SIMULATION OF SPRAY PAINTING INCIDENT INSIDE A CONFINED SPACE ON A DRAGLINE: CRITICAL LEARNINGS FOR MULTIPLE INDUSTRIES

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This paper covers the investigation and subsequent re-enactment testing of an incident that occurred while spray painting inside a confined space on a dragline, as conducted by Resource Safety and Health Queensland (RSHQ) to provide further learnings to industry.

While working on a dragline shutdown and performing spray painting activities under a Confined Space Entry Permit, two Coal Mine Workers became unresponsive and were rescued from inside the dragline revolving frame.

The purpose of re-enactment testing for this incident was to establish what the airborne concentrations of solvents were likely to have been in the working space, and what role the use of gas detectors and the wearing of respiratory protection, contributed to this event.

Findings from the investigation and subsequent testing results are reported and discussed. Recommendations for industry to raise awareness and prevent a reoccurrence are detailed.

1. Introduction

There were approximately fifty open cut mines in operation and 30,500 coal mine workers (CMWs) actively employed at open cut mine sites, throughout the Queensland coal mining industry during 2021-22.

Dragline machines are an integral part of the pre-strip operation at most open cut mines and are used to remove overburden material to expose the coal seam for extraction. There are approximately fifty dragline machines in operation at any one time within Queensland mines. Individual machines weigh up to 3000 tonnes and can lift and swing up to 150 tonnes of material in each bucket load. Routine maintenance on these machines dictates that each machine be shut down for at least one major overhaul every five years, across the Qld coal mining industry, this equates to an average of one major dragline shutdown every month. These are very large machines and usually house a spacious operator's cabin with separate meal room and amenities. A typical shut down can take from four to twelve weeks to complete and can involve up to three hundred CMWs performing skilled maintenance activities.

Maintaining the structural integrity of these large machines is essential and requires ongoing weld repairs and application of protective paint coatings, which is preferably done in-situ during the shutdown periods. A portion of this work is performed inside confined spaces in and around structural components within the dragline itself.

At 12:00 pm on 25 April 2021, an inspector of mines for RSHQ was notified that two CMWs had become unresponsive while spray painting inside a dragline and had to be rescued from inside the revolving frame of a dragline. The scene was immediately secured following the incident, to facilitate further investigation by RSHQ.

This paper provides a summary of the investigation findings, particularly in relation to the testing of respirators used and a re-enactment of the incident to determine the atmospheric concentrations of organic solvents present.

2. Incident description

During a routine shut down at a Central Queensland mine in April 2021, weld repairs had been carried out on structural components within the revolving frame at the base of the machine, and spray painting was required to provide a protective coating over the metal surfaces. The primer undercoat was applied and allowed 24 hours drying time before the top coat was applied, both using an airless spray method. The airless method was selected to deliver a high rate of paint volume onto the surface with minimal overspray. Due to supply constraints with obtaining paint products during the shutdown period, an alternative type of paint was sourced and used for the top coat. The paint composition was solvent rich containing a mixture of xylene, toluene and ethyl benzene up to 70% (wt/wt).

The spray painting work was conducted under a documented confined space permit, and this was underpinned by a detailed Job risk assessment (JRA), as was normal practice during the shutdown. The spray painting work inside the confined space was divided into two separate paint front areas with separate paint crews in each. Members of each crew had specific tasks including the spray painter working at the paint front, a dedicated hose assistant working several compartments back to feed and retract paint lines and air lines, and several spotters positioned at the entry and exit points to the confined space, to provide line of sight and two-way radio communication. Personal gas detectors were taken into the confined space to monitor for typical confined space gases including oxygen, carbon monoxide, flammable gases, and hydrogen sulfide. One detector was carried by the spotters, and another was positioned at the base of the ladder near the main entry point into the confined space. The top coat painting task was estimated to be completed within a short period of time (≈20-30 minutes) and ventilation was deliberately not introduced so as to contain fumes inside the space and prevent their emission to areas outside and exposing other workers performing maintenance tasks on the dragline. Painters, hose assistants and spotters inside the confined space were wearing full length disposable overalls, gloves, safety glasses and respirators. Respirators were selected to provide protection from spray paint emissions and based on the location and estimated relative exposure for each member. Spray painters were wearing continuous flow supplied-air respirators comprised of air-line blasting helmet style head covering, supplied with air from a compressor and in-line filter. The hose assistants were wearing negative pressure reusable half face respirators with A1/A2 organic vapour and P3 particulate class filters, and spotters were wearing P2 disposable respirators.

During top coat spray painting, the hose assistant from one of the paint crews became unresponsive and was required to be rescued. The spray painter from the other crew who had finished earlier, re-entered the confined space without respiratory protective equipment (RPE), to assist with the rescue, and also became unresponsive and required rescue.

3. Investigation

Two inspectors and a principal investigating officer from RSHQ were assigned to conduct an investigation into the nature and cause of the incident. A series of inspections and interviews were conducted, and a number of items seized and copies of documents obtained during the days and weeks that followed the incident.

Preliminary findings indicated that the two CMWs were overexposed to airborne solvents emitted during spray painting inside the confined space and the overexposure was contributed to by the absence of ventilation and inadequate respiratory protection standards and practices. However, it was also identified that the personal gas detectors commonly used for confined space entry were not suitable for monitoring paint solvents and the airborne concentrations of solvents generated during spray painting inside confined spaces were otherwise unknown and difficult to estimate. It was not clear whether the generation of airborne solvents in these situations would have exceeded toxic, lethal and/or flammable concentrations.

Without a reliable estimate of the airborne solvent concentrations generated by this activity, the decisions made by spray painters to select suitable controls are primarily derived from experience and are not evidence/ data based.

As part of the broader investigation, further testing was conducted by RSHQ in conjunction with SIMTARS, to provide learnings back to industry. The purpose of this testing was to establish:

1. What the airborne concentrations of solvents were likely to have been inside the space;
2. What was the performance and role of gas detectors employed; and
3. What was the performance and role of respiratory protection selected.

A summary of toxic and flammable properties for the organic solvent compounds present in the paint as shown in Table 1 below, and this formed the basis of testing. These three solvents all have adverse health effects on the central nervous system. Those overexposed to these solvents may present with symptoms such as headaches, dizziness, nausea and loss of consciousness.

Table 1: Hazardous properties of organic solvents in paint

Solvent	Vapour pressure mmHG 25°C	Vapour Density Air = 1	TWA (ES) ppm	STEL ppm	IDHL (NIOSH) ppm	Lethal Exposure ppm	AIT °C	LEL % Vol	10% LEL Trigger % Vol
Toluene	28.4	3.1	50	150	500	1,800	480	1.1	0.11
Notes						Human fatality reports 1,800-2,000ppm (fatal – 1 hr) 10,000-30,000ppm (unconscious – mins)		11,000 ppm	1,100ppm
Xylene	8.8	3.7	80	150	900	10,000	463	0.9	0.09
Notes						Human fatality reports 10,000ppm (fatal – 2 hr)		9,000ppm	900ppm
Ethyl Benzene	9.6	3.7	100	125	800	10,000	432	0.8	0.08
Notes						Animal studies LCS0 13,367 (2hrs)		8,000ppm	800ppm

Auto ignition temperature (AIT)

4. <u>Methodology</u>

4.1 Airborne concentration of solvents during spray painting.

A spray painting re-enactment was conducted inside a full scale replication of the dragline confined space compartments involved in the incident. This testing was conducted to determine the concentration of solvents present inside the space, for comparison with recommended workplace exposure standards (WES), Immediately dangerous to life and health (IDLH) concentrations and flammable limits (LEL) (1; 2).

The replica was constructed within an existing airborne contaminant test chamber located at the Simtars research facility in Redbank, Queensland. The test chamber was designed and fitted with a fixed extraction ventilation and an exhaust scrubber system, to facilitate experiments under controlled ventilation conditions. The replica was constructed with hinged wall panels to enable unrestricted access in and out of the test space. The replica and re-enactment spray painting was designed and executed to simulate as close as possible the activity and conditions present during the real life incident.

Table 2: Conditions at the time of the incident and at the re-enactment

Condition	**Incident (25 Apr 2021)**	**Re-enactment (30 Aug 2022)**
Spray paint method	Graco Airless, 313 spray tip, Pump ratio 70:1 @ Est. 25psi	Graco Airless, 313 spray tip, Pump ratio 70:1 @ 25psi
Surface area painted	40.52 m^2	34.67 m^2
Paint type (Volume)	Topcoat brand B (≈ 4 Litres)	Topcoat brand B (3-3.5 Litres)
Spray paint duration	≈ 15-20 mins	10 mins
Ambient temp (% RH)*	13.5 °C (70% RH)	19.3-22.3 °C (67-55% RH)
Ventilation flow rate	Nil - Static	Nil - Static

*Bureau of meteorology data from nearest airport.

Figure a: Applying undercoat to test panels

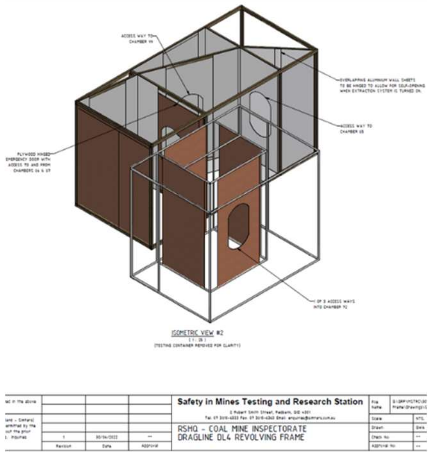
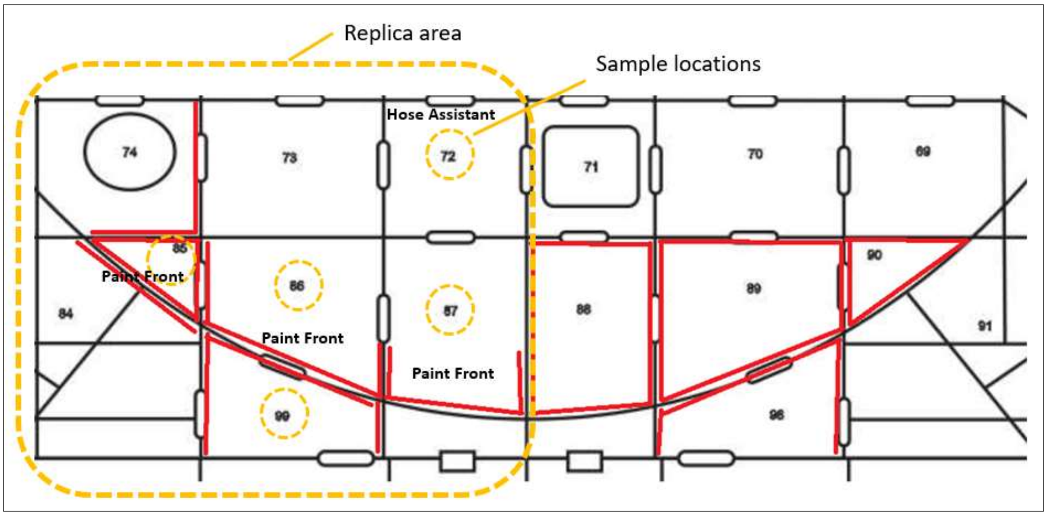


Figure b: Drawing of Replica

Figure c: Replica test chamber

Figure d: Drawing of dragline revolving frame showing paint fronts, compartment bays, replica area & sampler locations.



4.2 Monitoring methods

Static sampling was conducted at the centre of three bays (#86, #87, #72) with samplers positioned at a height of approximately 1.8 meters. The spray paint re-enactment was successfully repeated for two separate sessions, from which valid sampling data was obtained.

The main sampling method involved the use of charcoal tubes (SKC 226-01 & 226-09) and SKC AC3000 sampling pumps with low flow tube holders (SKC 224-26-01) and constant pressure controllers (SKC 224-26-CPC). The sample flow rates were set at two different flow rates (0.130 and 0.200 l/min) and samples collected simultaneously over a pre-programmed period of fifteen minutes, which coincided with the start of spray painting. Duplicate sampling trains were setup for each tube size and flow rate and were sampled simultaneously at each location, as a safeguard from the risk of breakthrough. The tube and flow rate setup including 226-01 tubes in tandem, was as follows:

Tandem 226-01 tubes (0.2L/min for 15mins)

Tandem 226-01 tubes (0.13L/min for 15 mins)

226-09 tube (0.2L/min for 15mins)

226-09 tube (0.13L/min for 15 mins)

Sampling and analysis followed SIMTARS in-house methods and was consistent with the 'Workplace air quality – Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography Part 1: Pumped Method' (3) and NIOSH Method 1501 - Hydrocarbons, Aromatic (4).

Ion Science PhoCheck Tiger photo ionisation detectors (PID) with 10.6 eV lamps and data logging capacity were also mounted alongside the charcoal tube samplers and sampled for the duration of the spray painting and clearance period, in order to indicate the time varying fluctuations in airborne solvent concentrations. The PIDs were zeroed with blank carbon filters prior to use and again checked for residual offset at the completion of each sampling period. The PIDs were calibrated to isobutylene and published correction response factors (C.F.) for these instruments were applied to estimate concentrations for the individual solvent compounds (xylene, toluene and ethyl benzene). The PIDs were supplied with an in-built Teflon (PTFE) filter disc mounted inside the sampling port to prevent particulate contamination entering the detector. In addition, an empty 37mm single orifice polycarbonate cassette was connected to the sampling port of the PID with a short length of Tygon tubing, to act as a further barrier and prevent overspray paint particles from entering the sample port.

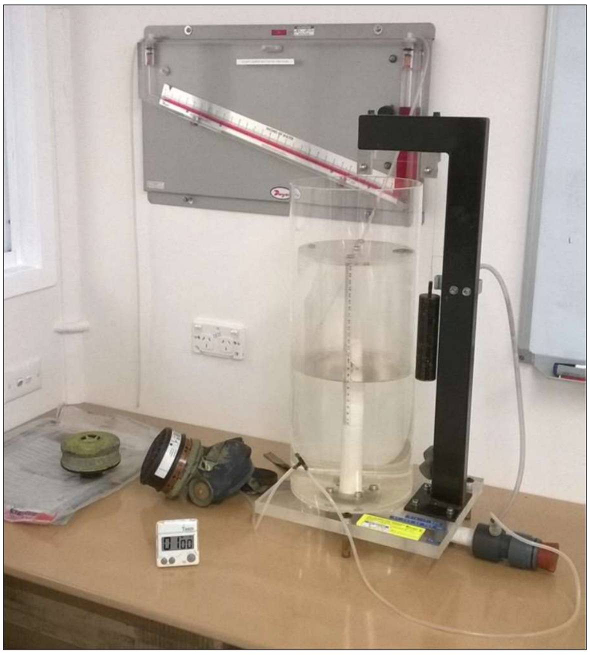
MSA Altair 5X multigas detectors were also positioned inside the test chamber, as a precautionary step, to provide an early warning alarm mechanism for flammable concentrations of contaminants while testing was in progress. These instruments were separately calibrated using 'Pentane Simulant' in accordance with manufacturer instructions, in order to improve the sensitivity and correction factor (1.0) applicable to toluene using the flammable sensor. Lengths of Tygon sampling tube (≈ 1-1.5 m) were attached to the sampling ports of these instruments, to extend the sampling point into the centre of the test chamber beside other samplers. The stored data from these instruments was also downloaded for comparison with the other instruments.

4.3 Respiratory Protection

An air quality test was conducted on the continuous air-supply respirator and in-line CPF filter set up, post the incident, and this indicated conformance with AS 1715-2009 Selection, use and maintenance of respiratory protection' for supplied-air respirators (5).

The two half face respirator and filter assemblies were sealed inside plastic bags and transported to product distributors Safety Equipment Australia (SEA) for inspection and testing for integrity and leakage. Visual inspection was performed to identify faulty, damaged and/or missing components and general maintenance condition. Leakage testing was performed by using a manometer and applying negative pressure to the facepieces with a spirometer bell after the filter inlet and face seal was blocked to prevent inward leakage. Leakage was measured through displacement of the spirometer bell and testing conducted at 20-23°C and 40-60% relative humidity. Leakage testing was repeated following the cleaning and replacement of individual components including valves and valve seats, to trouble shoot and identify the source of any inward leakage detected.

Figure e: Leakage test setup



The organic filters from both respirators were transported to the equipment manufacturer Sundstrom, to measure the breakthrough time and estimate the residual filtration capacity remaining. This testing used dichloromethane (5000ppm) at a flow rate of 30 l/min and breakthrough concentration of 10ppm, to measure the residual capacity remaining by comparison of breakthrough time with new unused filters. Testing was conducted at a temperature of 20°C and 70% relative humidity.

4.4 Personal gas detectors (PGDs)

The PGDs and docking station were transported to the equipment manufacturer Honeywell, to conduct visual inspection for instrument integrity, faulty/ damaged components, performance testing against specifications, and data downloading. Performance testing included functionality testing and T-90 response testing for each sensor.

5. Results & Discussion

5.1 Airborne concentration of solvents during spray painting

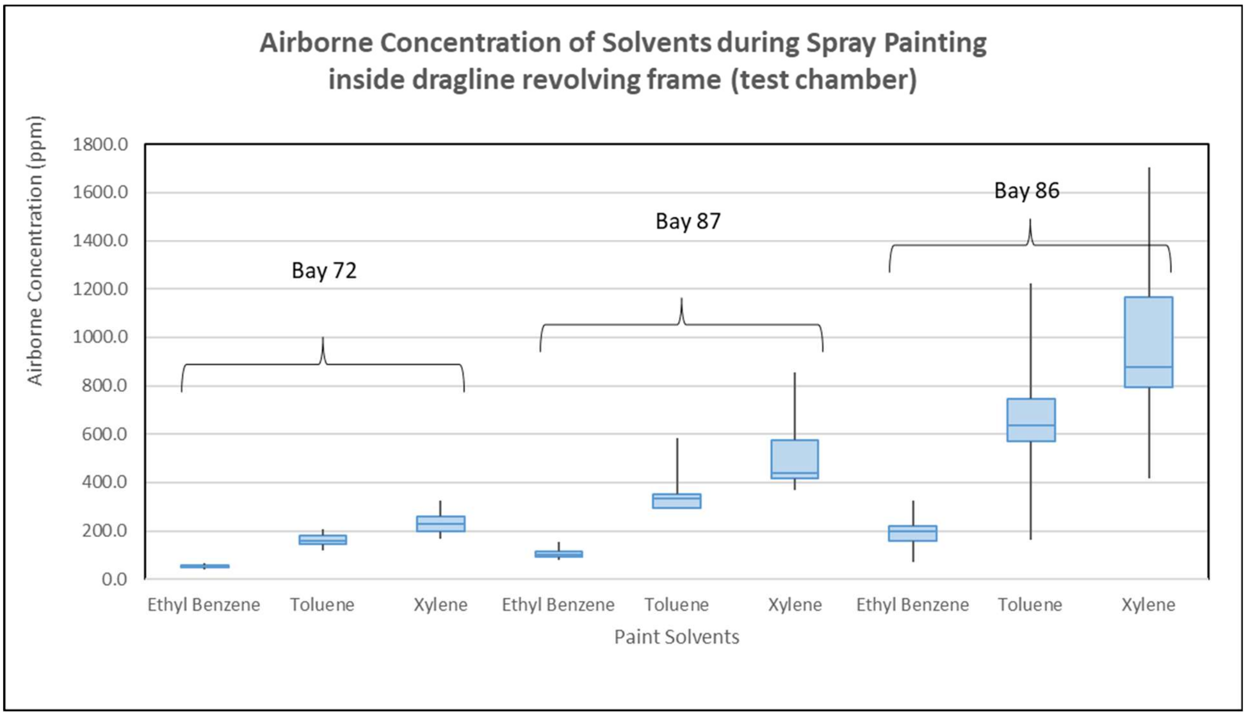
The results of charcoal tube analysis (Figure f) indicated that the ratio of organic solvent concentrations between different compounds measured in air, was consistent within each bay and approximated the relative maximum composition (% wt/wt) of individual compounds reported in the product safety data sheet (SDS)(Table 3). The airborne composition of solvents was directly proportional to their composition within the paint and this indicated that the direct discharge of paint into the atmosphere through the spray gun was the primary source of solvent emission. The ratio of airborne concentrations measured did not reflect the relative vapour pressures of individual compounds and this indicated that the emission from surface areas painted through evaporation was less significant.

Table 3: Ratio of organic solvent in the SDS and measured in the re-enactment

	Xylene	Toluene	Ethyl benzene
Composition - SDS (max)	45%	20%	9.4%
Composition – SDS (ratio)	1	2	5
Airborne concentration measured (ratio)	1	3	5

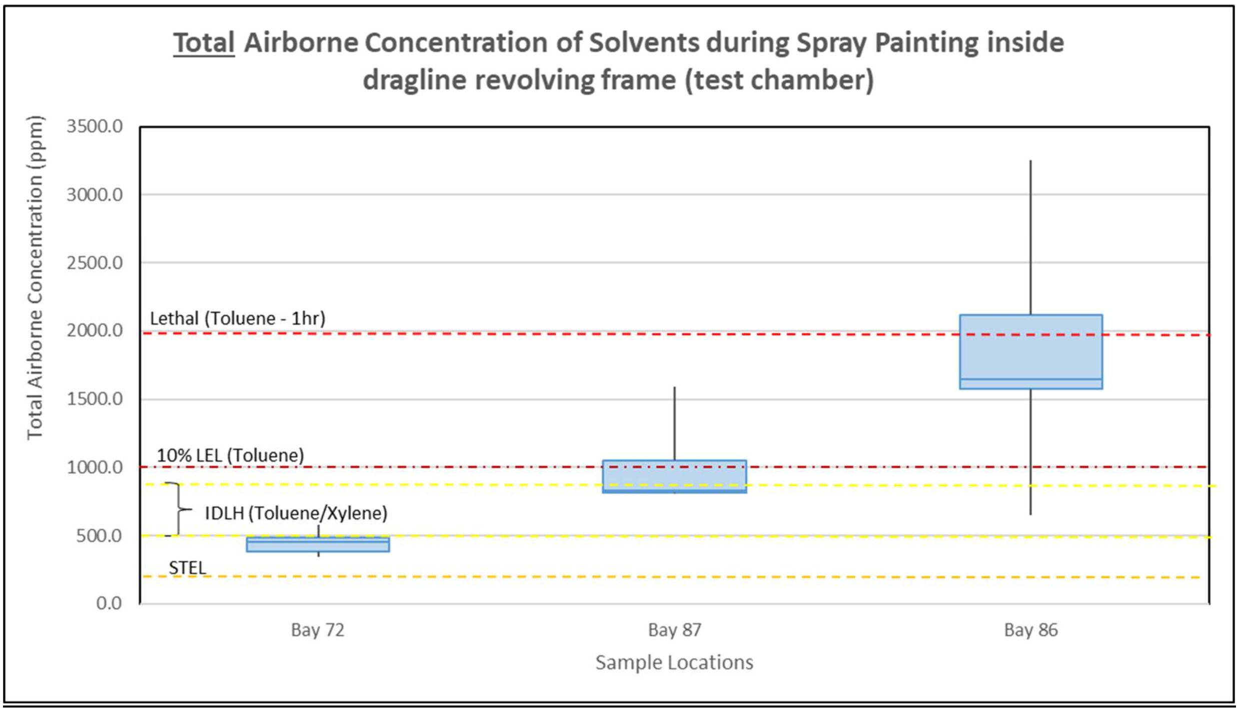
The concentration of organic solvents were higher in bays 86 & 87 where the paint front was located and highest in the bay 86 which the largest volume of paint sprayed onto adjoining walls and compartments. The range and variability of measured concentrations for all solvent compounds, increased with concentration.

Figure f: Airborne concentration of individual organic solvent compounds measured in re-enactment



Given that the individual organic solvent compounds have similar health impacts and target organs, the separate concentrations of individual solvent compounds were added together to estimate the total concentration (Figure g) of solvents. The total airborne concentration of organic solvents measured were above the Short Term Exposure Limit (STEL) in all three bays sampled, above the IDLH and 10% LEL values in bays 87 and 86, and above the reported lethal 1-hour exposure concentration for Toluene, in Bay 86 (6; 7; 8; 9). Given that the fifteen minute sample durations exceeded the ten minute spray paint duration, the measured airborne solvent concentrations are likely to have underestimated the actual concentration generated during spray painting.

Figure g: Total airborne concentration of organic solvents (additive effects) measured in re-enactment



The results of PID measurements are presented in Figure h & i below and these indicated that the maximum airborne solvent concentrations occurred as a direct result of spray painting and solvent being discharge through the spray gun nozzle. The maximum concentration was proportional to the spray paint duration and volume of paint discharged. A prolonged secondary plateau occurred after a short duration from when spray painting stopped, and this was attributed to the emissions from painted surface areas.

Figure h: Real time solvent concentration in air (PID measurement in Bay 87 – Valid Test #1 (6; 7; 8; 9)) measured in re-enactment

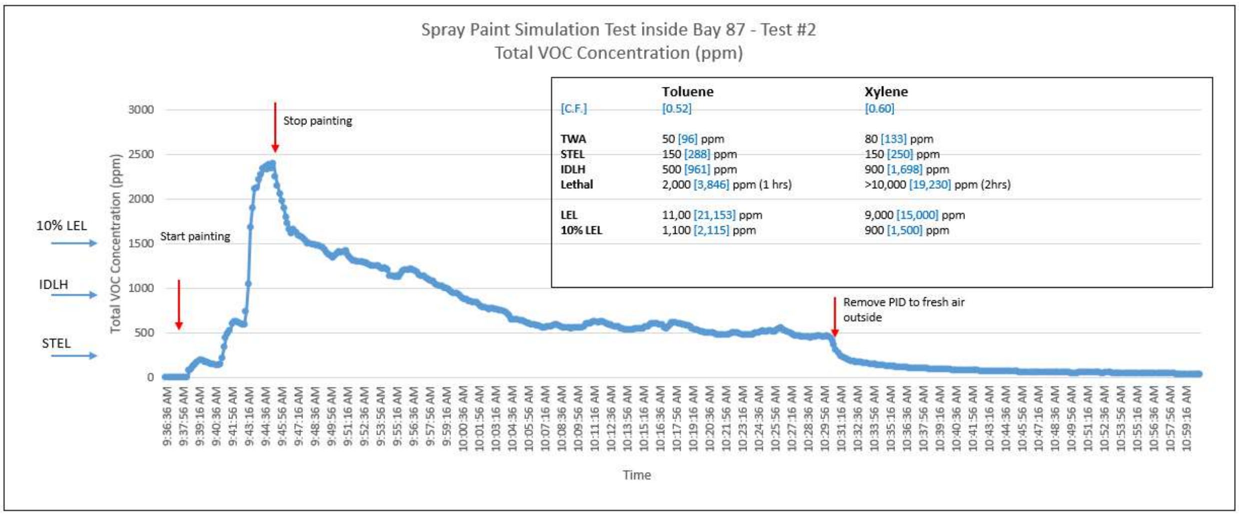
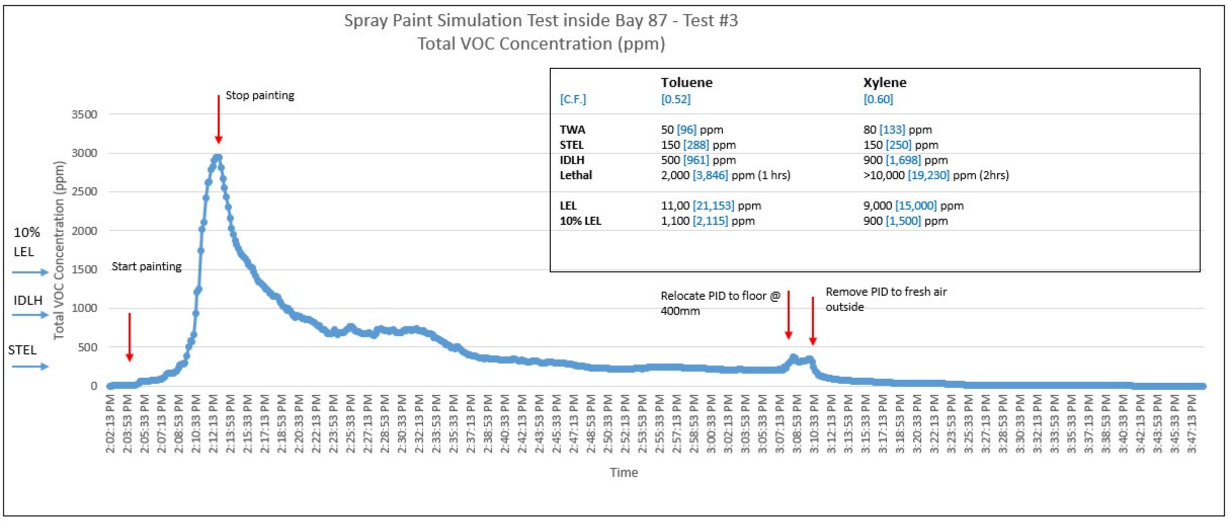


Figure i: Real time solvent concentration in air (PID measurement in Bay 87 – Valid Test #2 (6; 7; 8; 9)) measured in re-enactment



The PID measurements indicated that the instantaneous airborne concentrations exceeded the 10% LEL and IDLH values for the solvent compounds during spray painting and for a further 5 minutes and 20-30 minutes, respectively, after painting stopped. The STEL values were exceeded for a further 45-60 minutes after spray painting stopped.

Clearance monitoring was conducted inside the test chamber with PID and Altair multigas detectors, to confirm concentrations were below 100% LEL prior to activating the extraction fan, and below 5% LEL and 5ppm prior to re-entry with and without RPE, respectively. During this monitoring it was identified that significant layering was occurring on the floor of the bays prior to activating the extraction ventilation and this persisted for an extended period while applying ventilation. This observation is consistent with the high vapour density (≈3x air) reported for the solvent compounds present. The layout and dimension of individual bays and adjoining access holes, acted to limit the effectiveness of flow through ventilation from interacting with solvent vapour which had accumulated in the floor area. This prolonged the holding period before re-entry could occur after spray painting was stopped.

It was also observed that the three Altair multigas detectors which were located inside the test chamber during spray painting had not detected concentrations above the threshold alarm setting at 10% LEL. This was not consistent with concentrations measured using the PID and charcoal tubes located in the same locations and/or from using the same instruments during clearance monitoring. Based on these observations it was likely that the relatively short lengths (approximately 1.0 m) of sample tubing attached to the sample port of these instruments acted as a solvent trap preventing the effective transport of contaminants into the detector.

5.2 Respiratory Protection

Testing of the two half face respirator and filter assemblies worn by the hose assistants (Figure j) indicated that the devices had not been adequately cleaned and maintained and the capacity of A1 and A2 class organic filters were limited and not suitable for the concentrations of solvents present during the incident.

The respirator worn by the CMW who was found unresponsive after performing hose assistant duties, had not been cleaned and maintained (Figure j, RPE 1), there was no residual capacity remaining in the A2 class filter, and inward leakage (≈577cc/min) was measured in the facepiece under negative pressure (25 mm water column). This leakage was significantly higher compared with a new unused respirator (48cc/min) and was attributed to leaking exhalation valves and valve seats from being contaminated with paint. These findings were consistent with evidence provided by the CMW during interview, that they had not replaced the filter for approximately six months and had not participated in facial fit testing of their personal issued respirator.

The respirator worn by the other CMW performing hose assistant duties and unaffected by exposure, had been cleaned and maintained and the filter replaced at the start of shift. There was only 30% residual capacity remaining in the A1 class filter, and similar inward leakage (≈697cc/min) was measured for this facepiece, also attributed to leaking valves and valve seats from paint contamination.

Figure j) Image of respirators worn by the two hose assistants

The leakage contribution from valves and valve seats on both respirators was verified by systematically cleaning and replacing individual components and repeating the leakage testing. Final testing after cleaning a replacement of components indicated inward leakage measured for each facepiece (48 and 96 ml/min, respectively), was significantly reduced and approached that of a new unused respirator.

5.3 Personal gas detectors

The inspection and testing of personal gas detectors (PGDs) and the docking station used in the incident, confirmed that they were performing and functioning in accordance with the manufacturer's specification. Also, that they had been calibrated and bump tested using a mixture of methane and other gases, in accordance with procedures, prior to being used.

On inspection the manufacturer advised that the specific PGD type used in the incident was not designed to be used for toluene or ethyl benzene. It was confirmed that the flammable gas detector was a catalytic bead type sensor and also that the PGDs had been fitted with an in-built filter, specifically to prevent compounds including toluene, from entering and contaminating the detector. It is expected this filter would have similar filtration capacity for other similar compounds including the paint solvents xylene and ethyl benzene. It is understood that the filters are routinely replaced during periodic calibration servicing within twelve months. However, the condition and residual capacity remaining in these filters was not tested.

Downloading of data confirmed that the instrument located inside the confined space and at the base of stairs near the entry/exit point, detected flammable concentrations (4-7% LEL) for approximately thirty minutes during the spray painting and rescue events. Measured concentrations exceeded the pre-set alarm threshold and triggered a visual and audible alarm, for approximately thirteen minutes during the incident. Given the design limitations of these PGDs for detecting paint solvents and presence of a toluene filter, the accuracy and reliability of measurement data acquired from these devices was unknown. Consequently, this data was considered to be indicative only that flammable solvents were present at elevated concentrations. The other PGD which was being carried by the spotters did not detect flammable concentrations above the limit of detection.

Concentrations of carbon monoxide and hydrogen sulphide were not detected by the PGDs, and oxygen was within the normal atmospheric range.

6. Recommendations

As a result of the investigation and testing conducted, the following recommendations are made in relation to risk controls and monitoring, while spray painting inside confined spaces, within draglines or other similar environments.

- Ventilation mechanisms should be applied to confined spaces where spray painting with solvent based products are applied. This ventilation should be designed in consideration of the rapid increase in toxic and flammable concentrations of solvent vapours resulting from relatively small application quantities and durations of exposure. The high vapour density of solvents and their propensity for layering on the floor should also be considered.
- Air-Supplied respirators should be selected in preference to powered air purifying (PAPR) and/or negative pressure respirators, which rely on regular cleaning, maintenance, facial fit testing and particularly filtration performance and capacity, in order to provide an adequate level of protection.
- Ignition sources should be removed from spaces where there is a potential for flammable concentrations of solvent vapours to occur. Paint surfaces should be earthed to prevent static charge build-up and the autoignition temperature of

solvents and intrinsic safety requirements should be considered, when selecting portable equipment for use in these spaces (e.g. lighting, radios, personal gas detectors, mobile phones).

- Continuous monitoring of airborne solvent concentrations should be conducted inside the space, in addition to routine confined space monitoring (O_2, CO, % LEL, Tox), to verify the effectiveness and adequacy of controls being implemented. These controls include ventilation, respiratory protection, and confined space entry and withdrawal restrictions at 5-10% LEL. The use of extension sampling tubes to facilitate remote monitoring should be avoided when monitoring for organic paint solvents, to prevent the loss of sample and underestimating the true concentration at the point of sampling.

- Clearance monitoring should be conducted to ensure airborne concentrations are suitable for occupancy, prior to re-entering the space after spray painting has stopped.

7. Conclusions

The airborne concentrations of organic solvents (xylene, toluene, ethyl benzene) were measured while spray painting with solvent based paints inside an unventilated test space designed to replicate the revolving frame of a dragline. This testing confirmed that airborne concentrations rapidly increased during the spray painting activity and exceeded the toxic and flammable limits, normally applied to control exposures to these airborne contaminants.

Measured concentrations in areas normally occupied by painters and occasionally by hose assistants, exceeded the immediately dangerous to life and health (IDLH) concentrations and potential lethal concentration for humans, for all three compounds and toluene, respectively. The relative ratio of individual organic solvent concentrations measured in the air, was generally consistent with the compositional ratio (% wt/wt) of solvent ingredients reported in the product safety data sheet and did not reflect the relative vapour pressure of these compounds.

Concentrations also exceeded the 10% Lower Explosive Limit (LEL) standard threshold, usually applied to control the flammability risks in confined space entry work, in accordance with AS2865:2009 Confined Spaces (10).

Personal gas detectors including multigas types with electrochemical and catalytic bead sensors which are typically used in confined space entry work, are not suitable for the continuous monitoring of organic paint solvents in these situations, including for xylene, toluene and ethyl benzene. Alternative devices including photo ionisation detectors and/or colorimetric detector tubes, may provide a more accurate and reliable measure of instantaneous concentrations for control purposes.

8. References

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