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**Airborne Isocyanate from SMART (Small to
Medium Area Repair Technique) Spraying – Final
Report**

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EXECUTIVE SUMMARY

Objectives

1. Evaluation of the likely exposures caused by vehicle SMART spraying using isocyanate paints.

Main Findings

1. Isocyanate monitoring was carried out with three different SMART repair operators; a mobile repairer with no enclosure, a workshop based repairer and a mobile repairer with portable enclosure.
2. In all three cases, over the short period of paint application, airborne isocyanate concentrations in excess of $70 \mu\text{g}/\text{m}^3$ were measured.
3. Biological monitoring gave one positive result; this was for the mobile repairer. This result is indicative of poor control and does not relate to any health risk.
4. Replicate tests were performed in all exercises, considerable variation between tests was observed, as was expected. Six replicates were considered sufficient to indicate the likely exposure ranges.

Recommendations

1. Air fed respiratory protective equipment is essential when spraying isocyanate paints during SMART repair.
2. The exposure data collected from this study should be considered during the preparation of guidance for safe working with isocyanate paints in SMART repair.

1 INTRODUCTION

Isocyanates (NCO) are highly reactive species used in the motor vehicle repair, adhesives, polyurethane and coating industries. They are known respiratory tract and skin sensitizers and are the most common cause of occupational asthma in the UK (HSE, 2004). The Health and Safety Executive (HSE) has set workplace exposure limits (WELs), for total isocyanate exposure (i.e. all NCO species), below which exposure should be as low as is reasonably practicable, at $70 \mu\text{g}/\text{m}^3$ (short term, 15 minute) and $20 \mu\text{g}/\text{m}^3$ (8 hour TWA). Isocyanates paints can be applied by spraying or by brush or roller.

The hazards associated with use of isocyanate paints in conventional motor vehicle repair are well known (HSE, 2004; HSL, 2003; HSL, 2005a; HSL, 2005b; HSL, 2005c). This report details work carried out by HSL to determine the potential hazard during the application of 2-pack NCO based paints during SMART (Small to Medium Area Repair Techniques).

SMART repairs techniques are carried out as an alternative to larger scale and more complex body shop repairs, often for improving cosmetic appearance prior to sale of a vehicle. Typical areas for SMART repair include scuffed bumpers, stone chips, dents, scratches and damaged alloy wheels. It is not possible accurately to define a SMART repair, however, the repair would not require replacement or respray of a whole panel or bumper, is unlikely to exceed an area of 1000 cm^2 and typically would be carried out on site rather than in a spray booth or spray room.

SMART repair is a fast growing area, with a number of larger scale operations and franchises together with many single operators. HSE, together with industry and other interested parties is currently developing guidance for SMART repairs.

2 EXPERIMENTAL

Three different monitoring exercises were carried out using two-pack lacquers. In all cases, the lacquer hardener was the only product used containing isocyanates, consequently the sampling was only carried out during application of the lacquer. The actual paint used was different in all three visits, although all were polymeric 1,6 hexamethylene diisocyanate (HDI) based products. Dedicated SMART repair guns were used in all instances.

The sampling technique used an impinger containing 1-(2-methoxyphenyl) piperazine (MP) reagent in toluene solution with an MP coated filter as back-up (MDHS 25/3, HSE, 1999). Sampling flow rate was typically two litres per minute.

Biological monitoring was carried out using HSL's in-house method (Williams *et al*, 1999). The marker is 1,6-hexane diamine (HDA), the urinary metabolite of 1,6 hexamethylene diisocyanate (HDI). Samples were taken before and after spraying.

2.1 VISIT 1

This visit was to the headquarters of a large company who have a fleet of around 50 mobile SMART repairers, mostly carrying out work for franchised garages, to repair cars before going on sale. Competent personnel carry out training on-site. These mobile operators work mostly on or around garage forecourts, regular customers are encouraged to set aside an isolated area where the repairs can be carried out away from others.

To reflect the different conditions under which this companies operators may find themselves carrying out repairs, we monitored personal NCO exposure during four different repair scenarios;

Outside spraying

Outside spraying under a canopy

Spraying inside an industrial unit with a "homemade" extraction system on

Spraying inside an industrial unit with no extraction

The inside spraying was carried out in an industrial unit approximately 2 m inside the (open) roller doorway. See figure 1 for a schematic of the repair scenarios. The extraction system used was homemade and comprised of a "hood", positioned near the spraying, with ducting to a filter box unit (containing an unknown filter material of the type used spray booth) and further ducting to a powered fan.

The same operator carried out all spray operations. Half mask air -fed respiratory protective equipment was worn during all paint spraying. Each test comprised a single application of lacquer to a steel panel approximately 1000 cm² in area. This area was chosen to replicate the repair of a bumper corner and is at the top end of the size of repair this company would undertake. The estimated volume of paint used was between 20 and 30 ml. Each application of lacquer took between 13 and 20 seconds, approximately five minutes was left between each test. Six replicate tests were performed on all four scenarios and sampling equipment was changed between each test. A seventh combined test was then performed, involving six consecutive applications of paint and the same sampling equipment used for all six coats; this was carried out due to a concern that airborne concentrations may be so low that they would not be detected.

Urine samples were taken from the sprayer both before and after spraying. The occupational hygienist taking the samples also provided urine samples to give an idea of the secondary

exposure potential (others who may be working relatively close to the spraying activities; in this instance around 15 metres away).

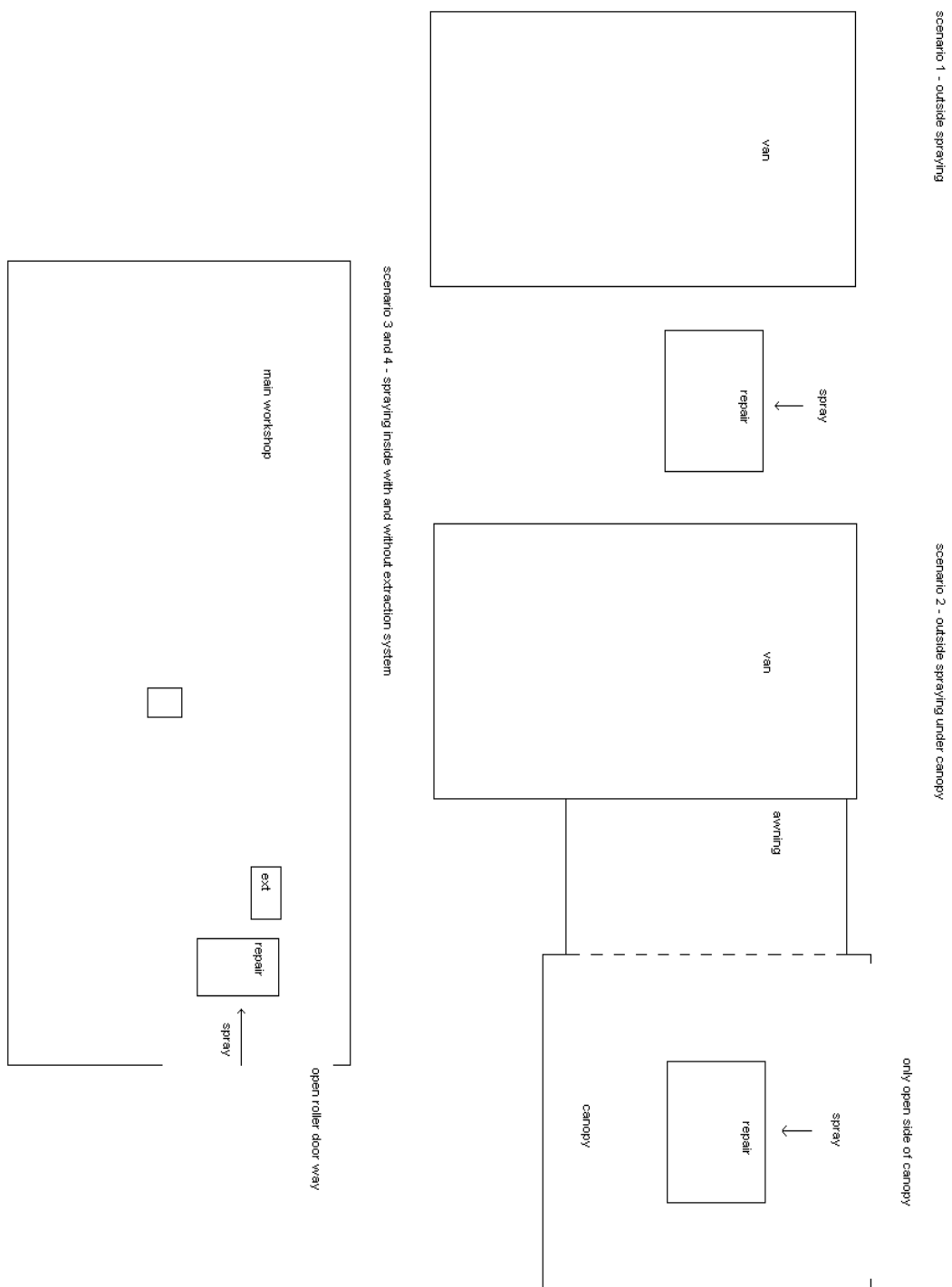


Figure 1. Sampling positions for visit 1.

2.2 VISIT 2

This site provides training on SMART repair techniques, is a large supplier of products for the SMART repair industry and also carries out repairs in its fixed workshop. The workshop was a typical industrial unit with roller shutter door allowing access, the door was closed for all tests except where specifically stated otherwise. The unit also included separate offices and a training room. The unit had no planned ventilation arrangements, only the natural ventilation provided by air movement through gaps around the roller or emergency exit doors. Personal and static NCO measurements were taken during four different repair scenarios at this site;

Inside using extraction system 1

Inside, with curtained area, using extraction system 2

Inside, with curtained area, no extraction

Inside, at roller shutter door (open) no extraction.

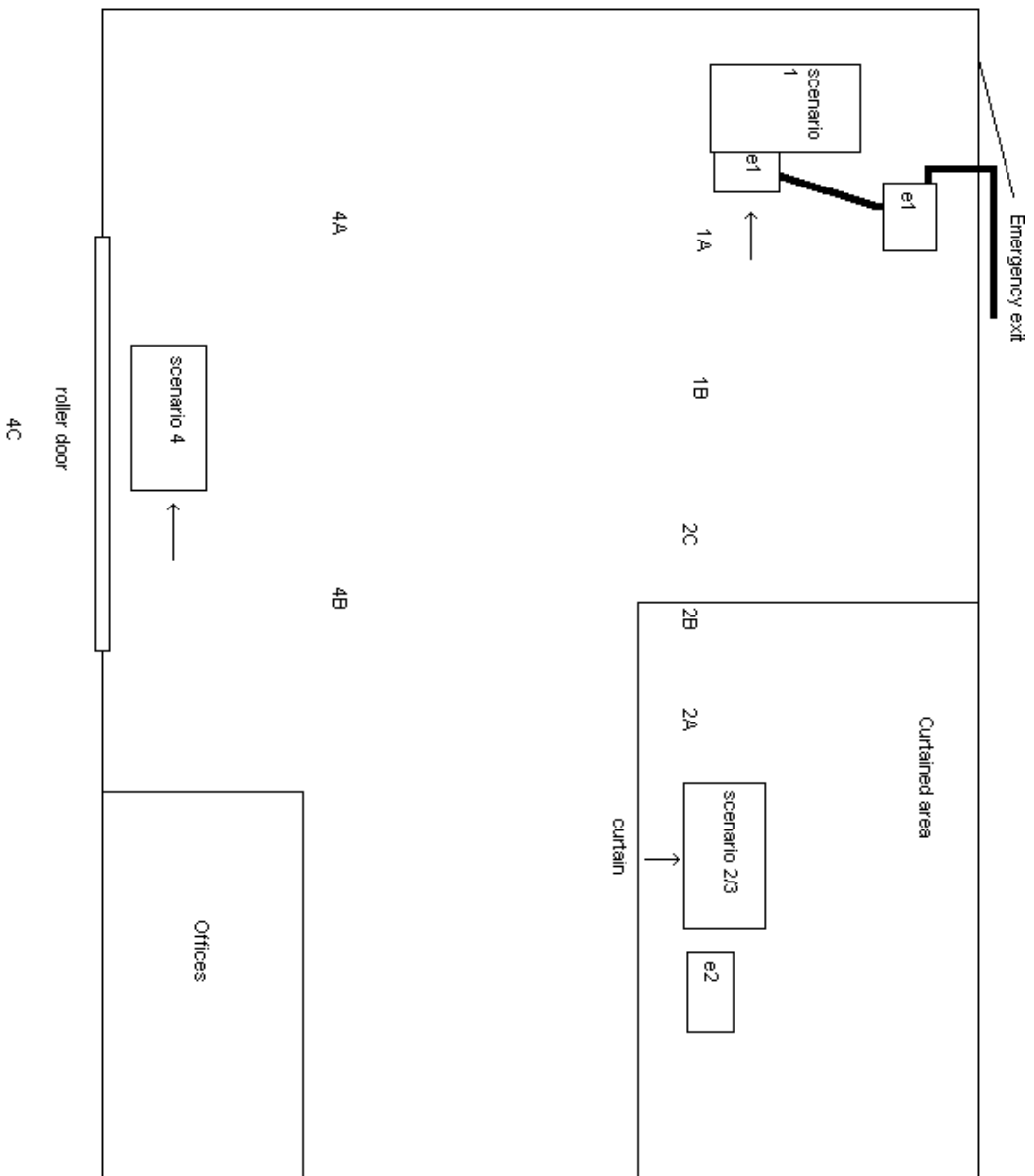
Extraction system 1 used a shroud which was placed over the repair area, the repair area was then masked up to the shroud. Air is pulled through the shroud and ducted through to a filter unit before being vented to atmosphere, in this instance outside via the emergency exit door.

Extraction system 2 drew air in at its base and through filters before expelling the filtered air out higher up through an inflatable boom extending over the repair area. The unit was primarily designed for removing solvent vapour and dust away from the repair.

See figure 2 for a schematic of the repair scenarios.

The same sprayer carried out all tests. A full-face 12 volt powered filtered air respirator was used during all paint application. The repair area was approximately 1000 cm², each test comprised a quick first coat, approximately a 30 second pause followed by a second heavier coat, estimated total spraying time per test was around 15 seconds. The estimated volume of paint used was between 20 and 30 ml. Six replicates of each test were performed, with approximately five minutes clearance time between each. Fresh sampling equipment was used each time. As with visit 1, a seventh replicate monitored a combined six tests using the same sampling equipment.

Urine samples were taken from the sprayer both before and after spraying. The occupational hygienist taking the samples also provided urine samples to give an idea of the exposure potential for others who may be working relatively close to the spraying activities. In this case it was around 10 metres away and always outside any curtained areas used during spraying. No personnel other than the sprayer and hygienist were present in the unit during testing.



NOTES

Diagram not to scale

The arrows indicate the direction of spray for each scenario

e1 = extraction system (2 part with ducting in between and then vented outside)

e2 = extraction system 2

Static sampling positions for scenario 1;

1A= ~ 1m from repair

1B= ~ 5m from repair

Static sampling positions for scenario 2 and 3;

2A= ~ 1m from repair (inside curtain)

2B= ~ 5m from repair (inside curtain)

2C= ~ 6m from repair (inside curtain)

Static sampling positions for scenario 4;

4A= ~ 5m from repair LHS

4B= ~ 5m from repair RHS

4C= ~ 2.5m from repair (outside workshop, door open)

Figure 2. Sampling positions for visit 2.

2.3 VISIT 3

This visit was to one operator of a national company operating a fleet in excess of 60 mobile SMART repair vehicles. Operators have their own portable enclosure, with extraction system, which is erected around the car being repaired. The extraction draws air in at its base and passes through a filter material before being discharged to atmosphere. Once the enclosure is assembled the car is fully enclosed. A ventilation assessment of the portable enclosure was made and is included below.

The portable spray booth consisted of a large single skin tent with a portable air mover at one end. A generator, contained within the van, provided power and compressed air for spraying operations. The approximate volume of the booth was 44 m^3 . The air mover had two inlet vents with coarse filters of area 0.36 m^2 each, and one outlet vent outside the tent of area 0.04 m^2 . The clearance time was determined by performing smoke tests using the Colt 4 Turbo smoke machine. Clearance times measured were between 3 minutes 30 seconds and 4 minutes 4 seconds, it is recommended displaying the clearance time for this booth as 4 minutes 30 seconds. It is worth noting that the performance of this booth will depend strongly on prevailing wind and weather conditions. The volume flow of air into and out of the air mover was estimated by measuring velocities at the vents. These measurements showed $0.93 \text{ m}^3\text{s}^{-1}$ entering the air mover and $0.71 \text{ m}^3\text{s}^{-1}$ exiting it, this discrepancy may be explained by the difficulty in taking accurate velocity measurements outside the booth where winds were high. Using the value of air entering the air mover and the volume an air change rate was calculated, this was 1.28 air changes per minute (acm). However, this figure does not take into account how the air moves within the booth, i.e how well mixed the air is.

Unlike the other visits, there was only the one repair scenario, personal and static NCO measurements were taken during this. Figure 3 shows the different sampling positions used.

The same sprayer carried out all tests. A full-face 12-volt powered air fed respirator was used during all paint applications. Spraying consisted of an initial shorter application of around 15 seconds duration with a second heavier coat of at least 30 seconds duration. The repair was made to a car panel with an area of around 7000 cm^2 . The estimated volume of paint used was between 75 and 100 ml. Due to time constraints it was only possible to perform four replicates, with sampling equipment being changed between each replicate. The final test comprised a single application of paint of 39 seconds duration.

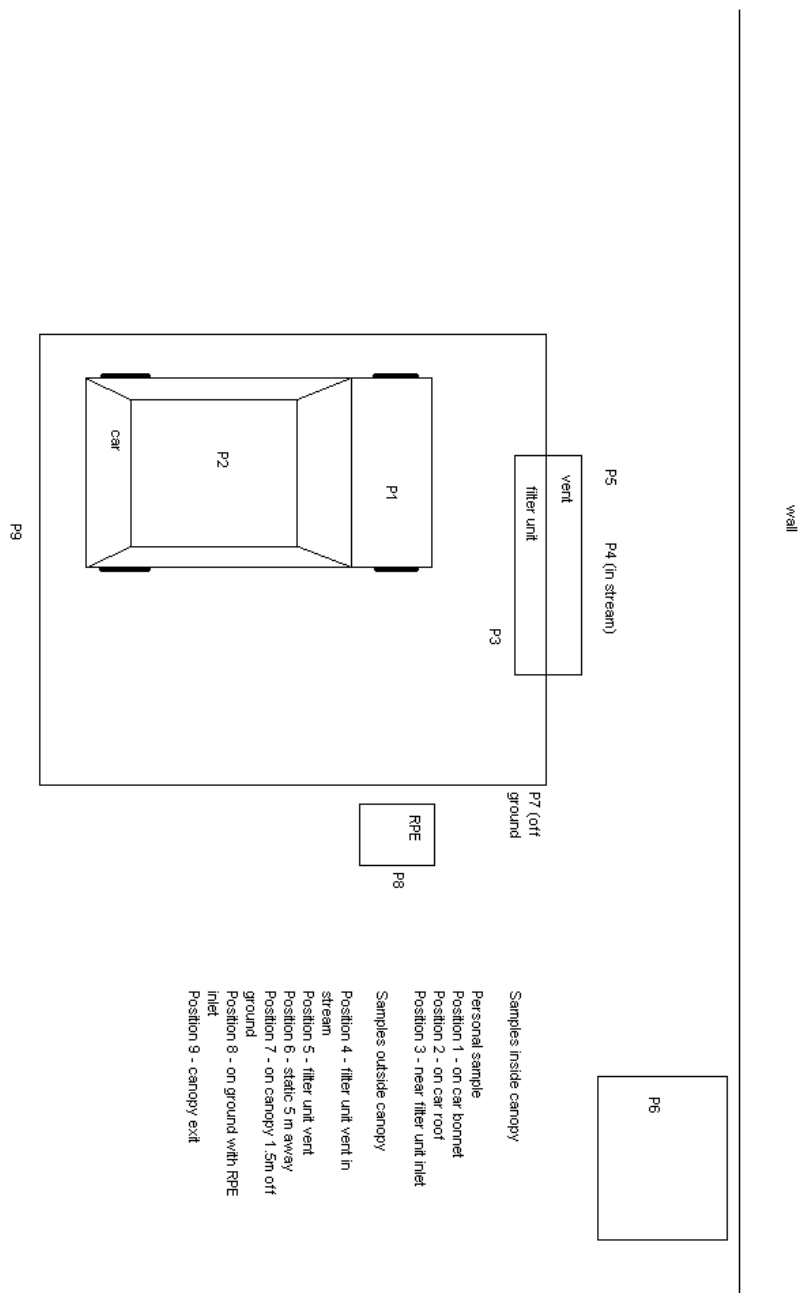


Figure 3. Sampling positions for visit 3.

3 RESULTS AND DISCUSSION

3.1 VISIT 1

Table 1. Airborne monitoring results summary for visit 1.

| | Personal exposure $\mu\text{g NCO}/\text{m}^3$ | | | |
|--------------------|--|-----------------------|----------------|-----------------|
| | Outdoors in open | Outdoors under canopy | Indoors ext on | Indoors ext off |
| Rep 1 | 11 | 13 | 53 | 171 |
| Rep 2 | ND (<5) | 25 | 233 | 64 |
| Rep 3 | 46 | 54 | 20 | 437 |
| Rep 4 | 150 | 20 | 205 | 347 |
| Rep 5 | 328 | 45 | 108 | 101 |
| Rep 6 | 62 | ND (<5) | 83 | 75 |
| Median | 54 | 22.5 | 95.5 | 136 |
| Mean | 100 | 26 | 117 | 199 |
| Rep 7 (x 6 sprays) | ND (<5) | 33 | ND (<5) | 19 |

The exposures relate to the task and are not time weighted. This is due to the hazardous nature of isocyanates – the dose-response relationship of isocyanates and asthma is not clear. Thus, high exposures for very short periods of time are strongly discouraged, even though as time weighted averages they may be under the WEL. Duration of each individual spray 13 – 20 seconds, over a single pass. Full results are given in appendix 1. A box and whisker plot of the results shows the spread and variation of exposures over the different scenarios.

Visit 1 - Personal exposure results summary

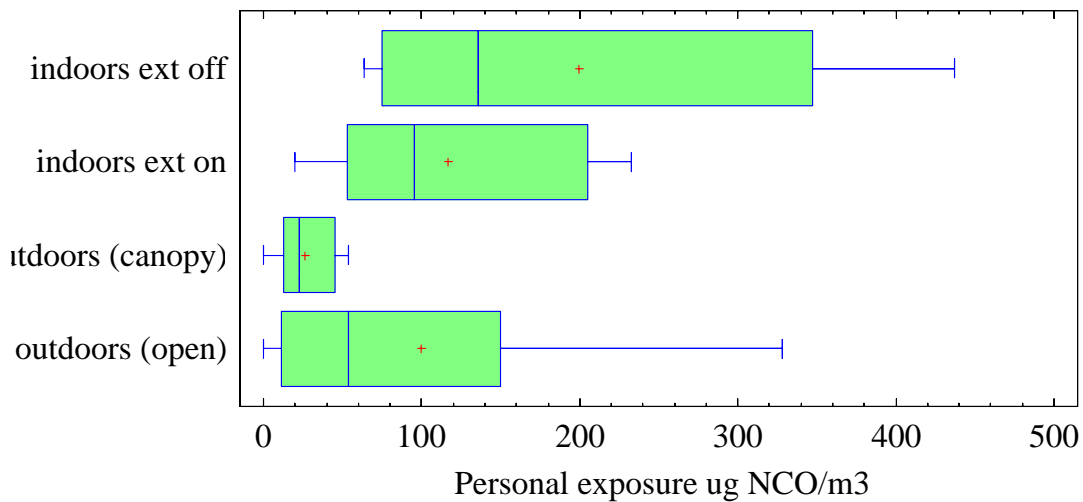


Figure 4. Box and whisker plot for visit 1.

- Notes; Ends of the whiskers show the lowest and highest results
- The box shows the upper and lower quartiles – 50% of data is inside the box
- The line in the box is the median
- The cross in the box is the arithmetic mean

The results show a large variation within the replicate tests. Each set of replicates for a given scenario were performed in relatively quick succession with around 5 minutes left between each test. It is assumed the biggest variable is the atmospheric conditions; the sampling staff noted that it was possible to see the over spray moving in different directions depending upon the prevailing wind. However, the data set indicates a likely exposure range for the scenario.

All scenarios generated significant NCO concentrations, although the “outdoors under canopy” are appreciably lower, and appear less variable, than the other three. The extraction system used indoors does reduce potential exposure.

The combined 7th test results all suggest lower exposures than the other six replicates. In particular the spraying outside in the open the combined tests show less than 5 µg NCO/m³, the hygienist notes showed that wind blew the spray away from the operator on two applications. So the apparent difference is likely to be attributable to varying atmospheric conditions and also the fact of a longer sampling time, which has a similar effect to applying a time weighting correction to the exposures.

No HDA was found in a pre-spraying urine sampling. A second urine sample taken after all spraying was completed contained 1.27 µmol HDA /mol creatinine. Both urine samples provided by the hygienist carrying out the sampling were found not to contain HDA, the hygienist was not using any form of RPE . Biological monitoring results relate to control and do not have any significance for health, HSE has set a guidance value of 1 µmol HDA /mol creatinine. The amount of spraying was equivalent to approximately two weeks work of a normal operative. The sprayer was using half-face air fed RPE, although whether this has any significance to the result is not known.

3.2 VISIT 2

Table 2. Airborne monitoring results summary for visit 2.

| | Personal exposure µg NCO/m ³ | | | |
|--------------------|---|--------------------------|------------------------------|-----------------------------------|
| | Extraction 1 | In doorway no extraction | Curtained area no extraction | Curtained areas with Extraction 2 |
| Rep 1 | 16 | 90 | 315 | 82 |
| Rep 2 | 10 | 153 | 267 | 962 |
| Rep 3 | 11 | 107 | 466 | 330 |
| Rep 4 | 29 | 87 | 339 | 476 |
| Rep 5 | 3 | 109 | 554 | 97 |
| Rep 6 | 9 | 83 | 549 | 219 |
| Median | 11 | 99 | 403 | 275 |
| Mean | 13 | 105 | 415 | 361 |
| Rep 7 (x 6 sprays) | ND | 65 | 328 | 62 |

The exposures are not time weighted – they relate to the task. Duration of spraying was around 15 seconds in total, comprising a quick light application followed by a longer heavier application around 30 seconds after the first. Static samples were also taken, see appendix 2 for full results.

Visit 2 - Personal exposure results summary

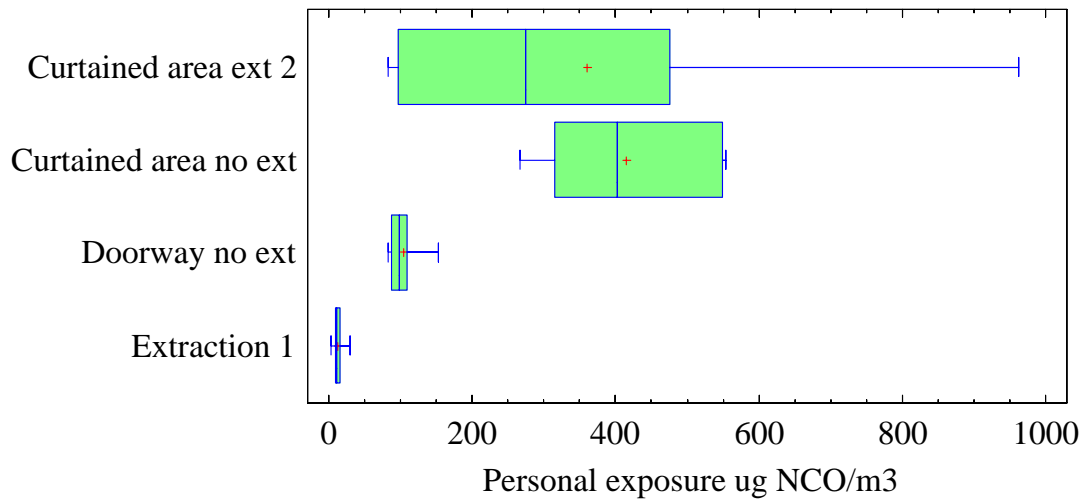


Figure 5. Box and whisker plot for visit 2.

Note. See figure 4 notes for an explanation of the box and whisker plot.

Those personal exposures measured using extraction system 1 are consistently low; the other three scenarios, which cover the same repair area and use approximately the same amount of paint, show much higher and more variable airborne concentrations in excess of the $70 \mu\text{g}/\text{m}^3$.

The enhanced natural ventilation introduced by working in the workshop doorway appears to reduce peak exposures, although they are still above the $70 \mu\text{g}/\text{m}^3$. Significant concentrations were also detected 6 m from the repair area.

Static samples showed that appreciable levels of NCO were being generated 5 m away from the repair area when using a curtained off area as a control measure, this was irrespective of whether an extraction system was on or off.

All urine samples provided by the sprayer and sampling hygienist (not using RPE) showed no trace of HDA, the detection limit being 5 nmol HDA/mol creatinine.

3.3 VISIT 3

Table 3. Airborne monitoring results summary for visit 3.

| | In enclosure exposure $\mu\text{g NCO}/\text{m}^3$ | | | |
|-----------------------|--|-------------------|-------------------|-------------------|
| | Sprayer | Static Position 1 | Static Position 2 | Static Position 3 |
| Rep 1 (50 s spraying) | 205 | 141 | 310 | 217 |
| Rep 2 (77 s spraying) | 888 | 197 | 191 | 306 |
| Rep 3 (85 s spraying) | 1820 | 213 | 38 | 269 |
| Rep 4 (39 s spraying) | 906 | 146 | 146 | 156 |

The exposures are not time weighted – they relate to the task. Static samples were also taken outside the enclosure, see appendix 3 for full results.

Visit 3 - Inside enclosure results

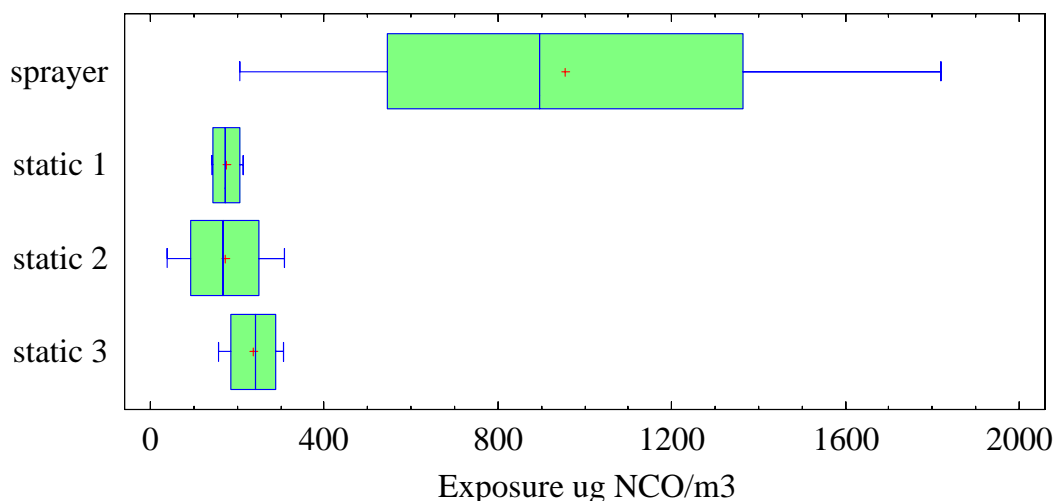


Figure 6. Box and whisker plot for inside enclosure results from visit 3.

Note. See figure 4 notes for an explanation of the box and whisker plot.

The results show that concentrations in excess of $70 \mu\text{g}/\text{m}^3$ are generated at various points within the enclosure. The concentrations around the sprayer are particularly high, presumably this is a consequence of the enclosed work area.

Biological samples provided by the sprayer before and after the spraying were found to contain no HDA, limit of detection $5 \text{ nmol HDA}/\text{mol creatinine}$.

4 CONCLUSIONS

SMART repairs can generate large airborne NCO concentrations, well in excess of the WEL. Therefore, the use of air fed respiratory protective equipment is essential.

Due to environmental factors SMART repairs conducted outside can generate varying concentrations of isocyanate. It is recommended that an exclusion zone around the vehicle repair should be applied. Repairs in the open workshop are not recommended unless occupants are excluded or wear suitable RPE.

A repair system using portable enclosure was evaluated and the isocyanate generated from the spraying operation was well contained, there are also benefits in that the work is less dependant on the prevailing weather.

5 REFERENCES

Health and Safety Executive (2004)

hse.gov.uk/asthma/substancesinfo

HSE website.

Health and Safety Laboratory (2003)

M Coldwell and J White

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HSL report # OMS/2003/06

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M Coldwell and J White

Measured Airborne Isocyanate for Mixing and Brush and Roller Application of Isocyanate Based 2-pack Paints

HSL report # OMS/2005/02

Health and Safety Laboratory (2005b)

M Coldwell and J White

Measurement of Airborne Isocyanate during Sanding and Bake Cycle

HSL report # OMS/2005/10

Health and Safety Laboratory (2005c)

M Coldwell and J White

Airborne Isocyanate from SMART Repair

HSL report # OMS/2005/12

Health and Safety Executive (1999)

Organic isocyanates in air

Methods for the determination of hazardous substances

Method 25/3.

Williams NR, Jones K and Cocker J (1999)

Biological monitoring to assess exposure from use of isocyanates in motor vehicle repair

Occup Environ Med, **56**, p598-601.

6 APPENDICES

6.1 APPENDIX 1 - FULL RESULTS FROM VISIT 1

| Sample No. | Sample Type | [NCO] $\mu\text{g}/\text{sample}$ | [NCO] $\mu\text{g}/\text{m}^3$ | Air volume (l) | Comments |
|--|-------------------|-----------------------------------|--------------------------------|----------------|------------------------------|
| Outside spraying | | | | | |
| 05278-05 | impinger + filter | 0.075 | 11.3 | 6.6 | Sample 1 – spraying for 20 s |
| 05279-05 | impinger + filter | N.D. | N.D. | 3.3 | Sample 2 – spraying for 16 s |
| 05280-05 | impinger + filter | 0.092 | 46 | 2 | Sample 3 – spraying for 20 s |
| 05281-05 | impinger + filter | 0.299 | 150 | 2 | Sample 4 – spraying for 15 s |
| 05282-05 | impinger + filter | 0.715 | 328 | 2 | Sample 5 – spraying for 15 s |
| 05283-05 | impinger + filter | 0.125 | 62.4 | 2 | Sample 6 – spraying for 18 s |
| 05284-05 | impinger + filter | N.D. | N.D. | 10.3 | Sample 7 – 6 x sprays |
| Outside spraying under canopy | | | | | |
| 05285-05 | impinger + filter | 0.035 | 13.1 | 2.7 | Sample 1 – spraying for 19 s |
| 05286-05 | impinger + filter | 0.058 | 24.9 | 2.3 | Sample 2 – spraying for 20 s |
| 05287-05 | impinger + filter | 0.143 | 53.6 | 2.7 | Sample 3 – spraying for 18 s |
| 05288-05 | impinger + filter | 0.050 | 20.0 | 2.5 | Sample 4 – spraying for 20 s |
| 05289-05 | impinger + filter | 0.090 | 45.0 | 2 | Sample 5 – spraying for 17 s |
| 05290-05 | impinger + filter | N.D. | N.D. | 2.3 | Sample 6 – spraying for 19 s |
| 05291-05 | impinger + filter | 0.524 | 32.8 | 16 | Sample 7 – 6 x sprays |
| Spraying inside – extraction on | | | | | |
| 05292-05 | impinger + filter | 0.089 | 53.4 | 1.7 | Sample 1 – spraying for 18 s |
| 05293-05 | impinger + filter | 0.816 | 233 | 3.5 | Sample 2 – spraying for 15 s |
| 05294-05 | impinger + filter | 0.047 | 20.1 | 2.3 | Sample 3 – spraying for 14 s |
| 05295-05 | impinger + filter | 0.479 | 205 | 2.3 | Sample 4 – spraying for 16 s |
| 05296-05 | impinger + filter | 0.252 | 108 | 2.3 | Sample 5 – spraying for 14 s |
| 05297-05 | impinger + filter | 0.193 | 82.9 | 2.3 | Sample 6 – spraying for 13 s |

| | | | | | |
|---|--|-------|------|------|------------------------------|
| 05298-05 | impinger + filter | N.D. | N.D. | 21.7 | Sample 7 – 6 x sprays |
| Spraying inside – extraction off | | | | | |
| 05299-05 | impinger + filter | 0.342 | 171 | 2 | Sample 1 – spraying for 15 s |
| 05300-05 | impinger + filter | 0.161 | 64.4 | 2.5 | Sample 2 – spraying for 14 s |
| 05301-05 | impinger + filter | 0.947 | 437 | 2.2 | Sample 3 – spraying for 20 s |
| 05302-05 | impinger + filter | 0.693 | 347 | 2 | Sample 4 – spraying for 16 s |
| 05303-05 | impinger + filter | 0.268 | 101 | 2.7 | Sample 5 – spraying for 16 s |
| 05304-05 | impinger + filter | 0.176 | 75.4 | 2.3 | Sample 6 – spraying for 13 s |
| 05305-05 | impinger + filter | 0.451 | 19 | 23.7 | Sample 7 – 6 x sprays |
| 05306-05 | Lacquer – LC/MS/MS detected HDI monomer and HDI- isocyanurate (major component). | | | | |
| 05307-05 | Hardener – LC/MS/MS showed very low levels of HDI-isocyanurate present. | | | | |
| 05308-05 | Mixed Laquer and Hardener – no isocyanate was detected, presumably because the free NCO had cured. | | | | |

Notes

Analysis of samples for isocyanate (NCO). Quantification was carried out by electro-chemical detection with UV/vis confirmation. Additional confirmation was carried out by LC/MS/MS (positive ion electro-spray mode, parent ion scan (200 – 1800 Th) of 193⁺ daughter ion). Estimated limit of detection (EC) is ~ 0.004 µg/ml solvent (estimated from lowest calibration standard for derivatized HDI monomer). For a 15 l air sample this corresponds to ~ 0.4 µg/m³

N.D. = not detected, i.e. < est. LOD

A sampling rate of 2 l/min. was taken for these samples because of the very short sampling times.

6.2 APPENDIX 2 - FULL RESULTS FROM VISIT 2

| Sample No. | Type | Samples details | Time (secs) | Volume (l) | NCO concentration (µg NCO/m ³) |
|---|------------|-----------------|-------------|------------|--|
| Scenario 1- Repair using extraction system 1 | | | | | |
| 11187/05 | Imp/filter | Replicate 1 | 90 | 3.0 | 16.1 |
| 11188/05 | Imp/filter | Replicate 2 | 105 | 3.5 | 9.53 |
| 11189/05 | Imp/filter | Replicate 3 | 104 | 3.3 | 11.5 |

| Sample No. | Type | Samples details | Time (secs) | Volume (l) | NCO concentration ($\mu\text{g NCO}/\text{m}^3$) |
|---|------------|---|-------------|------------|--|
| 11190/05 | Imp/filter | Replicate 4 | 68 | 2.2 | 29.1 |
| 11191/05 | Imp/filter | Replicate 5 | 105 | 3.6 | 3.19 |
| 11192/05 | Imp/filter | Replicate 6 | 75 | 2.4 | 8.56 |
| 11193/05 | Imp/filter | Static 1 – 1 m from extraction system | 1890 | 63 | 0.50 |
| 11194/05 | 2 x filter | Static 1 – 1 m from extraction system | 1890 | 56 | 0.74 |
| 11195/05 | Imp/filter | Static 2 – 5 m from extraction system | 1890 | 66.3 | 2.17 |
| 11196/05 | 2 x filter | Static 2 – 5 m from extraction system | 1890 | 64.1 | 0.52 |
| Scenario 2- Repair inside curtained area with extraction system 2 on | | | | | |
| 11197/05 | Imp/filter | Replicate 1 | 105 | 4.2 | 81.7 |
| 11198/05 | Imp/filter | Replicate 2 | 115 | 4.6 | 962 |
| 11199/05 | Imp/filter | Replicate 3 | 115 | 4.6 | 330 |
| 11200/05 | Imp/filter | Replicate 4 | 90 | 3.6 | 476 |
| 11201/05 | Imp/filter | Replicate 5 | 110 | 4.4 | 96.9 |
| 11202/05 | Imp/filter | Replicate 6 | 85 | 3.4 | 219 |
| 11203/05 | Imp/filter | Replicate 7 (6 x sprays) | 820 | 32.8 | 62.3 |
| 11204/05 | Imp/filter | Static 1 – 1 m from repair | 2340 | 78 | 35.6 |
| 11205/05 | 2 x filter | Static 1 – 1 m from repair | 2340 | 69.4 | 23.6 |
| 11206/05 | Imp/filter | Static 2 – 5 m from repair, at curtain | 2340 | 82.1 | 54.2 |
| 11207/05 | 2 x filter | Static 2 – 5 m from repair, at curtain | 2340 | 79.4 | 23.5 |
| 11208/05 | Imp/filter | Static 3 – 6 m from repair, outside curtain main workshop | 2040 | 69.5 | 13.4 |
| 11209/05 | 2 x filter | Static 3 – 6 m from repair, outside curtain main workshop | 2040 | 72.9 | 16.5 |
| Scenario 3 - Repair inside curtained area with extraction system off | | | | | |
| 11210/05 | Imp/filter | Replicate 1 | 120 | 4.8 | 315 |

| Sample No. | Type | Samples details | Time (secs) | Volume (l) | NCO concentration ($\mu\text{g NCO}/\text{m}^3$) |
|--|------------|---|-------------|------------|--|
| 11211/05 | Imp/filter | Replicate 2 | 340 | 13.6 | 267 |
| 11212/05 | Imp/filter | Replicate 3 | 180 | 7.2 | 466 |
| 11213/05 | Imp/filter | Replicate 4 | 145 | 5.8 | 339 |
| 11214/05 | Imp/filter | Replicate 5 | 125 | 5 | 554 |
| 11215/05 | Imp/filter | Replicate 6 | 132 | 5.3 | 549 |
| 11216/05 | Imp/filter | Replicate 7 (6 x sprays) | 925 | 37 | 328 |
| 11217/05 | Imp/filter | Static 1 – 1 m from repair | 2640 | 88 | 254 |
| 11218/05 | 2 x filter | Static 1 – 1 m from repair | 2640 | 78.3 | 68.9 |
| 11219/05 | Imp/filter | Static 2 – 5 m from repair, at curtain | 2640 | 92.6 | 432 |
| 11220/05 | 2 x filter | Static 2 – 5 m from repair, at curtain | 2640 | 89.5 | 257 |
| 11221/05 | Imp/filter | Static 3 – 6 m from repair, outside curtain main workshop | 2640 | 90 | 98.7 |
| 11222/05 | 2 x filter | Static 3 – 6 m from repair, outside curtain main workshop | 2640 | 94.4 | 66 |
| Scenario 4 – Repair inside workshop doorway no extraction | | | | | |
| 11223/05 | Imp/filter | Replicate 1 | 110 | 4.4 | 90.4 |
| 11224/05 | Imp/filter | Replicate 2 | 60 | 2.4 | 153 |
| 11225/05 | Imp/filter | Replicate 3 | 50 | 2 | 107 |
| 11226/05 | Imp/filter | Replicate 4 | 100 | 4 | 87.2 |
| 11227/05 | Imp/filter | Replicate 5 | 75 | 3 | 109 |
| 11228/05 | Imp/filter | Replicate 6 | 60 | 2.4 | 83.3 |
| 11229/05 | Imp/filter | Replicate 7 (6 x sprays) | 480 | 19.2 | 65.1 |
| 11230/05 | Imp/filter | Static 1 – 5 m from repair in workshop LHS | 1260 | 42 | 103 |
| 11231/05 | 2 x filter | Static 1 – 5 m from repair in workshop LHS | 1260 | 37.4 | 69.7 |
| 11232/05 | Imp/filter | Static 2 – 5 m from repair in workshop RHS | 1260 | 44.2 | 112 |

| Sample No. | Type | Samples details | Time (secs) | Volume (l) | NCO concentration ($\mu\text{g NCO}/\text{m}^3$) |
|------------|------------|--|---------------------|------------|--|
| 11233/05 | 2 x filter | Static 2 – 5 m from repair in workshop RHS | 1260 | 42.7 | 78.6 |
| 11234/05 | 2 x filter | Static 3 – 2.5 m from repair, outside workshop | 1260 | 45.1 | 7.65 |
| - | Imp/filter | Static 3 – 2.5 m from repair, outside workshop | Pump failure | | |

Notes

Samples were taken according to MDHS 25/3, in addition dual filter static samples were taken for method development purposes. The results shown below are the total sampled onto both filters.

Samples were analysed for isocyanate (NCO) content by liquid chromatography with mass spectrometry (LC/MS). Quantification for all polymeric species was carried out using the response factor obtained from the isocyanurate standard.

Note the Workplace Exposure Limit (WEL) for total isocyanate is $20 \mu\text{g NCO}/\text{m}^3$ as an 8-hour time weighted average (TWA), or $70 \mu\text{g NCO}/\text{m}^3$ as a 15-minute TWA.

6.3 APPENDIX 3 - FULL RESULTS FROM VISIT 3

| Sample Number | Type | Samples details | Time (min:sec) | Volume (l) | NCO ng/sample | NCO $\mu\text{g m}^3$ |
|---|------------|---------------------|----------------|------------|---------------|-----------------------|
| Test 1, 1st coat = 15 s spraying, 15 s pause, 2nd coat = 35 s spraying | | | | | | |
| HSL/02724/06 | Imp/filter | Pump 24, personal | 10:10 | 10.6 | 2160 | 205 |
| HSL/02725/06 | Imp/filter | Pump 3, position 1 | 31:30 | 31 | 4370 | 141 |
| HSL/02726/06 | Imp/filter | Pump 1, position 2 | 31:15 | 32.4 | 10100 | 310 |
| HSL/02727/06 | Imp/filter | Pump 14, position 3 | 31:30 | 32.1 | 6970 | 217 |
| HSL/02728/06 | Imp/filter | Pump 4, position 4 | 15:00 | 15.3 | 312 | 20.4 |
| HSL/02729/06 | Imp/filter | Pump 19, position 5 | 15:00 | 14.7 | ND | ND |
| HSL/02730/06 | Imp/filter | Pump 9, position 6 | 12:55 | 13 | Detected | Detected |
| HSL/02731/06 | Imp/filter | Pump 27, position 7 | 13:30 | 13.9 | Detected | Detected |

| Sample Number | Type | Samples details | Time (min:sec) | Volume (l) | NCO ng/sample | NCO $\mu\text{g m}^3$ |
|---|------------|---------------------|----------------|------------|---------------|-----------------------|
| HSL/02732/06 | Imp/filter | Pump 20, position 8 | 13:30 | 13.7 | ND | ND |
| HSL/02733/06 | Imp/filter | Pump 26, position 9 | 13:25 | 12 | Detected | Detected |
| Test 2, 1st coat = 25 s spraying, 12 s pause, 2nd coat = 52 s spraying | | | | | | |
| HSL/02734/06 | Imp/filter | Pump 24, personal | 4:10 | 4.4 | 3890 | 888 |
| HSL/02735/06 | Imp/filter | Pump 3, position 1 | 18:05 | 18.5 | 3620 | 197 |
| HSL/02736/06 | Imp/filter | Pump 1, position 2 | 18.05 | 18.3 | 3500 | 191 |
| HSL/02737/06 | Imp/filter | Pump 14, position 3 | 17:15 | 17.4 | 5340 | 306 |
| HSL/02738/06 | Imp/filter | Pump 4, position 4 | 12:35 | 13.1 | 312 | 23.9 |
| HSL/02739/06 | Imp/filter | Pump 19, position 5 | 12:25 | 12.4 | Detected | Detected |
| HSL/02740/06 | Imp/filter | Pump 9, position 6 | 11:10 | 11.7 | Detected | Detected |
| HSL/02741/06 | Imp/filter | Pump 27, position 7 | 10:40 | 11.3 | ND | ND |
| HSL/02742/06 | Imp/filter | Pump 20, position 8 | 10:35 | 10.9 | ND | ND |
| HSL/02743/06 | Imp/filter | Pump 26, position 9 | Pump failure | | | |
| Test 3, 1st coat = 44 s spraying, 11 s pause, 2nd coat = 41 s spraying | | | | | | |
| HSL/02744/06 | Imp/filter | Pump 24, personal | 4:00 | 4.2 | 7620 | 1820 |
| HSL/02745/06 | Imp/filter | Pump 3, position 1 | 40:42 | 41.2 | 8750 | 213 |
| HSL/02746/06 | Imp/filter | Pump 1, position 2 | 41:30 | 42.1 | 1600 | 38 |
| HSL/02747/06 | Imp/filter | Pump 14, position 3 | 39:50 | 40.2 | 10800 | 269 |
| HSL/02748/06 | Imp/filter | Pump 4, position 4 | 39:33 | 42 | 480 | 11.4 |
| HSL/02749/06 | Imp/filter | Pump 19, position 5 | 40:10 | 40.8 | 214 | 5.25 |
| HSL/02750/06 | Imp/filter | Pump 9, position 6 | 19:00 | 20 | ND | ND |
| HSL/02751/06 | Imp/filter | Pump 27, position 7 | 19:15 | 19.1 | Detected | Detected |
| HSL/02752/06 | Imp/filter | Pump 20, position 8 | 19:30 | 19 | ND | ND |

| Sample Number | Type | Samples details | Time (min:sec) | Volume (l) | NCO ng/sample | NCO $\mu\text{g m}^3$ |
|--|------------|---------------------|----------------|------------|---------------|-----------------------|
| HSL/02753/06 | Imp/filter | Pump 26, position 9 | 19:25 | 19.8 | Detected | Detected |
| Test 4, single coat = 39 s spraying | | | | | | |
| HSL/02754/06 | Imp/filter | Pump 24, personal | 2:40 | 2.5 | 2220 | 906 |
| HSL/02755/06 | Imp/filter | Pump 3, position 1 | 20:55 | 21.2 | 3080 | 146 |
| HSL/02756/06 | Imp/filter | Pump 1, position 2 | 20:25 | 20.7 | 3030 | 146 |
| HSL/02757/06 | Imp/filter | Pump 14, position 3 | 21:05 | 21.6 | 3370 | 156 |
| HSL/02758/06 | Imp/filter | Pump 4, position 4 | 18:30 | 19.2 | 143 | 7.48 |
| HSL/02759/06 | Imp/filter | Pump 19, position 5 | 18:35 | 19.6 | ND | ND |
| HSL/02760/06 | Imp/filter | Pump 9, position 6 | 9:30 | 9.91 | ND | ND |
| HSL/02761/06 | Imp/filter | Pump 27, position 7 | 9:25 | 10.0 | ND | ND |
| HSL/02762/06 | Imp/filter | Pump 20, position 8 | 9:25 | 9.8 | ND | ND |
| HSL/02763/06 | Imp/filter | Pump 26, position 9 | 9:45 | 10.1 | ND | ND |
| Other samples | | | | | | |
| HSL/02764/06 | Imp/filter | Blank 1 | - | - | ND | ND |
| HSL/02765/06 | Imp/filter | Blank 2 | - | - | ND | ND |
| HSL/02766/06 | Imp/filter | Blank 3 | - | - | ND | ND |

Notes.

Samples were taken according to MDHS 25/3.

Samples were analysed for total isocyanate content, as monomeric Hexamethylene diisocyanate and its oligomers and polymers, by liquid chromatography with mass spectrometry (LC/MS). The results calculated are expressed as an airborne concentration.

Please note the workplace exposure limit (WEL) for isocyanate is $20 \mu\text{g NCO/m}^3$ (8 hour limit) or $70 \mu\text{g NCO/m}^3$ (15 minute).

Estimated analytical uncertainty = $\pm 30\%$

Reliable limit of quantitation, based on a 15 minute, 15 litre sample = $5 \mu\text{g NCO/m}^3$.

ND = not detected, i.e. below the limit of detection (estimated at 2 $\mu\text{g NCO/m}^3$).

Detected = Isocyanate has been detected in the sample but the amount is small enough that the result cannot be quantified with confidence i.e. < 5 $\mu\text{g NCO/m}^3$.

All four tests used the same paint, which was identified by LC/MS as containing predominantly HDI isocyanurate, with traces of HDI monomer and HDI diisocyanate present. Note the diisocyanate was quantified using the response factor from the isocyanurate standard