Usage of Air Monitoring and Biomarkers of Isocyanate Exposure to Assess the Effect of a Control Intervention

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Exposure to isocyanates is known to have respiratory effects in workers and therefore it is essential to monitor the occupational exposure. An earlier study of a continuous foaming plant using toluene diisocyanate (TDI) showed that the exposure to isocyanates can be high. Since then several preventive actions were implemented at the plant. The aim of this study was to observe the effect of these actions measured by air and biological monitoring. Four workers were monitored in the year 2000 and six in 2005, with air measurements during the continuous foaming process, and with measurements of biomarkers in one plasma sample each year and with two urinary samples being collected in the year 2000 and one in 2005. The median TDI air concentrations in 2005 were ~20% of the 2000 levels and the median levels of biomarkers in 2005 were ~10% of the 2000 levels. According to our measurements the preventive action had a real effect to decrease the exposure to TDI. As the workers both before and after the preventive actions used personal protective equipment, the use of biomarkers was necessary to assess the real gain in the preventive actions.

Keywords: biomonitoring; continuous foaming plant; control; occupational; polyurethane; TDI

INTRODUCTION

Exposure to isocyanates is known to have respiratory effects in workers (Ott et al., 2003) and therefore it is essential to monitor the occupational exposure. The aromatic diisocyanates toluene diisocyanate (TDI) and methylene diphenyl diisocyanate (MDI) are the most used isocyanates and comprise ~90% of the total diisocyanate market (Allport et al., 2003b). The major use is in the production of polyurethanes such as flexible and rigid foam.

The most common way to monitor the exposure is by measuring the isocyanates in the air, and the production of flexible foam in continuous foaming plants was one of the first work environments studied regarding occupational exposure to TDI (Peters et al., 1970). Several publications have since then reported air levels of TDI in continuous foaming plants (Dharmarajan et al., 1978; Rando et al., 1987; Jones et al., 1992; Omae et al., 1992; Cummings and Booth, 2002) and have shown that the exposure to TDI can be high. Biomarkers of exposure have also been used for workers in continuous foaming plants (Maire et al., 1993; Persson et al., 1993; Carbonelle et al., 1996; Tinnerberg et al., 1997; Kääria et al., 2001). Biomarkers in urine have a short half-life, about 2–8 h (Lind et al., 1997) reflecting the exposure during the sampling day. The half-life in plasma is ~20 days (Lind et al., 1996) and reflects the exposure during the last month. Biomarkers are of special interest in this environment as the workers regularly use personal protective equipment (PPE) during at least a part of the foaming process and air monitoring is very difficult to perform under PPE. There is also a discussion in the literature what role dermal exposure of isocyanates has for development of asthma and how to prevent and assess dermal exposure (Bello et al., 2007). However, it is not known if dermal exposure to isocyanates can be seen with an increase in the level of biomarkers, but this is indicated in some studies (Creely et al., 2006; Robert et al., 2007).

In 2000 we performed a survey of isocyanate exposure in 13 Swedish industries where the exposure was assessed by air and biological monitoring (Sennbro et al., 2004b,c). One of these 13 industries was...
a continuous foaming plant that showed high exposure to isocyanates. Since then a number of technical improvements had been performed at that plant to reduce the exposure to TDI. The reasons for the performed improvements were in part not only the measured high exposure levels but also a need to modernize the continuous foaming machine due to age.

The aim of this study was to investigate the exposure to TDI using biological and air monitoring in a continuous foaming slab stock plant before and after a number of preventive actions.

**MATERIALS AND METHODS**

**Continuous foam process**

Continuous foam process or flexible polyurethane foam slab stock production is a process where a mix of the foam is continuously dispensed onto a carrier paper on a conveyor which then draws the rising foam into a ventilated tunnel (Allport et al., 2003a). The rising foam is surrounded by top and side papers. When the foam has risen to the right size and stabilized, the papers are removed. The area of the produced foam is typically around 1 \times 2 m and the length depends on the storing facilities. At the end of the tunnel the foam blocks are sawn in appropriate length. The ready-made foam blocks need to be stored for at least 24 h before further processing.

**Description of the plant in the year 2000**

The plant manufactured TDI-based flexible polyurethane foam in a semi-enclosed ventilated tunnel system. The dimensions of the tunnel were approximately 2.2 \times 3 \times 58 m. At the end of the tunnel the foam blocks were sawn in 60-m pieces and stored in a storage area. The stripping of the side, bottom and top paper and the sawing of the blocks were located outside the foaming tunnel. The ventilation airflow rate during foaming was around 50,000 m$^3$ h$^{-1}$ with ducting situated along the tunnel. Different qualities are produced in different colours. When during the continuous foaming process the quality was changed, seen as a mix of two colours, the ‘mixed’ part was removed at the saw and was placed in the working area next to the foaming line before moving to destruction. Also the start piece, which cannot be used in the further production, was placed in the working area.

PPE (half-masks, type Sundström SR 100 + pre-filter SR221 + particle filter SR 510P3 + gas filter SR 294 ABE2; Sundström Safety AB) were used by personnel working close to the mixer during the foaming and when working inside the tunnel during start-up and at termination of the process.

**Preventive actions between 2000 and 2005**

The semi-enclosed foaming tunnel was replaced by an enclosed and more airtight system and also extended closer to the mixer. The area of the inlet of the tunnel was reduced to increase the speed of the ventilation air inside the tunnel. To maintain a laminar airflow around the mixer towards the ventilation duct, sheets were placed at the mixer. The stripping of the side, bottom and top paper and the sawing of the blocks were now also in the enclosed area. The amount of amine in the mixture was reduced by ~15%, giving a slower reaction. The slower reaction made it possible to widen the top paper by 10–15 cm (5–7%) without causing splits in the foam. The widening of the top paper probably reduced the TDI exposure inside the tunnel as the foam surface where unreacted TDI could emit was decreased. The ventilation airflow rate was the same as in 2000. At last, the start and mixed foam parts were now immediately moved outside the building which probably reduced the emissions of TDI.

The PPEs used in 2000 were replaced by a full-face mask system (Sundström SR 200 + pre-filter SR221 + particle filter SR 510P3 + gas filter SR 294 ABE2; Sundström Safety AB). The filter type was the same as before but the new masks could also be connected to compressed fresh air by airline connections along the tunnel. The employer required that the employees use PPE during the continuous foaming process. The new masks had a built-in communication radio system which allowed the workers to communicate with each other without taking the masks off resulting in a more disciplined usage of the PPE. The filters were replaced every week or earlier according to instructions from the supplier. The workers used the same type of gloves both in 2000 and 2005 and there were no obvious changes in the use of gloves between the years. During foaming, ordinary working gloves made of leather was used but sometimes latex gloves were used when handling the mixer. The workers usually wore ordinary working clothes. Short sleeves were used at both the monitoring days but long sleeves are preferred during wintertime.

**Description of the work procedure at the continuous foaming plant**

Each day the foaming line was used for ~2 h, usually between 10 a.m. and 12 noon. At the start of the foaming process two workers are situated inside the tunnel until the foam has moved to the place in the tunnel where the top and side papers are removed from the rising foam. The time spent inside the tunnel is ~5 min. In 2000 this work were performed by Workers B and D and in 2005 this was performed by Workers B and E. During foaming one worker (A) observed the process on a computer close to the mixer. Two workers (B and E) were occupied at the mixer and top paper and two workers (D and F) were occupied further down the tunnel handling the side papers. One worker (C) was operating the saw...
and cutting the foam in blocks. During the rest of the working day, the workers were occupied with preparation for the next foaming, taking care of mixed foam pieces and used papers, cleaning, administrative or complementary work or maintenance. Worker A had most administrative and management tasks and Worker C worked together with the primary storing facilities. The other four workers had very varying tasks. Exposure to TDI could occur when the storing tanks were filled with new TDI which was performed together with the driver who delivered it to the plant. However, this work was performed in a totally enclosed system. New TDI was delivered about —one to two times per week, but not on any of the days sampled. When working with complementary work, especially inside the tunnel or when taking care of used paper and mixed foam pieces, there could be contact with newly made foam. Further, when cleaning the mixer usually the polyol was used and this could result in dermal exposure to foam. This work was performed by Workers B, D, E or F. There was no rotation between the workers and the workers participating in the study in 2000 were working at the same positions during foaming in 2000 as in 2005.

Air sampling methods

2000 Both stationary and personal air samples were collected using a single filter impregnated with 1-(2-methoxyphenyl)piperazine (2MP method) (HSE, 1999). Immediately after sampling, the filters were transferred to glass vials containing 2MP reagent in toluene. The samples were kept away from light and stored in a refrigerator until analysis.

2005 Stationary air samples were collected using an impinger flask containing 0.01 M di-butylamine (DBA) in toluene, in series with a filter (DBA method) (Spanne et al., 1996; Karlsson et al., 2000). Immediately after sampling, the impinger solution was transferred to a glass vial containing 0.01 M DBA in toluene. After transport to the laboratory all samples were stored at −20°C until analysis.

Personal air samples were collected using a modified 2MP method with double filters impregnated with 1-(2-methoxyphenyl)piperazine (FINMP method) (Henriks-Eckerman et al., 2002). Immediately after sampling, the filters were transferred to glass vials containing acetonitrile. After transport to the laboratory all samples were stored at −20°C until analysis.

Collection of air samples

Stationary samples were taken during foaming outside the tunnel close to the mixer, at the control panel a few metres from the mixer, close to the saw and between the mixer and the saw outside an office. The office is placed ~35 m from the mixer down the process line and the saw is ~25 m further down the process line. The stationary samples taken in 2005 were taken in the same places as described in 2000. The sampling times for stationary monitoring ranged between 10 and 20 min, except for the stationary samples collected at the saw and outside the office in 2000 when the sampling time was ~120 min.

In 2000 five workers worked at the department and four participated in the study. The fifth worker was absent on the day of monitoring. In 2005 six workers worked at the department and all six participated in the study. The air sampling was performed on a Tuesday in 2000 and on a Wednesday in 2005. Personal monitoring was performed both during foaming for 2 h and when no foaming was performed for 2 h. The filters were attached in the breathing zone outside the PPE. The sampling times for personal monitoring ranged between 107 and 127 min. Air sampling was performed during one work shift and the production was reported to be normal in both 2000 and 2005.

Collection of urine and plasma samples

Two urinary samples were collected in the year 2000 and one sample in 2005. Each sample was a pooled sample for each worker during the last 4 h of the work shift. This means that shortly after the foaming the workers urinated in the toilet and thereafter they collected all urine in the same bottle. When they finished for the day ~16.30, the workers urinated in the bottle. One urinary sample was collected the day when the air monitoring was performed and the other urine sample in the year 2000 was collected the day when the blood sample was taken. The blood samples were collected within a 2-week period of the air sampling using arm-vein puncture in Venoject® blood sampling tubes containing heparin. The plasma was separated by centrifugation at the laboratory and both the plasma and urine were stored at −20°C until analysis.

The study was approved by the Ethical Committee at Lund University, Sweden, and was performed with the written informed consent of the workers.

Analysis

Air samples The samples collected with the 2MP method and the FINMP method were quantified by high-performance liquid chromatography and tandem mass spectrometry (LC-MS/MS) as described by Östin et al. (2002) with the exception that a deuterium-labelled internal standard was used. The limit of quantification (LOQ) was 20 ng per sample.

The samples collected with the DBA method were quantified by LC-MS/MS as described by Karlsson et al. (1998). The LOQ was 2 ng per sample. The results from the DBA samples are given as the sum of the levels in the impinger and on the filter.

All samples were analysed regarding TDI, MDI, naphthalene diisocyanate (NDI), hexamethylene...
diisocyanate, isophorone diisocyanate and for the FINMP and DBA methods also methylisocyanate and isocyanic acid.

The biomarker levels in plasma and urine were analysed as described by Sennbro et al. (2003). After alkaline hydrolysis of human urine or plasma the corresponding amines were derivatised and analysed with gas chromatography mass spectrometry. The limit of detection was 0.1 ng ml⁻¹. All samples were analysed regarding toluenediamine, methylenediphenylamine and naphthalenediamine.

**Back-calculation of levels of biomarkers to air levels**

As the workers at the plant use PPE during the process, their total exposure cannot be assessed by air monitoring alone, as the air measurements were performed outside the PPE. One way to assess the exposure is by using levels of biomarkers and back-calculating it into air levels. These calculated air levels can then be compared with the occupational exposure limit (OEL). Sennbro et al. (2004c) presented correlations between measured air concentration of TDI and levels of biomarkers in hydrolysed urine and plasma. The correlations presented were better for groups than for individuals. We have back-calculated the median group exposure in air from both the median urinary and median plasma levels for the measurements performed in 2000 and 2005.

For urine the equation \( x = (y - 0.1)/2.2 \) was used for the total amount of excreted biomarker and for plasma \( x = (y - 0.01)/2.5 \) for the total amount of biomarkers. In the formulae \( x \) is the 8-h time-weighted average (TWA) air exposure in micrograms per cubic metre and \( y \) is the biomarker level in urine or plasma expressed in nanograms per millilitre.

**RESULTS**

**Air sampling of isocyanates**

The results from the stationary and personal sampling are displayed in Tables 1 and 2. When comparing 2000 with 2005, there is a decrease in the measured concentrations of TDI in air. For the stationary samples the most obvious decrease is for the sample taken outside the office and the decrease is less pronounced close to the mixer. For the personal measurements there is a decrease for all but one worker, who in fact had higher airborne exposure to 2,6-TDI in 2005 than in 2000. The median air concentrations in 2005 were \( \sim 20\% \) of the 2000 levels.

The samples taken when no foaming was performed showed no levels of 2,4-TDI both for 2000 and 2005, but levels up to 0.2 \( \mu \text{g m}^{-3} \) and 0.3 \( \mu \text{g m}^{-3} \) of 2,6-TDI were found in 2000 and 2005, respectively.

No other isocyanates in the air samples were detected above the limit of detection.

**Biomarkers of exposure**

The levels of biomarkers in hydrolysed urine and plasma are displayed in Fig. 1 and Table 3. For the respective worker the urine samples collected in 2005 were lower or much lower than the two samples collected in 2000. For the biomarker in plasma the workers had much lower concentrations in 2005 compared to 2000. The median levels of biomarkers in urine and plasma were about 9–14% in 2005 compared to the levels in 2000.

When back-calculating the air concentrations of TDI (Table 2) from the group median levels of biomarkers in urine, the air level in 2000 was 18.8 lgm⁻³ and that in 2005 was 1.6 lgm⁻³. For the same calculations for the biomarkers in plasma the air level in 2000 was 15.1 lgm⁻³ and that in 2005 was 1.8 lgm⁻³.

No biomarkers of MDI or NDI exposure were detected above the limit of detection.

**DISCUSSION**

We have in this study used air and biological monitoring to assess the exposure to isocyanates at a continuous foaming plant before and after preventive actions to decrease the occupational exposure to TDI.

<table>
<thead>
<tr>
<th>Location</th>
<th>2000*</th>
<th>2005*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sampling</td>
<td>Sampling</td>
</tr>
<tr>
<td></td>
<td>time (min)</td>
<td>time (min)</td>
</tr>
<tr>
<td></td>
<td>2,4-TDI (( \mu \text{g m}^{-3} ))</td>
<td>2,6-TDI (( \mu \text{g m}^{-3} ))</td>
</tr>
<tr>
<td>Close to mixer</td>
<td>12</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Close to control panel</td>
<td>130</td>
<td>3.5</td>
</tr>
<tr>
<td>At the saw</td>
<td>128</td>
<td>4.6</td>
</tr>
<tr>
<td>Outside office</td>
<td>131</td>
<td>5.0</td>
</tr>
</tbody>
</table>

The stationary samples were taken at similar locations at the two occasions.

*Using the 2MP method.

*Using the DBA method.
With the air monitoring methods the decrease seems to be in the order of a factor 5 but with biological monitoring the decrease in exposure seems to be a factor 10. Biomarkers are preferred compared to air monitoring when assessing the effect of preventive actions when the workers are using PPE.

This study has several limitations and the most severe is probably the limited sample size. But all the workers at the department participated in the study during both occasions so the number of workers could not be increased. One could of course argue that the number of samples at each occasion could be increased. On the other hand when we performed the survey at 13 different plants in 2000 our intention at that time was to cover different uses of isocyanates and not to perform a follow-up after preventive actions.

### Table 2. Personal airborne exposure during 2 h during foaming, 2000 and 2005, and the ratio of the level in 2005 with the level in 2000

<table>
<thead>
<tr>
<th>Worker</th>
<th>2,4-TDI (µg m⁻³)</th>
<th>2,6-TDI (µg m⁻³)</th>
<th>Total TDI (µg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000⁰</td>
<td>2005⁰</td>
<td>2005/2000⁰</td>
</tr>
<tr>
<td>A</td>
<td>24.0</td>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>B</td>
<td>30.2</td>
<td>29.0</td>
<td>0.96</td>
</tr>
<tr>
<td>C</td>
<td>12.6</td>
<td>0.4</td>
<td>0.03</td>
</tr>
<tr>
<td>D</td>
<td>18.6</td>
<td>1.4</td>
<td>0.07</td>
</tr>
<tr>
<td>E</td>
<td>6.4</td>
<td>52.6</td>
<td>0.10</td>
</tr>
<tr>
<td>F</td>
<td>6.9</td>
<td>9.2</td>
<td>1.44</td>
</tr>
<tr>
<td>Median</td>
<td>21.3</td>
<td>3.9</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Back-calculated air levels from urine

- A: 18.8
- B: 15.1
- C: 11.7
- D: 10.7
- E: 9.2
- F: 8.1
- Median: 13.6

Back-calculated air levels from plasma

- A: 1.6
- B: 1.5
- C: 1.4
- D: 1.3
- E: 1.2
- F: 1.2
- Median: 1.3

The samplers were placed outside the PPE.

*Using the 2MP method.

*Using the FINMP method.

The calculated ratio between the measured levels in 2005 and 2000.

The back-calculated air levels were calculated from the group mean values of total amount of toluenediamine found in hydrolysed urine and plasma.

### Table 3. The biomarkers of exposure in hydrolysed plasma from 2000 and 2005

<table>
<thead>
<tr>
<th>Worker</th>
<th>Plasma P-2,4-TDA (ng ml⁻¹)</th>
<th>Plasma P-2,6-TDA (ng ml⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>27.2</td>
<td>0.7</td>
</tr>
<tr>
<td>B</td>
<td>10.5</td>
<td>2.0</td>
</tr>
<tr>
<td>C</td>
<td>2.9</td>
<td>0.5</td>
</tr>
<tr>
<td>D</td>
<td>3.6</td>
<td>0.6</td>
</tr>
<tr>
<td>E</td>
<td>1.3</td>
<td>3.0</td>
</tr>
<tr>
<td>F</td>
<td>1.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Median</td>
<td>7.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

TDA, toluenediamine.

*This is the calculated ratio between the measured levels in 2005 and 2000.

Fig. 1. The biomarkers of exposure in hydrolysed urine from 2000 and 2005. The first two bars for the respective worker reflect the measured toluenediamine in the two urine samples collected in 2000 and the third bar the results from 2005.
measures. However, the biomarker in plasma with a half-life \(\sim 3\) weeks is a measure of an integrated dose for a longer time, which makes it the most useful in assessing a change in average exposure and the decrease in the exposure levels is obvious.

For the measurements in air, different methods and techniques were used. For stationary sampling we used the filter-based 2MP method in 2000 and an impinger method with DBA in 2005. Sennbro et al. (2004a) did a comparison between these two methods and found that for short-term sampling, the DBA method gave \(\sim 10\%\) higher results than the 2MP method. Further for long-term sampling using the 2MP method a time-dependent decrease were seen. When interpreting the stationary samples with this in mind, a calculated ratio between 2005 and 2000 would be biased upwards. Two of the samples taken in 2000 had a sampling time of 2 h (saw and outside office) which according to Sennbro et al. (2004a) is an underestimation as there is a time-dependent decrease for long-term sampling. This would also bias a calculated ratio upwards. The observed changes for the stationary samples could be due to different time points for collection, but the decreases are large and further the decrease in the personal measurements and that for the biomarkers increase the credibility of the stationary samples.

For the personal monitoring two different 2MP methods were used (2MP and FINMP) and according to Sennbro et al. (2004a) the FINMP method collect \(\sim 10\%\) more 2,4-TDI than the 2MP method but there were no differences for 2,6-TDI. This will also bias the ratio upwards. There are no differences between FINMP and 2MP in the decrease for the long-term sampling (Mattsson et al., 2007). The results from the personal air samplings show that the levels of isocyanates have decreased compared with the study performed in 2000.

The same plant was studied previously in 1995 (Tinnerberg et al., 1997) but other air monitoring techniques and other methods for treatment of the biological samples were used which makes it difficult to compare the exposure levels directly. However, in 1995 the calculated 8-h TWA to TDI using a filter tape instrument was 30 \(\mu\)g m\(^{-3}\). This level could be compared with the measured air levels in 2000 and 2005 that, calculated as the 8-h TWA for the group from the levels of isocyanates. It is has long been known that dermal contact with TDI produces hypersensitivity in guinea pigs (Karol et al., 1981). Only recently there have been papers discussing how to assess the dermal exposure (Fent et al., 2006; Pronk et al., 2006). In a recently published review (Bello et al., 2007) it is stated that biomarkers could be an attractive way to monitor dermal exposure to isocyanates. It is also indicated that workers with large dermal exposure have increased

Because PPE was used during the foaming, isocyanate metabolites rather than air sampling will reflect the exposure of isocyanates. Further, because the variation in exposure at most workplaces differs considerably between days and the biomarker in plasma reflects the exposure for the last weeks, the biomarker may be the more interesting. The ratio between 2005 and 2000 for the biomarker in plasma indicates that the actual exposure has decreased with a factor between 10 and 20. The numbers would be lower if the calculations would be performed only on the four subjects who participated both in 2000 and 2005. The isocyanate metabolites in urine indicate an even larger decrease but are more influenced by a day-to-day variation.

When doing the back-calculation from levels of biomarkers to air concentrations, we simplify, for example for the individual metabolism of isocyanates, but the correlation between concentration of TDI in air and level of biomarkers is high, especially at a group level (Sennbro et al., 2004c). The calculated average 8-h TWA for the group from the levels of biomarkers is very low in 2005, between 1 and 2 \(\mu\)g m\(^{-3}\). This can be compared with the measured air level when calculated as 8-h TWA at 3 \(\mu\)g m\(^{-3}\).

As the workers are using PPE during the high exposure period the back-calculated levels were expected to be lower.

Further, the individual difference between the studied workers are high as Worker A has a back-calculated air exposure from the plasma biomarker at 1.5 \(\mu\)g m\(^{-3}\) and Worker B has a back-calculated air exposure at 3.6 \(\mu\)g m\(^{-3}\). These levels could be compared with the Swedish OEL (2 p.p.b.; 14 \(\mu\)g m\(^{-3}\)); the highest is about a factor 4 below the OEL, and the lowest about a factor 10, although the workers are using PPE during the continuous foaming work. In UK there is a control-based biological monitoring guidance value for isocyanates in urine of 1 \(\mu\)mol isocyanate-derived diamine/mol creatinine. To compare our results with the guidance value we need to correct our urine samples for creatinine and also adjust for different hydrolysis conditions (Sennbro et al., 2003) as in the UK acidic hydrolysis is used instead of alkaline hydrolysis. With these calculations two of the six workers had urinary levels over the guidance value in 2005.

One of the advantages with biological monitoring is that it takes all exposure routes into consideration. It is has long been known that dermal contact with TDI produces hypersensitivity in guinea pigs (Karol et al., 1981). Only recently there have been papers discussing how to assess the dermal exposure (Fent et al., 2006; Pronk et al., 2006). In a recently published review (Bello et al., 2007) it is stated that biomarkers could be an attractive way to monitor dermal exposure to isocyanates. It is also indicated that workers with large dermal exposure have increased.
levels of biomarkers (Creely et al., 2006; Robert et al., 2007). In this study the workers only used latex gloves for some tasks and for other tasks ordinary leather working gloves and further they were usually working with short sleeves. When this study was performed we unfortunately did not considered the possibility of dermal exposure to such a degree as we would have done today. However when interpreting the data, if dermal exposure produces biomarkers it could explain the relatively high levels of biomarkers compared with the measured air exposure, when also taking the use of PPE into account. Dermal exposure to isocyanates and the correlation to the biomarkers of exposure need to be further studied to better interpret biomonitoring data.

According to our measurements the preventive action has had a real effect at the continuous foaming plant to decrease the exposure to TDI. The airborne exposures have been reduced by about a factor 5 and the total exposures as measured with the biomarkers have been reduced with a factor 10. We think that the main reasons for the lowered TDI exposure are improved enclosure of the tunnel, new PPE with built-in communication radio and the possibility to connect the mask to compressed fresh airline system and better discipline using the PPE. As the workers both before and after the preventive actions used PPE, the use of biomarkers was necessary to assess the real gain in the preventive actions.

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