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Respiratory and dermal exposure to disinfectants: a study in slaughterhouses and the meat processing industry

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Summary

In this study exposure to disinfectants during disinfection of rooms in slaughterhouses and meat processing companies was assessed. In addition, associations between exposure levels and characteristics of work practice and work place were described. The study was done because no exposure data are available for comparable disinfection procedures and no insight exists in determinants of exposure, whereas disinfectants can cause serious health effects. For risk assessment authorization procedures of biocides, estimates have to be made of exposure levels for situations in which these biocides will be used.

Respiratory and dermal exposure were assessed for 15 workers in 10 companies. Companies were selected on the use of disinfectants containing alkyldimethylbenzylammoniumchloride as active compound. The selection for this compound was made because of reasons for laboratory analysis.

In three companies (three workers), mixing and loading was done manually. In others an automatic dosing system was used. In all cases the method of application can be described as spraying with low pressure. The Biocide Steering Group (BSG, 1998) has ranked this type of application as a method with a relative large potential for exposure. The total work period lasted 14 to 108 minutes, with a median of 32 minutes. Applied concentration ranged from 0.008 to 12.3 g/l (median 1.2 g/l). Disinfected floor area ranged from 125 to 3650 m² (median 375 m²).

During the period of disinfection including mixing and loading, the geometric mean respiratory exposure was 53.6 µg/m³ (GSD 2.9, range 11.4 - 424). Actual hand and potential whole body exposure were assessed separately. Hand exposure was assessed by hand washing, separately for mixing/loading and disinfection. The total dose received during both activities was 2.1 mg (GM, GSD 8.0, range 0.04-27.2), and during application alone 1.4 mg (GM, GSD 7.9, range 0.04 - 27.2). There was an appreciable difference in exposure during application between those wearing and not wearing gloves, with average exposure levels of 0.16 and 6.1 mg, respectively.

Expressed in received dose per hour, actual hand exposure was 3.3 mg/h (GM, GSD 12.9, range 0.08 - 109) over both activities.

Potential whole body exposure was assessed by means of a Tyvek® coverall. Exposure was 32.2 mg (GM, GSD 5.4, range 2.3 - 440) and 61.4 mg/h (GM, GSD 5.1, range 4.5 - 1370). Most of the exposure was found on the lower legs: on average 51%.

For identification of determinants of exposure (in weight units), a large number of work procedure and work environment characteristics were registered. Despite the limited number of observations, several statistically significant associations could be found.

Variation in respiratory exposure (in $\mu\text{g}/\text{m}^3$) could be explained best by difference in material of flooring. Those working in companies with concrete flooring had on average a higher exposure than those disinfecting rooms with tiles or granite flooring.

Variation in actual hand exposure during disinfection (in μg) could be explained best by use of gloves: those wearing gloves had an exposure which was about 40 times lower than those not using gloves. Depending on the model, also applied concentration, disinfected floor area and pressure level explained part of the variation.

Disinfected floor area was the strongest determinant of potential whole body exposure (in μg). Depending on the model, also material of flooring, applied concentration, and duration of disinfection were strongly or weakly related to exposure levels.

For modelling purposes for authorization of biocides, surrogate exposure levels were derived, expressed in ml spray liquid per m^3 or per hour. The 90th-percentile exposure levels were taken as the surrogate exposure value. For disinfection, using a low pressure spray, the surrogate value for respiratory exposure is 2 ml/m^3 and for potential whole body exposure 700 ml/h , both referring to exposure during application including mixing and loading, if applicable. For hand exposure during application alone, two rounded surrogate exposure values were derived: 100 ml/h for workers disinfecting without gloves, and 5 ml/h for workers wearing gloves.

Samenvatting

In dit onderzoek werd de blootstelling aan desinfectantia bepaald tijdens het desinfecteren van ruimtes in slachthuizen en de vleesverwerkende industrie. Daarnaast werden relaties tussen blootstelling en kenmerken van de werkmethode en -omgeving beschreven. Dit onderzoek werd gedaan omdat er weinig informatie beschikbaar is over blootstelling in vergelijkbare situaties, terwijl desinfectantia ernstige gezondheidsklachten kunnen veroorzaken. Verder is het verplicht bij de toelating van nieuwe biociden een inschatting te maken van de te verwachten blootstelling aan deze middelen.

Voor vijftien schoonmakers in tien bedrijven werd de respiratoire en dermale blootstelling gemeten. De bedrijven in het onderzoek werden geselecteerd op het gebruik van desinfectantia met alkyldimethyl-benzylammoniumchloride als actieve component. Dit selectie criterium werd alleen toegepast om de laboratorium analyses zo eenvoudig mogelijk te houden en om de resultaten vergelijkbaar te maken voor verschillende personen.

In drie bedrijven (totaal drie werknemers) werd het mengen en laden van de desinfectantia handmatig gedaan; in de andere bedrijven was een automatische doseersysteem aanwezig. In alle situaties werd gedesinfecteerd door de middelen met een lage druk te verspuiten. De Biocide Steering Group (BSG, 1998) heeft deze toepassingmethode gekwalificeerd als een methode met een relatief hoge blootstelling. De totale duur van de desinfectieprocedure inclusief mengen en laden bedroeg 14 tot 108 minuten, met een mediaan van 32 minuten. De concentratie van het toegepaste middel varieerde van 0,008 tot 12,3 g/l, met een mediaan van 1,2 g/l. Het oppervlak van de gedesinfecteerde ruimte varieerde van 125 tot 3650 m² (mediaan 375 m²).

Tijdens het desinfecteren (inclusief mengen en laden), was de geometrisch gemiddelde respiratoire blootstelling 53,6 µg/m³ (GSD 2,9, range 11,4 - 424).

De actuele hand en de potentiële 'whole body' blootstelling werden apart vastgesteld.

De blootstelling van de handen werd bepaald door middel van het wassen van de handen. Dit werd apart gedaan voor het mengen en laden en het toepassen.

De totale dosis over beide activiteiten tezamen bedroeg 2,1 mg (GM, GSD 8,0, range 0,04-27,2), en tijdens het toepassen alleen 1,4 mg (GM, GSD 7,9, range 0,04-27,2). Er werd een aanzienlijk verschil gevonden in blootstelling tussen werknemers die handschoenen droegen tijdens het desinfecteren en degenen die geen handschoenen droegen: hun blootstelling was gemiddeld respectievelijk 0,16 and 6,1 mg.

Uitgedrukt in dosis per tijdseenheid was de gemiddelde actuele handblootstelling over beide activiteiten samen 3,3 mg/uur (GM, GSD 12,9, range 0,08 - 109).

De potentiële 'whole body' blootstelling werd bepaald door de werknemers een Tyvek® coverall te laten dragen over de totale periode van mengen/ laden en

toepassen. De blootstelling was gemiddeld 32,2 mg (GM, GSD 5,4, range 2,3 - 440) en uitgedrukt per tijdseenheid 61,4 mg/uur (GM, GSD 5,1, range 4,5 - 1370). Het grootste deel van de blootstelling, 51 procent, werd gevonden op de onderbenen.

Om de relatie te kunnen beschrijven tussen kenmerken van werk en werkomgeving en het niveau van de blootstelling, werden veel kenmerken geïnventariseerd. Hoewel het aantal observaties beperkt was, bleken er toch enkele statistisch significante relaties aan te geven te zijn.

De variatie in respiratoire blootstelling (uitgedrukt in $\mu\text{g}/\text{m}^3$) kon het best verklaard worden door het verschil in type vloer. Degenen die ruimten desinfecteerden met een betonnen vloer hadden een hogere blootstelling dan degenen die ruimtes met een tegel- of granieten vloer desinfecteerden.

Het gebruik van handschoenen verklaarde het grootste deel van de variatie in actuele handblootstelling tijdens het toepassen (in μg). Schoonmakers die handschoenen droegen werden gemiddeld ongeveer 40 maal lager blootgesteld. Afhankelijk van het geselecteerde model, verklaarden ook de toegepaste concentratie, de grootte van het gedesinfecteerde vloeroppervlak en het niveau van de gehanteerde druk een deel van de variatie.

De grootte van het gedesinfecteerde vloeroppervlak was de belangrijkste determinant van de potentiële 'whole body' blootstelling (in μg). In een model met meer variabelen, waren ook het type vloer, de toegepaste concentratie en de duur van de activiteit in sterke of zwakke mate gerelateerd aan het blootstellingsniveau.

Voor het gebruik van de resultaten bij de toelating van nieuwe biociden, werden surrogaat-waarden geselecteerd, uitgedrukt in ml spuitvloeistof per m^3 of per uur. Hiervoor werden de 90-percentiel waarden genomen. Voor het verspuiten van desinfectantia met lage druk, bedraagt de surrogaatwaarde voor respiratoire blootstelling 2 ml/m^3 en voor potentiële 'whole body' blootstelling 700 ml/uur . Deze waarden gelden voor het toepassen inclusief het eventueel handmatig mengen en laden. Voor handblootstelling werden twee waarden geselecteerd voor het toepassen alleen: 100 ml/uur voor desinfecteren zonder handschoenen, en 5 ml/uur voor desinfecteren met handschoenen.

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1. Introduction

1.1 Background

Because of their properties, disinfectants are potentially harmful for those who are exposed to them. The use of disinfectants for disinfection of rooms and contaminated materials is widespread, for example in medical or related institutions, in the production or processing of food, and in animal husbandry. Reports on health effects are merely restricted to health care centres, although for some other settings health effects have been suggested as well. Information on exposure levels is limited. Again, most of the (limited) information is based on studies in medical centres.

Because of their capacity to kill micro-organisms, disinfectants are classified as biocides (non-agriculture pesticides), since in 1998 the Biocidal Products Directive (Directive 98/8/EC) was brought into use. This Directive requires risk assessment of biocidal active substances, and biocidal products or preparations before they can be placed on the market. For the risk assessment, levels of exposure need to be compared to 'no adverse effect levels'. These 'no adverse effect levels' are based on human or animal studies taking the different routes of exposure into account. If studies on occupational exposure to the product or active substance for relevant use scenarios and with a representative sample size are present, a direct comparison with the 'no adverse effect level' is possible. However, if exposure data are lacking one should seek for other ways to estimate worker exposure, for example by using other suitable reference studies. For the structuring of the exposure assessment process in the risk assessment for registration of pesticides a tiered approach has been developed (Henderson *et al.*, 1993; EUROPOEM, 1997; BSG, 1998). The Biocide Steering Group, partly financed by the European Commission, DG XI, made an inventory of the current level of knowledge on occupational and non-occupational (consumer) exposure to biocides. Since data on exposure for different use scenarios is either lacking or not sufficient, studies focussed on different exposure scenarios are required.

Frequent (and abundant) use of disinfectants is required in the meat processing industry. This type of occupational setting was selected to perform exposure assessment of a disinfectant and to study associations between exposure and potential determinants of exposure. Information will be used for range finding of exposure levels in this type of industry, as well as a source of information for risk assessments.

This study was undertaken as part of the Health Hazard Survey program, supported by the Ministry of Social Affairs and Employment.

1.2 Aims and objectives of the study

The main objective of this study was to characterize occupational exposure during the disinfection process in slaughterhouses and meat processing companies. The study was done for exposure range finding as well as for exposure modelling purposes.

The following questions were addressed in the study:

- What is the level of respiratory exposure?
- What is the level of dermal exposure?
- What is the relation between exposure levels on one hand and work environment and process characteristics on the other hand?

Since results of exposure measurements with different or multiple disinfectants are difficult to compare, situations were selected for exposure assessment in which one specific quaternary ammonium compound was used as active agent.

The study is described in this report as follows. In Chapter 2 a summary is given of studies reporting on exposure to disinfectants and their health effects among professional users. To get insight in the working conditions and potential determinants of exposure, prior to the field study several companies were visited. The results of this investigation are presented in Chapter 3, describing the process of disinfection, the used equipment and the procedures. Chapter 4 describes the sampling strategy and materials and methods. Results are presented in Chapter 5. In Chapter 6 results and the use of data for modelling purposes are discussed. Chapter 7 presents the conclusions of the study.

2. Literature review

2.1 Population

In the Netherlands about 850 companies can be found in the meat processing industry, according to the classification of the Chamber of Commerce (Wagenaar projecten B.V., 1995). Furthermore, more than 5,600 specialized retail trade selling meat, meat products or game and poultry exist. In Table 2.1 the number of companies is given by type of meat industry and according to company size. The meat processing industry employs approximately 22,000 workers, which is about 0.3% of the national working population. The majority of the companies is small, but there is tendency of scaling up. In the smaller companies, disinfection is mostly performed by one or more company employees. In the larger slaughterhouses or meat processing companies, specialized companies carry out the cleaning and disinfection. In the Netherlands about 5800 companies are specialized in cleaning buildings. These companies employ a total of 152,400 workers. Only a small percentage of the total sales (1.3%) is made up by industrial cleaning in the food-industry, the turnover in 1996 was 52.1 million (CBS, 1998). Based on the number of companies it is expected that at least a thousand workers, excluding the retail trade, are exposed on a regular basis to disinfectants in this industry sector.

Table 2.1 Number of companies in the Dutch meat sector by type of industry, grouped according to size of companies

Type	Number of employees per company			total*
	< 10	10-49	50 or more	
Slaughterhouses, contract slaughters	353	76	38	487
Grease melting-works	6	9	1	16
Poultry industry	40	23	24	90
Meat products	151	69	36	264
Retail trade (meat, fish, poultry)	5395	115	0	5645

* for some companies number of employees unknown

2.2 Exposure to disinfectants

Little quantitative information on occupational exposure to disinfectants is available. As far as known, only one study on exposure to disinfectants has been reported in the international literature in which exposure was studied extensively. Popendorf and Selim (1995) measured respiratory and dermal exposure to disin-

fectants of 40 applicators in different occupational settings, including agriculture (hog or poultry), commercial, institutional, residential and medical settings. The disinfectants involved in that survey were o-benzyl-p-chlorophenol, o-phenolphenol and 2-(hydroxymethyl)-2-nitro-1,2-propanediol. Exposure was assessed during various methods of application, varying from mopping and wiping to high pressure spraying. Application time varied from five to 128 minutes. In only five out of 40 cases respiratory exposure could be assessed, but exposure levels were not given. The authors suggest that measurable airborne biocides were due to aerosolization. In their study dermal exposure was assessed outside as well as under clothing. 'Unprotected' dermal exposure levels (outside clothing) were consistently higher than the deposited dermal doses that actually reached the skin, implying that typical work clothing protects the worker against dermal exposure. The authors estimated the total dermal dose (measured under clothing) of active ingredients to be the highest while applying low pressure spraying. Although the high pressure sprayers received the highest exposure outside their clothing, the low pressure sprayers had the highest total dermal dose, because the workers normally did not wear protective clothing and/or gloves.

Most health effects have been reported among personnel in medical institutions. In this occupational setting usually disinfectants containing glutaraldehyde and formaldehyde have been suspected of posing a health risk. Norbäck (1988) conducted a study on disinfectants using actual exposure measurements among workers in medical services. When using manual procedures, workers were exposed to airborne glutaraldehyde levels ranging from less than 0.01 mg/m³ to 0.57 mg/m³ (15 minutes average). Leinster *et al.* (1993) measured personal exposure levels ranging from 0.003 to 0.11 mg/m³ in hospital settings after short duration of exposure.

Binding and Witting (1990) performed research into exposure to formaldehyde and glutardialdehyde in operating theatres. During routine disinfection activities in operating theatres using low concentrations of disinfectants (0.5% cleansing solutions), the 8-hr time weighted average TLVs were not exceeded. During disinfection to prevent infectious diseases, involving the use of higher disinfectant concentrations (3% cleansing solutions), German TLVs for formaldehyde and glutardialdehyde may be exceeded. All measurements confirmed that disinfection activities performed overhead always resulted in exposure to high air concentrations.

Recently, Leutscher *et al.* (1997) described respiratory exposure to glutaraldehyde in two Dutch hospital settings. Average personal exposure was 0.01 and 0.003 mg/m³, respectively.

Schipper *et al.* (1996) measured dermal and respiratory exposure to the disinfectants o-phenylphenol (OPP) and o-benzyl-p-chlorophenol (BCP) in Lyorthol®, which is used by hospital workers performing disinfection activities in operation theatres and rooms with an isolation regime. Personal respiratory exposure to OPP and BCP was found to be negligible compared to dermal exposure. Respiratory

exposure was assessed using a method based on active sampling over a silica gel tube. Dermal exposure was assessed by washing the workers hands. Potential dermal exposure was 3.0 mg on average for OPP and 3.5 mg for BCP. The workers wearing gloves, had a significantly lower actual dermal exposure.

In another study, dermal and respiratory exposure to OPP were measured for 16 workers carrying out disinfection tasks in hospitals and related institutes (De Zeeuw, 1998). On average (GM), respiratory exposure was $10.5 \mu\text{g}/\text{m}^3$ (range 6.2 - 83.3). The potential hand exposure was 2.05 mg (range 0.36 - 12.8), while actual hand exposure was ten times lower than potential exposure, on average 0.17 mg (0.03 - 1.58). Workers disinfecting sanitary or kitchen/scullery received higher exposure compared to workers disinfecting operating rooms, isolation rooms or incubators. This difference was statistically significant for all measures.

During disinfection with formaldehyde and glutaraldehyde (fogging and pressure spraying) in poultry farms, much higher levels were measured then observed in medical settings (De Haan *et al.*, 1994). For measuring formaldehyde and glutaraldehyde exposure active personal air sampling was applied, in which two impregnated filters were used for adsorbence of the components. For potential overload, an impinger was used as back up. The potential exposure to formaldehyde and glutaraldehyde during disinfection ranged from 7.8 to $283 \text{ mg}/\text{m}^3$ and 0.28 to $3.5 \text{ mg}/\text{m}^3$, respectively.

To our knowledge no studies on exposure to disinfectants in slaughterhouses or the meat processing industry have been reported.

2.3 Health effects

2.3.1 Respiratory effects

General

Various respiratory health effects have been reported in connection with exposure to disinfectants, including allergic and non allergic effects of the upper and lower respiratory system. Most reports are based on single cases or small groups. In general, no large epidemiological studies have been performed. An exception to this is a study among Dutch pig farmers. Preller *et al.* (1995) reported in their study associations between characteristics of the disinfection procedure and health parameters. The frequency of disinfection in pig farms is about once a week and the procedure takes generally less than ten minutes. Chloramine-T, and quaternary ammonium compounds with or without aldehydes were mostly used. Application by pressure washer using a pressure of less than 20 bars was most common. In that study, higher pressure and longer disinfection procedures were associated with more symptoms of chronic non specific lung disease and lower base line lung function, suggesting that exposure does adversely affect respiratory health. Information on actual exposure levels was lacking, but duration of the procedure and pressure are likely to be important factors of actual exposure levels and dose.

Glutaraldehyde

In his study, Norbäck (1988) reported differences in symptom prevalence of the upper respiratory tract between workers exposed to glutaraldehyde in medical services and unexposed controls. There was no difference in symptom prevalence of effects on the lower respiratory tract. The workers were exposed to glutaraldehyde levels ranging from less than 0.01 mg/m³ to 0.57 mg/m³ (15 minutes average). Gannon *et al.* (1995) reported that glutaraldehyde can cause occupational asthma in endoscopy and X-ray departments. Eight workers were investigated by serial measurements of peak expiratory flow (PEF) and specific bronchial provocation tests. The diagnosis of occupational asthma was confirmed in seven workers. The mean level of glutaraldehyde in air during the challenge tests was 0.068 mg/m³, which is about one tenth of the British short term occupational exposure standard of 0.7 mg/m³. The exposure levels measured in the workplace suggest that sensitization may occur at levels below the current occupational exposure standard.

Chloramine-T

Chloramine-T is an organic, highly reactive derivative of chlorine with potent bactericidal properties, and is used as a disinfectant in the food industry. In various occupational settings, several effects following exposure to chloramine-T have been reported. The effects include respiratory symptoms such as cough, wheezing and dyspnea, and immediate and late asthmatic reactions, potentially IgE mediated. Effects on eyes and the upper respiratory system are reported either together with or without symptoms of the lower respiratory system (Bourne *et al.*, 1979; Dijkman *et al.*, 1981; Wass *et al.*, 1989; Blomqvist *et al.*, 1991; Blasco *et al.*, 1992). Kujala *et al.* (1995) described the provocation of occupational asthma by exposure to a commercial chloramine-T solution. They showed that the risk of developing hypersensitivity reactions, rhinitis and bronchial asthma was increased after exposure to an aerosolized chloramine-T solution.

Quaternary ammonium compounds

Only recently, exposure to disinfectants containing quaternary ammonium compounds has been described as a cause of occupational asthma. One case of a worker in a factory in which household cleaning products were produced and one case of a pharmacist whose working area was cleaned with quaternary ammonium compounds have been reported (Bernstein *et al.*, 1994; Burge and Richardson, 1994). The latter report implies that effects can occur in situations with very low exposure levels. Quaternary ammonium compounds are also known muscle relaxant allergens (Didier *et al.*, 1987).

In the study among Dutch pig farmers the use of quaternary ammonium compounds in disinfectants was associated with a higher rate of atopic sensitization to common allergens. In addition, pig farmers with atopic sensitization to common allergens and exposure to disinfectants with quaternary ammonium compounds showed the largest prevalence of chronic non specific lung disease (Preller *et al.*, 1996). This suggests that quaternary ammonium compounds can also have an adjuvant effect.

2.3.2 Dermal health effects

Information on health effects due to dermal exposure is even less available than on respiratory health effects. Some studies suggest an association between use of disinfectants and dermal effects. In a study by Rustemeyer *et al.* (1994), relevant occupational allergens for persons engaged in the personal care of the ill and the elderly, were found to be benzalkonium chloride and aldehydes in disinfectants. Susitaival *et al.* (1994) found that among farmers, daily handling of disinfectants was one of the risk factors of hand dermatoses. A case has been described of a dental nurse with dermatitis due to use of a quaternary ammonium compound. The nurse reacted positively on N-benzyl-N,N-dihydroxyethyl-N- cocosalkyl-ammonium-chloride, a quaternary ammonium compound in a disinfectant wipe used (Placucci *et al.*, 1996). Recently, a case has been presented of a hospital employee with contact dermatitis caused by cleaning with a disinfectant containing quaternary ammonium compounds (Dejobert *et al.*, 1997). Later, the woman was working in a new location, without direct contact with disinfectants. However, she again experienced effects on eyelids, face and arms after disinfection of a room by colleagues a day before. New episodes could only be prevented when she waited entering rooms until the floor was completely dry, implying that exposure levels during re-entry may, at least occasionally, still be high enough to provoke allergic reactions.

3. Disinfection

In a feasibility study and in the pilot study several companies were visited. During these visits characteristics of the companies and the disinfection process were investigated. This information was used for description of the disinfection process.

3.1 Disinfection process

Every day, after the production process, the machinery and the rooms in the meat industry need to be cleaned thoroughly. The cleaning process has three steps beginning with the cleaning that includes sweeping and scrubbing. Afterwards the rooms and the machinery are treated with an acid or alkaline soap. The machinery is rinsed with water. Disinfection is the last step in the cleaning process. For a good result the disinfectant is left on the machinery at least for 15 to 30 minutes before it is rinsed off with water. In other situations the disinfectant stays on the machinery overnight. In these situations the employees of the meat processing companies or slaughterhouses start their work with rinsing the disinfectant off the machinery. In smaller companies the disinfection process takes approximately 10 minutes, in larger companies about 60 minutes. The total cleaning process takes two to eight hours. In most cases the meat production begins five to six hours after the disinfection.

3.2 Method of mixing/loading and application

Different application methods were observed. In some companies the disinfectant was applied by pressure spraying, in other situations by foam application. In some companies a tank was used, in other companies the water supply system was used. When the water supply system was used there were several valves in the building where the water could be drawn off.

When a tank is used the disinfectant needs to be diluted before use. The undiluted product is poured manually into a tank. When a closed system is used, in which the disinfectant and the water are mixed mechanically, no contact takes place with the undiluted disinfectant.

In the situations that a water supply system was used workers carried a small container with the disinfectant around from one valve to the other. A tube was led from the container to the spray gun of lance. Via this small tube the disinfectant in the container was sucked into the water (as a result of the existing under pressure), mixed and sprayed.

The concentration sprayed was tuned to the pressure in the water supply system and could not be changed. The pressure with which the liquid was sprayed was in most situations, when asked, unknown. During spray application a visible mist of disinfectants came into the air. Foam is obtained by mixing water and chemicals by air pressure. No visible airborne exposure was observed.

3.3 Disinfection products

Products varied from one company to another but there was relatively little variation in active components. To disinfect, all companies visited in the feasibility study used quaternary ammonium compounds. Four companies alternated the use of disinfectants based on quaternary ammonium compounds with a chlorine-based disinfectant.

The quaternary ammonium compounds used in the visited companies were:

- alkyldimethylbenzylammoniumchloride;
- didecyldimethylammoniumchloride.

The active components of chlorine-based disinfectants were:

- sodium hypochlorite and sodium hydroxide;
- sodium hypochlorite potassium hydroxide;
- sodium hypochlorite;
- sodium-p-toluene sulfon chloramide (chloramine-T).

3.4 Worker exposure

The number of people disinfecting was mainly determined by the size of the company. One to four workers were observed being present or working in the same room during disinfection. Workers working directly with disinfectants potentially receive the highest exposure. Next, bystanders present in the rooms where disinfection takes place may be exposed to dispersed disinfectants as well. Workers in the meat industry may be exposed at time of re-entry, by rinsing off machinery on which the disinfectants is left overnight, or during disinfection of hands and small equipment.

Activities observed which may lead to exposure were:

- *Dilution (mixing/loading) of the disinfectant*

If the disinfectant is spilled during this activity, it is possible that the worker is dermally exposed to a high concentration of active components. Respiratory exposure is not likely to occur.

- *Application*

A visible and perceptible mist of disinfection components comes into the air during spray application. Workers can be exposed to these particles, either directly or by backslash.

Respiratory exposure or dermal exposure directly by airborne particles containing disinfectants during foam application seems unlikely.

- *Re-entry of disinfected rooms*

Dermal exposure may occur as a result of contact with disinfectants present on surfaces. Respiratory exposure during re-entry after application doesn't seem very likely.

3.5 Personal protective equipment

Most companies in the meat industry prescribe a dress code to prevent unhygienic situations. The use of personal protection equipment is also advised by the producers of the disinfectants. During the company visits in the feasibility study it became clear that the use of personal protection varied widely among companies. For example, in one of the visited companies there were strict rules. The personnel in this company wore a water resistant and protective overall. Gloves were taped to the overall to prevent the liquid disinfectant to contact the skin. Also, boots and helmets were used. Employees in another company worked with a cotton coverall and boots, without wearing gloves.

In most companies rubber or plastic gloves, boots, a helmet and a cotton overall were worn during the disinfection. Protective, water-resistant overalls or aprons were not present in most situations.

During mixing and loading workers used the protective gloves (plastic or rubber gloves) and sometimes a protective mask, but during the disinfection this was not always the case. Especially, in situations where mixing/loading was not necessary, these protective measures were not always used. None of the cleaners wore respiratory protective equipment during application.

4. Materials and Methods

4.1 Selection of disinfectant

Criteria for the selection of the disinfectant for the present study were: frequent and large-scale use, the availability of an analytical method, and a relative high dosage. To disinfect, most companies used quaternary ammonium compounds and some also used chlorine-based disinfectants. The choice was made to investigate formulations based on quaternary ammonium compounds. These products can contain two different quaternary ammonium compounds. The used formulations contain either alkyldimethylbenzylammoniumchloride or didecyldimethylammoniumchloride, or both components. Experts in the field were asked for information on sale and use of the different active substances. No clear answer could be given. Finally, the availability of an analytical method was decisive for the choice of alkyldimethylbenzylammoniumchloride. All products used in the field study contain this quaternary ammonium compound (quats). Information on the products and the amount of active substance is summarized below.

Name:	Stafquat SU 314 [®] (36 gram a.s. per litre formulation) P3-triquart TH [®] (26 gram a.s. per litre formulation) Quatdet SU 321 [®] (95.4 gram a.s. per litre formulation)
CAS NR:	61789-71-7
Active substance:	Alkyldimethylbenzylammoniumchloride
Formulation:	Liquid

The disinfectant can be applied using low or high pressure spraying or foam application. The actual concentrations applied varied between products. The labels prescribe concentrations up to 3.5%.

4.2 Selection of companies

The selections started with informing several occupational hygienists having contacts with slaughterhouses, abattoirs or meat processing companies on the project. They were asked to help finding companies for participation. Additionally, addresses obtained from the Chamber of Commerce were used. Slaughterhouses will either let their own workers disinfect the company, or hire a cleaning company. Several cleaning companies were contacted for participation in the study. A total of 50 slaughterhouses and cleaning companies was phoned. Both small and larger meat companies were phoned and companies where pigs, chickens or cows were slaughtered, were asked to participate in the study. When the person responsible for the disinfection procedure was interested, and the company used a formulation based on alkyldimethylbenzylammoniumchloride, information on the study was sent (n=20). Some weeks later the company was phoned to ask whether they wanted to participate in the study (n=8). Two companies were recruited with the help of a manufacturer of disinfection products.

4.3 Exposure assessment

4.3.1 Respiratory exposure

Personal respiratory exposure was measured using an IOM sampling head. The sampling head contained two (front and back) glass fibre filters (25 mm, pore diameter 8.0 μm , Millipore Corporation, USA) which were placed in the cassette holder in the IOM sampling head. The IOM sampling head was attached to a constant flow air sampling pump, operating at 2 L/min (Dupont Personal Air sampler S2500, Delaware, USA), estimating the inhalable aerosol fraction (CEN, 1992). Flow rates were checked before and after sampling using pre-calibrated rotametre tubes (ROTA, Dr. Henning GmbH, Germany). The IOM sampling head was worn in the breathing zone of the worker. After sampling the IOM sampling head was removed, covered by a cap, and brought to the laboratory where the filters and the cassette holder were removed from the sampling cassette and analysed the next morning.

Before respiratory exposure could be calculated the flow rates were checked. When flow rates differed more than 10%, the measurement was not found reliable and would not be used. In practise, the flow rates did not differ more than 5 percent, so all measurements could be used. To calculate the personal respiratory exposure, the amount found on the front and back filters and cassettes were adjusted, by the amount found on the blank sample. Observations below the limit of detection (LOD) were set on one third of the LOD, assuming a log normal distribution (Hornung and Reed, 1990). Concentrations measured using the IOM sampling heads were calculated in $\mu\text{g}/\text{m}^3$, using the amount found on the filter (μg), the average flow rate (L/min) and the sampling time (min).

4.3.2 Hand exposure

In the study actual hand exposure was measured. Workers were asked to work according to their normal working procedures. Whether gloves were used was usually decided by the worker. The material and type of gloves available varied between companies. Hand exposure was determined using a hand wash method. When workers wore gloves, these were removed. The worker washed his hands twice after a work activity, which could be: dilution of the product, disinfection, or rinsing off the disinfectant with water. The activities performed and hence the frequencies with which hand washes were taken varied between workers. All workers washed their hands once before the work started to be sure that no residues were present on the hands.

For the handwash a polyethylene bag was used, which was filled with 500 ml IPA/Water 60:40. The sampling liquid was transported in 1 L polyethylene bottles. Hands were washed for 30 seconds in the liquid. The hands were taken out the polyethylene bag and the water was poured back in the 1 L polyethylene bottles. For the second handwash another 500 ml IPA/Water 60:40 were used following the same procedure. Samples were stored at 2 - 8°C until analysis.

Exposure to the hands was calculated by adding the exposure levels measured in both hand washes. Observations below the limit of detection (LOD) were reported as one third of the LOD. Exposure was presented as total dose per activity and was

also recalculated to hourly values to compensate for differences in working time. The wash efficacy, determined in a small experiment with three volunteers (see chemical analysis), varied between 73% and 91%. No correction was made for this recovery.

4.3.3 Potential body exposure

Potential dermal body exposure of workers was measured during application (including mixing/loading) of the disinfectant and in one situation during removing the disinfectant by spraying with water. The dermal exposure was assessed using a Tyvek® coverall (Pro tech, Dupont). The capuchin of the coverall was worn to sample deposition on the head. After sampling the coverall was cut into pieces, using a pair of scissors. The samples were collected in polyethylene bottles and stored at 2- 8°C until analysis. The coverall was cut into pieces and the samples were composed according the list below:

- head
- left and right lower leg
- left and right upper leg
- left and right arm
- torso front
- torso back

Adding the exposure levels measured on the different body parts, exposure to the body was calculated. Observations below the limit of detection (LOD) were reported as one third of the LOD. Exposure was presented as total dose per activity and was also recalculated to hourly values to compensate for differences in working time.

4.3.4 Stationary air samples

Static measurements were done to get an indication of the potential exposure for the bystander or during re-entry of disinfected rooms. The concentration of disinfectant in the air was measured directly after the disinfection was done. Two high-volume samplers (Gravicon VC25, Strohlein Instruments, Germany) were placed in a disinfected room, at a representative place. One Gravicon was used with a sampling head designed for total dust, the other for fine dust. The sampling rate of the Gravicons was 22.5 m³/hour. In the cassette holder a front and back glass fibre filter (Gelman Sciences, Inc. Prod. Nr. 4600000, lotnr 990 84564C) was placed. The Gravicon sampled for 15 minutes, after which the filters were changed and the Gravicons sampled for a second sampling period of 15 minutes. The filters were stored in film cassettes. Samples were stored at 2 - 8°C until analysis. To calculate the exposure levels, the amount found on the front and back filters were added. Observations below the limit of detection (LOD) were reported as one third of the LOD. The air concentration in the rooms where disinfection took place was calculated using the amount measured on the filters (μg), a sampling rate of 22.5 m³/h and the sampling time (min).

4.4 Workplace and work exposure characterisation

During work activities workers were observed and time registration was made. In companies where more than one worker was measured, a time registration of at least one worker per shift was made. In the time registration different work activities like mixing/loading, disinfection of walls, floors, material and machines, collecting of materials after disinfection and several more were distinguished. Besides the time registration, information on the characteristics of the treated rooms was collected such as the area treated, the height of the room, whether there was machinery inside the room, type of machinery in the room and what surfaces were disinfected. In Appendix D a list is included of the characteristics of work place and procedures that have been registered.

4.5 Quality control

Spiked samples were taken in the companies to assess the stability of the samples during transport. The samples were prepared in the laboratory and the product that would be used in the field situation was taken as a standard. Two spike concentrations were used per matrix. The concentrations varied between companies because of different formulations used. One sample was taken into the field, the other bottle stayed closed during the sampling period.

Blank samples were taken to assess whether background exposure or contamination of samples as result of the sampling procedure occurred. Blank filters for personal and stationary sampling were taken before the sampling took place. One of the field workers imitated a hand wash procedure. The spike and blank samples were treated in the same way as all other samples. After sampling, spikes and blank samples were transferred to the laboratory, where they were stored until analysis in a cooling chamber at a temperature between 2 and 8 °C.

4.6 Chemical analysis

Tyvek® matrices, filters and cassettes, and hand wash liquid

The filters and the Tyvek® coverall were extracted using methanol/water 60:40. The volumes added to the Tyvek® matrices varied between 200 and 500 ml depending on the weight of the dosimeter.

5 ml methanol/water 60:40 was added to the glass fibre filters (back, front and cassettes separately) used for personal sampling and 100 ml was added to the filters (front and back) used for stationary air sampling. Tyvek® matrices and filters were extracted by placing them in an ultrasonic bath for 5 to 10 minutes. Consecutively, the samples were shaken for 30 minutes in a shaking apparatus at 300 strokes per minute. Handwash liquid needed no extraction.

Analytical chemical methods

In a disinfectant solution alkyldimethylbenzylammoniumchloride consists of more than one component, the lengths of the alkyl groups vary. The standard of alkyldimethylbenzylammoniumchloride used, existed for 66% of C12 alkyl groups and for 34% of C14 alkyl groups. For calculation of the total amount of alkyldimethylbenzyl-ammoniumchloride the area under the curve of the C12 and C14 component in the mixture were added. Further information on the standard and the chromatography process is given in Appendix E.

Quaternary ammonium compounds were determined by HPLC using a Lichrosorb CN, Hibar, 250/4.0, 5 μ m column. The eluents for analysis of filters contained 58% demi-water, 33% acetonitril and 9% 2-propanol (pH= 2.2). For analysis of the Tyvek® coverall and the handwash liquid eluents containing 69% demi-water, 25% acetonitril, and 6% 2-propanol (pH= 2.2) was used. The flow was set on 1.0 ml per minute and the UV detection at 210 nm. For analysis 10 to 100 μ l of the extraction liquid was directly injected on the HPLC system. Linearity was found for all calibration curves in the concentration range from 0 to 200 mg/l. The LOQ (Limit of Quantification) of alkyldimethylbenzylammoniumchloride varied between 50 and 100 μ g/l. On the blank Tyvek® samples, the glass fibre filters and in the handwash liquid no background was found.

In an experimental setting the wash efficiency was tested. Three volunteers washed their hands after application of one high and one low dose. After a period of waiting, hands were washed three times for 30 seconds with 500 ml IPA/water 60:40. The wash efficiency for the lower dose was in the first wash on average 73% (range 72-74%). In the second wash less than 5% was washed off. For the higher dose 84% (range 80-87%) was rinsed off in the first wash and less than 4% was washed off in the second wash. Neither for the lower nor the higher dose a detectable amount of alkyldimethylbenzylammoniumchloride was found in the third wash.

Recovery, stability and coefficient of variation

For the Tyvek® coveralls the coefficient of variation for between days (n=6) and within days (n=3) was below 10% and 5%, respectively. The recovery of alkyldimethylbenzylammoniumchloride by extraction from the Tyvek® coverall was >85% (n=6). Stability was tested during the field work period. The Tyvek® matrices were stable for at least 51 days.

Glass fibre filters used for personal sampling were sampled for 2 hours, at 2 L/min at 23 to 24 °C and a relative humidity in the rooms that varied between 46 and 52%. The recovery found was above 95%. The coefficient of variation between days (n=8) and within days (n=3) was below 5%. The glass fibre filters were stable for at least 55 days.

For the handwash samples the coefficient of variation between days (n=5) and within days (n=6) was below 5%. The hand wash samples were stable for at least 26 days.

The filters used for stationary sampling were also tested. The sampling rate of the Gravicons was 22.5 m³/hour, temperature was 20°C and the relative humidity was

24%. The Gravicons sampled for 90 minutes and both front and back filters were tested. The glass fibre filters were spiked with alkyldimethylbenzylammonium-chloride in demi-water. The filters were spiked with two concentrations, 1050 μg ($n=2$) and 105 μg ($n=2$) respectively. The recovery for the high spike was 99% and for the lower spike 87%. No alkyldimethylbenzylammoniumchloride was measured in the back filters.

4.7 Data management and statistical analysis

Data analyses was done using SAS (version, 6.12). First, the distribution of all exposure parameters was tested with PROC UNIVARIATE (Shapiro Wilk test). In describing the association between exposure level and determinants of exposure, all determinants with sufficient distribution within the population were selected for evaluation. A complete list of all potential and selected determinants is given in Appendix D.

As dependent variables were taken the following exposure measures: personal respiratory exposure (in $\mu\text{g}/\text{m}^3$) and dermal whole body dose (μg) during the total sampling time, and dermal hand dose (μg) during application. In all models log transformed values were taken. Modelling exposure was done with linear regression analysis using PROC REG. Multivariate models were constructed using default SAS stepwise selection procedures (using default p-values for entry in and deletion from the model, 0.50 and 0.10, respectively). In addition, the association of all variables with the dependent variable was evaluated separately in order not to miss potential relevant variables due to correlation with other variables selected by the stepwise procedure. Selected were those multivariate models with a minimum of independent variables, the highest significance of the model, and the largest explained variance. Influence of single observations on parameter estimates was evaluated based on Cook's D. If necessary, observations were deleted and stepwise regression procedures were performed again to select optimal multivariate models.

Some variables, such as type of flooring could not be assessed for all workers since not all workers were followed on work characteristics. Per company at least one worker was followed. Inclusion of such variables in the model reduced the already limited number of observations and hence most likely the outcome of the regression analyses. Therefore, if applicable, models are presented in the results section for the total population and a subpopulation based on completeness of information on work characteristics.

In some companies the exposure of more than one person was assessed. Observations within a company may not be independent and hence bias regression modelling. Therefore, selected multivariate models were tested again with company average values. If parameter estimates (beta) and p-values did not change considerably, within-company dependency was considered negligible. Model validity was further evaluated by analysis of residuals.

To use the results of the study for exposure assessments for registration purposes, the data needed to be converted to generally applicable units. Respiratory exposure is expressed in ml spray fluid per m^3 . Hand and body exposure are expressed in ml

spray liquid per hour of work. For conversion of the exposure levels from mg/m^3 to ml/m^3 or from mg/h to ml/h , the actual measured applied concentration (mg/ml) was used.

5. Results

5.1 Population and work environment

Personal respiratory exposure and dermal exposure of hands and body were assessed for 15 workers in 10 companies. Measurements were performed in two meat processing companies, seven slaughterhouses and one company which had both activities. The size of the companies varied. The disinfection processes in the companies differed, among others as a result of the type of animals slaughtered (i.e. cows, pigs, chickens, rabbits) and the degree of mechanisation.

In seven companies exposure for one worker was measured. In two companies two workers, and in one company four workers were measured working in different shifts. The workers were all male and their age varied between 21 and 53.

A difference can be made between the types of rooms disinfected. In slaughterhouses there were one or several areas with machinery to slaughter cows, chickens or pigs (this is called the dirty slaughter line). The machinery used to slaughter chickens or cows show enormous differences. The meat is cut into pieces in the clean slaughter area, in these rooms one can find conveyor belts for transport and tables for cutting the meat to smaller pieces. In other rooms one can find the machines for packing the meat, the cooling chambers for storage or the expedition rooms. In smaller companies the different tasks can be found in one room. In the meat processing industry the machinery can be very different from the ones found in slaughterhouses.

The area that was treated by one worker was registered and varied between 118 and 3650 m². The height of the rooms varied between 2.5 and 8 m. The walls were treated up to a height of 6 m.

During the measurements, characteristics of the room were registered. A difference was made between workers disinfecting rooms with no, little, much, or very much machinery. The results show that most workers treated both, and empty rooms as well as rooms with much machinery. Disinfection of the ceiling was not observed in either of the companies. Seven workers treated both floors and walls. A total of five workers disinfected only machinery and tables in the rooms. In these situations the floor was not intentionally sprayed, but in most situations the amount of water used was that large that water would drip off the machinery or tables on the floor, which resulted in indirect disinfection.

5.2 Personal exposure levels

5.2.1 Sampling scheme

The work activities measured were, if applicable, mixing/loading, disinfection and rinsing. Disinfection was in all cases applied by spraying. In the study no foam application was measured. Rinsing the disinfectant with water was only measured when this took place within a period of an hour after disinfection. This was the case in only one company. In only three companies a tank was used for disinfection, in all other situations there was an automatic dosing system. Therefore, only

three workers were measured during mixing/loading of the disinfectant. In all other situations workers attached the spray gun or lance to the conduit pipes in which the formulation was diluted by water. The product was either available in a large storage tank or in a smaller container which the worker carried with him. The concentrations measured in the spray liquid for the different companies is presented in Appendix A. Mixing and loading of the product took about 2 minutes but was in one situation not recorded. The disinfection time was on average 38 minutes and varied between 14 and 108 minutes. Rinsing was performed by only one worker in one company and took 9 minutes. In Table 5.1 the sampling scheme is presented.

Table 5.1 Sampling scheme for distinguished matrices

Type of exposure	Sampling period	Number of workers	Sampling time (min)
Respiratory exposure	Disinfection <u>including</u> mixing and loading	15	11 - 108
	Rinsing	1	9
Actual hand exposure	Mixing and loading tank	3	2
	Disinfection using a tank	3	7 - 53
	Disinfection using an automatic dosing system	12	14 - 108
	Rinsing	1	9
Potential body exposure	Disinfection <u>including</u> mixing and loading	15	7 - 108
	Rinsing	1	9

5.2.2 Respiratory exposure

The respiratory exposure was measured during the period of disinfection. For three workers this was including the time for mixing and loading. The concentrations measured are presented in Table 5.2. In Appendix B the personal exposure levels per worker are presented. Exposure for one worker was measured during rinsing, the respiratory exposure being $14.1 \mu\text{g}/\text{m}^3$.

Table 5.2 Respiratory exposure during disinfection

	n	Exposure concentration ($\mu\text{g}/\text{m}^3$)			
		AM (SD)	GM (GSD)	90-perc.	Range
Disinfection <u>excluding</u> workers mixing/loading	12	83 (98)	54.3 (2.5)	142	14.8 - 369
Disinfection <u>including</u> workers mixing/loading	15	97 (128)	53.6 (2.9)	369	11.4 - 424

AM (SD) = arithmetic mean and standard deviation

GM (GSD) = geometric mean and geometric standard deviation

5.2.3 Actual hand exposure

Results of hand exposure are presented in Table 5.3. Hand exposure is presented as total dose per activity (in mg) and is recalculated to hourly values (mg/h). For three workers hand exposure was measured separately for mixing and loading and disinfection. For the other workers only the exposure during the period of disinfection is given. For 12 workers in this group the exposure value is the sum of disinfection and some other activities such as walking with the container filled with concentrated disinfectant through the rooms that needed disinfection. Hand exposure for the whole population during disinfection including mixing/loading, excluding rinsing is presented in the last row. One worker rinsed off the disinfectant. His hand exposure was 0.02 mg and 0.1 mg/h (task time= 9 minutes). The exposure levels for each worker are presented in Appendix B.

Table 5.3 Hand exposure during different activities

Task	n	Actual exposure (mg)				n	Actual exposure (mg/h)			
		AM (SD)	GM (GSD)	90-perc	Range		AM (SD)	GM (GSD)	90-perc.	Range
Mixing/loading	3	8.5 (11)	4.2 (4.2)	-	1.5 - 21.7	2	360 (410)	213 (4.8)	-	70 - 650
Disinfection	15	5.0 (7.1)	1.4 (7.9)	11	0.04 - 27.2	15	17.3 (33)	2.7 (10.1)	81.1	0.08 - 109
Total exposure *	15	6.7 (8.2)	2.1 (8.0)	23	0.04 - 27.2	14	15.1 (28)	3.3 (12.9)	24.6	0.08 - 109

AM (SD) = Arithmetic mean and standard deviation

GM (GSD)= Geometric mean and geometric standard deviation

* Mixing/loading and disinfection excluding rinsing off

Because of the large variation within the population (GSD of 8.0), actual exposure is presented separately for workers wearing and not wearing gloves. Table 5.4 shows that workers not wearing gloves received higher exposure levels during disinfection than workers wearing gloves.

Table 5.4 Actual hand exposure during disinfection according to use of gloves

	Actual hand exposure (mg)			
	n	GM (GSD)	90-perc.*	Range
Not wearing gloves	9	6.1 (2.2)	13	1.9 - 27
Wearing gloves	6	0.16 (3.3)	0.65	0.04 - 0.9

GM (GSD)= Geometric mean and geometric standard deviation

* because n< 10, for the 90-perc. value a value between highest and second highest level is calculated

The average exposure is about a factor 30 - 40 lower when protective gloves are worn. The variation within these two groups was smaller than in the total population. The GSDs were 3.3 and 2.2, respectively. The difference in actual exposure

between the two groups was statistically significant (t-test on log transformed values).

5.2.4 Potential whole body exposure

Potential body exposure was calculated as the sum of the different coverall parts, including the cap which was used to measure head exposure. The individual exposure data are presented in Appendix C. The whole body exposure in Table 5.5 is presented as total dose per activity (in mg) and is recalculated to hourly values (mg/h). Sampling covered mixing/loading and disinfection. Exposure for one worker was measured during rinsing off the disinfectant. During this period the worker wore another coverall. After disinfection the worker waited 15 minutes before he started rinsing the rooms and machinery with water. The exposure measured on the coverall was 0.10 mg or 0.66 mg/h, which was much lower than all other observations on whole body exposure.

Table 5.5 Potential body exposure during disinfection including mixing/loading excluding rinsing off

n	Body exposure (mg)				Body exposure (mg/h)			
	AM (SD)	GM (GSD)	90-perc.	Range	AM (SD)	GM (GSD)	90-perc.	Range
15	101 (142)	32.2 (5.4)	342	2.3 - 440	192 (349)	61.4 (5.1)	433	4.5 - 1370

AM (SD) = Arithmetic mean and standard deviation

GM (GSD) = Geometric mean and geometric standard deviation

5.2.5 Distribution of potential body exposure

Exposure distribution over the body was calculated by comparing the amount of disinfectant present on a specific coverall part with the total amount on the coverall. In Figure 5.1 the distribution is shown as a percentage of the total potential body exposure, as the arithmetic mean of the percentages found for the distinguished body parts for the individual workers. Figure 5.1 shows that the majority of the disinfectant exposure is found on the lower and upper legs: 51 and 22 %, respectively. Exposure on the arms was 12% of the total exposure. The contribution of (actual) hand exposure to total whole body exposure (hand and potential whole body exposure) varied between 0 and 2% for those wearing gloves and between 6 and 62% for those not wearing gloves. 62% was found for a worker with a relatively low whole body, and a relatively high hand exposure.

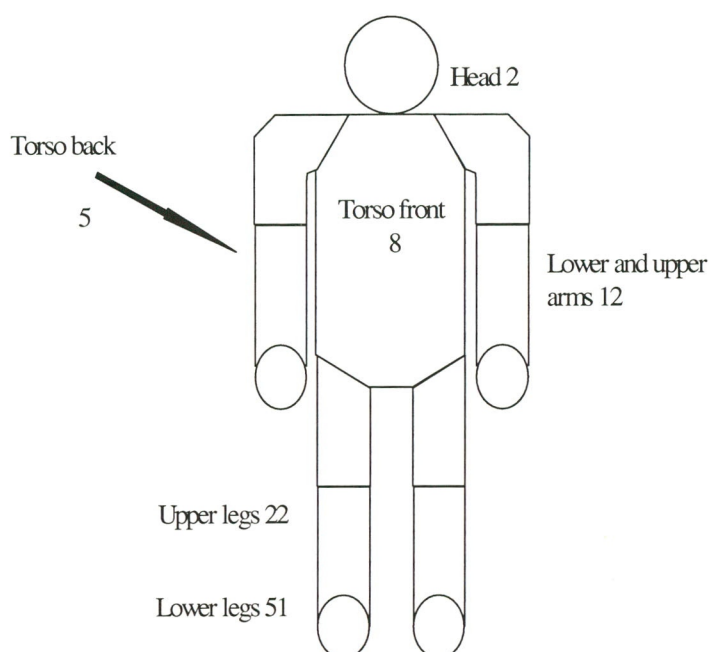


Figure 5.1 Average distribution of potential dermal exposure over the body (% of total exposure).

5.3 Stationary exposure

Concentrations in the air were measured after a room was disinfected, by means of static sampling. The concentrations as they were measured, using a total dust and a fine dust sampling head in two periods of 15 minutes following each other in time, are presented in Table 5.6. As can be seen from the results, the concentration measured during the first 15 minutes was in most situations higher than the concentration measured during the second period. Only in company No. 7 the concentration measured in the second period was slightly higher than the concentration measured during the first 15 minutes. No reason can be given for this observation. In 6 of the 8 situations measured, using the total dust sampling head, the concentration dropped with a percentage of 75% or more within a period of 15 minutes. For the fine dust sampling head in only 4 situations this percentage was higher than 75%. When the concentration levels measured using the two different sampling heads are compared, the results seem to be not very consistent. Sometimes the concentration measured using the total dust sampling head was higher, in other situations it was the other way round.

Table 5.6 *Air concentration of disinfectants as measured by static sampling during 2 consecutive periods of 15 minutes with different sampling heads*

Premise ¹ number	Concentration ($\mu\text{g}/\text{m}^3$) total dust sampling head			Concentration ($\mu\text{g}/\text{m}^3$) fine dust sampling head		
	0-15 minutes	15-30 minutes	Drop in concentration (%)	0-15 minutes	15-30 minutes	Drop in concentration (%)
3	9.6	-	-	11.5	-	-
4	4.5	0.44	89	3.2	0.4	84
5	7.9	1.3	84	6.1	0.29	95
6	10.1	5.4	47	8.9	5.3	42
7	15.4	10.1	34	42.6	42.9	< 1*
8	-	-	-	-	-	-
9	120	24.3	80	129	28.7	78
10	6	1.1	82	5.1	2.1	59
11	36.9	2.9	92	35.9	20.3	43
12	21.3	2.5	88	21.3	3.6	81

¹ Premise number 1 and 2 represent the pilot measurements, these results are not presented

- Concentration was not measured

• increase in concentration

5.4 Clothing regime and hygiene

Fourteen workers were asked which clothing they wear during disinfection in normal circumstances. All workers wear boots. A total of seven workers wear underclothing, which can be a shirt, a blouse or a sweater, another six workers wear combinations like a shirt or blouse with a sweater. One worker wears a body warmer in combination with a shirt. Eleven workers wear long trousers, the three workers not wearing trousers wear a cotton coverall. Three workers use both trousers and a cotton coverall. One worker uses an apron and three workers use the trousers of a rain suit. Only one worker uses goggles.

Workers were asked if they smoked, ate or rubbed their face during disinfection. Nobody smoked and only one of the 14 workers ate during work. Four workers told the field worker they touched their face during work activities.

5.5 Determinants of exposure

5.5.1 Respiratory exposure

In general, exposure was modelled by describing associations between determinants of exposure and exposure levels in multivariate regression models (see par. 4.7). For respiratory exposure, primarily a regression model was selected with the applied concentration of the disinfectant as independent variable. One observation of a worker using an extremely high concentration determined the strength of the association between exposure and concentration. His exposure was, with seven times the population average, by far the highest within the population. Therefore, regression analyses were done without this observation. In the then selected models, applied concentration was not related to exposure level anymore despite a rather large variation within the population. It can not be concluded whether this characteristic is not actually strongly related to exposure, or whether lack of association is due to the potentially large error with which the concentration was assessed: in some companies repeated tank samples were taken and the concentration could vary largely between them.

The best statistical model was the one with only type of applied system as independent variable (Table 5.7). Two workers working with a tank system, had a lower exposure than those working with a automatic dosing system, but this was not statistical significant ($p = 0.12$).

For part of the population not all potential determinants of exposure could be assessed completely, such as material of flooring (see par. 4.7). Within the sub-population in which these characteristics were known, the respiratory exposure was statistically explained best by material of floor, total disinfected floor area, and number of areas with objects requiring up- and downward disinfection.

Table 5.7 Results of respiratory exposure modelling (log of concentration in $\mu\text{g}/\text{m}^3$) in multivariate regression analyses

Population ¹⁾ and model No	Variable	F value	Expl. variance (%), R^2 (adj. R^2)	Parameter estimate ²⁾	p value
Total, model #1		0.12	19 (12)		
	Type of system (Automatic dosage system vs tank)			1.12	0.12
Sub*, model #2		0.04	44 (37)		
	Material of flooring (concrete vs. tiles/granite)			0.93	0.04

¹⁾ the observation with the highest applied concentration is discarded in the analyses. If this observation does not affect parameter estimation(s), this is indicated with *)
total: $n=14$, sub: $n=10$ (population with all variables known)

²⁾ interpretation of coefficients beta: per increase in unit or difference between categories: exposure is a factor e^{beta} higher. An example: The respiratory exposure (model #1) is a factor $e^{1.12}=3$ times higher for the automatic dosing system than for the tank system.

Exposure was statistically significantly higher among those disinfecting rooms with a concrete floor compared to a tile or granite floor, among those with a larger disinfected floor area, and those with less areas needing up and downwards disinfection. The direction of association of the latter variable is not plausible. Excluding the variable from the model yielded a model with only material of flooring as independent variable. Surface area did not contribute to the explained variance anymore (Table 5.7). For comparison, the latter model is presented without the observation with extremely high applied concentration, although its influence on the parameter estimate was restricted.

5.5.2 Actual hand exposure

Two models were about equal in explaining variance in dose of dermal hand exposure: a model with use of gloves alone (clearly protective effect of gloves), and a model with, next to use of gloves, the concentration of the applied disinfectant, disinfected floor area (positive association, meaning here: larger area, higher exposure), and applied pressure (2 categories: high versus low, positive association) (Table 5.8). Somewhat unexpectedly, duration of disinfection procedure appeared not to be related to the dose. This could not be explained by collinearity between duration and disinfected floor area.

Because of its large influence, the model with applied concentration is given without the cleaner using the highest concentration. For the model with use of gloves alone as explanatory variable the observation had little influence on the parameter estimate and model performance. For comparison though, that model is presented without the observation as well.

Table 5.8 Results of actual dermal hand exposure modelling (log of total dose in μg) in multivariate regression analyses

Population ¹⁾ and model No	Variable	F value	Expl. variance (%), R^2 (adj. R^2)	Parameter estimate ²⁾	p value
Total*, model #1		0.0001	86 (84)		
	Use of gloves (yes vs no)			-4.0	0.0001
Total, model #2		0.0001	95 (92)		
	Use of gloves (yes vs no)			-3.3	0.0001
	Applied concentration (g/l)			0.9	0.01
	Disinfected floor area (m^2) (log transformed)			0.75	0.02
	Pressure (high vs. low)			1.5	0.07

¹⁾ the observation with the highest applied concentration is discarded in the analyses. If this observation does not affect parameter estimation(s), this is indicated with *)
total population: $n=14$.

²⁾ interpretation of coefficients beta: per increase in unit or difference between categories: exposure is a factor e^{beta} higher. An example: The exposure is a factor $e^{0.9} = 2.5$ times higher if the applied concentration is 1 g/l higher (model #2).

5.5.3 Potential whole body exposure

Regression models for the total population and the subpopulation with those for whom type of flooring was known differed. For the total population, variance in exposure was explained by disinfected floor area alone (positive association with the log transformed area) (Table 5.9). The observation with the extremely high applied concentration had little influence on the parameter estimate, but was deleted because of comparison with the models in the subpopulation presented hereafter.

In the subpopulation, two models were about equal: the model with floor area alone (positive association) and the model with floor area, duration of disinfection, applied concentration (all: positive association) and material of flooring (concrete higher exposure than tiles or granite) (Table 5.9).

Table 5.9 Results of dermal whole body exposure modelling (log of total dose in μg) in multivariate regression analyses

Population ¹⁾ and model No	Variable	F value	Expl. variance (%), R^2 (adj. R^2)	Parameter estimate ²⁾	p value
Total*, model #1		0.0007	63 (60)		
	Disinfected floor area (m ²) (log transformed)			1.15	0.0007
Sub, model #2		0.0001	87 (85)		
	Disinfected floor area (m ²) (log transformed)			1.10	0.0001
Sub, model #3		0.0017	95 (91)		
	Disinfected floor area (m ²) (log transformed)			1.03	0.004
	Duration disinfection (minutes)			0.02	0.06
	Applied concentration (g/l)			0.32	0.08
	Material flooring (concrete vs. tiles/granite)			0.73	0.05

¹⁾ the observation with the highest applied concentration is discarded in the analyses. If this observation does not affect parameter estimation(s), this is indicated with *)
total: n=14, sub: n=10 (population with all variables known)

²⁾ interpretation of coefficients beta: per increase in unit or difference between categories: exposure is a factor e^{beta} higher. 2 examples: if the floor area is 2.71 times as large, then exposure is a factor $e^{1.15}=3.2$ times higher (model #1). The exposure is a factor $e^{0.73}=2.1$ times higher for workers in companies with concrete flooring than for workers with tiles or granite flooring (model #3).

Within-company dependency

In some companies the exposure of more than one person was assessed. Observations within a company may not be independent and hence bias regression modelling. Therefore, all selected multivariate models were tested again with company

average values. For all types of exposure, presented models were stable if applied to the data set with company average values. Therefore, results seem not to be influenced by within-company dependency.

5.6 Exposure values for registration purposes

For registration purposes, estimates are made based on observed exposure levels or on models with determinants of exposure in it. The 90-percentile is generally taken as the statistic of choice for 'reasonable worst case' estimates from data bases. For use of data for registration purposes, exposure values have to be converted to a suitable format. For respiratory exposure, exposure can be expressed in ml spray fluid per m^3 . For conversion of the exposure levels in mg/m^3 to ml/m^3 , the actual measured applied concentration was used. Results are presented in Figure 5.2. The arithmetic mean is $0.7 \text{ ml}/\text{m}^3$, the geometric mean is $0.12 \text{ ml}/\text{m}^3$, and the 90th-percentile value is $1.7 \text{ ml}/\text{m}^3$ during the period of disinfection including mixing/loading, if applicable.

In Figure 5.3 actual hand exposure during disinfection is presented for the total population and the subpopulations (gloves/without gloves). Exposure is expressed in ml spray liquid per hour of work. For the workers wearing gloves the geometric

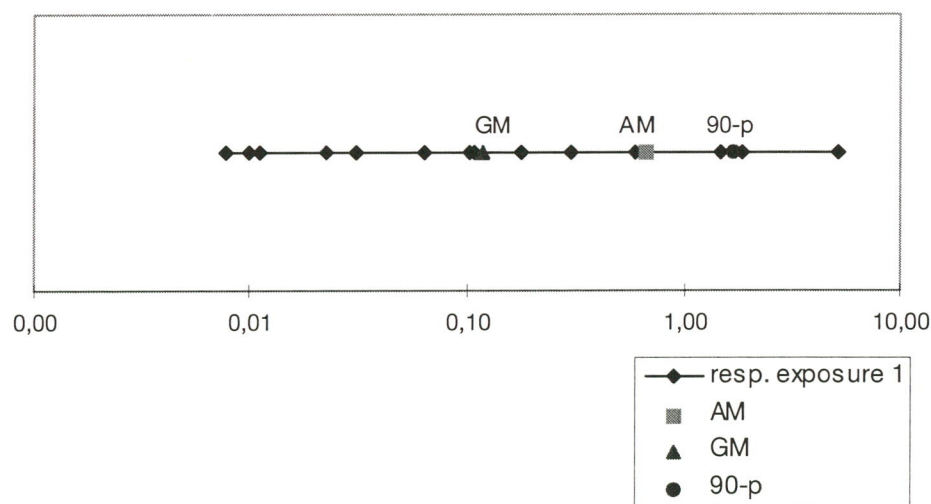


Figure 5.2 Respiratory exposure during disinfection ($\text{ml spray liquid}/\text{m}^3$)

mean, arithmetic mean and 90th-percentile values are 1.1, 2.4 and $5.3 \text{ ml}/\text{h}$ respectively. For workers not wearing gloves the 90th-percentile is $99 \text{ ml}/\text{h}$. The geometric and the arithmetic means are 15 and 33 ml per hour, respectively. The 90th-percentile value for the total population is approximately 63 ml per hour.

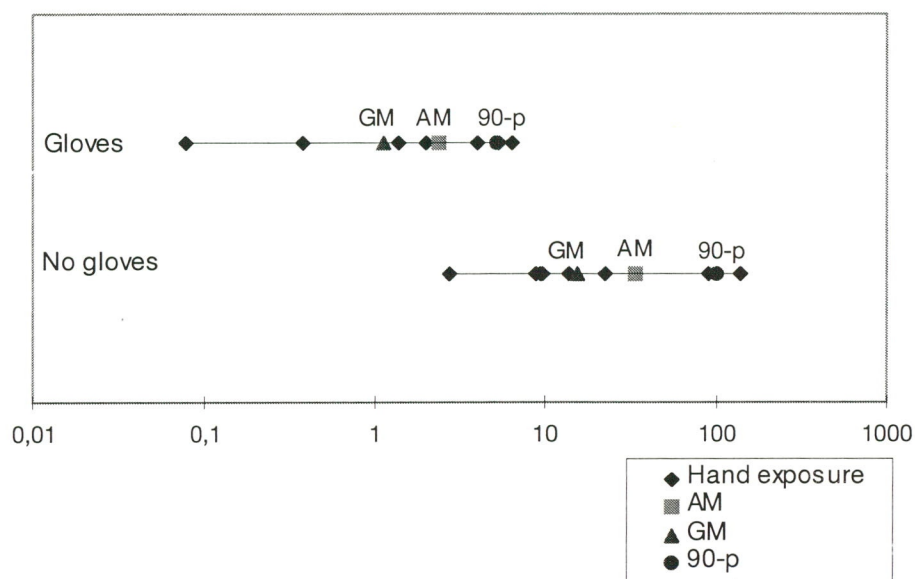


Figure 5.3 Hand exposure during disinfection (ml spray liquid/h)

The data on potential body exposure for disinfection including mixing/loading is presented in Figure 5.4. Exposure is expressed in ml spray liquid per hour. The geometric and the arithmetic means are 122 and 254 ml per hour, respectively. The 90 percentile value is approximately 700 ml per hour.

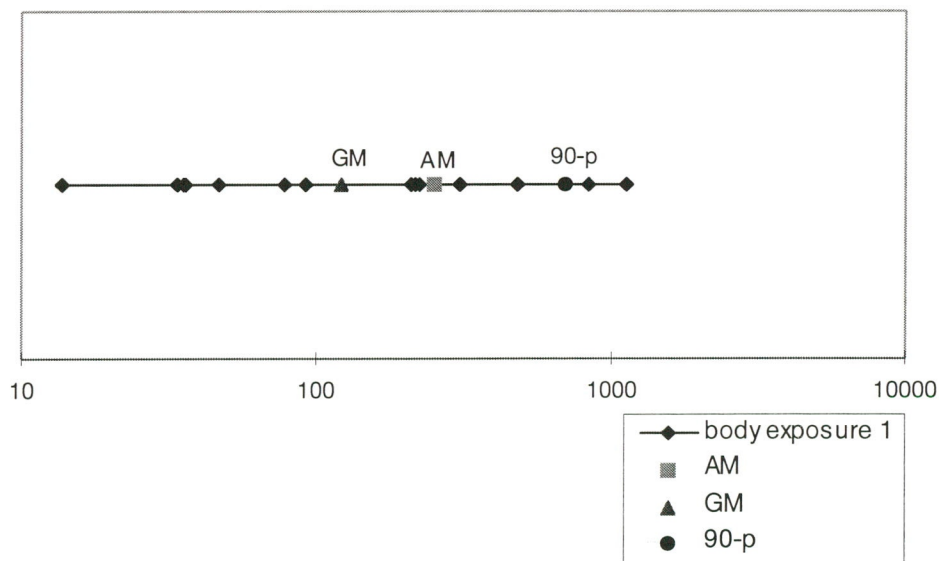


Figure 5.4 Potential whole body exposure during disinfection (ml spray liquid/h)

Also regression models selected in our study could be used for exposure estimates in potential exposure situations. However, since modelling was done with expo-

sure levels in weight units, estimates are also expressed in these units. This restricts its direct use for registration purposes. For estimation, 90th-percentile values of determinants are taken as values for determinants. For bivariate variables, the value yielding the highest exposure levels is taken.

For respiratory exposure no determinants were in the regression models which could be used for registration purposes.

For potential hand exposure, model #2 (Table 5.8) can be used for estimation, assuming pressure to be high, no use of gloves (because of potential exposure) and for other determinants the 90th-percentile value (3 mg/L for applied concentration, 1700 m² for floor area). The estimated worst case exposure expressed in mg is 163. This is about six times higher than the maximum (actual) hand exposure observed in the study.

For potential whole body exposure, the model with floor area alone as well as the model with floor area, duration of disinfection, applied concentration, and material of flooring can be used (models #1 and #3, Table 5.9). In the first case, using the 90th-percentile for floor area (1700 m²), the model yields a worst case estimate of 139 mg, much lower than observed in the population. Using the second model, assuming 90th-percentile values (3 mg/L for applied concentration, 1700 m² for floor area and a duration of 65 minutes) except for flooring for which a concrete floor is taken, the estimate expressed in mg is 335, which is similar to the 90th-percentile of the exposure distribution in the population.

6. Discussion

6.1 General

The present study describes personal exposure of cleaners to disinfectants in slaughterhouses and the meat processing industry. This is, as far as known, the first study in which dermal as well as respiratory exposure to disinfectants in this sector is presented quantitatively. Since disinfectants potentially induce respiratory as well as dermal effects as is known mostly from workers in medical settings, information on both types of exposure should be available for risk assessment. Exposure measurements were done in a variety of companies, ranging from slaughterhouses for different types of animals to companies producing meat products such as sausages. Slaughterhouses and meat processing companies were chosen as an example for its frequent use of disinfectants. Also in many other settings, such as other parts of the food industry and in animal husbandry, disinfectants are used regularly to disinfect relatively large spaces. Next to that, disinfection of transport means can be mentioned as an example of smaller spaces. Because of disease epidemics, more strict regulations have been implemented on disinfection of transport means. Part of the results of this study may therefore be indicative for exposure in other occupational settings, although different methods of disinfection may yield different exposure levels.

In the present study the type of disinfectant was restricted to one specific quaternary ammonium compound. This was done because of logistic reasons. The laboratory analyses could be restricted to one compound only, and exposure levels in different workplaces could be compared. The hazard of this compound did not determine its selection. Restriction to one compound only has most likely restricted the variation in methods of disinfection encountered. Variation was also restricted by the selection procedure of companies. Selection of companies depended on cooperation of both cleaning companies and meat companies in which alkyldimethylbenzylammoniumchloride was used. Many companies were interested and willing to participate in the study, but the criteria on the disinfectant was often a limiting factor. Measurements were done in all companies willing to participate and using the right quaternary ammonium compound. Selection on method of disinfection was not possible.

6.2 Exposure measurements

No standard methods exist for exposure assessment of disinfectants. For dermal exposure assessment, two methods were used next to each other: hand washing for assessment of actual hand exposure, and use of Tyvek® coveralls to assess potential whole body exposure. OECD guidelines (OECD, 1997) suggest the use of cotton overalls to assess whole body exposure, but this was not possible in this setting since some workers would have become extremely wet. These workers use under normal circumstances usually a rain suit or similar protection. In addition, static measurements were done to evaluate potential respiratory exposure of bystanders and the risk of exposure during re-entry.

6.3 Personal exposure levels

In this study, respiratory and dermal exposure (hand and potential whole body) to quaternary ammonium compounds was assessed. No other studies are known to us in which exposure to quaternary ammonium compounds was measured.

Respiratory exposure was on average about 0.05 mg/m^3 (GSD: 2.9, range: 0.001 - 0.4). If these exposure levels are compared to reported exposure levels of glutaraldehyde in medical settings, then levels as expressed in mg/m^3 are in about the same range. Norbäck (1988) reported 15 minutes' average levels of less than 0.01 mg/m^3 to 0.57 mg/m^3 , and Leinster *et al.* (1993) reported exposure levels ranging from 0.003 to 0.11 mg/m^3 after short duration of exposure. Recently, Leutscher *et al.* (1997) described exposure to glutaraldehyde in two Dutch hospital settings. Average personal exposure was 0.01 and 0.003 mg/m^3 , respectively. Reported exposure levels of glutaraldehyde in poultry farms, were about a factor 10 higher (De Haan *et al.*, 1994).

Average actual hand exposure in the present study (expressed in mg) was in the same range as the potential dermal hand exposure to o-phenylphenol (OPP) and o-benzyl-p-chlorophenol (BCP) in Lyorthol® reported by Schipper *et al.* (1996) and de Zeeuw (1998), who did their studies among cleaners in medical settings. In the study of Schipper *et al.*, average exposure, as measured in total dose (in mg), was 3.0 mg for OPP and 3.5 mg for BCP, respectively (both GM). In the study of de Zeeuw (1998) potential dermal exposure was 2.05 mg OPP (GM). These levels are comparable with the actual total exposure found in the present study (2.1 mg (GM)).

Exposure among those working without gloves, comparable to the potential exposure as measured by Schipper *et al.* (1996), was on average 6.1 mg (GM). The workers using gloves in the present study had, with 0.16 mg, a comparable exposure with the workers in the study of de Zeeuw (GM 0.17 mg) and a somewhat lower actual exposure than those wearing gloves in the study of Schipper *et al.*, where the actual exposure was about 0.5 mg for OPP as well as BCP. The variation in exposure between workers in the present study was very large, with a GSD of 8.0. This was caused by the large difference in actual exposure between those wearing and not wearing gloves. Within these two groups, the GSD was 3.3 and 2.2, respectively.

For three workers exposure was measured during mixing and loading as well as during disinfection. For two of them, not wearing gloves during this activity, the total hand dose was nearly completely determined by mixing and loading, making up 94 and 96 percent of the total hand exposure.

No studies are known reporting whole body exposure levels with which the results of the present study can be compared. Exposure found on the legs, especially lower legs, contributed on average most to the potential whole body exposure. When considering potential total whole body exposure including hands (for the workers not wearing gloves) exposure on hands contributed for most workers between 6 and 14 percent, for one worker 22 percent, and the highest contribution of hands was found to be 62%. Since the recovery from coverall and hands were in the same range, this suggests that total dermal exposure could be decreased considerably by wearing (good) gloves. For whole body exposure, the variation between

workers was large, with a GSD of 5. This may partly be caused by the variation in contact with the contaminated hose as was observed during field work. This type of contact was observed during disinfection itself, most often with the legs, and during change of rooms, sometimes requiring carrying of the hose.

The distribution of exposure over the body shows that the lower legs receive the highest exposure (51%), followed by the upper legs (22%). Exposure on the head was the lowest (2%). Actual exposure levels on the hands vary. For workers wearing gloves the contribution of hand exposure to total body exposure varied between 0 and 2%, for workers disinfecting without gloves the contribution varied between 6 and 62%.

Two other studies showed comparable results with respect to exposure of lower and upper legs. Brouwer *et al.* (1997) investigated body exposure after spray application with propoxur in glasshouses with carnations. They also found the highest exposures on the lower legs (45%) and upper legs (18%). Lansink *et al.* (1998) studied the dermal exposure during airless spray painting. The results of this study show that for both situations investigated, spraying the inside or the outside of a container, exposure on the lower legs was the highest, 48 and 54% respectively. Exposure on the upper legs was 17 and 18% respectively. Hand exposure in this study was low (2 and 4%, respectively). De Vreede *et al.* (1994) measured dermal exposure to the pesticide methomyl during spray application in chrysanthemums. Exposure on lower and upper legs was 22 and 14% respectively of total body exposure. These percentages were somewhat lower than the percentages found in the other studies. The differences in contribution of hands to the total body exposure for the different studies are difficult to explain. However, it is likely that the used spray technique, the pressure with which was sprayed, the particle size, the dispersion of particles, and the moments of accidental contact, or a combination of these, may account for the large differences found.

6.4 Stationary sampling

Static measurements of airborne exposure were done to evaluate potential exposure of bystanders and of those present in recently disinfected rooms. The two times consecutive 15 minutes' measurements show that airborne exposure decreases quite rapidly: within a period of 15 minutes a decrease of about 80% is seen in most companies, with a slightly smaller decrease when using the results of the fine dust sampling head. Based on the results the respiratory exposure of bystanders will most likely be several factors lower than those actively disinfecting. However, no reliable information is present on the performance of and fractions sampled by both sampling heads. Based on the relatively large size of the aerosolised droplets with disinfectant, the sampling heads seem not to perform very well for this type of exposure because of the small difference obtained with both sampling heads.

6.5 Use of personal protective equipment

Use of gloves and protective clothing in normal working circumstances varied. As was shown, not wearing gloves implies a relevant increase in potential dermal exposure. In some cases protective clothing was expected to be effective. In most other cases, however, cotton overalls or aprons not protecting lower legs were used. Although no information was obtained on actual whole body exposure in this study, it seems likely that workers receive dermal exposure through clothing. This can also be inferred from the results of the study by Popendorf and Selim (1995) on dermal exposure of disinfection workers.

In only one company respiratory protection was used, whereas some workers mentioned respiratory effects.

Given the potential health effects by use of disinfectants as reported in other studies, the risk perception of these workers and supervisors seem inadequate.

6.6 Risk

No conclusions can be drawn on potential health risks by comparing exposure levels found in this study with OELs, since the latter are not available for quaternary ammonium compounds. This group of compounds covers several different compounds used as disinfectants and preservatives. Due to lacking knowledge, indicating differences in hazard between the various compounds is not possible. Preller *et al.* (1995, 1996) found in their study among pig farmers strong associations between disinfection procedures with quaternary ammonium compounds and sensitization to common allergens on the one hand and with respiratory health effects on the other hand. No exposure levels were assessed in that study. Most pig farmers apply disinfectants by means of high pressure spraying. Exposure levels are therefore expected to be higher than found in this study. Pig farmers do, however, not disinfect each day and total time spent on it each time is usually less than by the workers in the present study. Total respiratory dose and risk may therefore be in the same range. Also, among the pig farmers using quaternary ammonium compounds, one farmer had specific IgE against a selected quaternary ammonium compound, implying that an allergic reaction is possible (Preller, unpublished data). Other indications of risk by airborne exposure among workers who are exposed to quaternary ammonium compounds either directly or during re-entry can be found in studies by Bernstein *et al.*, 1994; Burge *et al.*, 1994 and Dejobert *et al.*, 1997.

For dermal effects, no quantitative exposure relationships have been reported, but case studies of dermal effects due to the use of quaternary ammonium compounds are known (Rustemeyer *et al.*, 1994; Placucci *et al.*, 1996).

In current documents for authorisation of biocides little toxicological information is given on hazards of specific quaternary ammonium compounds. Although the information given above is not specific for the type of quaternary ammonium compound, it seems that the toxicological information on quaternary ammonium compounds is highly insufficient for aspects like sensitisation. Because of the widespread use and the potential serious health effects, more valid information in this field should be required before a biocide is accepted for use.

6.7 Exposure modelling

In this study much attention was paid to assessing potential determinants of exposure, including characteristics of the disinfection procedure and the disinfected rooms. Because a priori little was known on the potential determinants, many were assessed. An elaborate list of potential factors was made based on company visits before exposure assessment, based on the information gathered in the feasibility study. This list is presented in Appendix D. Potential determinants include characteristics of work environment and work practice. For the latter, within each company at least one worker was followed intensively during the disinfection process. Tasks, location and work characteristics were registered. To our knowledge, only Leutscher *et al.* (1997) describe an empirically found association between exposure levels and a determinant, in this case the association between the number of disinfected endoscopes and exposure to glutaraldehyde in two Dutch hospitals. Possibilities of describing exposure levels as a function of determinants of exposure depend on the variation in the determinants within the population and the error with which the determinant is assessed. Without sufficient variation within the population, associations are difficult or impossible to find. In the present study, the studied population depended on the cooperation of meat companies and cleaning industries. The variation in potential determinants of exposure was completely dependent on what was encountered in the companies. It was not possible to select on disinfection characteristics, such as type of system used, which inhibits the possibility to make inferences on control measures. Further, if the 'error' with which the determinant is assessed is large, the association is attenuated, meaning that the regression line is less steep. This also means that the chance on finding a statistically significant association with the determinant is limited. In practice, several factors appeared difficult to assess for modelling: e.g. determinants varied between rooms disinfected by the same person. Also, the variation in several potential determinants of exposure within the population was limited.

Results of exposure modelling have to be used with some caution: the number of observations and consequently, the number of observations in the cells is limited. The observed effect of a characteristic on the exposure level, can also be a random difference induced by other factors not present in the model. For example, observations of only two persons working with a tank system were included in the data set. The regression model # 1 for respiratory exposure suggests a lower exposure when using a tank system (although not statistically significant). When the exposure of the workers with a tank system just happens to be below average, caused by an unmeasured factor such as difference of type of company e.g. slaughterhouse or meat product company, which might require other disinfection procedures, the observed association does not say anything about the causal association between type of system and level of exposure. Such effects can also be responsible for finding different models based on the total population and the subpopulation for which more variables were known. Also, because of limited number of observations, the size of the effect found should be considered as indicative. Next to that, since the association between dependent and independent variable is valid within the range of observed values, it can not be concluded whether these associations

are valid for values outside the ranges. Also no conclusion can be drawn on the true form of the association, e.g. whether the physiological association is reflected better by transformed or untransformed value. Use of transformed values depended on model performance. Transforming variables was considered especially if the distribution of the variable was highly skewed, and hence the chance that observed associations were determined by one or a few high values was large.

Despite the limited number of observations, several factors were found to be strongly related to respiratory and dermal exposure. In summary, variation in respiratory exposure might be explained best by material of flooring, actual hand exposure by use of gloves, and potential whole body dermal exposure by disinfected floor area.

Considering respiratory exposure, the effect of material of flooring is difficult to explain. Exposure was higher in companies with concrete flooring. It is possible that material of flooring stands for other related factors. Concrete flooring is most likely more difficult to clean and disinfect because of its rough structure. In these companies, factors which could not be measured well such as actually applied concentration, total amount used, and pressure level may be higher, causing higher exposure levels, but conclusions on this are highly speculative. Type of flooring was also related to whole body exposure in model #3, with four independent variables, the direction of the effect being the same and the size of the effect being in the same range as for respiratory exposure. This strengthens the idea that material of flooring or related variables do affect exposure.

In the total population, respiratory exposure is suggested to be higher for those using an automatic dosing system compared to those using a tank system, although the effect is not statistically significant. No explanation can be given for this weak association.

The models for actual hand exposure suggest a strong effect of use of gloves. When using gloves, exposure was on average about a factor 30-40 lower. Contribution of hand exposure to total whole body exposure as assessed for those working without gloves was about 10 percent as found in the present study. However, the contribution to dermal uptake is potentially underestimated since for other parts the potential exposure was assessed outside the normal clothing, while for the hands actual exposure was measured. Clothing will diminish contamination to reach the skin, the measure of protection depending on type of clothing and e.g. the humidity of the clothing.

Since dermal effects have been observed for disinfectants similar to the ones used in the companies and other disinfectants potentially used in comparable situations, use of gloves should be strongly advised to reduce potential health risks.

Disinfected floor area was strongly and positively related to potential whole body exposure. Most likely, area stands for factors such as the total amount of used disinfectant, explaining the higher dose of whole body exposure. Intervention on this characteristic cannot be used for risk reduction. Knowledge on this effect can, however, be used for modelling purposes e.g. for risk assessment of biocides for

registration purposes. This determinant is easy to assess. Depending on the model, disinfected area was also related to hand exposure, the size of the effect being somewhat smaller than for whole body exposure. Also for hand exposure, the total amount of disinfectant used may cause the higher exposure.

Only in models with more independent variables, applied concentration was related to hand and whole body exposure only, but not to respiratory exposure, after deleting the observation with the by far highest concentration. Producers advise use of specific concentrations. In the present study, it was clear that the advice was not strictly followed, partly because maintaining the exact concentration is difficult, partly presumably to reduce microbial contamination. The estimated effect of an increase in applied concentration of 1 g/l is a 2.5 times higher hand exposure and a 1.3 times higher potential whole body exposure. Within the population, the difference between low (less than 1 g/l) and moderate concentrations (1.2 - 1.4 g/l) was similar to this increase of 1 g/l. Three times a much larger difference was found, with measured tank concentrations of 2.4, 3.6 and 12.3 g/l, respectively. Optimising the applied concentration may therefore reduce the potential dermal health risk. The true effect of applied exposure may even be larger than the one estimated, since the concentration was measured with a relatively large error as can be inferred from several repeated measurements in some companies, thereby most likely attenuating the association.

Only in one model for whole body exposure a weak, positive association existed with duration of the procedure. Duration of exposure was expected to be related to dermal exposure, since the dependent variable was given in total dose. 'Duration' explained only part of the variance of whole body exposure, its effect being close to statistical significance ($p=0.06$). Lack of association with hand exposure can probably be explained by the fact that hand exposure is affected more by random direct contact during e.g. spilling. It was observed that such contact occurred regularly, but this was not registered systematically during the field study for modelling purposes.

Pressure level was expected to be related to exposure levels as well, especially respiratory and whole body exposure. Higher pressure yields smaller droplets, which are more within sampling range and longer airborne, and higher pressure also gives more backslash, as was visible in some situations. No association could be found with these types of exposure. Since workers did not know the used pressure, only crude estimates of pressure level could be made with potential large error, potentially limiting the chance of finding a statistical significant association. Preller *et al.* (1995) did find strong associations between estimated pressure level and respiratory symptoms in pig farmers, suggesting higher biological relevant exposure. The pressure applied by pig farmers was usually much higher, making it difficult to draw conclusions for the meat industry.

6.8 Data for registration purposes

For registration purposes, exposure values expressed in ml spray liquid per m³ for respiratory exposure or ml per hour for dermal exposure have been selected. For 'reasonable worst case' estimates the 90-percentile is generally taken as the statistic of choice from the data. The selected surrogate values can be used in estimations for dispersive liquid application of disinfectants with low pressure (1-8 bar), according to the list of application methods as identified by the Biocides Steering Group (BSG, 1998). The BSG estimated the exposure levels with this type of application to be relatively high within the group of dispersive liquid applications. In the ranking of the different application techniques by the BSG, no difference was made between respiratory and dermal exposure. The selected surrogate values are based on a maximum of 15 observations with a relative large variation in work environment.

For hand exposure the actual exposure was assessed, which means an underestimation of potential exposure for those wearing gloves. However, if the 90th-percentile value is taken of the distribution for workers not wearing gloves, the surrogate value is in the same range as the value based on the total population: 63 and 99 ml spray liquid/h, respectively.

Exposure for all types of matrices was estimated by assessing the contamination in weight unit. To obtain the surrogate values the exposure values had to be adjusted for applied concentration. The applied concentration was measured with an unknown error, but based on repeated measurements in some companies the error may be large. Therefore, exposure surrogate values may be inaccurate. The size of this effect can not be estimated, but could be large because of the small population size in combination with the use of 90th-percentile values.

In regression models exposure levels expressed in $\mu\text{g}/\text{m}^3$ or μg were used as dependent variable. Therefore, the models can not be used directly to quantify the effect of determinants on surrogate values, but only indirectly. For example, the difference in potential total hand dose is estimated to be a factor seven between disinfecting a small and large floor area (data not shown). Using regression outcomes for estimation of worst case potential hand exposure expressed in mg, substituting 90th-percentile values for continuous variables and worst case values for dichotomous variables in the model, the estimation is several factors higher than the observed exposure levels in the present study. It is possible that none of the workers in the population had this worst case combination of determinants. It can not be excluded, however, that this worst case combination will not be encountered in exposure situations for which surrogate values are derived. The surrogate value underestimates in that case the worst case exposure.

For potential whole body exposure, the estimated exposure for the worst-case situation was similar to the observed 90th-percentile value using the model with most explanatory variables, but was about 2.5 times lower using the restricted model with disinfected floor area alone. This difference shows that construction and selection of models for registration purposes can be very critical for the estimates.

7. Conclusions and recommendations

In this study respiratory and dermal exposure to alkyldimethylbenzylammonium-chloride was assessed for range finding as well as for modelling purposes for authorization of biocides. Disinfectants were applied by low pressure dispersive liquid spraying, one of the categories identified by the Biocides Steering Group as a situation with potential high exposure. For all observations exposure was detectable and average levels were in the same range as found in medical settings, if expressed in weight units. Average exposure during application to alkyldimethylbenzylammoniumchloride in weight units was: $53.6 \mu\text{g}/\text{m}^3$ for respiratory exposure (GM, GSD 2.9, range 11.4 - 424), 1.4 mg for actual hand exposure (GM, GSD 7.9, range 0.04 - 27.2), and 32.2 mg for potential whole body exposure (GM, GSD 5.4, range 2.3 - 440).

For modelling purposes for authorization of biocides surrogate exposure levels (expressed in ml spray liquid) were derived. The choice of the statistic is especially important, since the variation in actual level of exposure is large for many reasons such as variation in work practice, climatic condition, applied equipment and especially personal hygiene. Therefore, the 90-percentile is generally taken from exposure data as the statistic of choice for 'reasonable worst case' estimate. The following surrogate exposure values were chosen: $1.7 \text{ ml}/\text{m}^3$ for respiratory exposure, and 700 ml/h for potential whole body exposure for application including mixing and loading, if applicable. For actual hand exposure two surrogate exposure values were derived: 99 ml/h for workers disinfecting without gloves and 5.3 ml/h for workers wearing gloves. These values were derived for application alone. It is proposed to use rounded values for registration purposes, i.e. $2 \text{ ml}/\text{m}^3$ for respiratory exposure, 700 ml/h for body exposure, 100 ml/h for hand exposure for workers not wearing gloves and 5 ml/h for hand exposure for workers wearing gloves, respectively.

Several determinants of exposure levels (in weight units) could be identified within the population. For respiratory exposure the strongest determinant was type of flooring. Those working in companies with concrete flooring had on average a higher exposure than those disinfecting rooms with tiles or granite flooring. Use of gloves was a strong determinant of actual hand exposure: those wearing gloves had an exposure which was about 30 to 40 times lower than those not using gloves. Also applied concentration, disinfected floor area and pressure level explained part of the variation.

Disinfected floor area was the strongest determinant of potential whole body exposure. In addition, also material of flooring, applied concentration, and duration of disinfection were strongly or weakly related to exposure levels. Part of this information can be used for authorization of new biocides. For dermal exposure disinfected floor area seems to be a stronger determinant of exposure than duration of exposure. Both models are used for exposure assessment for authorization, but based on results of the present study models with floor area are preferred above those with time.

For the specific quaternary ammonium compound selected for this study, no quantitative risk assessment can be made since no OELs are derived. With respect to hazard though, it seems indicated that the lack of information given on potential sensitisation effects of quaternary ammonium compounds in general does not correspond with the serious health effects reported in some case studies and epidemiological studies. Therefore, before biocides with quaternary ammonium compounds are accepted in a formal risk assessment process, more information on hazards should be given.

Also because of absence of OELs for the specified component, no conclusions are drawn on the need for risk reduction. However, because of the potential hazards of disinfectants, exposure should be minimized. Based on the results, several suggestions for risk reduction in similar exposure situations can be given. Use of effective gloves can reduce actual dermal exposure. Since the major part of potential whole body exposure was found on the lower legs, protection of this part of the body should also be considered. However, the study does not give any information on the permeability of the clothing. To estimate the relevance of protective clothing for risk reduction, more information should be obtained on the actual protection effect by clothing worn in similar practical situations.

Use of respiratory protection was observed in only one company. Use of respiratory protection during application should be considered.

Apart from use of personal protective equipment, only few other indications were obtained for reduction of exposure. Applied concentration should not be higher than necessary. For explanation of the effect of material of flooring, more information is needed on the potential causal factors. It was suggested that concrete flooring requires more disinfectant, but this can not be supported by observations since this information was not available. In future studies more effort should be put in obtaining this information.

With respect to exposure studies and epidemiological studies, these are virtually lacking except for some studies in medical settings. Conservative estimates show that at least 1000 workers in slaughterhouses and meat processing companies are daily exposed to disinfectants, part of them in a comparable way as is this study. Next to that, there are many other types of food related occupational settings with exposure to disinfectants as studied and to other disinfectants with similar reported health effects. There are another 2700 companies in other sectors of food production industry, and some 5400 meat retail trade shops. The number of companies involved in animal transport and animal husbandry is estimated to be high. More quantitative information is needed on exposure levels and determinants of exposure. Overall, studies for deriving surrogate exposure levels and for assessment of determinants of exposure should be larger than the present study. In addition, because very little is known on actual health risks among disinfection workers, epidemiological studies should be performed.

8. Acknowledgement

The Department of Chemical Exposure Assessment (Division of Toxicology) of TNO Nutrition and Food Research Institute investigates health risks of exposure to chemical substances in the working environment at the request of the Ministry of Social Affairs and Employment. The present study forms a part of the Health Hazard Surveys.

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9. Signature

A handwritten signature in blue ink, consisting of a series of loops and a long horizontal stroke, positioned above a horizontal line.

Dr. J.J. van Hemmen

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Appendix A Information on the active ingredient in the formulation, the dosage and the concentrations measured in spray liquid during disinfection

Company number	Concentration in product (g a.s./l)	Prescribed dosage or concentration	Concentration in spray liquid measured (mg/L)	Calculated concentration (%)
3	36	1 litre on 100 litre water (1%)	512	1.42
4	36	3 - 3.5%	1328	3.7
5	26	probably < 1%	1272 528	0.5 9.7
6	26	probably < 1%	7.9 46.5 24 16.7	0.03 0.18 0.09 0.06
7	36	0.25 - 0.5%	1223	4.7
8	26		3622	13.9
9	95.4	Unknown	1099 948	1.2 1.0
10	95.4	Unknown	1188 1281 1067 1259 1191	1.2 1.3 1.1 1.3 1.2
11	95.4	Unknown	13003 11661	13.6 12.2
12	95.4	Unknown	2386 2568 2170	2.5 2.7 2.3

Appendix B Individual exposure data

Preno	Worker	Task code	Respiratory exposure	Actual hand exposure		Potential whole body exposure		Concentration measured in spray liquid	Disinfection 1= tank with spray gun 2 = automatic dosing system with spray gun	Area treated	Gloves (Y/N)	Material floor 1= tiles 2= concrete 3= both
			($\mu\text{g}/\text{m}^3$)	mg	mg/h	mg	mg/h	(mg/L)		(m ²)		
3	1	1	27.26	2.33	69.9	7.8	33.2	-	1	320	-	-
		2		0.15	0.7			512			Y	
		3	14.1	0.02	0.1	0.1	0.66	-			N	
4	1	2	142.1	0.5	0.5	292	282.7	1328	2	1460	Y	-
4	2	2	41.4	10.8	18.5	170	291.4	1381	2	3650	N	1
5	1	2	14.8	3.6	3.7	51.	47.3	1327.5	2	1408	N	1
6	1	2	30	1.9	1.1	12.1	6.7	7.9	2	160	N	1
6	2	2	104.5	0.08	0.1	10.7	15.3	46.5	2	175	Y	2
6	3	2	29.5	0.04	0.08	2.3	4.5	24	2	125	Y	1
6	4	2	27.8	0.07	0.13	5.0	9.7	16.7	2	180	Y	2
7	1	2	35.9	27.2	109	342	1366	1223	2	375	N	-
8	1	1	11.4	1.5	?	5.8	49.9	-	1	124	N	1
		2		9.5	81			3622			N	
9	1	2	369.3	2.9	9.7	10.3	34.3	1023.5	2	118	N	3
10	1	2	75.1	5.8	10.8	60.9	114.1	1234.5	2	559	N	2
10	2	2	95.	6.5	10.9	54.4	90.6	1172.3	2	830	N	2
11	1	1	424.3	21.7	650.2	439.9	432.7	-	1	1865	N	2
		2		0.85	0.96			12332			Y	
12	1	2	31.0	5.5	12.7	48.1	111	2374.7	2	760	N	2

Appendix C Individual exposure levels on coverall parts per worker

Preno	Pin	Task code	Total exposure (μg)	Time (min)	Exposure on different coverall parts (μg)					
					Head	Upper legs	Lower legs	Arms	Torso front	Torso back
3	1	2	7751	14	19	931	6007	380	316	98
		3	99	9	3.3	69	6.7	6.7	6.7	6.7
4	1	2	292123	2	4304	55278	169709	31109	22306	9417
4	2	2	169957	35	638	41038	91511	5899	28358	2513
5	1	2	51019	64.7	130	9229	34337	3736	1326	2261
6	1	2	12077	108	151	2609	6108	1616	706	887
6	2	2	10721	42	255	1645	5473	1953	921	474
6	3	2	2305	31	141	306	1532	159	70	97
6	4	2	5022	31	211	743	2635	737	423	273
7	1	2	341562	15	90	106590	194178	6133	30241	4330
8	1	2	5828	7	6.67	2877	2316	396	219	13.33
9	1	2	10278	18	438	1756	2959	2645	1268	1212
10	1	2	60870	32	1607	12474	23327	10574	4454	8434
10	2	2	54361	36	1143	11718	27733	6925	3580	3262
11	1	2	439912	61	1460	108619	124930	1234-78	40183	41242
12	1	2	48096	26	583	15416	19681	5750	4089	2577

Appendix D List of potential and selected determinants of exposure

Table D.1. Characteristic on the formulations used and disinfection equipment

Determinants of exposure		Remarks
Product	1= Stafquat SU 314 2= P3-triquart TH 3= Quatdet SU321	The concentrations applied were determined by the products used
Type of formulation	ga = 'gas' li = 'liquid' so = 'solid' po = 'powder' wp = 'wetable powder' dr = 'dry flowable' gr = 'granulate' em = 'emulsion' md = 'mixed dust' ot = 'other (eg tablet)';	The products used were all liquids
Product Package	1 = 'Container (>200 L)' 2 = 'Container (20-25 L)' 3 = 'Bottles (1-5 L)' 4 = 'Other , nl..';	not used for modelling purposes
Method of preparation	1 = 'tank or automatic dosing unit' 2 = 'manual. M/L 20-25 L' 3 = 'manual M/L 1-5 L' 4 = 'not applicable' 5 = 'other..';	Only the difference between preparing the product manually or not applicable was used.
Task code	0 = 'preparing disinfection' 1 = 'mixing/loading solution' 2 = 'disinfection' 3 = 'rinsing off';	used in regression analyses
Type of disinfection	1 = 'foaming' 2 = 'mist spraying' 3 = 'spraying' 4 = 'high pressure spraying';	used for modelling purposes
Equipment	1 = 'spray pistol or lance high pressure' 2 = 'spray pistol or lance low pressure' 3 = 'foam application' 4 = 'others, nl..';	not used for modelling purposes

Appendix D

Table D.2 Characteristic of the exposure, personal work conditions, and hygiene

Determinants of exposure		Remarks
Exposure Pattern	O = 'occasional' I = 'intermittent' C = 'continual';	Not used for modelling purposes
Frequency of exposure	D = 'daily' W = 'weekly' M = 'monthly' Y = 'yearly';	Not sufficient variation
- wore respiratory protection during task - wore dermal protection during task	0 = 'no' 1 = 'yes'	used in regression analyses
Length of the used gloves	0 = 'short' 1 = 'long';	not used for modelling purposes
Glove Typ	1 = 'work gloves' 2 = 'household gloves' 3 = 'chem resist gloves'	not used for modelling purposes
Clothing worn during disinfection (24 items)	0 = 'no' 1 = 'yes' 2 = 'don't know'	not used for modelling purposes
Smoking during disinfection	0 = 'no' 1 = 'yes' 2 = 'don't know'	not used for modelling purposes
Eating during disinfection		not used for modelling purposes
Rub face during disinfection		not used for modelling purposes
Other factors of influence on exposure that day		not used for modelling purposes
Opinion of the worker on the level of exposure	1 = 'normal' 2 = 'higher than normal' 3 = 'lower than normal';	not used for modelling purposes
Opinion of the field worker on: - respiratory exposure - hand exposure - body exposure	1 = 'low' 2 = 'normal' 3 = 'high';	not used for modelling purposes
Opinion of the field worker on exposure per treated room	1 = 'Low' 2 = 'Normal' 3 = 'High';	not used for modelling purposes

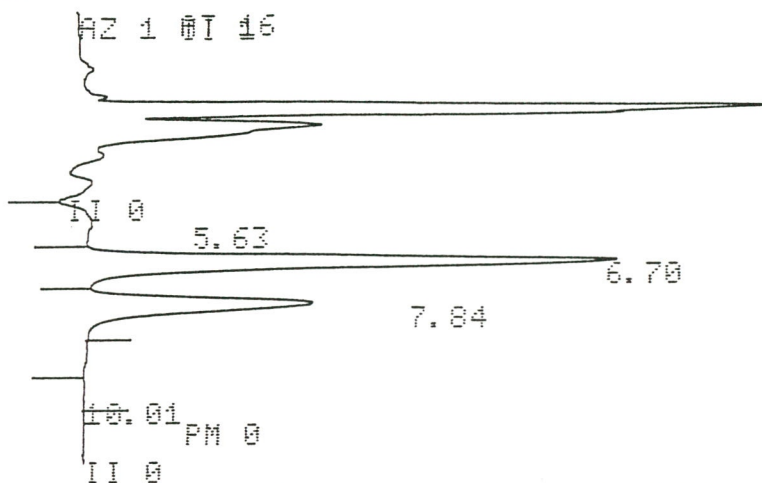
Table D.3 Characteristic of the disinfected rooms

Determinants of exposure		Remarks
Work area	1 = 'confined' 2 = 'enclosed';	not used for modelling purposes
Ventilation	1 = 'no' 2 = 'natural' 3 = 'mechanical';	not used for modelling purposes
Relative humidity (%RV)		not used for modelling purposes
Temperature (°C)		not used for modelling purposes
Estimate floor surface (m ²)		sum of all the rooms treated
Treated surface per room	1 = 'floors' 2 = 'walls' 3 = 'ceilings' 4 = 'machinery' 5 = 'tables' 6 = 'equipment' 7 = 'other,.....';	just floors and walls were used for modelling purposes
Material floor	1 = 'tiles' 2 = 'concrete' 3 = 'stone' 4 = 'combination of materials' 5 = 'other.....';	two categories were used in regression analyses; tiles/granite and concrete.
Material walls	1 = 'tiles' 2 = 'concrete' 3 = 'stone' 4 = 'combination of materials' 5 = 'other.....';	not used for modelling purposes
Machinery in disinfected rooms	1 = 'no machines' 2 = 'little/not much machines' 3 = 'a lot of machines' 4 = 'very much machines'	As result of summation of the rooms treated, existing variation disappeared. Variable could not be used for modelling purposes
Type of machines	1 = 'open machines' 2 = 'closed system machines' 3 = 'conveyor belt' 4 = 'other,';	As result of summation of the rooms treated existing variation disappeared. Variable could not be used for modelling purposes
Height op machinery (m)		not used for modelling purposes
Treated surfaces	1 = 'mainly horizontal' 2 = 'mainly vertical' 3 = 'other.....';	As result of summation of the rooms treated existing variation disappeared. Variable could not be used for modelling purposes

Appendix E

Chromatography of
alkyldimethylbenzylammoniumchloride

CHANNEL A AUA40361.RAW INJECT 12-12-97 13:00:07



4. A DATA CAPTURED TO: \ROEL\AUA40361.RAW

QUATS/HPLC

12-12-97 13:00:07

CH= "A" PS= 1.

FILE 1. METHOD 5. RUN 22 INDEX 1

NAME	MG/L	RT	AREA BC	RF
1	0.	5.63	34223 02	
BAC-C12	344.415	6.7	269428 02	782.278
BAC-C14	1294.101	7.84	139946 03	108.141
4	0.	10.01	879 01	
TOTALS	1638.516		444476	

Measured in standard: C12= 65.8% and C14= 34.2%*

*In the standard is also a small percentage of C16 present, this was not used to calculate exposure levels

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PAGE 1

CERTIFICATE OF ANALYSIS

PRODUCT-NO.	12060
PRODUCT	BENZALKONIUMCHLORID, 95-104% BENZALKONIUM CHLORIDE, 95-104%
PURITY	PURUM
FORMULA	
MOLECULAR MASS	
CHARGE/LOT	370224/1
TITRATION	
TITRATION	100.5 %
GEHALT (HPLC)	
ASSAY (HPLC)	96.5 %
ANMERKUNG HPLC	
REMARKS ON HPLC	62.3 % DODECYL, 34.2 % TETRDECYL
ASPEKT	
APPEARANCE	FAINTLY YELLOW VISCOUS LIQUID
LOESLICHKEIT (FARBE)	
SOLUBILITY (COLOUR)	COLOURLESS
LOESLICHKEIT (TRUEBUNG)	
SOLUBILITY (TURBIDITY)	CLEAR (<3.5 TE(F))
LOESLICHKEIT (METHODE)	
SOLUBILITY (METHOD)	1 G IN 10 ML H2O HOT
WASSER	
WATER	5.80 %
GLUEHRUECKSTAND (SULFAT)	
SULFATED ASH	< 0.05 %

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Projectnummer : 480309

Opdrachtgever : SZW
(of financieringsbron)

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