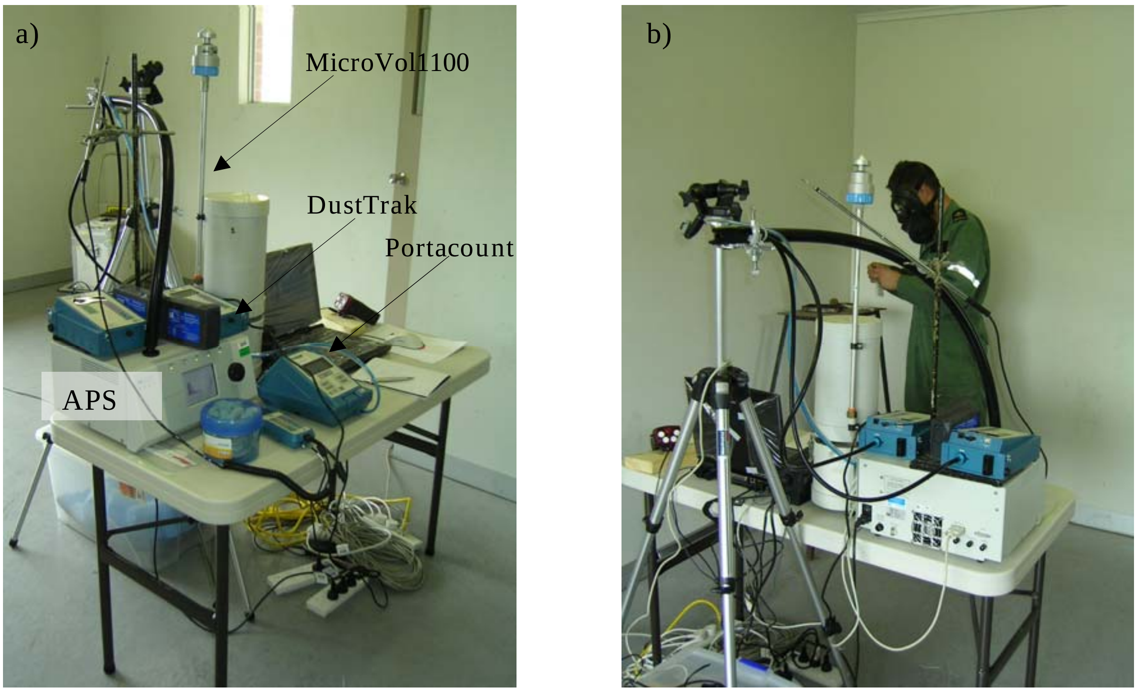

Figure 5: Experimental setup in the MTF: (a) front view and (b) rear view

2.6 Measuring procedures

2.6.1 Measurements description

The experiments were conducted in March 2006 and included laboratory measurements and three field trials (Run #1–3). Run #1 was a feasibility study conducted in MTF to test the experimental set-up, measuring methodology, instruments response and to validate the optical method (DustTrak) against gravimetrical sampling (filter). CS aerosols were generated using CS pellets (batch A) following the same SOP as applied during the training. Navy instructors assisted with the measurements. Run #2 and Run #3 were conducted during the training of RAN recruits using batch B pellets.

2.6.2 Validation of optical sampling against gravimetric method

The DustTrak instrument is an optical photometer allowing measurements of PM mass concentration. Due to its reliability, robustness and fast response it is frequently used for various research and industrial applications, such as environmental monitoring. In this study the feasibility of DustTrak application for real-time measurements of CS concentration in the MTF was evaluated. The DustTrak response is dependent on the optical properties of sampled airborne material and (although factory calibrated) its suitability for CS aerosol monitoring requires validation against another reference method (e.g. [8]). In this study we compared the DustTrak response to the data obtained from gravimetric sampling. The weight of CS aerosols collected on a filter (change in filter weight before and after aerosol sampling) was compared to CS mass estimated from DustTrak readings integrated over the volume of sampled air.

Comparison of the gravimetric and optical methods was conducted for CS aerosols in $PM_{2.5}$ size range. Two filters (glass micro-fibre reinforced with woven glass cloth and bonded with PTFE, PALL EMFAB-TX-40HI20WW, ID 47 mm) were used for CS aerosols sampling using MicroVol air sampler in the MTF facility during Run #1. The sampling flow rate of was 3 L / min and sampling intervals 37 min and 22 min for filters #1 and #2, respectively. The CS concentration during air sampling varied between 1.5 and 10.0 mg / m^3 (average ~4.5±1.5 (±Std) mg / m^3) for filter #1; and between 3.9 and 3.5 mg / m3 (average 3.7±0.1 mg / m^3) for filter #2. Filters were weighed in the laboratory prior to the measurements and approximately 3 hours after the sampling was completed. Filters were transported in sealed Petri Dish placed in a thermally insulated container in order to minimise the effect of environmental conditions on the weight of the collected material.

2.6.3 SOP for CS application in MTF

The CS aerosols in the MTF were generated as described in Section 2.2 , as per SOP [5]. In general, one CS pellet was combusted about one minute prior to the first detail (group of 7–10 trainees) entering into the MTF. After the group completed their training (the activity took approximately 10 minutes) and exited the MTF, second pellet was combusted; one minute time interval allowed for air mixing and detail number two entered into MTF. After the first two details, two CS pellets were applied in-between the consecutive details. Figure 6 shows the trainees entering into MTF, and conducting the training activities inside.

2.6.4 Sampling procedure

The measuring equipment was located inside of the MTF with the sampling point approximately 2 m away from the walls and 1.7 m above the ground, i.e. in personnel breathing zone. The two DustTrak units and APS operated continuously and in parallel, sampling air via 1 m long conductive rubber tubing (ID 6 and 10 mm, respectively). The aerosol losses in the sampling lines were assessed and found to be insignificant. A similar sampling configuration was used in the lab studies for size characterisation of CS aerosols with the SMPS and APS.

The homogeneity of CS aerosols concentration in the MTF was assessed approximately one minute after the generation process was completed. $PM_{2.5}$ concentration was measured across the room at several sampling locations at 1.7 m height. The CS levels within the MTF were almost uniform with the variation of measured concentration levels within ±10%.

Mass concentration in the MTF was measured for PM_1, $PM_{2.5}$ and PM_{10} size categories using two DustTrak units running in parallel. Prior to CS being introduced into the MTF, aerosol background levels, both outdoors and in the MTF, were characterised to evaluate the effect of initial conditions indoors and outdoors on the CS levels during the measurements.

$PM_{2.5}$ levels were monitored continuously during the trials, while PM_1 and PM_{10} levels were monitored alternatively for quantification of PM size fractions.

a) b)

Figure 6: Group of trainees: (a) entering; and (b) inside of MTF

2.6.5 Combustion efficiency of CS pellets

The products of CS pellet combustion include aerosols, vapour and solid residue (ash) [9]. The CS pellet combustion efficiency (PCE) parameter characterises the fraction (mass) of pellet material emitted as aerosols. The fraction attributed to the vapour was assumed to be negligible since immediately after its emission most of the vapour is transformed into secondary aerosols via condensation and heterogeneous nucleation mechanisms [10]. Thus the PCE is calculated as

$$PCE = 1 - (M_{Ash} / M_{Pellet}) \quad (1)$$

Where

M_{Ash} – mass of the ashes (combustion residue) (g)

M_{Pellet} – mass of a CS pellet before combustion (g)

The PCE parameter can be used for the prediction of CS aerosols concentration C_{CS} in the MTF from pellet's weight and MTF volume (V_{MTF}). Assuming perfect air mixing, the predicted C_{CS} is calculated as

$$C_{CS} = (M_{Pellet} \times PCE) / V_{MTF} \quad (2)$$

The value of PCE = 1 (i.e. all material is emitted as aerosol during pellet combustion), is a conservative estimate currently used for calculation of CS concentration in MTF. This is likely to result in an overestimation of the actual CS levels in MTF. Figure 7 shows CS pellets before and after combustion (residue ash) and weighting procedure in the MTF.

Figure 7: Weighing of CS pellets in the MTF (main picture); pellets before combustion (top right); pellets after combustion (remaining ash) (bottom right)

2.6.6 Chemical composition of CS aerosols

In addition to CS, the pellets contain other materials such as binders and additives, which could be also generated as aerosols. The chemical composition of airborne material emitted during the pellets combustion was determined in laboratory using air filter sampling from small experimental chamber (see section 2.3). The generated aerosols were collected on an air filter and analysed by GCMS technique. The air was sampled for 30 minute at an airflow 1.7 L / min using an open faced air filter holder located inside of the chamber. Details of the chemical analysis procedure are presented in [11] and [12].

3. Results and Discussion

3.1 Optical vs. Gravimetric sampling

Aerosol concentration measured by optical photometers, such as DustTrak TSI Inc., is material dependent. The factory calibration covers a broad range of materials, however for sampling of some specific materials, such as CS aerosol, validation of the measured data against another reference method, is required.

In this study the DustTrak was validated against a gravimetric method. The mass of CS aerosols collected on an air filter was compared to the value estimated from DustTrak data (measured concentration integrated over the air flow rate and sampling interval). Two rounds of validation were conducted with the DustTrak and MicroVol 1100 air sampler sampling $PM_{2.5}$ of CS aerosol side by side in the MTF. A comparison of the results is presented in Figure 8, for the complete set of data see Appendix B.

Larger uncertainty for the data based on the gravimetric method is associated with relatively small mass of CS collected and error of measurements. The effect of CS aerosol losses from the filter surface due to the sublimation during the air sampling period was estimated theoretically from known volume of sampled air and CS vapour pressure [13]. The calculated maximum losses were estimated at 15.1% and 15.2%, respectively.

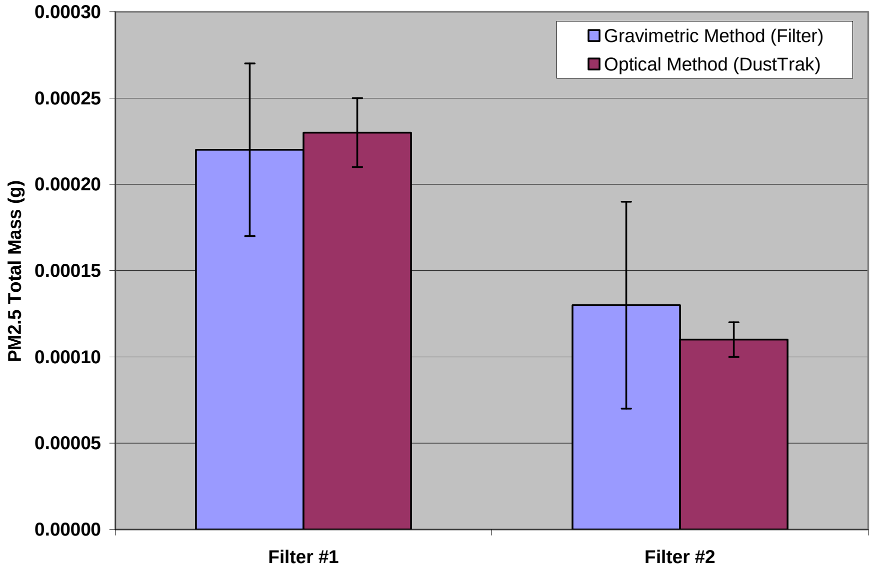

Figure 8: Total Mass of CS aerosol in $PM_{2.5}$ size range measured by optical (DustTrak) and gravimetric (air filter) methods. The presented values are Average± STD. Number of DustTrak measurements n_1=47; n_1=22; number of gravimetric measurements n_1=5; n_2=5, for round #1 and #2 assessment.

The average values of $PM_{2.5}$ mass concentration determined by gravimetric and optical methods were in good agreement for both rounds of measurements. A Student t-test showed that the mean values were not statistically different ($p=0.05$). The presented results indicate that DustTrak is suitable for the measurements of CS aerosol concentration.

3.2 CS aerosol in MTF

3.2.1 Mass concentration

The $PM_{2.5}$ concentrations in MTF prior testing (background) were comparable to ambient air levels (0.005–0.035 mg/m^3) and insignificant compared to the CS levels in the MTF during training.

The overall statistics for $PM_{2.5}$ and PM_{10} of the CS levels in the MTF during training activities is presented in Figure 9. These values indicate the exposure level to unprotected personnel in MTF and could be used for comparison with exposure standard.

The maximum measured $PM_{2.5}$ concentrations were 13.5 mg/m^3 (Run#2) and 9.7 mg/m^3 (Run#3), which is 35 and 25 times the STEL-C (0.39 mg/m^3, ACGIH Standard). The mean values for $PM_{2.5}$ concentration were 5.4 mg/m^3 (Run#2) and 5.0 mg/m^3 (Run#3), which is 14 and 13 times the STEL-(C) guideline.

Comparable results were observed for PM_{10}. This could be expected since $PM_{2.5}$ represented approximately 95% of the PM_{10}. The maximum measured PM_{10} concentrations were 14.5 mg/m^3 (Run#2) and 10.4 mg/m^3 (Run#3), which is 38 and 27 times the standard. The mean PM_{10} value were 5.8 mg/m^3 (Run#2) and 5.3 mg/m^3 (Run#3), which is 15 and 14 times the STEL-C level. Detailed statistics for the PM_1; $PM_{2.5}$ and PM_{10} CS mass concentration are presented in Appendix C.

In could be concluded that average CS concentrations measured in the MTF during the training sessions were significantly higher than the ACIH Standard (STEL–Ceiling). The mean value was an order of magnitude, and the maximum concentration almost 40 times the standard value.

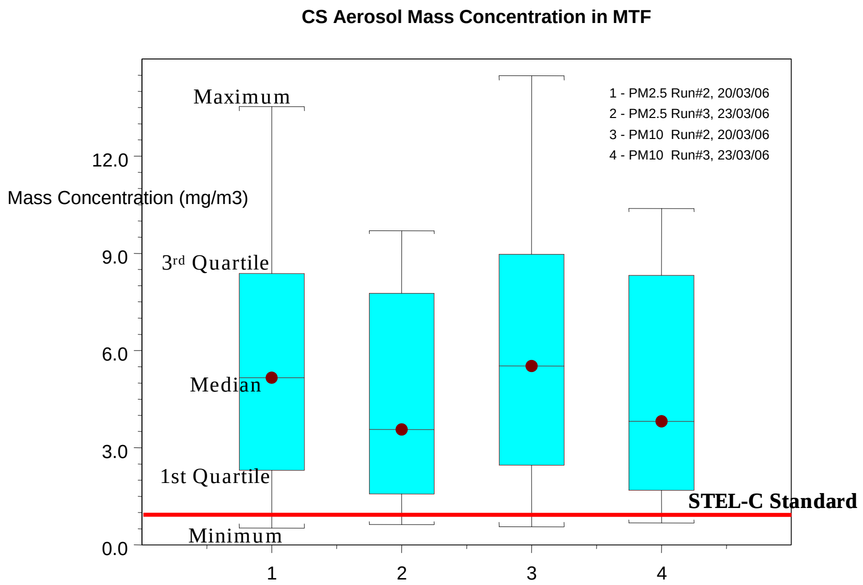

Figure 9: Box Plot of $PM_{2.5}$ and PM_{10} mass concentrations of CS aerosols measured in the MTF during gas mask testing. Presented data relates to the exposure levels of unprotected personnel during the Run#2 and #3 (each set of data was collected during approximately 30 minute time interval),respectively. The STEL-C Standard value is 0.39 mg/ m^3.

3.2.2 Personnel exposure

The ACGIH standard relates to STEL-C (ceiling) exposure value for unprotected personnel. Since the personnel in the MTF wear protective equipment including protective clothing and gas masks and the time of exposure in MTF is in average 5–10 minutes [5], the actual dermal (skin) and respiratory exposure to protected personnel will be significantly lower. For example, a full face respirator provides protection factor of at least 50, which means a personnel wearing full face respirator can operate in environment with up to 50 times the STEL-C exposure levels and not breach the ACGIH Standard.

Some activities that are part of the training process, such as breaking the gas mask seal and canister exchange, can however cause personnel's exposure to exceed the standard. In addition, instructors may be in an increased risk due to the prolonged time of exposure in the MTF. The dermal exposure to instructors in MOPP2 [5] can be reduced by using surgical gloves and neck protection. Quantification or assessment of the actual exposure to personnel during training in MTF is however beyond the scope of this study, since its aims were validation of measuring technique, quantification of concentration levels in MTF and physical characterisation of CS aerosols.

3.2.3 Number concentration

CS aerosols number characteristics were measured by a Portacount and Aerodynamic Particle Sizer (APS). The relevancy for measuring these parameters (in addition to aerosol mass characteristics measured by DustTrak) stems from the role particle number and surface area exhibit in the exposure vs. health effects relationship. The causal mechanism remains unknown and as the recent inhalation and clinical studies indicate, the role of fine (smaller than 2.5 µm) and submicrometer particles, with significant number but negligent mass concentrations, may be of a critical importance [14], [15]. Portacount was used for the measurements of total number concentration of particles larger than 0.02 µm and APS measured concentration and size distribution of aerosol in the 0.5–20 µm range.

3.2.3.1 Portacount data

Total particle number concentration of CS aerosols measured by the Portacount in the MTF during field trials followed the same trends as observed for $PM_{2.5}$ mass concentration measured by DustTrak. The ambient air (outdoor) and MTF background levels were comparable, both in the range of $(0.1–1.0)\times10^4$ particle / cm^3. This is consistent with the average urban ambient air background level in Australia, which is about 1.0×10^4 particle / cm^3 [16]. Relatively lower ambient levels observed during the Run #2 are associated with the wash–out effect of rain on the aerosols the night before the measurements.

The total number concentration of CS aerosols in the MTF during the training was in the range of $(0.3–3.0) \times 10^5$ particle / cm^3 with the average value (± Std. error) $(1.7\pm0.1) \times 10^5$ and $(0.7\pm0.1) \times 10^5$ particle / cm^3 for the Run #2 and #3, respectively. In terms of aerosol numbers, this is up to 30 times the average ambient background and up to two orders of magnitude higher than in typical indoor, office type of environment with the levels about $(3.0–5.0) \times 10^3$ particle / cm^3 [16] [17].

3.2.3.2 APS data

Particle number concentration in the super-micrometer size range (larger than one micrometer) was monitored in the MTF by Aerodynamic particle Sizer (APS). The time series followed similar trends (correlation coefficient $R^2\sim0.89$) as observed for the Portacount however the concentration levels were lower. This is due to different measuring ranges of both instruments (0.5–20 µm and 0.02–20 µm for APS and Portacount, respectively).

The ambient (outdoor) air and the MTF background levels were about 70 particles / cm^3 and 60 particles / cm^3, respectively. The concentration levels of CS aerosols in the MTF during the training were in the range of $(2.0–6.0) \times 10^3$ particle / cm^3, which is between 33 and up to 100 times higher than the background levels. The results are indicating that the exposure level to CS aerosols in the supermicrometer size range is very high.

Comparison of particle number concentration measured by Portacount and APS in MTF indicate that the majority of CS aerosols fall into submicrometer size range. Aerosol of that size can penetrate deeply into the respiratory tract and have higher deposition rates compared to larger aerosols [18] [19]. Although there are currently no existing exposure standards in relation to submicrometer particles or an exposure standard in relation to particle number concentration, the results indicate that the exposure to CS aerosols in submicrometer size range is significant [20].

3.2.4 PM size fractions

Aerosol behaviour and interaction with the environment is dominated by particle size. For example the aerosol residence time, dispersion, deposition rate and penetration through IPE, all are governed by particle size. Fine particles stay airborne for long time periods (up to days and weeks), can penetrate deep into alveolar region of the respiratory tract and have high deposition rate [19]. Large particles play a dominant role in terms of aerosol mass, surface contamination and are governed by different removal mechanisms compared to fine aerosols [21]. Provision of the size characteristics for aerosol mass and number concentration is therefore important in order to assess the exposure levels and for developing efficient mitigation strategies.

DustTrak and APS were used for the measurements of fractional concentration for aerosol mass and number, respectively. The parameter represents a ratio of aerosol concentrations measured within certain size range to the total concentration measured.

The fractions of CS aerosol number and mass concentration measured in the MTF by APS are presented in Figure 10 and in tabulated form in Appendix D. The PM fractions determined from DustTrak data for ambient air, MTF background and CS aerosols in the MTF (Run#3) are presented in Table 2.

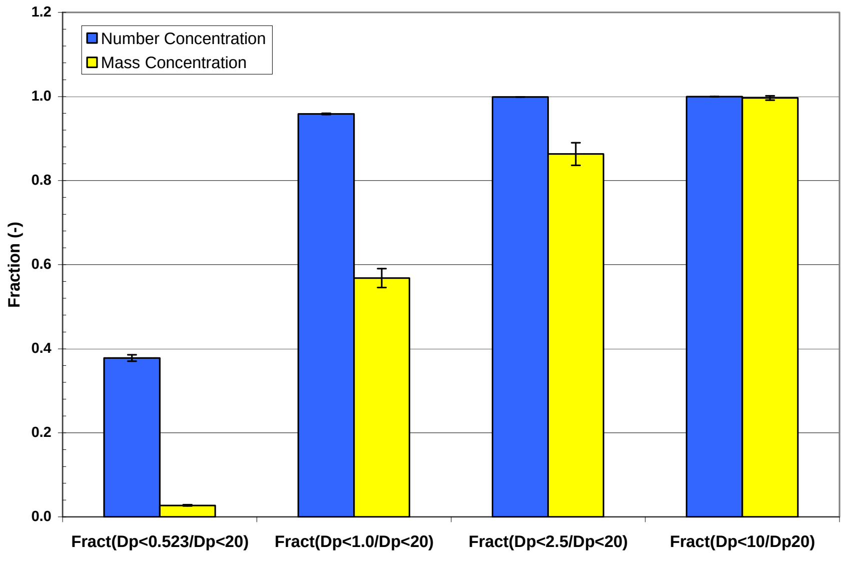

Figure 10: Fractions of number and mass concentration for CS aerosols measured in the MTF by APS. Fract(D_p<0.523/D_p<20) denotes fraction of concentration for particles with particle diameter D_p smaller than 0.523 µm in total (concentration of particles with D_p< 20 µm). Similar annotation is used for particles of other size classes.

Based on the APS mass concentration data, approximately 99.7% of CS aerosols are smaller than 10 µm (PM_{10} / PM_{20}); 86.3% smaller than 2.5 µm ($PM_{2.5}$ / PM_{20}) and 56.8% smaller than 1 µm (PM_1 / PM_{20}).

In terms of particle number concentration measured by APS, about 99.9 % of CS aerosols are smaller than 2.5 µm ($N_{2.5} / N_{20}$) and 95.6% smaller than 1 µm (N_1 / N_{20}).

Table 2: PM size fractions of CS aerosols measured by DustTrak in MTF for Run #3

	PM1/PM2.5	**PM2.5/PM10**	**PM1/PM10**
Average	0.879	0.934	0.822
STD	0.030	0.034	0.045

The DustTrak PM mass concentration data are indicating that approximately 93.4% of CS aerosols are smaller than 2.5 µm ($PM_{2.5} / PM_{10}$) and 82.2% smaller than 1 µm (PM_1 / PM_{10}).

The difference between the values of PM mass fractions determined from DustTrak and APS data (93.4% versus 86.3% for $PM_{2.5}$) is due to different measuring techniques (optical photometer versus time-of flight method) and differences in the particle size range measured, where the maximum particle size is 10 µm for DustTrak and 20 µm for APS.

In general, in can be concluded that CS aerosol number concentration is dominated by submicrometer particles, where 96% are smaller than 1 µm. For CS aerosol mass concentration, about 99.7% of total mass is attributed to particles smaller than 10 µm (APS data) and approximately 90% particles smaller than 2.5 µm.

3.3 CS Pellets combustion efficiency

Currently, the estimates of CS aerosol concentration in MTF are based on the assumption that 100% of pellet material is emitted as an aerosol. This conservative approach results in an overestimation of CS aerosol levels and inaccurate estimates for personnel exposure. Accurate quantification of aerosol generation from the CS pellet combustion process will reduce errors in exposure assessment. The weight fraction of material being emitted from a pellet during its combustion is expressed as the pellet combustion efficiency (PCE) defined in the section 2.6.5 of this report. Mass and concentration of CS aerosols in the MTF can be predicted from pellets weight, MTF space volume and PCE values.

The PCE value can be determined from gravimetric measurements of a pellet before combustion and the remaining ash residue. PCE for two batches of pellets (batch A and B) used for training in the MTF was determined. The results for PCE and other relevant parameters (weight of pellets and emitted aerosols) are presented in Figure 11. The data in tabulated form are presented in the Appendix E.

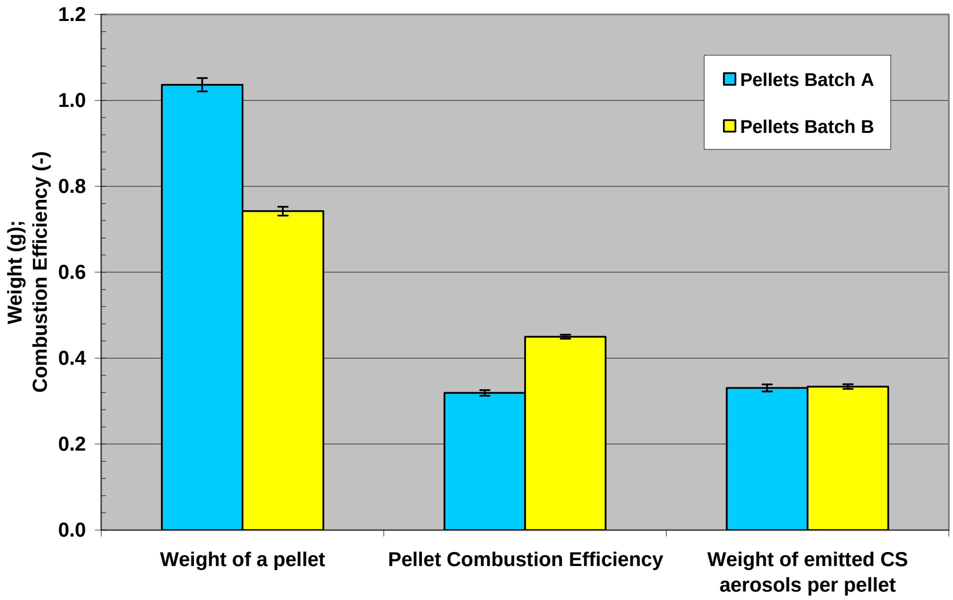

Figure 11: Pellet Combustion Efficiency (PCE), weight of CS pellet and emitted aerosols measured in the MTF. The results are presented as average ± Std. Error.

The combustion efficiency was 31.9±0.01% and 45±1% for pellets batch A (n=5) and B (n=7), respectively. Despite the difference in the PCE, it is interesting that the estimated values of aerosol mass emitted from both batches were comparable (0.331±0.010 g for pellets batch A and 0.334±0.010 g batch B). This suggests that the pellets may have been designed by the manufacturer (Pains Wessex Australia Pty Ltd) to generate the same mass of CS aerosols. The issue was not investigated since it was beyond the scope of this study.

In summary, the estimated combustion efficiency of CS pellets used in the MTF for training purposes is in the range of 32–45%. This indicates that the currently used value of 100% combustion efficiency significantly over-estimates the expected levels in the MTF. The obtained pellet combustion efficiency could be used for more accurate estimates of the CS aerosol concentration levels in MTF, either for the exposure assessment or for the purpose of achieving targeted levels of aerosol concentration in the MTF.

3.4 Particle size distribution

Particle size distribution of the CS aerosol was measured in laboratory using Scanning Mobility Particle Sizer (SMPS) and Aerodynamic Particle Sizer (APS). The instruments provide information about the number concentration and size distribution of airborne particles in the size range of 0.01–0.5 µm and 0.5–20 µm, respectively. Aerosol sampling was conducted in parallel directly from a small experimental chamber, approximately 5 minutes after CS aerosol generation. Figure 12 shows a typical particle distribution with the corresponding size characteristics presented in Table 3.

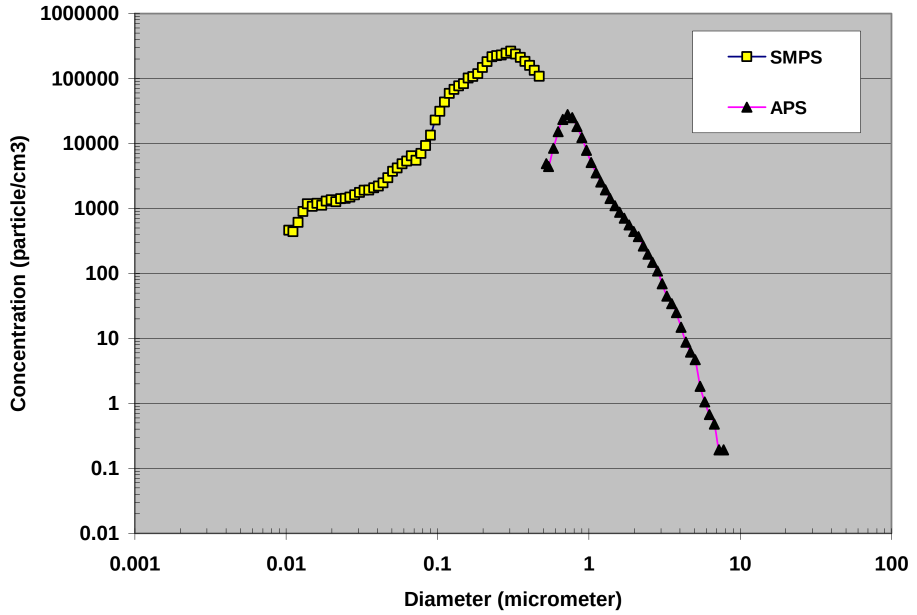

Figure 12: Typical particle size distribution of CS aerosols sampled from an experimental chamber. The noticeable peak for APS data at about 0.7 µm is an artefact caused by a decreased detection limit of the instrument near the lower boundary of its measuring size range.

The size distribution is dominated by particles in submicrometer size range with a dominant mode with a peak at about 0.3 µm and a smaller, less pronounced mode with a peak at about 0.02 µm. Based on the previous studies of combustion aerosols [22] the authors would speculate that the dominant mode is likely to be associated with primary emissions (i.e. particles generated during the combustion process) while the smaller mode may be attributed to secondary emissions, i.e. particles created through the nucleation (gas-to-particle) process from the vapour phase [10] [23, 24]. The PSD is polydisperse (geometric mean ~1.6) with the count median diameter at about 0.26 µm (SMPS data).

Table 3: Size characteristics for CS aerosols measured in 0.01–0.5 µm (SMPS) and 0.5–20 µm (APS) size ranges

Size Characteristics	**Median Diameter (µm)**	**Mean Diameter (µm)**	**Geometric Mean (µm)**	**Mode (µm)**	**Geom. STD**
SMPS Data	0.263	0.266	0.243	0.305	1.59
APS Data	0.754	0.815	0.787	0.723	1.28

Particle concentration in the size range above 0.5 µm (measured by APS) is significantly lower than the concentration measured by SMPS. The APS data correspond to the tail of a broad CS aerosol size distribution dominated by aerosols of smaller sizes, falling predominantly into the SMPS measuring range. The noticeable peak for APS data at about 0.7 µm (Figure 12) is an artefact caused by a decreased detection limit of the instrument near the lower boundary of its measuring size range.

The presented particle size distribution shows characteristics typical for aerosol generated by the combustion process, such as aerosol originating from diesel combustion and biomass burning, [25]. For example the CMD (Count Median Diameter) for the diesel emission is typically between 0.1–0.2 µm [26], [27].

Aerosol penetration through filter media, fabrics and other protective materials is size dependent with the most penetrating aerosol size in the range 0.1–0.3 µm [28]. The CMD of CS aerosols measured is within this range and the provided size characteristics could be used for an evaluation of existing and development of new enhanced protective materials and equipment.

3.5 Summary of conclusions

- The DustTrak (an optical photometer, manufactured by TSI Inc.) has been identified as a suitable instrument for monitoring of the CS mass concentration (mg / m^3) in the MTF. The DustTrak method has been validated against gravimetric sampling.
- The CS aerosol was further characterised by other methods, including time-of-flight and optical counting which measured the CS aerosol concentration, number of particles and size characterisation.
- The size distribution of CS aerosols is broad polydisperse with a dominant peak at about 0.26 micrometers.
- The CS concentrations measured at the HMAS Cerberus MTF during personnel training were in the range of 0.6–15 mg / m^3.
- Approximately 32–45 % of the CS pellet ignited for CS aerosol generation is emitted in an aerosol form.
- Chemical analyses of the aerosol material emitted from CS tablets showed that CS represents the most dominant compounds with the other compounds (e.g. additives) not detected.
- Comparison of measured CS concentrations to that of the current exposure standard (STEL-C (ceiling) standard value of 0.39 mg / m^3; ACGIH 2006) shows the exposure levels for an unprotected individual is significantly exceeded. Unprotected individuals operating in this environment are in breach of the OH&S standards for respiratory protection. However, protected individuals operating in this environment (wearing a correctly fitted full face respirator with an assigned protection factor of 50) are in compliance with the OH&S standards for respiratory protection.

3.6 Recommendations to ADF

The results from this study indicated that CS exposure to unprotected personnel in MTF exceeds the current Australian OH&S standard by up to 40 times the STEL ceiling.

Use of correctly fitted full face respirator within the MTF provides an assigned protection factor of 50, according to the US NIOSH [29]. This means when wearing a respirator, personnel can safely be in an environment up to 50 times the STEL. Contact with the skin is minimised by wearing either industrial overalls or the CBRN MkIV Overgarment. This protective clothing does not reduce exposure to less than the STEL, and according to the MSDS for CS, prolonged exposure can cause skin irritation but it is not specified at what concentrations this occurs.

From these results obtained in the MTF at HMAS Cerberus, there is little hazard to personnel entering the MTF in correctly fitted IPE. However exposure to CS during the three mask serials will be above the allowed STEL for brief periods of time (10–30 sec) [6].

There have been a number of studies into the health implications of CS exposure which have been summarised in a Defence Health Report [2]. This summary found no conclusive long term effects of CS on those who had been exposed to high concentrations.

However, while inconclusive in its long term health effects, exposure to CS outside of STEL values is not desired. Three approaches could be considered to address this issue

1) Discontinue use of CS in the MTF and replace it with an alternative that poses a reduced or no health hazard to personnel.
2) Use serials that do not involve breaking the seal of the respirator.
3) Change practices within the MTF such that the concentration of CS is reduced. Assessment of the relationship between CS levels and physiological response aiming at exposure reduction while maintaining CBRN training effectiveness in MTF is presented in [6].

The results of this study indicate suitability of the commercial off-the-shelf instrument, DustTrak TSI Model 8520 for monitoring of the concentration of CS aerosols in the MTF and the instrument could be utilised within MTF to implement option 3 listed above.

The DustTrak could also be enhanced to provide ADF specific information on the accumulated exposure levels or time remaining before a new pellet needs to be ignited. The DSTO HPPD has the capability to develop the enhanced monitoring and control system if necessary.

The ADF could use the measured pellet combustion efficiency to calculate more accurate estimates of CS levels in MTF.

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Appendix A: Characteristics of CS Pellets

Chem Alert Report

Product Name ***CS RESPIRATOR TEST KIT PELLETS***

IDENTIFICATION

Ingredient	Formula	Conc.	CAS No.
POTASSIUM CHLORATE	CI-O3-K	Not Available	3811-04-9
DEVOLITE		Not Available	Not Available
LACTOSE		Not Available	14641-93-1
2-CHLOROBENZALMALONONITRILE	C10-H5-CI-N2	Not Available	2698-41-4

CLASSIFIED AS HAZARDOUS ACCORDING TO NOHSC CRITERIA

Shipping AMMUNITION, TEAR-PRODUCING with burster, expelling charge or propelling charge

Synonyms 58020 - P.W. REF. NO, RESPIRATOR TEST KIT PELLETS.

Appearance PELLETS

Odour STRONG ODOUR

Use(s) RESPIRATOR TEST KIT.

Supplier PAINS-WESSEX (AUSTRALIA) PTY LTD , 4/1955 Malvern Road, East Malvern Victoria, 3145, AUSTRALIA Ph: (03) 9885 0444 FAX(03) 9885 5530

Stock No. 635.

Poison Sched None Allocated **Hazchem** 1Z **UN No.** 0301 **D.G Class** 1.4G

Pkg Group None Allocated **EPG** None Allocated **Sub/Tert Risk** None Allocated

HEALTH HAZARDS

Health Hazard Summary Low to moderate toxicity - irritant. This product is designed for smoke/gas generation. Over exposure to smoke/gas levels may cause harm and irritation of the eyes, nose and throat. Activating near the face may result in injury or blindness. Individuals with pre-existing respiratory disorders (eg. asthmatics) may be more susceptible to the development of adverse health effects.

Eye Irritant. Due to product form an eye hazard is not anticipated. However direct contact with contents or fumes may result in irritation, lacrimation and conjunctivitis.

Inhalation Irritant- moderately toxic. Over exposure may result in respiratory irritation. Persons with pre-existing respiratory disorders are more susceptible to developing adverse health effects & should avoid atmospheres contaminated with smoke/fume. Toxic effects may result from inhalation.

Skin Product encapsulation minimizes skin contact potential, however contact with contents may cause irritation and skin redness.

Ingestion Moderate toxicity. Ingestion may result in nausea, vomiting, abdominal pain and diarrhoea. Due to product form, ingestion is considered unlikely.

PRECAUTIONS

Flammability EXPLOSIVE. Product is designed to produce a controlled explosion when activated. Will evolve smoke and toxic gases (metal/ carbon/ sulfur/ nitrogen oxides and fumes) when exploded or heated to decomposition.

Reactivity Incompatible with oxidising agents (eg. hypochlorites, peroxides), acids (eg. sulfuric acid), heat and ignition sources.

Ventilation Do not inhale smoke/fog generated. Mechanical extraction ventilation is recommended when removal of the atmospheric contaminants is required.

PERSONAL PROTECTIVE EQUIPMENT

PPE No personal protective equipment is normally required. Where high levels of smoke/fog are generated (eg. when simulating a fire), wear safety glasses, PVC/rubber gloves, a Type A-Class P1 (Organic vapour, Particulate) respirator and coveralls.

Colour Rating AMBER

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Chem Alert Report

Product Name ***CS RESPIRATOR TEST KIT PELLETS***

EMERGENCY

Spillage If cartridges are spilt or containers damaged contact emergency services where appropriate. Evacuate individuals from area. Eliminate all heat or ignition sources and incompatible materials. Collect and place in sealed containers for disposal. CAUTION: Heating, impact or static charge may cause explosion.

Fire and Explosion EXPLOSIVE. Exposure to heat may result in detonation, however effects are expected to be limited to the package. Toxic gases may be evolved. Remain upwind and notify those downwind of hazard. Evacuate all non-emergency personnel. Wear full protective equipment including self contained breathing apparatus when fighting fire. DO NOT attempt to fight fire if other explosives are present. Use water to cool unexploded cartridges.

Extinguishing DO NOT attempt to extinguish burning explosives. Once product is ignited it cannot be extinguished. Evacuate area and contact emergency personnel.

FIRST AID

Eye Flush gently with running water for 15 minutes.

Inhalation If over exposure occurs leave exposure area immediately. If irritation persists, seek medical attention.

Skin Remove contaminated clothing and gently flush affected areas with water. Seek medical attention if irritation develops. Launder clothing before reuse.

Ingestion For advice, contact a Poisons Information Centre on 13 11 26 (Australia Wide) or a doctor.

SAFE HANDLING

Storage Store in cool, dry, well ventilated area, removed from oxidising agents, acids and foodstuffs. Ensure containers are adequately labelled, protected from physical damage and sealed when not in use.

Waste Disposal Collect and reuse/return to container. Contact the manufacturer for additional information.

Transport Class 1.4 Explosive. Do not transport with chemicals of any other class. Store any premixed material in a suitably approved magazine for Class 1.4 explosives. Products in this class should not be exposed to impact/shock, friction or any other heat or ignition source. Segregate in accordance with the Australian Explosives Code and relevant Commonwealth, State or Territory explosives legislation.

PHYSICAL AND CHEMICAL PROPERTIES

Flammability:	EXPLOSIVE	**Flash Point**:	NOT AVAILABLE
Boiling Point:	NOT AVAILABLE	**Melting Point**:	NOT AVAILABLE
Exposure Standard:	NOT AVAILABLE	**Evaporation Rate**:	NOT AVAILABLE
pH:	NOT AVAILABLE	**% Volatiles**:	NOT AVAILABLE
Specific Gravity:	NOT AVAILABLE	**Solubility (water)**:	NOT AVAILABLE
Vapour Pressure:	NOT AVAILABLE	**Upper Explosion Limit**:	NOT AVAILABLE
Lower Explosion Limit:	NOT AVAILABLE	**Autoignition Temperature**:	460 C

ADDITIONAL INFORMATION

RISK AND SAFETY PHRASES

Risk and Safety Phrases are standardised phrases allocated to Hazardous Substances. Risk phrases convey a general description of the physicochemical, environmental and health hazards of a substance. Safety phrases provide information on safe storage, handling, disposal, personal protection and first aid.

R36/37/38 Irritating to eyes, respiratory system and skin.
S15 Keep away from heat.
S36/37/39 Wear suitable protective clothing, gloves and eye/face protection.

HAG PHRASES

Colour Rating AMBER

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Chem Alert Report

Product Name ***CS RESPIRATOR TEST KIT PELLETS***

ADDITIONAL INFORMATION cont.

HAG stands for Hazmat Action Guide. HAG phrases describe in simple terms the hazard associated with chemical products and the appropriate action to take in the event of an emergency involving the product. HAG phrases are commonly used by emergency services.

(11) Explosive.
(40) Irritant.
(62) Avoid personal/skin contact.
(64) Avoid dust.
(65) Prevent from entering drains.
(8) Form: Solid.

ADDITIONAL INFORMATION FOR : LACTOSE

Concentration in this product : Not Available

ADDITIONAL INFORMATION FOR : 2-CHLOROBENZALMALONONITRILE

Concentration in this product : Not Available
Molecular Formula : C10-H5-Cl-N2
Molecular Weight : 188.62

HEALTH HAZARDS - HEALTH HAZARD SUMMARY
2-Chlorobenzalmalononitrile's production and use as a riot control agent may result in its release to the environment through various waste streams. The major hazards encountered in the use and handling of 2-chlorobenzalmalononitrile stem from its toxicologic properties. Toxic primarily by inhalation and dermal contact, exposure to this pepper-smelling, white crystalline substance may occur from its production or use as an incapacitating agent by military and law enforcement personnel. Effects from exposure may include lacrimation, headache, contact burns to the eyes and skin, bronchospasm, laryngospasm, hypersensitivity reactions, and pulmonary edema.

HEALTH HAZARDS - EYE
Mild eye irritant.

HEALTH HAZARDS - SKIN
Prolonged contact may cause severe irritation.

HEALTH HAZARDS - INHALATION
ES-TWA : 0.05 ppm 2-chlorobenzalmalononitrile
TCLo (Inhalation) : 1500 ug/m3/90 months (human)
LCLo (Inhalation) : 1806 mg/m3/45 months (rat)

HEALTH HAZARDS - INGESTION
LD50 (Ingestion) : 178 mg/kg (rat)

HEALTH HAZARDS - TOXICITY DATA
LD50 (Intravenous) : 28 mg/kg (rat)

ADDITIONAL INFORMATION FOR : POTASSIUM CHLORATE

Concentration in this product : Not Available
Molecular Formula : Cl-O3-K
Molecular Weight : 122.55

HEALTH HAZARDS - HEALTH HAZARD SUMMARY
Potassium chlorate is a powerful oxidiser and very reactive chemical which has been responsible for many industrial explosions.

Colour Rating AMBER

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Chem Alert Report

Product Name ***CS RESPIRATOR TEST KIT PELLETS***

ADDITIONAL INFORMATION cont.

HEALTH HAZARDS - EYE
Irritant. Contact with the powder or vapour may cause burns.

HEALTH HAZARDS - INHALATION
Inhalation of the dust or mist can produce sore throat, coughing, cyanosis (grey-blue discolouration of the skin), dizziness and faintness.

HEALTH HAZARDS - SKIN
Irritant. Contact with the powder or vapour may cause burns.

HEALTH HAZARDS - INGESTION
Moderately toxic via ingestion. May cause nausea, vomiting, and abdominal pain, followed by cyanosis, haemolysis (destruction of red blood cells) and subsequent renal (kidney) failure.
LDLo (Ingestion) : 1200 mg/kg (dog)
LD50 (Ingestion) : 1870 mg/kg (rat)

HEALTH HAZARDS - TOXICITY DATA
LDLo (Intraperitoneal) : 1500 mg/kg (rat)

ADDITIONAL INFORMATION FOR : DEVOLITE

Concentration in this product : Not Available

ADDITIONAL SAFE HANDLING INFORMATION

RESPIRATORS: In general the use of respirators should be limited and engineering controls employed to avoid exposure. If respiratory equipment must be worn ensure correct respirator selection and training is undertaken. Remember that some respirators may be extremely uncomfortable when used for long periods. The use of air powered or air supplied respirators should be considered where prolonged or repeated use is necessary.

COLOUR RATING SYSTEM: Chem Alert reports are assigned a colour rating of Green, Amber or Red for the purpose of providing users with a quick and easy means of determining the hazardous nature of a product. Safe handling recommendations are provided in all Chem Alert reports so as to clearly identify how users can control the hazards and thereby reduce the risk (or likelihood) of adverse effects. As a general guideline a Green colour rating indicates a low hazard, an Amber colour rating indicates a moderate hazard and a Red colour rating indicates a high hazard.

PERSONAL PROTECTIVE EQUIPMENT GUIDELINES:
The recommendation for protective equipment contained within this Chem Alert report is provided as a guide only. Factors such as method of application, working environment, quantity used, product concentration and the availability of engineering controls should be considered before final selection of personal protective equipment is made.

HEALTH EFFECTS FROM EXPOSURE:
It should be noted that the effects from exposure to this product will depend on several factors including: frequency and duration of use; quantity used; effectiveness of control measures; protective equipment used and method of application. Given that it is impractical to prepare a Chem Alert report which would encompass all possible scenarios, it is anticipated that users will assess the risks and apply control methods where appropriate.

ABBREVIATIONS:
mg/m3 - Milligrams per cubic metre
ppm - Parts Per Million
TWA/ES - Time Weighted Average or Exposure Standard.
CNS - Central Nervous System
NOS - Not Otherwise Specified
pH - relates to hydrogen ion concentration - this value will relate to a scale of 0 - 14, where 0 is highly acidic and 14 is highly alkaline.
CAS# - Chemical Abstract Service number - used to uniquely identify chemical compounds.
M - moles per litre, a unit of concentration.

Colour Rating AMBER

Chem Alert Report

Product Name ***CS RESPIRATOR TEST KIT PELLETS***

ADDITIONAL INFORMATION cont.

IARC - International Agency for Research on Cancer.

STATUS OF CHEM ALERT REPORTS

Chem Alert reports are compiled as an independent source of information by RMT's scientific department. The information is based on the latest chemical and toxicological research, and in compliance with relevant standards, guidance notes and legislation (where applicable). The Chem Alert report is not intended as a replacement to the manufacturer's original MSDS that is provided to Chem Alert subscribers for convenience. In many instances, Chem Alert reports are compiled on behalf of manufacturers, in which case they serve as the "Manufacturer's MSDS" and are clearly identified as such on the relevant reports.

Last Reviewed : 8th September 2005
Date Printed : 16th August 2006

END OF REPORT

AMBER

Printed by : RMT

Appendix B: Gravimetric Results for CS Aerosols

Table 4: Results of the gravitational method: weight of air filters before (Blank) and after sampling CS aerosols in the MTF. The sampling was conducted using MicroVol particulate sampler with $PM_{2.5}$ inlet sampling head; air flow rate 3 lpm and sampling interval 37 and 22 minutes, respectively. Filters were conditioned (Temp and RH) for 24 hours prior to sampling and weighted 3 hours before and after air sampling.

Meas. No.	FILTER #1 Weight (g)		FILTER #2 Weight (g)	
	Before Sampling (Blank)	After Sampling	Before Sampling (Blank)	After Sampling
1	0.09094	0.09121	0.09036	0.09048
2	0.09098	0.09116	0.09036	0.09053
3	0.09095	0.09114	0.09039	0.09042
4	0.09096	0.09115	0.09035	0.09045
5	0.09096	0.09115	0.09029	0.09052
Average	**0.09096**	**0.09116**	**0.09035**	**0.09048**
STD	0.00001	0.00003	0.00004	0.00005

Table 5: Comparison of CS aerosol mass ($PM_{2.5}$) determined from gravimetric sampling and optical method using DustTrak

	FILTER #1 Weight of collected CS aerosols (g)		FILTER #2 Weight of collected CS aerosols (g)	
	Gravimetric Method	Estimate from DustTrak	Gravimetric Method	Estimate from DustTrak
Average	**0.00020**	**0.00023**	**0.00013**	**0.00011**
STD	0.00003	0.00002	0.00006	0.00001

Appendix C: Statistics of CS Data measured in MTF

Table 6: Statistics of the aerosol mass concentration measured in the MTF before CS generation (i.e. MTF Background). The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #1.

STATISTICS	PM_1 (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)
Mean	0.023	0.025	0.027
Standard Error	0.001	0.001	0.001
Median	0.024	0.026	0.027
Standard Deviation	0.004	0.005	0.005
Sample Variance	0.000	0.000	0.000
Kurtosis	-0.335	-1.448	-0.335
Skewness	0.440	0.000	0.440
Range	0.016	0.015	0.019
Minimum	0.018	0.019	0.020
Maximum	0.034	0.033	0.039
Count	29	29	29
Largest (5)	0.028	0.031	0.032
Smallest (5)	0.018	0.019	0.021
Confidence Level (95.0%)	0.002	0.002	0.002

Table 7: Statistics of the aerosol mass concentration measured of ambient (outdoor) air measured outside of the MTF. The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #2.

STATISTICS	PM_1 (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)
Mean	0.002	0.005	0.006
Standard Error	0.000	0.000	0.000
Median	0.002	0.005	0.006
Standard Deviation	0.000	0.000	0.000
Sample Variance	0.000	0.000	0.000
Kurtosis	-1.498	3.880	3.880
Skewness	0.515	-1.837	-1.837
Range	0.000	0.001	0.001
Minimum	0.002	0.005	0.005
Maximum	0.003	0.006	0.006
Count	7	7	7
Largest (3)	0.003	0.005	0.006
Smallest (3)	0.002	0.005	0.006
Confidence Level (95.0%)	0.000	0.000	0.000

Table 8: Statistics of the aerosol mass concentration measured in the MTF before CS generation (i.e. MTF Background). The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #2.

STATISTICS	PM_1 (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)
Mean	0.004	0.007	0.008
Standard Error	0.000	0.000	0.000
Median	0.004	0.007	0.008
Standard Deviation	0.001	0.001	0.001
Sample Variance	0.000	0.000	0.000
Kurtosis	2.072	-0.649	-0.649
Skewness	0.762	0.150	0.150
Range	0.004	0.006	0.006
Minimum	0.003	0.005	0.005
Maximum	0.006	0.011	0.012
Count	72	72	72
Largest (3)	0.005	0.010	0.010
Smallest (3)	0.003	0.005	0.006
Confidence Level (95.0%)	0.000	0.000	0.000

Table 9: Statistics of the aerosol mass concentration measured in the MTF during the personnel training (data subset "personnel in MTF"). The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #2

STATISTICS	PM_1 (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)
Mean	5.031	5.415	5.798
Standard Error	0.538	0.584	0.625
Median	5.501	5.163	5.528
Standard Deviation	3.275	3.552	3.802
Sample Variance	10.724	12.613	14.459
Kurtosis	-0.966	-1.092	-1.092
Skewness	0.349	0.324	0.324
Range	12.328	13.006	13.925
Minimum	0.510	0.523	0.560
Maximum	12.837	13.529	14.485
Count	37	37	37
Largest (3)	9.486	10.230	10.952
Smallest (3)	1.032	1.100	1.178
Confidence Level (95.0%)	1.092	1.184	1.268

Table 10: Statistics of the aerosol mass concentration measured of ambient (outdoor) air measured outside of the MTF. The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #3.

STATISTICS	*PM_1 (mg/m^3)*	*$PM_{2.5}$ (mg/m^3)*	*PM_{10} (mg/m^3)*
Mean	0.026	0.035	0.037
Standard Error	0.000	0.000	0.000
Median	0.026	0.035	0.037
Standard Deviation	0.001	0.001	0.001
Sample Variance	0.000	0.000	0.000
Kurtosis	-0.602	0.996	0.996
Skewness	0.497	-0.622	-0.622
Range	0.002	0.003	0.004
Minimum	0.025	0.033	0.035
Maximum	0.027	0.036	0.039
Count	13	13	13
Largest (5)	0.027	0.035	0.038
Smallest (5)	0.025	0.034	0.036
Confidence Level (95.0%)	0.000	0.001	0.001

Table 11: Statistics of the aerosol mass concentration measured in the MTF before CS generation (i.e. MTF Background). The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #3.

STATISTICS	*PM_1 (mg/m^3)*	*$PM_{2.5}$ (mg/m^3)*	*PM_{10} (mg/m^3)*
Mean	0.026	0.035	0.037
Standard Error	0.000	0.000	0.000
Median	0.026	0.035	0.037
Standard Deviation	0.001	0.001	0.001
Sample Variance	0.000	0.000	0.000
Kurtosis	-0.602	0.996	0.996
Skewness	0.497	-0.622	-0.622
Range	0.002	0.003	0.004
Minimum	0.025	0.033	0.035
Maximum	0.027	0.036	0.039
Count	13	13	13
Largest(5)	0.027	0.035	0.038
Smallest(5)	0.025	0.034	0.036
Confidence Level (95.0%)	0.000	0.001	0.001

Table 12: Statistics of the aerosol mass concentration measured in the MTF during the personnel training (data subset "personnel in MTF"). The presented results are PM_1; $PM_{2.5}$ and PM_{10} concentration measured by DustTrak at the HMAS Cerberus during the Run #3.

STATISTICS	PM_1 (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)
Mean	4.778	4.962	5.313
Standard Error	0.587	0.611	0.654
Median	3.470	3.566	3.818
Standard Deviation	3.104	3.235	3.463
Sample Variance	9.633	10.462	11.993
Kurtosis	-1.538	-1.550	-1.550
Skewness	0.257	0.259	0.259
Range	8.739	9.063	9.703
Minimum	0.592	0.633	0.678
Maximum	9.331	9.696	10.381
Count	28	28	28
Largest(5)	9.209	9.568	10.244
Smallest(5)	1.372	1.395	1.494
Confidence Level (95.0%)	1.203	1.254	1.343

Appendix D: Size Fractions of CS Aerosols

Table 13: Size Dependent Fractions for Number and Mass concentration of CS aerosols measured by APS in the size range 0.5–20 micrometer in the MTF during the Run #2. All data included in the data analyses.

	NUMBER CONCENTRATION			
	Fract(Dp<0.523/Dp<20)	**Fract(Dp<1.0/Dp<20)**	**Fract(Dp<2.5/Dp<20)**	**Fract(Dp<10/Dp20)**
AVERAGE	**0.378**	**0.959**	**0.999**	**1.000**
STD	0.008	0.001	0.000	0.000
STDEV/AVG	0.021	0.002	0.000	0.000

	MASS CONCENTRATION			
	Fract(Dp<0.523/Dp<20)	**Fract(Dp<1.0/Dp<20)**	**Fract(Dp<2.5/Dp<20)**	**Fract(Dp<10/Dp20)**
AVERAGE	**0.027**	**0.568**	**0.863**	**0.997**
STD	0.002	0.023	0.027	0.005
STDEV/AVG	0.065	0.040	0.031	0.005

Note: Fract(D_p<0.523 / D_p<20) denotes fraction of concentration for particles with particle diameter D_p smaller than 0.523 µm in total (concentration of particles with D_p< 20 µm). Similar annotation is used for particles of other size classes.

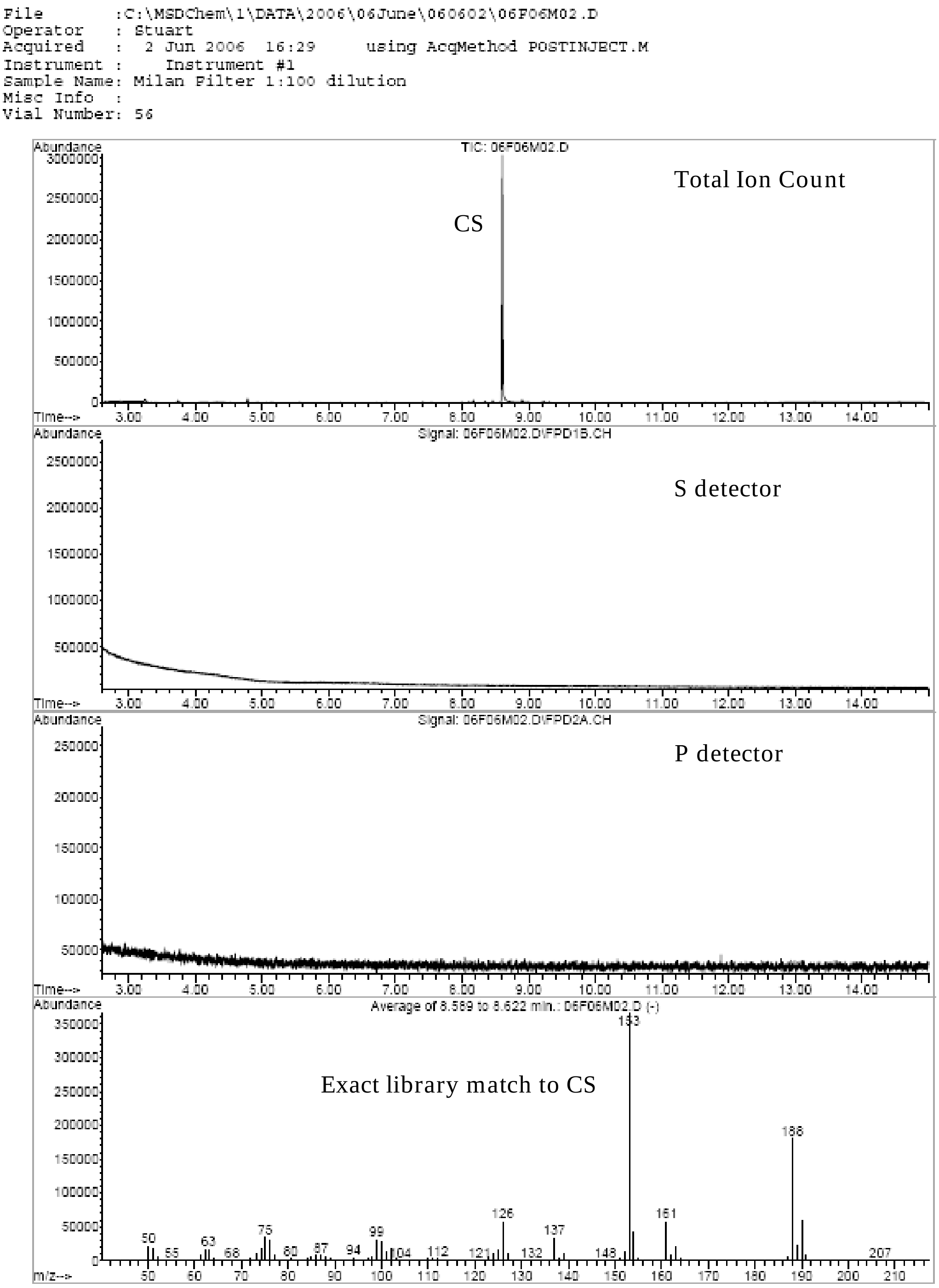
Appendix E: Combustion Efficiency of CS Pellets

Table 14: Pellet Combustion Efficiency (PCE); weight of non-combusted CS pellets and weight of emitted aerosols measured in the MTF. Number of pellets tested: n= 5, pellets batch A; and n=7 batch B.

CS PELLETS	STATISTICS	WOP Weight of Pellet (g)	PCE Pellet Combustion efficiency (-)	WEA Weight of Emitted Aerosols (g)
Batch A	**Average**	**1.03639**	**0.319**	**0.331**
	STD	0.01547	0.006	0.008
	STD/Average	0.015	0.02	0.025
	n	5	3	3
Batch B	**Average**	**0.74219**	**0.45**	**0.334**
	STD	0.01018	0.005	0.005
	STD/Average	0.014	0.009	0.016
	n	7	4	4

Appendix F: Chemical Analysis of CS Aerosols

Table 15: GS/MS chemical analysis of CS aerosols collected on a filter. The peak in the top section corresponds to CS and the last graph is the exact library match to CS.



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CS aerosol, CBRN training, exposure, monitoring, Mask test facility

19. ABSTRACT

CS aerosol (o-chlorobenzylidene malonitrile) is a low to moderate toxicity irritant used by Australian Defence Force for respiratory protection training. It is classified as a hazardous substance with an occupational exposure limit of 0.39 mg/m3 (STEL-C). Currently the ADF has no means of measuring the concentration of CS aerosol used within the Mask Test Facilities (MTF) during CBRN training. Driven by the health concern associated with CS exposure to personnel in MTF, this study aimed to: (i) characterise the physico-chemical properties of CS aerosol; (ii) validate the use of a commercial off-the-shelf equipment to monitor CS aerosol concentrations, and (iii) quantify CS levels in MTF.

The CS aerosol was identified as a poly-disperse, uni-modal aerosol with a dominant peak at 0.26 micrometers. The COTS optical photometer DustTrak, (TSI Inc Model 8520) was validated to accurately measure CS aerosol concentration. As anticipated, the CS levels in the MTF exceeded the concentrations that unprotected individuals could safely operate in by a factor of up to 40. However, protected individuals wearing a correctly fitted full face respirator are in compliance with the OH&S standards for respiratory protection.