An evaluation of the respiratory health status of automotive spray-painters exposed to paints containing hexamethylene di-isocyanates in the greater Durban area

Bernard W Randolph, Umesh G Lalloo, Eleanor Gouws, Mark S E Colvin

Objective. A survey of automotive spray-painting establishments was undertaken to evaluate the respiratory health status of spray-painters exposed to paints containing hexamethylene di-isocyanates (HDIs).

Design. This was a cross-sectional study.

Setting. Spray-painting establishments in the Durban municipal area.

Participants. Spray-painters from a random sample of 40 (25%) of the registered spray-painting establishments were studied.

Main outcome measures. Responses to an interviewer-administered standardised respiratory health questionnaire and a cross-shift spirometric lung function test were obtained for each spray-painter; questionnaires assessing the firm's compliance with the spray-painting safety requirements were also obtained.

Results. The mean cross-shift decrease in forced expiratory volume in 1 second (FEV_1) was 130.5 ml (SD 203.19) ($P = 0.0002$). The lung function data indicated that of the 40 spray-painters examined, 10 (25%) showed clinically significant cross-shift decreases in FEV_1, viz. decreases > 250 ml. Only 2 subjects had a diagnosis of asthma. Chronic respiratory symptoms of cough, wheeze and wheeze with breathlessness were similar to those noted in community-based studies. A high proportion had eye irritation (55%) and dermatitis of the hand (32%).

Department of Environmental Health, Technikon Natal, Durban

Bernard W Randolph, MDipTech

Respiratory Unit, Department of Medicine, University of Natal, Durban

Umesh G Lalloo, MD, FCCP

Medical Research Council, Durban

Eleanor Gouws, BSc Hons

Mark S E Colvin, BSc, MB ChB, DOH

The potential determinants of FEV_1 were examined in a ultiple linear regression analysis and only the isocyanate oncentration levels approached statistical significance $P = 0.082$), suggesting that other factors such as duration f exposure, spray-paint 'bounce-back' phenomenon, and ealthy worker' effect may be more important. ('Bounce ack' refers to the phenomenon whereby some of the mist om the spray-gun, after striking the surface being ainted, is deflected back into the operator's breathing one in the form of fine droplets or aerosols.) Forty per ent of the 40 spray booths had ventilation standards ubstantially below that specified in current South African egislation. Only 21 (55%) spray-painters were provided vith the regulation respiratory protective equipment, and n the cases where it was provided, 7 (33%) of these spray-painters used the positive pressure air-line espirator recommended by the leading manufacturers of socyanate-based paints.

***Conclusions.* The findings in this study confirm the risk of exposure to HDIs in the spray-painting industry and highlight the need for more stringent industrial hygiene controls.**

S Afr Med J 1997; **87:** 318-323.

Isocyanate compounds, which include toluene di-isocyanates (TDIs) and hexamethylene di-isocyanates (HDIs), contain nitrogen, carbon and oxygen and are highly reactive with certain other chemical compounds, including human proteins.[1] Exposure to HDIs is known to cause irritation of contact areas and, in more severe cases, breathing difficulties, decrease in lung function and the sensitisation of the individual, with consequent asthma.[2]

It is well known that approximately 5 - 10% of workers exposed to TDIs develop asthma.[3] Typically, the asthmatic symptoms develop weeks or months after initial exposure. However, with HDIs the clinical hazards are not well documented. Inhalation appears to be a major hazard in the use of HDIs. The symptoms, depending on the total dose, may appear 4 - 8 hours after exposure and usually respond to supportive measures. It is important to note that since the cough and/or wheeze are frequently worse in the evening after leaving work, neither the medical practitioner nor the patient may relate the condition to the work situation.[4]

Four general patterns of respiratory response to HDIs have been described. These are chemical bronchitis, asthma in 'sensitised' workers, cross-shift decreases in forced expiratory volume in 1 second (FEV_1) and progressive decline in lung function following prolonged exposure.[5]

The problem of HDI exposure in the automotive industry has not been adequately documented. Routine inspection of automotive spray-booths by one of the authors (B W R) while employed as a Senior Inspector of Occupational Safety revealed that many spray-painters were using inadequate respiratory protective equipment and that, in some instances, the correct equipment was not provided.

A comprehensive investigation of the health status and the environmental conditions of automotive spray-painters was therefore undertaken.

Methods

Subjects

From a list of 163 spray-painting establishments registered with the Department of Manpower and the City Health Department, Durban, 40 establishments were sampled by means of a table of random numbers. Only 1 spray-painter at each establishment was selected for study. In 2 establishments where more than 1 worker was employed to undertake the spraying of motor vehicles, the longest-serving worker was investigated.

A Vitalograph Alpha, which conformed to the American Thoracic Society's (ATS) specifications, was used.[6] The spirometer was calibrated before each survey. Height of the subject (barefoot) was measured with a calibrated ruler. All tests were performed according to standardised ATS procedures. Subjects were allowed several practice attempts. The highest of three acceptable readings, which were within 5% of each other, was recorded.[6] Tests were performed with the subject loosely clothed in the standing position[7] without shoes. The spirometric readings were taken before and after each work shift, which involved a full vehicle respray lasting approximately 30 minutes.

The microprocessor within the Vitalograph Alpha automatically calculated the vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC, forced expiratory flow in the middle half of the FVC ($FEV_{25-75\%}$) and peak expiratory flow (PEF). The European Community Coal and Steel (ECCS) predicted values were used, which were discounted by 15% for non-whites.[8]

The following three questionnaires were completed by one interviewer (B W R): (*i*) the employers' questionnaire, which was concerned with an employer's attitudes towards his spray-painting staff with regard to health and safety matters; (*ii*) a general questionnaire on the employee's knowledge of the safe handling of paints containing HDIs; and (*iii*) a detailed respiratory health questionnaire based on the standardised ATS questionnaire.[6]

From each of the 40 spray-booths, one sample of airborne isocyanate group concentration was taken during a complete respray of a motor vehicle and analysed in accordance with the protocol of the National Institute for Occupational Safety and Health.[9]

To investigate spray-booth efficiency, airflow measurements were also taken inside the spray booths using a calibrated Airflow thermal anemometer model TA-2-2 (Airflow Developments, UK). These measurements were then evaluated against a prescribed airflow standard.[10]

Turbulence was assessed by use of the standard Dräger smoke tube and plotting of the resultant airflow patterns.

Statistical analysis

Data from the study on the lung function results were analysed using the SAS version 6.04 statistical package.[11] A paired *t*-test was used to compare the cross-shift decrease in FEV_1, and the prevalence of symptoms in smokers and non-smokers was compared using the chi-square test.

The potential determinants of FEV_1, viz. age, length of service, smoking status, booth type, booth efficiency, turbulence, isocyanate index, respirator type, mask usage factor and day of the week when sampled, were examined in a stepwise multiple linear regression analysis.

Results

Forty establishments were studied, which included 40 spray-painters. The questionnaires were completely filled in and a 100% response was obtained for all aspects of the study. The demographic data, including baseline spirometric lung function results and isocyanate concentration levels, are presented in Table I. Concentration levels are expressed as 'index values' i.e. the concentration divided by the threshold limit values (as defined in the ACGIH 1991/92 booklet). In this study, the Oregon permissible exposure limit (PEL) of 1 mg/m^3 for HDI polyhexamethylene di-isocyanates was used as a suitable comparison.[12]

Table I. Demographic data, lung function results and isocyanate exposure levels of 40 spray-painters* exposed to paints containing HDIs

	Mean	SD	Range
Age (yrs)	32.03	8.17	20 - 55
Height (cm)	169.95	8.75	137 - 188
Length of service (yrs)	11.90	8.07	1 - 30
Spirometric lung function pre-test results			
FVC (meas) [l]	4.41	1.11	0.77 - 6.59
FVC (pred)† [l]	3.95	0.49	2.19 - 4.95
FVC (% pred)	109.98	20.24	35.16 - 157.57
FEV_1 (meas) [l]	3.61	0.91	0.70 - 5.67
FEV_1 (pred)† [l]	3.33	0.41	1.98 - 4.14
FEV_1 (% pred)	107.03	20.56	35.35 - 152.80
PEF (meas) [l]	569.30	110.00	210 - 785
PEF (pred)† [l]	491.15	59.94	356 - 636
PEF (% pred)	115.70	17.76	59 - 146
Isocyanate group levels			
Concentration (mg/m^3)	6.46	6.64	ND - 23.5
Index = conc/PEL	6.46		

ND = not detected; meas = measured; pred = predicted.
PEL for polyhexamethylene di-isocyanate = 1 mg/m^3 (Oregon).
* 20 coloureds, 15 Indians, 3 whites, 2 blacks.
† ECCS predicted spirometric lung function values, and also reflected values discounted for non-caucasian subjects.

The low FVC and FEV_1 and height of 1.37 m presented in Table I were attributable to a spray-painter with kyphoscoliosis. In view of the small numbers in each race group, the data were analysed with the four groups combined. The number of subjects in each race group is indicated in the footnote to Table I. The prevalence of chronic respiratory symptoms in the 40 spray-painters is shown in Table II.

Table II. Prevalence of chronic respiratory symptoms of 40 isocyanate-exposed automotive spray-painters in relation to smoking status

Respiratory symptoms	Ever smoked (N = 27)		Never smoked* (N = 13)		All (N = 40)	
	No.	%	No.	%	No.	%
Usual cough	8	29.6	2	15.4	10	25.0
Usual phlegm	9	33.3	2	15.4	11	27.5
Ever wheeze	4	14.8	2	15.4	6	15.0
Shortness of breath with wheezing	3	11.1	1	7.7	4	10.0
Cough and phlegm	4	14.8	1	7.7	5	12.5

* Difference between ever smokers and never smokers were not statistically significant for any of the symptoms listed.

The presence or absence of a symptom was determined by a 'yes' or 'no' response to the question, 'Have you ever had (symptom)?'. As expected all symptoms were more common in sometime smokers than in those who had never smoked. The differences were, however, not statistically significant. In response to the relevant questions, only 2 subjects stated that they had ever had asthma and in each case they had been diagnosed as asthmatics in childhood.

Only 3 (7.5%) stated that they had ever had chronic bronchitis, and all had been or were smokers. Of the spray-painters interviewed, 55% suffered from some form of eye irritation and 32% responded positively to the question on dermatitis of the hands.

The mean cross-shift decrease in FEV_1 was found to be 130.5 ± 203.19 ml, the difference being statistically significant (P = 0.0002). The lung function data indicated that 10 (25%) subjects had clinically significant cross-shift decreases in FEV_1 of > 250 ml.

The distribution of the potential determinants of FEV_1 are presented in Table III.

Booth efficiency referred to four classification categories, viz. good, fair, poor and very poor, which were selected according to airflow efficiency in relation to percentage compliance with the minimum legal standards.[10] Length of service in Table III refers to the number of years each subject had worked as a spray-painter, not necessarily in the same establishment.

The isocyanate index was derived as described earlier. The results of the multiple regression analysis indicated that none of the potential determinants of FEV_1 examined was statistically significant and only the isocyanate index approached statistical significance (P = 0.082).

Fig. 1 shows the three basic spray-booth designs and Fig. 2 indicates the employer's provision of respiratory protective equipment and the employee's use thereof. As is evident from Fig. 2, few subjects used the respirator provided by the employer and in 5 instances the spray painters had elected not to wear the respirator at all.

All establishments had provided some form of respiratory protection for the employees' use, varying from the least efficient dust mask to the most efficient air-line respirator. Nineteen (47.5%) establishments did not provide the air-line mask as recommended by the leading manufacturers of twin pack isocyanate paints.

Fig. 1 shows the spray-booth efficiency in the 40 establishments, which were rated from 'good' to 'very poor'. The study examined each of the three basic booth designs, viz. the horizontal, vertical side, and vertical down draught types. There were 15 horizontal, 5 vertical side and 20 vertical down draught booths. Efficiency was judged by comparison of actual measured airflow velocity rates with the legal minima prescribed for that particular booth type, viz. 0.5 m/s horizontal, 0.4 m/s vertical side and 0.3 m/s vertical down draught types, respectively.[10]

Discussion

This study of the respiratory health status of spray-painters in the automotive refinishing industry in the Durban municipal area highlights the problems of HDI exposure in this industry. While TDI is one of the compounds of low

Table III. Cross-shift change in FEV_1 (ΔFEV_1) in 40 isocyanate-exposed automotive spray-painters in relation to age, smoking status, length of service, mask type, booth efficiency and index levels

Ref. No.*	ΔFEV_1 (ml) (%)	Age (yrs)	Smoking status† (pack yrs)	Length of service (yrs)	Mask type‡	Booth effic. (%)	Poly. isocy. index§
01	220 (–6.13)	33	C (10)	18	CM	46.5	9.42
02b	80 (+ 2.96)	35	C (16)	18	DM	71.0	6.88
03	10 (–0.31)	20	N	2	CM	43.3	1.00
04	170 (–4.94)	35	C (20)	4	DM	46.6	19.20
05	50 (–1.60)	35	E 9	17	CM	71.6	9.60
06	20 (–0.44)	23	N	4	Nil	88.8	4.35
07a	260 (–5.92)	28	C 2.5	12	Nil	55.8	2.54
08	450 (–11.78)	23	C 6	4	CM	118.0	3.62
09	210 (–5.36)	25	N	6	CM	91.5	7.82
10	180 (–5.57)	29	N	15	Nil	62.6	6.88
11	140 (–4.33)	26	C 4.5	5	CM	116.6	4.17
12b	30 (+1.15)	47	C 27	30	AM	50.0	23.54
13	30 (–0.93)	29	N	7	DM	33.3	7.61
14	60 (–1.35)	44	E 12	27	DM	38.8	11.21
15	130 (–2.49)	29	C 16	11	CM	87.5	6.52
16	220 (–7.21)	35	C 8	9	Nil	46.6	16.66
17	700 (–16.91)	26	N	6	CM	81.6	0.36
18	240 (–5.44)	28	N	6	AM	122.0	1.45
19b	110 (+ 3.75)	27	C 8	4	CM	27.5	12.68
20	420 (–12.77)	30	C 15	14	AM	100.0	8.33
21	90 (–2.92)	55	C 38	30	CM	93.8	0.54
22	310 (–10.69)	39	C 10	20	AM	89.6	1.81
23a	220 (–6.09)	26	N	7	AM	75.0	9.77
24	30 (–0.78)	27	C 5	10	CM	164.0	8.33
25	120 (–2.32)	42	C 38	23	CM	116.6	1.80
26	60 (–8.53)	37	N	10	CM	29.0	10.19
27	130 (–3.16)	29	E 8	11	AM	161.1	1.09
28	Nil (Nil)	52	N	30	CM	110.0	Nil
29	360 (–6.35)	22	N	4	CM	91.6	0.90
30	80 (–2.16)	26	C 2.5	10	CM	141.6	1.27
31	240 (+5.31)	24	C 7	3	CM	153.0	3.80
32	160 (+4.52)	30	N	8	CM	100.0	7.24
33	280 (–6.86)	22	C 4	1	DM	40.0	11.59
34	180 (–5.81)	36	C 3.5	8	AM	36.0	4.70
35	410 (–9.83)	39	N	20	Nil	126.6	0.72
36	330 (+9.76)	35	C 5	17	DM	102.7	Nil
37	50 (+1.06)	27	C 5	9	CM	69.4	7.06
38	320 (–7.79)	34	E 14	17	CM	136.1	4.35
39	330 (–14.04)	30	C 11	12	CM	147.2	2.90
40	150 (+5.93)	42	C 29	29	CM	161.1	16.66

* Symptoms: a = asthma, b = chronic bronchitis.
† Smoking: C = current, E = ex, N = never.
‡ Mask type: Nil = no mask, DM = dust mask, CM = cartridge mask, AM = air-line mask.
§ Index = $\frac{\text{isocy. conc.}}{\text{TLV}}$

molecular weight which is the leading cause of occupational asthma,[13] the effects of HDI exposure are not as clearly defined.

In general isocyanates pose a serious health risk in industry because, once sensitised, a significant proportion of workers develop lifelong morbidity, despite removal from exposure, and even death in some instances.[14,15]

The cross-shift change in FEV_1 in this study showed that 25% of subjects had a drop of > 250 ml, which has been defined as significant and requiring referral for further medical evaluation by the Health and Safety Executive in the UK.[16] Ten per cent had shortness of breath with wheezing, which is considered highly predictive of asthma. An explanation for the small number of subjects with diagnosed asthma could be the 'healthy worker' effect which presupposes that the worker who develops symptoms of asthma leaves the industry.[17] The remaining workforce is therefore comprised of 'healthy' subjects. This phenomenon suggests that the adverse health effects may well have been underestimated in the present study. Despite these findings, none of the subjects in the present study had a diagnosis of asthma made during employment in the spray-painting industry. The 2 subjects with a diagnosis of asthma had been asthmatic since childhood.

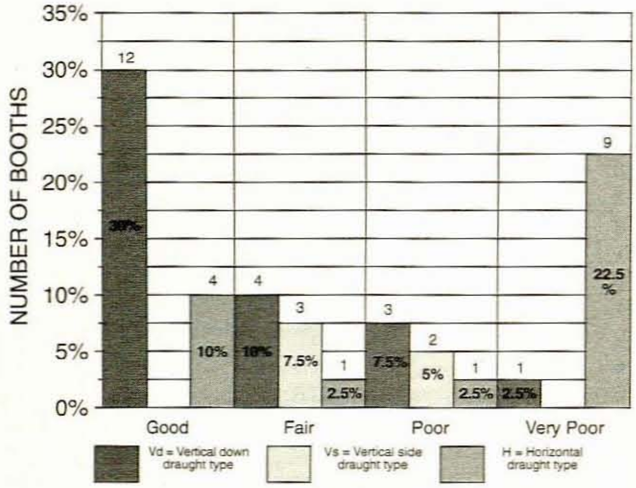

Fig. 1. Efficiency rating distribution of the three basic spray booth types (N = 40).

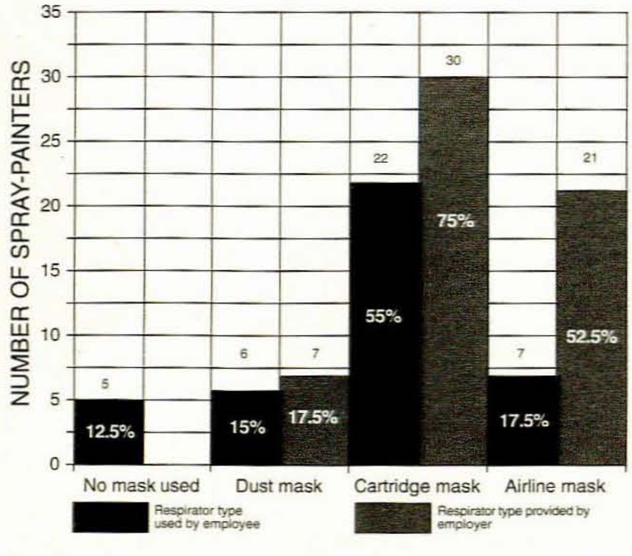

Fig. 2. Distribution of respiratory protective equipment in relation to types provided versus types used. Some form of respiratory protective equipment was provided to all employees (N = 40).

A factor which may have overestimated the risk in the spray-painting industry was that many spray-painters 'moonlight'. Moonlighting often takes place in the worker's domestic environment without the employer's knowledge and under poor conditions of industrial hygiene.

Asthma may develop insidiously in the worker exposed to HDIs, which may be the reason for the underdiagnosis in the present study. Initially there may be little or no effect but, if the worker becomes sensitised, with each successive exposure the response in the individual may become more acute until even the slightest exposure brings on an attack. In some cases sensitised individuals could respond to concentration levels as low as 0.0001 parts per million, which is well below the threshold limit value-time weighted average (TLV-TWA) of 0.005 parts per million.[18,19] It is important to identify the individuals with asthma and to remove them from further exposure.[20]

In a follow-up study of 16 subjects with TDI-induced asthma, Paggiaro *et al.* found that 7 subjects were still responsive to TDI after 30 - 48 months.[21] This study concluded that recovery only takes place after long-term work cessation, but that nonspecific bronchial hyperresponsiveness to methacholine can persist even in the absence of bronchial hyperresponsiveness to TDIs, suggesting permanent chronic damage to the mechanisms that control airway tone. A similar problem may exist with regard to HDI exposure.

The prevalence of chronic respiratory symptoms in this cohort of workers was similar to that reported in community based respiratory health surveys.[22,23]

The lack of an effect of smoking on chronic respiratory symptoms may be that the isocyanate exposure was a more important determinant of the symptoms and that the number of subjects was too small for an effect to be detected.

A high proportion of workers were also found to have eye irritation or experienced a burning sensation of the eyes while spray-painting. This is a recognised hazard of spray-painters, particularly when the worker does not comply with the safety regulations and wear a full face mask. The majority of spray-painters in this study had no form of eye protection and, furthermore, only 7 (17.5%) had availed themselves of the adequate respiratory protection provided.

At least 50% of the establishments used the vertical down draught booth, which is considered to be the most efficient type and is said to conform to principles of good design. Despite this, excessive concentrations of HDI were found in the operator's breathing zone. When the Oregon 1980 - 1990 study[12] was compared with this study, the percentage samples exceeding the current Oregon PEL of 1 mg/m^3 for polyhexamethylene di-isocyanates were 66% and 82%, respectively. The spray-booth concentration ranges varied from not detected (ND) to 18.4 mg/m^3 in the Oregon study compared with ND to 23.54 mg/m^3 in the present study.

During the evaluation of the spray-booths, spray-mists were observed returning into the operator's breathing zone, despite the fact that air movement was in many instances above the minimum regulatory requirements.[10] This phenomenon may be explained by the term 'bounce back', where the spray-mist caused by high spray-gun pressures, strikes the surface to be painted then bounces back into the spray-painter's 'breathing zone' prior to its removal by the spray-booth airflows. For this reason DeVillbiss, a leading manufacturer of spray-booths and spray-booth equipment, has recently introduced a new spray-gun design called the 'duo-tech' system.[24] This design addresses the problem of 'bounce back' caused by operation under a low-volume, high-pressure system, by replacing the conventional spray-gun with one that operates at high volume and low pressure, thereby reducing the excessive overspray in the spray-booth. In this study, all the atomising spray-guns were of the conventional high-pressure, low-volume type.

In the USA, the South Coast Air Quality Management District in California has effectively banned the use of conventional spray-guns which give rise to 'bounce back'; it is now a legal requirement that the spray-gun transfer efficiency not be < 65%. However, it was difficult to explain why isocyanate concentrations approached, but did not attain, statistical significance as a determinant of FEV, (P = 0.082).

The isocyanate concentration measurement, being a ngle measurement, may not have reflected the true 8-hour me-weighted average exposure levels experienced by the oray-painters. According to Vandenplas *et al.*,[24] the main eterminant of bronchial responsiveness to TDI is ependent on neither concentration nor duration of xposure, but determined by the product of both factors, i.e. otal dose exposure. As discussed earlier, length of service as not significant, probably because of the 'healthy worker' ffect.

Booth type and ventilation efficiency were also not ignificant, since spray-gun characteristics and operating ressures leading to the 'bounce back' phenomenon ppeared to be more relevant; this therefore warrants further tudy.

It was obvious from this study that compliance with the xisting statutory requirements was lacking in the South frican automotive industry and that the health of the spray-ainters was being compromised.

In order to investigate the chronic effects of HDIs on lung unction, a 4-year follow-up study of the original cohort of 0 spray-painters is currently under way.

EFERENCES

1. New Brunswick Occupational Health And Safety Commission. *A Guide for Coating Operations using Material containing Hexamethylene Diisocyanates*. New Brunswick, Canada: New Brunswick Occupational Health and Safety Commission, 1986: 1-10.
2. Health and Safety Executive. *Hexamethylene Diisocyanates: Toxic Hazards and Precautions* (Environmental Hygiene Guidance Notes. EH16 rev). London: HSE, 1984.
3. Brooks SM. Bronchial asthma of occupational origin. *Scand J Work Environ Health* 1977; **3:** 53-72.
4. Zwi AB. Hexamethylene diisocyanates and health — a review. *S Afr Med J* 1985; **67:** 209-211.
5. Peters JM, Murphy H. Pulmonary toxicity to isocyanate. *Ann Intern Med* 1970; **73:** 654-655.
6. American Thoracic Society. Standardisation of spirometry — 1987 update. *Am Rev Respir Dis* 1987; **136:** 1285-1298.
7. Lalloo UG, Becklake MR, Goldsmith CM. Effects of standing versus sitting position on spirometric indices in healthy subjects. *Respiration* 1991; **58:** 122-125.
8. European Community For Coal and Steel. Standardisation of lung function tests. *Bull Eur Physiopathol Respir* 1983; **19:** suppl 5, 1-95.
9. National Institute for Occupational Safety and Health. NIOSH Manual of Analytical Methods #5505: Isocyanates. In: *NIOSH Manual of Analytical Methods*. 3rd ed. Vol. 2. Cincinnati, Ohio: US Department of Health and Human Services, 1984.
10. Republic of South Africa. Department of Labour. Machinery and Occupational Safety Act 1983 (Act No. 6 of 1983). In: *General Safety Regulations 1986* (*Government Gazette* 1986; Notice No. 1031).
11. *SAS/STAT Users Guide*. Release 6.04 ed. Cary, NC: SAS Institute, 1988.
12. Janco M, McCarthy K, Fajer M, Van Raalte J. Occupational exposure to 1.6 hexamethylene diisocyanate-based polyhexamethylene diisocyanates in the state of Oregon, 1980 - 1990. *Am Ind Hyg Assoc* 1992; **53:** 331-338.
13. Venables KM. Preventing occupational asthma (Editorial). *Br J Ind Med* 1992; **49:** 817-819.
14. Moller DR, McKay RT, Bernstein IL, Brooks SM. Persistent airways disease caused by toluene diisocyanate. *Am Rev Respir Dis* 1986; **134:** 175-176.
15. Fabbri LM, Danieli D, Crecioli S, *et al.* Fatal asthma in toluene diisocyanate sensitised subjects. *Am Rev Respir Dis* 1988; **137:** 1494-1498.
16. Health and Safety Executive. *Hexamethylene Diisocyanates* (Medical Surveillance Guidance Note M.S.8). London: HSE, 1983.
17. Becklake MR. Occupational and environmental lung diseases — chronic airflow limitations. Its relationship to work in dusty environments. *Chest* 1988; **4:** 611-613.
18. O'Brien DM, Hurley DE. An evaluation of control technology for spray painting. *Am Ind Hyg Assoc J* 1982; **43:** 695-703.
19. American Conference of Governmental Industrial Hygienists (ACGIH). *Threshold Limit Values and Biological Exposure Indices for 1991/92*. Cincinnati, Ohio: ACGIH, 1991.
20. Chan-Yeung M, Lam S. State of art — occupational asthma. *Am Rev Respir Dis* 1986; **133:** 686-703.
21. Paggiaro PL, Vagaggini B, Dente FL, *et al.* Bronchial hyperresponsiveness and toluene diisocyanate. *Chest* 1993; **103:** 1123-1128.
22. Lalloo UG. Respiratory health survey in an Indian South African community: Distribution and determinants of symptoms, diseases and lung function. Doctor of Medicine thesis. University of Natal, 1992; 174.
23. Lebowitz MD, Knudsson RJ, Burrows B. Tuscon epidemiological study of obstructive lung disease — methodology and prevalence of disease. *Am J Epidemiol* 1975; **102:** 137-152.
24. Vandenplas O, Cartier A, Ghezzo H, Cloutier Y, Malo J. Response to hexamethylene diisocyanates: Effect of concentration, duration of exposure, and dose. *Am Rev Respir Dis* 1993; **147:** 1287-1290.

Accepted 27 Aug 1996.