

Isocyanate exposure control in motor vehicle paint spraying: evidence from biological monitoring

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Aims: The purpose of this work was to assess the changes in control of exposure to hexamethylene diisocyanate based paints used in vehicle spraying after a Health & Safety Executive (HSE) national project.

Methods: Paint sprayers and managers from motor vehicle repair (MVR) bodyshops across the UK, were invited to one of 32 Safety and Health Awareness Days (SHADs) to increase their understanding of the hazards, and practical ways of controlling of exposure to isocyanate based paints. Exposure measurement based on biological monitoring was offered, free of charge, to each of the roughly 4000 participants and used to assess the effectiveness of controls and methods of working. Results are compared with pre and post SHAD measurements.

Results: Urine samples were received from 995 paint sprayers. Hexamethylene diamine (HDA) levels in urine, indicative of exposure to hexamethylene diisocyanate (HDI), were significantly lower (Mann-Whitney, $p < 0.0001$) than had been seen in a wider population from previous HSE inspections and routine sampling. Where a sprayer's urinary HDA was above the quantification limit they were asked to send another sample after reviewing and improving exposure control measures. The results from these repeat samples were significantly lower than the original results. There was no difference in the exposures of sprayers using air-fed half-mask face-pieces compared with visor type air-fed breathing apparatus, or between spray booths and rooms.

Conclusions: The analysis of HDA in urine is a useful technique for assessing exposure to isocyanates in paint sprayers. The simplicity of this approach has allowed wide-scale use of biological monitoring in an industry dominated by small and micro businesses. Biological monitoring of exposure has enabled individual companies, and sprayers, to check that their control measures are working.

This study showed overall lower levels of HDA in paint sprayers following SHADs. These lower levels have been maintained across a wider population of UK paint sprayers over the succeeding years. Whilst there may be many reasons for the reduction in exposure, the weight of evidence suggests that the key messages about exposure control measures, delivered through the SHADs and other means, were influential.

Keywords: air-fed breathing apparatus; behaviour; biological monitoring; clearance time; exposure; HDI; improving control; isocyanates; motor vehicle repair; spray booths; spray painting; urine

INTRODUCTION

In 2001, the Health and Safety Executive (HSE) initiated a Disease Reduction Programme (DRP), with a key strand focussing on respiratory diseases. One DRP target was a 30% reduction in occupational

asthma by 2010. Isocyanates have long been recognised as the leading cause of occupational asthma in the UK (HSE, 2010a). Spray painters using isocyanate-based paints in the motor vehicle repair (MVR) industry were the work group at greatest risk, with eighty times the incidence compared to the UK industry average. There are approximately 21,000 spray painters in the UK of which MVR sprayers comprise about 60%, or about 12,000 workers.

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Over half work in small and micro businesses (fewer than ten employees) and many are the only painter (Broughton et al, 2010). There are about 8000 MVR bodyshops in the UK (HSE 2007a).

Initially it was not obvious why occupational asthma risk for MVR sprayers was so high. Most worked in specialised enclosing spray booths and wore air-fed breathing apparatus. Site visits, assessment of the hygiene literature and discussions with employers and industry suppliers showed:

- That none of the stakeholders questioned, including the suppliers, realised that spraying created a fine invisible paint mist, or,
- That airborne isocyanate concentrations created during spraying are high; in spray booths (comprising cross-draft, semi-downdraft and wet-back booths) and downdraft booths (with air blown in through ceiling filters and extracted, usually through a pit in the floor) they are in the hundreds of micrograms per cubic metre of air ($\mu\text{g}/\text{m}^3$) and in spray rooms (generally home-constructed internal rooms with rudimentary extraction and filters) often in the thousands of $\mu\text{g}/\text{m}^3$ (Pronk et al 2006, White et al 2006, Fent et al 2008).
- That many employer and supplier stakeholders did not realise that spray booths and rooms had a clearance time, and needed to be kept under slight negative pressure to prevent paint mist leakage (HSE 2008a)
- That many sprayers did not understand that lifting visors to examine the paint quality, or removing their respiratory protective equipment (RPE) before the booth/room has cleared could expose them to isocyanates (Williams et al, 1999).
- That appreciation of the health risk was misperceived, as was the main exposure route. When sprayers were asked what was the main risk from using 2-pack isocyanate paints they invariably, and wrongly, replied “cancer”. And when asked ‘*how does the isocyanate get into your body*’, many said that it went through the skin, some adding ‘*especially the thin skin around the eyes*’ (Coldwell and White 2005a/b; O’Hara, 2006a; HSE 2009a/b).

To improve understanding and awareness, and give advice on controlling exposure in ways accessible to small businesses, HSE developed the MVR Bodyshop Project (started in 2004, HSE, 2007a). The overall aim was to improve isocyanate exposure control by 2008 in at least 20% of premises (approximately 1600 MVR bodyshops) via three interlinked strands of work comprising:

- A programme of Safety and Health Awareness Days (SHADs) involving key stakeholders,
- On-site visits by HSE Inspectors or Health & Safety Awareness Officers, and,
- Engagement with third party stakeholders (spray booth and equipment manufacturers, local suppliers, trade associations, occupational health providers, training providers such as colleges).

Biological monitoring, based on the analysis of isocyanate-derived diamines in urine, can assess exposure to isocyanates, including the behavioural aspects of controls (Rosenberg & Savolainen, 1986; Williams et al, 1999; Gaines et al 2010). Prior to the SHADs HSE collected 1350 urine samples from workers in more than 160 bodyshops (~2% of total UK bodyshops) over a ten-year period. Where ‘good occupational hygiene practice’ was observed, results were generally ‘none detected’ (HSE 2005a). Following the UK approach of setting Biological Monitoring Guidance Values (BMGVs) at the 90th percentile, an isocyanate BMGV of 1 $\mu\text{mol}/\text{mol}$ creatinine was approved (HSE 2005b).

This paper describes the use of biological monitoring to assess isocyanate exposures during and after the SHADs.

METHODS

Format of Safety and Health Awareness Days (SHADs)

MVR bodyshop owners and managers, together with their sprayers were invited to attend a SHAD, by the local area HSE office. Invitations were not stratified by business size, and all bodyshops in a geographical area were contacted. The aim was to invite as many local businesses as possible. The SHADs (each a half-day event) provided spray painters, body shop managers and other industry representatives (as well as HSE and Local Authority Inspectors) with clear evidence of the harm caused by isocyanates, how exposures can occur, how to control exposures and simple ways of checking that controls are working and being used appropriately. Key messages included checking the clearance time of the booth, maintaining the booth under negative pressure and not removing RPE whilst in the booth. Speakers at the SHADS (from the MVR supply industry and HSE) gave short presentations involving clear explanatory videos and working model demonstrations of a spray booth and spray room. Drama by professional actors encapsulated key messages and further engaged the audiences (HSE, 2010b). The mixed-media format was developed

and structured based on previous HSE research into engaging with small and micro-businesses (Strutt et al, 2004). Part of the effective communication strategy included repeating key messages in a variety of different and engaging ways. The SHADs were piloted and amended to have maximum impact on bodyshop audiences, using before and after evaluation forms as simple measuring tools (O'Hara et al, 2006a).

SHADs sample collection

All attendees (approximately 4000) at the events were offered free biological monitoring sampling kits to check their exposure to isocyanates after making any changes they felt necessary as a result of information gained from the SHAD. Biological monitoring was conducted in accordance with HSE procedures (HSE, 1997) and volunteers gave informed consent. Participants were instructed to provide urine samples within an hour of the end of spraying due to the short half-life of HDA (roughly 2 hours, Brorson et al, 1990; Gaines et al 2010). An information sheet (HSL, 2007), packaging and postage were provided and samples were sent directly by the sprayer or bodyshop manager to the laboratory (to arrive within two days). A brief work task form was also provided, asking for consent, type of RPE, local exhaust ventilation and the duration of spraying. Type of RPE was divided into "air-fed full face", "air-fed visor" (where the visor is liftable), "air-fed half-mask", or "other" (for the worker to specify). Local exhaust ventilation was divided into "spray booths", "downdraft booths" and "spray rooms". Workers whose results were positive were offered a free re-test following any improvements in controls or their use (referring them to the information received during the SHAD). It was not possible to advise individually on necessary improvements prior to the re-test or to collate what action was taken in each case, however examples of improved practice (such as new working methods, measuring clearance time, new equipment) have been previously reported (O'Hara et al, 2006b).

Urine samples collected as part of the SHADs were compared to routine samples analysed by HSL before the campaign (2000 to 2004, N=433) and those analysed since (2008 to 2011, N=8374). Around half the pre-SHAD samples (213 out of 433 samples, 49%) were taken as part of HSE investigation visits whereas virtually all of the post-SHAD samples were provided independently by companies, following advice provided by HSE/HSL (HSL, 2007). In all cases samples were sent directly to the laboratory by post (to arrive within two days).

Analysis of urine samples

On receipt at the laboratory, all samples were stored frozen until analysis. In-house testing has shown that samples are stable (using sample bottles containing citric acid) for at least two days at room temperature and long-term (>4 weeks) when frozen at -20°C. Urine samples were analysed for hexamethylene di-isocyanate-derived diamine (HDA) by gas chromatography with mass spectrometric detection (Williams et al, 1999; Creely et al, 2006). Urine samples (2 ml) were hydrolysed with sulphuric acid (200 µl), made alkaline with 10M sodium hydroxide (2 ml) then extracted into ether (4 ml). The ether extract was evaporated under nitrogen and the residue derivatised with heptafluorobutyric anhydride. Excess derivatisation was removed by evaporation and samples were reconstituted in toluene for analysis. Aliquots (4 µl) were injected (splitless, 350°C) onto a BP-5 equivalent column (30m × 0.32mm, 1 µm film, helium flow 1 ml/min) at 100°C and the oven was ramped up to 300°C over 15 minutes. Detection was by negative ion chemical ionisation mass spectrometry (methane reagent gas) using selected ion monitoring (m/z 488 & m/z 448 HDA, m/z 462 internal standard (heptane diamine)). The quantification limit was 5 nmol/l (typically equivalent to 0.42 µmol/mol creatinine) and inter-assay variation was 14%.

Statistics

Due to the high proportion of samples below the quantification limit, descriptive statistics were restricted to ninetieth percentiles. The Mann-Whitney test was used to compare data for different air-fed breathing apparatus mask types. The Kruskal-Wallis test was used to compare data from the three different data sets (pre-SHAD, SHAD and post-SHAD) and from the three different spray booth/room types. Matched pairs Wilcoxon signed rank was used compare the data of individuals before and after any improvements in working practice or controls. These tests were chosen because they are fairly insensitive to censoring at the limit of detection, and suitable for non-parametric data. Kendall's tau-b was used to measure the correlation between reported spray time and reported paint volume used.

RESULTS

Four pilot SHADs were run in 2004, each with 50 – 75 participants. Following their success (O'Hara, 2006a), review and improvement, a further 28 events were held across the UK between 2005

Table 1. Comparison of data from before and after the SHAD events with that from SHAD attendees.

	N	%ND ^a	90 th percentile ^b	% > BMGV ^c
Pre-SHAD	433	66	1.34	14
SHAD	990	83	0.60	6
post-SHAD	8374	79	0.68	6
2008	1987	84	0.55	5
2009	1776	74	0.76	7
2010	2291	77	0.70	7
2011	2320	83	0.60	6

^aBelow the quantification limit (5 nmol/l, typically equivalent to 0.42 $\mu\text{mol/mol}$ creatinine)

^bResults in $\mu\text{mol/mol}$ creatinine

^cExceeded the Biological Monitoring Guidance Value (BMGV) of 1 $\mu\text{mol/mol}$ creatinine.

and 2007. Approximately 4000 people, representing 1400 bodyshops (18% of the UK total) attended a SHAD. Nine hundred and ninety five urine samples were received out of about 4000 kits issued, representing approximately a 25% return. Sample return rates for individual events ranged from zero to 80% with a trend for later events (in 2007) to have greater return rates, as knowledge and interest in the project from the industry increased. Eighty one percent of samples were returned with a work task form giving brief details of the work undertaken and personal protective equipment (PPE) used.

Levels of hexamethylene diamine (HDA) in urine samples ranged from below the quantification limit in 826 (83%) samples to a maximum of 20 μmol HDA /mol creatinine. Table 1 compares the data from SHAD events with the pre-SHAD data, and data from subsequent years following the end of the events. Using the Kruskal-Wallis test, there was a significant difference between the three groups ($p < 0.0001$) with both the SHAD attendees

and post-SHAD data being significantly lower (Mann-Whitney $p < 0.0001$ in both cases) than the pre-SHAD data. There was no significant difference (Mann-Whitney $p = 0.1011$) between the SHAD and post-SHAD data sets.

The use of the terms “air-fed full-face mask” and “air-fed visor” were used interchangeably by respondents (the majority in the industry use visor type face-pieces), and so could not be analysed separately. Eighty-five respondents (13% of those stating their mask (face-piece) type) reported using air-fed half-mask face-piece as opposed to visors. The biological monitoring results for each mask type are shown in Figure 1. Using the Mann-Whitney test, there was no significant difference ($p = 0.1239$) in urinary HDA levels between the two mask types.

Using the Kruskal-Wallis test, there was no significant difference ($p = 0.6459$, Figure 2) in urinary HDA levels between workers using any of the three main enclosing room types (spray booths, downdraft booths and spray rooms).

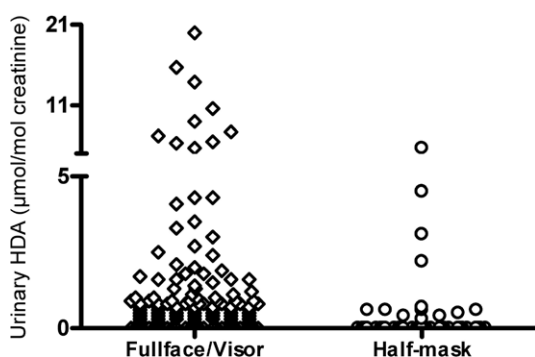


Fig 1. Comparison of urinary HDA results from workers wearing a full-face mask or visor (90th percentile = 0.6 μmol HDA/mol creatinine) and those wearing a half-mask (90th percentile = 0.5 μmol HDA/mol creatinine). All masks were air-fed. Difference is not statistically significant (Mann-Whitney, $p = 0.1239$).

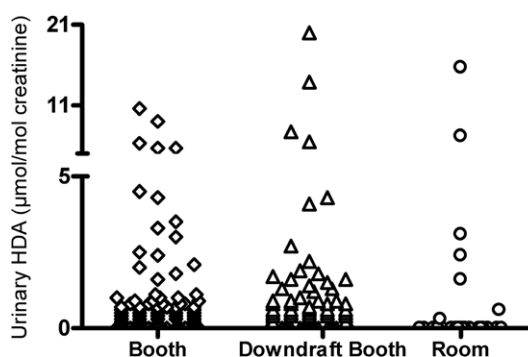


Fig 2. Comparison of urinary HDA results from workers using a booth (90th percentile = 0.6 μmol HDA/mol creatinine), a downdraft booth (90th percentile = 0.6 μmol HDA/mol creatinine) or a spray room (90th percentile = 2.8 μmol HDA/mol creatinine). Differences are not statistically significant ($p = 0.6459$, Kruskal-Wallis test).

The work task forms also requested details of the spray duration and the volume of paint used prior to providing the sample submitted for analysis. The Kendall's tau-b correlation between these two variables was 0.5126 ($p=0.0000$), indicating that there is (as would be expected) a positive correlation between the volume of paint used and the time taken to spray. This suggests that workers' responses on the task forms were real and accurate. The work task forms also indicated that nearly 95% of samples (408 out of 432 forms analysed) were provided within the requested one hour from the end of spraying. The maximum time reported (in the forms analysed) between spraying and sampling was three hours.

In 52 of the 168 cases (31%) where the initial sample was quantifiable for isocyanates, a repeat sample was submitted after an evaluation of controls and working practices. Eighty-five percent of the repeat samples (after any necessary changes) were below the quantification limit and the results were significantly lower than the initial results ($p < 0.0007$, matched pairs Wilcoxon signed-rank test) (Figure 3). This does not conclusively demonstrate that the reduction is due to improved control because only

workers with quantifiable results were selected for repeat sampling. However the consistent reduction in the repeat samples (only two samples were higher on re-test) makes this the most likely explanation.

As a result of the HSE MVR project SHADs, follow-up inspections/visits and issue of guidance by HSE (HSE, 2009a), use of biological monitoring in the MVR bodyshop industry has increased substantially (samples received by HSL for analysis, Figure 4).

DISCUSSION

The aim of the HSE MVR Bodyshop Project was to demonstrably improve exposure control measures for isocyanates in at least 20% of UK MVR bodyshops (HSE 2007a). In this kind of intervention practical difficulties make it impossible to demonstrate conclusively by biological monitoring that exposure has been reduced, but the results, in conjunction with supporting evidence, make it highly likely that this is the case.

The exposure control measures in this, as in many cases, are a mixture of having the correct equipment and understanding and adopting the correct methods of working (Figure 5). At each SHAD the HSE speaker made clear that the risk of occupational asthma was preventable, and the bulk of each event focused on simple, practical control measures. Post event questionnaires showed the SHADs were very well received by the audience and substantially improved their knowledge of the hazards of isocyanates, the means of controlling exposure and how to check control measures were working. Eighteen percent of UK body shops attended a SHAD and 90% of attendees intended to take some action to improve their control of exposure to isocyanates (O'Hara, 2006a). A follow-up survey, after one of the pilot events, found that over 50% of MVR bodyshops had actually improved exposure control measures (O'Hara et al, 2006b). A subsequent independent evaluation of the project impact (Broughton et al, 2010) showed that some of the key messages, for instance, concerning spray booth clearance time, have been adopted in the large majority of UK bodyshops.

Biological monitoring for isocyanates derived diamines in urine is a simple, non-invasive and direct measure of the effectiveness of exposure controls. Where control measures involve a mix of options, especially where these involve RPE and correct methods of working, biological monitoring is often the only practical method of checking that exposure is adequately controlled. As such it is a recommended occupational hygiene technique in the Control of Substances Hazardous to Health (COSHH) Regulation 10 Approved Code of Practice (HSE 2005c, para 190).

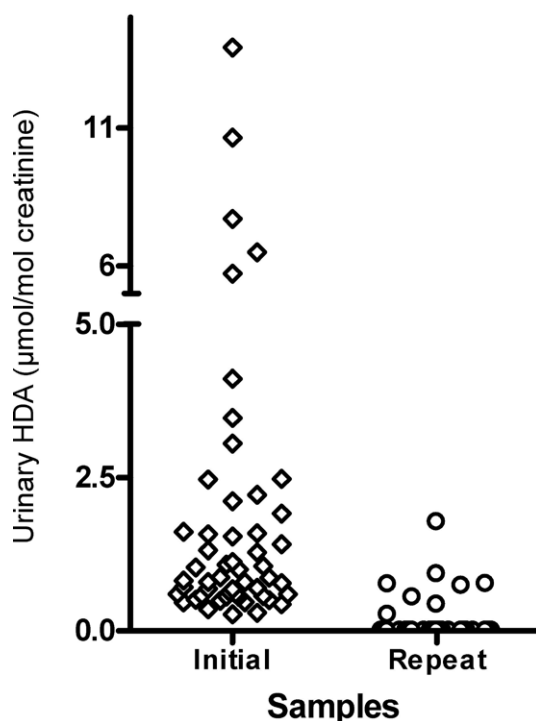


Fig 3. Repeat urinary HDA results from workers whose initial test result was positive. Difference is statistically significant (matched pairs Wilcoxon signed-rank test, $p=0.0007$).

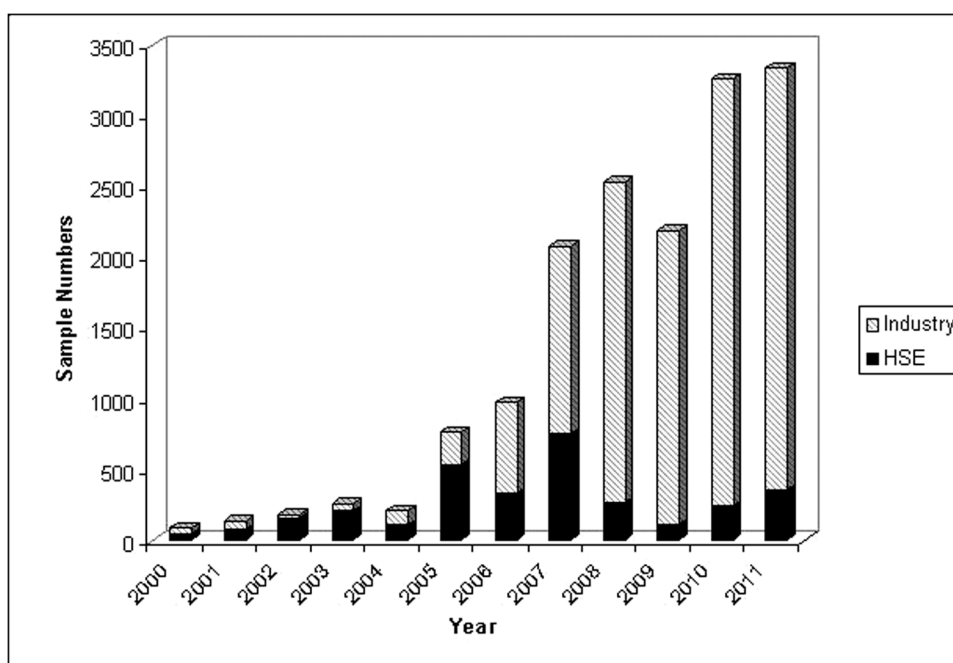


Fig 4. Samples received by the Health & Safety Laboratory for analysis showing increased use of isocyanate biological monitoring for sprayer exposure over time (HSE MVR project samples within 2004 – 2008). Samples received from either “HSE” (through research, inspections or the SHAD programme) or “Industry” (directly from individual companies or occupational health providers).

The metabolism of HDI and its oligomers is not well understood so extrapolating from biological monitoring results to inhaled concentrations of isocyanates is problematic. Volunteer studies show a good correlation between airborne concentrations of HDI monomer and urine HDA with predicted concentrations at the United Kingdom Workplace Exposure Limit ($20 \mu\text{g}/\text{m}^3$ NCO, HSE 2011) between $10 \mu\text{mol}$ HDA /mol creatinine (Maitre et al 1996) and $30 \mu\text{mol}$ HDA /mol creatinine (Brorson et al 1990). However, the concentration of HDI monomer in paints is usually less than 1% with the major components being various HDI oligomers (Rosenberg & Savolainen 1986, Fent et al 2008). Rosenberg and Savolainen (1986) exposed 5 car painters for 15 minutes without respiratory protection to HDI based paints at a concentration of $118 \mu\text{g}/\text{m}^3$ (NCO). The concentration of isocyanates in the hardener was 0.24% monomer and 34% oligomer. The peak urine concentration of HDA occurred 15 minutes after exposure and averaged $63 \pm 33 \mu\text{mol}$ HDA /mol creatinine, suggesting that more than the monomer (which was only a minor constituent) was being detected. The results are broadly in line with expectations from volunteer studies using pure monomer. Whatever

the exact relationship between isocyanate diamines in urine and isocyanate in air, biological monitoring is still an effective way to assess the adequacy of exposure controls. In past studies it has been shown that, where controls are correctly selected, applied, and used correctly, no HDA is found in urine from sprayers (Rosenberg & Savolainen 1986; Williams et al, 1999; Creely et al, 2006).

Biological monitoring results from SHAD attendees were significantly lower ($p < 0.0001$) than had been seen in previous HSE inspections and routine sampling where there was no prior training or control information given (Table 1). This result must be interpreted with caution because it is possible that overall there was a difference between pre- and post- SHAD bodyshop populations. Some of the pre-SHAD bodyshops were visited because HSE inspectors were concerned at conditions however the majority were chosen because they were in a certain geographic area, and were visited as part of a local initiative. Similarly for SHADs, all MVR bodyshops in a certain area were contacted and invited to attend. But, unlike HSE visits, invitees had a choice. It is likely that there will have been some selection bias with bodyshop managers/owners with an interest in occupational health attending. The impact of this

bias is likely to have been limited because, until the HSE MVR Project few bodyshops, or their suppliers, or indeed that many HSE staff, knew why and how sprayers (and others entering booths) were being exposed to isocyanate. Most sprayers, in most UK bodyshops, worked in spray booths or rooms, and wore air-fed breathing apparatus. The control issues were all about awareness of how exposure could occur, and the methods of working and behaviours to minimise exposure. Initially there would have been little difference between the bodyshop population visited before the Project, and those attending the SHADs. Both are likely to have had similar methods of working and behaviours. Thus, although there will have been some differences between the two bodyshop populations initially the impact on isocyanate exposure is likely to have been small. The results clearly suggest that SHAD attendees' expressed intention to act was actually carried out amongst a large proportion of the audience. Also, that information on how to improve, and check, exposure control measures, had not only been received but had been acted upon. Significantly reduced results upon

repeat testing of workers showing previously detectable HDA levels (Figure 3) is also consistent with workers acting on the information given when personal exposure was confirmed. The data also show that isocyanate exposure can be kept below the UK BMGV by bodyshops adopting good practice control measures (Figure 5).

Although the project appears to have been successful in reducing isocyanate exposure, there are a number of limitations that should be acknowledged. The project was not designed as a traditional 'intervention' study with a population evaluated before and after the SHADs and a 'control group'. In a work setting, where the change is based on risk and control information, it is difficult to set-up and separate such groups. Also it was HSE's intention to promulgate the control messages as widely as possible in order to protect health and "change the culture" of the industry. SHAD attendees were self-selected and at most only about a third of invitees actually attended. There is the possibility that they reflected the 'better end' of the industry, which already felt that they were legally compliant. Also, only a quarter

Isocyanate paint exposure "control measures "

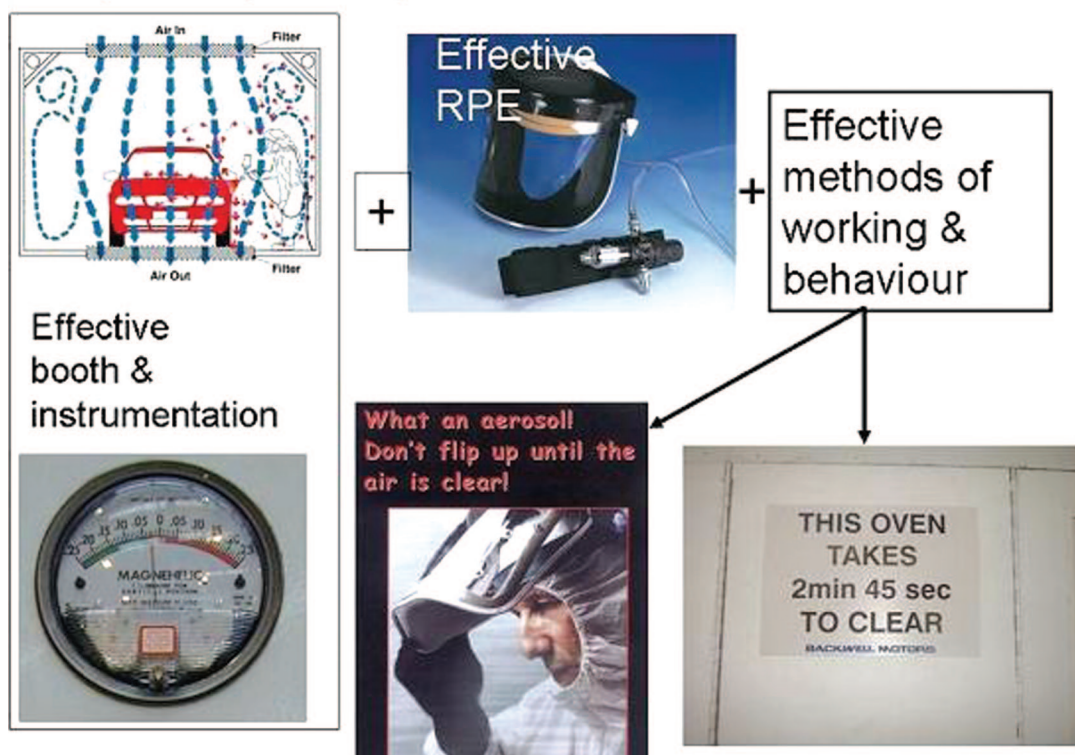


Fig. 5. Summary of Motor vehicle repair (MVR) bodyshop 2-pack isocyanate paint exposure control measures.

of the attendees returned urine samples and a similar selection bias may have applied. The pre-SHAD comparison population was more randomly selected because about half were visited as a result of routine inspections. The populations, pre- and post-SHAD attendees, may differ in commitment to health and safety management. It is also possible that some of the pre-SHAD and SHAD companies are the same i.e. that there is some overlap in the 'pre-' and 'post-' populations. Urine samples returned during the SHADs were not identified by individual company so it is not possible to define the degree of overlap. There may also be sampling time bias between the populations. About half of the pre-SHAD population provided urine samples at the end of a spraying session when the inspector or hygienist was on site (although the remainder were provided independently). SHAD attendees were unsupervised and simply asked to provide samples within an hour of the end of a spray event. Although there is no guarantee that all sprayers were compliant, analysis of a subset of work task forms showed that nearly 95% of samples were provided within an hour. The repeat sampling (where initial results were detectable and a second sample was collected, [Figure 3](#)) suggests that employers and sprayers could follow the simple sampling instructions.

A recent study reported by Gaines et al (2010) looked at workers exposed to HDI based paints and from 417 urine samples found detectable levels in 259 (62%) with a geometric mean of 0.1 µg/l and a geometric standard deviation of 6.68 µg/l, range <0.04 µg/l to 65.9 µg/l (~ <0.03 - 47 µmol/mol creatinine). Higher values were found by Pronk et al (2006) in 55 vehicle and industrial spray painters using HDI based paints. Median levels were around 20 µmol HDA /mol creatinine with a maximum of 150 µmol HDA /mol creatinine. The use of respiratory protective equipment (RPE) was described as 'widespread during spray painting' but the type was not identified. In both studies the maximum urinary HDA levels were higher than recorded in the UK. The reason for these differences are uncertain but the near-universal use of air-fed breathing apparatus in the UK is an important factor in minimising the exposures of UK sprayers.

During the development of the MVR project HSE had internal discussions about the type of air-fed breathing apparatus that should be recommended. The recommendation, since the 1980s, has been that sprayers should wear air-fed devices, but the exact type had not been specified (HSE, 1984). In practice MVR sprayers use air-fed breathing apparatus and choose either visor type face-pieces (BS EN

2000) or half-mask face-pieces (BS EN 1999). UK guidance indicates that air-fed breathing apparatus using visors has an assigned protection factor (APF) of 40, whereas apparatus using half-masks has an APF of 20 (HSE, 2005c). Therefore, according to the APFs, visors should provide greater protection than half-masks. In practice actual workplace protection factors are likely to be higher than the APF numbers indicate, and another factor comes into play. As with the selection of much personal protective equipment (PPE), it is better to choose the device that interferes the least with the task in hand, and is most comfortable and easy to wear. Interviews with sprayers, and observations, showed that sprayers tended to flip up their visor straight after spraying was finished. This was done because there's short window of time (10–20 seconds) while the paint film is 'wet' and can be added to. Sprayers flip up the visor to get the best view of the paint film so they can spray on additional paint in areas that need it, during the time window. Half-mask facepieces allow the best view of the new paint-film at all times whilst being protected from inhalation hazards, and for this reason many sprayers prefer them. The data in [Figure 1](#) show that there was no measured difference in average exposure between sprayers wearing air-fed visors, and half-masks. It would appear that air-fed half-masks can provide sufficient protection to protect sprayers from isocyanate exposure, in both spray booths and rooms.

There was no significant difference in exposure for paint sprayers using all types of ventilated enclosing room, although the numbers using spray rooms was small (n=25, 3%). Isocyanate exposures in spray rooms are usually far greater than in spray booths, often being in the thousands of micrograms per cubic metre of air (µg/m³) compared with the hundreds in booths. Despite the order of magnitude exposure differences, the biological monitoring results suggest that air-fed breathing apparatus can provide sufficient protection, when correctly used. This is in contrast to the work of Gaines et al (2011) where booth type was a significant factor; however the range of respirator types worn was greater in their study, including filtering respirators, with relatively low APFs.

Repeat sampling for sprayers who had previously tested positive (above the quantification limit) were significantly lower on re-test (p=0.0007, [Figure 3](#)). Effective isocyanate exposure control measures in MVR rely heavily on people, especially sprayers, behaving correctly and adopting the right working procedures ([Figure 5](#)). It is possible to reduce sprayer exposure by persuading them to work differently. Biological monitoring of exposure showed sprayers how exposed they were, and that this could be

minimised by changing their behaviour and working practices.

Biological monitoring is a simple and effective way to provide sprayers with personal exposure results and feedback. It also provides bodyshop managers/owners with an indication of where control measures may need improving. A recent telephone survey indicated that about 13% of the UK industry now measure exposure using biological monitoring, with about 25% take-up in medium-large companies and about 5% in small and micro-businesses (Broughton et al, 2010).

The levels of isocyanate exposure (as measured by biological monitoring) were lower after the SHADs than before. The post-SHAD data demonstrates that the biological monitoring results for subsequent years (for a much larger population of sprayers) are similar to the SHAD data and that these lower biological monitoring results are being maintained on a year-by-year basis some four years after the end of the project (Table 1). These data suggest that the key control messages have been fairly widely disseminated, and continue to influence working practice in a significant proportion of the industry. The post-project biological monitoring results, and other project assessment evidence, suggest that it is reasonable to infer that exposure control of isocyanates has improved in a significant proportion of bodyshops. Further consolidation work is needed, especially with the bodyshop micro-businesses.

Further details on isocyanate exposure control measures and guidance can be found on the HSE MVR Website (HSE 2007a, 2008a, 2009a/b). The HSE Sector Information Minute (HSE 2008b) summarises the issues, including the use of biological monitoring as a means of monitoring control of exposure to isocyanates.

CONCLUSIONS

The analysis of HDA in urine is a useful technique for assessing exposure to isocyanates in paint sprayers. The simplicity of this approach has allowed wide-scale use of biological monitoring in a primarily micro and SME dominated industry. Biological monitoring of exposure has enabled individual companies, and sprayers, to check that their control measures are working.

This study has shown overall lower levels of HDA in paint sprayers following SHADs. These lower levels have been maintained, across a wider population of UK paint sprayers over the succeeding years. Whilst there may be many reasons for the reduction in exposure, the weight of evidence suggests that the key messages about exposure control measures,

delivered through the SHADs and other means, were influential.

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An edited film of the SHAD, and a CD of the presentations is available from the corresponding author on application.

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