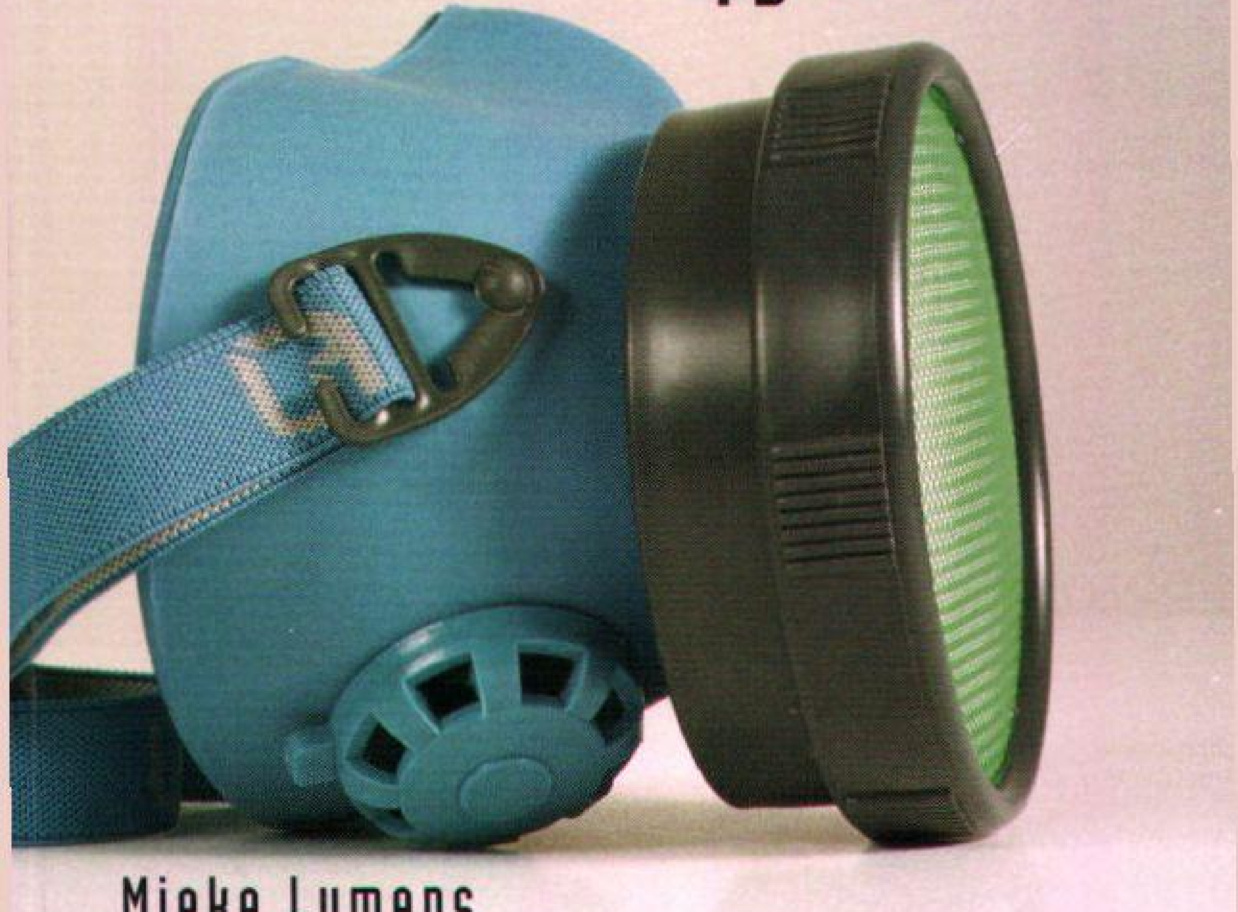
Aspects of Control Measures in Occupational Hygiene



Mieke Lumens

Stellingen

1. De keuze voor effectieve beheersmaatregelen kan vereenvoudigd worden door het toepassen van blootstellingsmodellen in arbeidshygiënische veldonderzoeken.
   (dit proefschrift)

2. Individuele verschillen in hygiënisch gedrag verklaren voor een relatief groot deel de variatie in opname van chemische stoffen in de arbeidssituatie.
   (dit proefschrift)

3. Het gebruik van P1 adembeschermingsmiddelen bij kwartsblootstelling in de bouwnijverheid geeft de drager een vals gevoel van veiligheid en dient daarom ten zeerste ontraden te worden.

4. Er bestaat een duidelijke interactie tussen de inrichting van een werkplek en het hygiënisch gedrag van werknemers.

5. Het herhaald uitstellen van de invoering van de verlaagde MAC waarde voor kwartsstof in de bouwnijverheid prikkelt deze branche onvoldoende tot het ontwikkelen van noodzakelijke stofbeheersende maatregelen.

6. Voor beheersmaatregelen gericht op verandering van werkhandelingen zijn arbeidshygiënische meetmethoden, die blootstelling aan chemische stoffen meteen zichtbaar maken (bijv fluorescentie-techniek en videomixer) een belangrijk hulpmiddel.

7. Bij het opstellen van een levenscylusanalyse (LCA) van produkten dient ook rekening te worden gehouden met de gezondheidseffecten van het produktieproces op de werknemers.

8. Arbo-opleidingen moeten opleiden tot capabele arbodeskundigen en niet tot account-manager.

9. Het toenemend gebruik van grafische software-pakketten verhoogt de leesbaarheid, maar ook de eenvormigheid van diapresentaties.

10. De opkomst van de computer ging gepaard met de verwachting van het papierloze bureau. Evenzo is de verwachting dat het Internet de mobiliteit zal verlagen onterecht.

11. Het zou om polemologische en economische redenen zeer wenselijk zijn dat de aarde in contact komt met een vijandelijke buitenaardse beschaving.

12. Hard gillen maakt een ritje in de achtbaan minder eng.

Stellingen behorende bij het proefschrift "Aspects of Control Measures in Occupational Hygiene".
Mieke Lumens, Wageningen, 1 december 1997

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Aspects of control measures in occupational hygiene

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Voor Theo en Peter

Abstract

This thesis focuses on two aspects which are of major importance in the broad field of control measures in occupational hygiene: the selection of control measures in a structured way and the impact of factors modifying the effectiveness of these control measures.

The main objectives of the thesis are to determine the feasibility of a model approach in the selection of control measures and to assess the impact of work practices on the exposure to and uptake of chemical agents.

Two models, i.e. the "dynamic model of exposure, susceptibility and effect" and the "multiple source model" describe the impact of control measures on workers' exposure. The feasibility of these models and the impact of the factors modifying the effectiveness of control measures was studied in the occupational hygiene practice by performing field studies at different types of workplaces: chromium plateries, lead smelter, battery factory and at construction sites.

In the lead and chromium industries environmental and biological monitoring was carried out together with observations and questionnaires to assess hygienic behaviour. In the construction industry quartz exposure was characterized by personal air sampling and workplace observations.

From the results of these studies it can be concluded that the application of the two models proved to be an important aid in the determination of sources of exposure. Consequently the selection of control measures in different branches of industry was facilitated.

The differences in individual hygienic behaviour and working methods proved to be an important modifier of the relation between external and internal exposure. These results indicate that work practices need to be considered in the implementation of control measures.

Contents

Chapter 1. Introduction

General introduction

In a large number of professions workers are exposed to chemical agents and are at risk for developing adverse health effects, related to this exposure. Whether these workers will really develop clinical effects depends on a number of factors, such as level of exposure, combination of exposures, duration of exposure, individual susceptibility and personal protection against exposure.
The impact of the working environment on workers' health is recognized for centuries. In almost every introductory textbook on occupational health and hygiene historical sources are mentioned which called for attention to the severe working conditions and the resulting ill health of the labourers involved. Ramazzini and Agricola are almost always referred to as historical godfathers of occupational health (eg Hunter 1978, Morgan 1984). These historical occupational hygienists and physicians not only described the occupational illnesses due to exposure but also tried to advise employers and workers on how to cope with these problems. Their possibilities and knowledge however were limited and their advices not always led to improvement of the workplaces. For instance up till the beginning of the twentieth century a universally held doctrine prevailed that the only way to prevent industrial poisoning was to keep the skin clean instead of preventing uptake by inhalation (Hamilton 1948).
Occupational diseases like silicosis and lead poisoning are literally known for millennia. Although knowledge about working conditions causing these diseases is available, millions of people are still working in workplaces which may affect their health. Even though solutions for these problems are available, these are not applied, and in the meanwhile new problems have arisen (Millar 1991).
Workplace conditions in most cases are part of a complex system. Exposure is rarely solely dependent of the presence of a source of a certain substance. Several factors play an important role in the development of a risk. Consequently many factors have an impact on the way controls eventually are to be implemented, like acknowledgement that risks may occur, inclination to change these situations, availability of control measures, information on the use and efficiency of these control measures.
In occupational hygiene control measures can be defined as all possible means to control health hazards. This means that control measures can include both

complete solutions that eliminate exposure and measures that reduce exposure to an acceptable level.
To improve workplace conditions choices need to be made about which control measures to take. Several approaches can be followed to come to these choices. A common sense approach may offer solutions in those cases when the risks are well defined and control measures are clear and available. In many cases however a more thorough analysis of the risks is necessary. In an analytical approach information on workplace conditions, exposures and risks is needed to detect the sources of exposure and the potential modifiers of the sources and of the relation between exposure and health risks. A solution oriented approach will depend more heavily on an analysis of production process and organisation in its risk assessment as has been shown in two recent theses (Kant 1994, Swuste 1996).

The objective of occupational hygiene is to protect workers' health and well-being and to safeguard the community at large by anticipating, recognizing, evaluating and controlling health hazards in the working environment (IOHA 1988).
Controlling health hazards in the working environment thus is one of the explicit tasks of the occupational hygienists. This task did not get as much attention as the elements "recognizing" and "evaluating". Despite a rich history of etiological research, the field of occupational safety and health does not have a thorough history of research on what works and what does not work to prevent and control occupational diseases and injuries (Schulte et al 1996).
Occupational hygiene journals show that the majority of the scientific research is aimed at describing causal relationships between factors present at the workplace and parameters which are an indication for affected health. Goldenhar et al (1996) reviewed three computerized databases on relevant scientific literature published between 1988 and 1993 and found that publications on the development and application of control measures are scarce.
The limited knowledge and application of control measures is further illustrated by a survey of the number and type of control measures applied in Dutch industry. Spee et al (1990) asked occupational hygienists of 140 companies after their experience with control measures. Only 21% of the measures were taken at the point of emission. 49 Percent of the control measures applied consisted of supplying personal protection equipment. The remaining measures concerned extraction of polluted air and separation of worker and source. Important reasons for the dominant position of the use of personal protection

equipment were the lack of expertise in the companies, the lack of exchange of technical solutions between companies, lack of attention for working conditions at the design stage of the process and the widespread and easy availability of personal protection equipment.
Recently, attention for prevention and control of health hazards is growing. At the first IOHA conference in Brussels (1993) a workshop was dedicated to this issue (Swuste and Buringh 1994). Since that time an international network has become active on the subject of sharing knowledge on preventive measures (Swuste et al 1995).

The need for more effective control measures is still growing, among others because of the implementation of legislation concerning occupational health care. The preventive approach is encouraged by the Dutch administration (Ministry of Social Affairs and Employment 1990). In the Netherlands all companies have an obligation to have their workplaces investigated by a risk inventory and evaluation from 1994 on. The results of this inventory will be the main source of information on possible risks in working conditions. Based on this information companies annually have to formulate new aims on how they intend to improve working conditions within their premises.
It is since the last years that a systematic effort is made to find the underlying causes for high exposures and to study ways to prevent or control these high exposures.
In the USA a control strategy is proposed in which it is stated that engineering controls are preferred above organizational controls, which in turn are to be preferred above controls depending on behaviourial changes (NIOSH 1988).
The same principles are applied in the European control strategy. In Council Directives 80/1107 and 89/391 these principles are elaborated (European Union 1992). In compliance with European legislation in the Netherlands in 1997 the Resolution on Working Conditions (Arbobesluit) has come into force. This Resolution indicates that a systematic approach has to be followed in which the types of measures have to be considered in a hierarchic order. Basically, measures have to be taken as close as possible to the source of emission. Only if a solution of the highest step can not be found, it is allowed to continue with solutions of the following step.

This occupational hygiene strategy, as it is called, ranks solutions in order of preference.
The four levels of measures are:

1. reduction of the source of emission
2. extraction of polluted air from the workplace atmosphere
3. separation of worker and source
4. application of personal protective equipment (Arbobesluit §4.1.11)

Even stricter regulations for controlling exposure are required in the EU Directive on Carcinogenic Substances (EEC 1990). In 1994 this is embodied in the Dutch legislation. In this act recommendations are given how to cope with exposure to carcinogenic agents (Arbobesluit §4.2.3). Wherever technically possible carcinogenics must be substituted by less dangerous agents. If this is not possible immediately exposure should be kept as low as possible.

Scope of the thesis

Presently both professional interest and legislative requirements are triggering further research for control measures.
This thesis focuses on two aspects which are of major importance in the broad field of control measures: the selection of control measures in a structured way and the impact of factors modifying the effectiveness of these control measures.

The main objectives of the thesis are:
- to determine the feasibility of a model approach in the selection of control measures
- to assess the impact of work practices on the exposure to and uptake of chemical agents

The application of control measures is aimed at the prevention of adverse health effects and thus covers the complete field from design to health effects. As indicated in figure 1.1, in this thesis the attention will be mainly on control measures at the workplace itself. Aspects dealing with the stage of design or the stage of controlling eventual health effects are not included in this thesis.

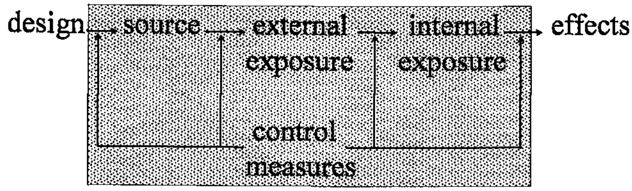


Figure 1.1 Illustration of the area within the larger field of occupational hygiene on which this thesis focuses.

The feasibility of a model approach and the impact of work practices as part of control measures was studied in the occupational hygiene practice by performing field studies at different types of workplaces, in the lead and chromium industry and in the construction trade.
Part of the study was carried out at the Coronel Laboratory for Occupational and Environmental Health of the University of Amsterdam. The impact of hygienic behaviour and working methods on the uptake of lead and chromium were studied within the project "Scoring of Hygienic Behaviour". These studies were performed in close cooperation with Dr Paul Ulenbelt. The results of his research are described in his thesis: "Handling exposure to chemical agents: threshold values, hygienic behaviour and decision latitude" (Ulenbelt 1991).
At the department of Air Quality of the Wageningen Agricultural University the application of control measures in the construction industry was studied. In a project concerning quartz exposure in the construction industry the contribution of four categories of sources on total external exposure was studied.
The results of these two projects are applied to address the objectives of this thesis.

Model approaches

In a systematic approach of determining the feasibility and impact of control measures models might be very useful. Generally a model can be described as a simplified way of representing reality. A model is needed which describes the process of exposure to chemical substances in relation to health effects in such way that it is possible to develop control measures following this model.
In the literature two models are described which may be valuable instruments

for this objective.
In "the dynamic model of exposure, susceptibility and effect" of van Dijk et al (1988) several interrelated phases in the process from source to final health effects can be distinguished.

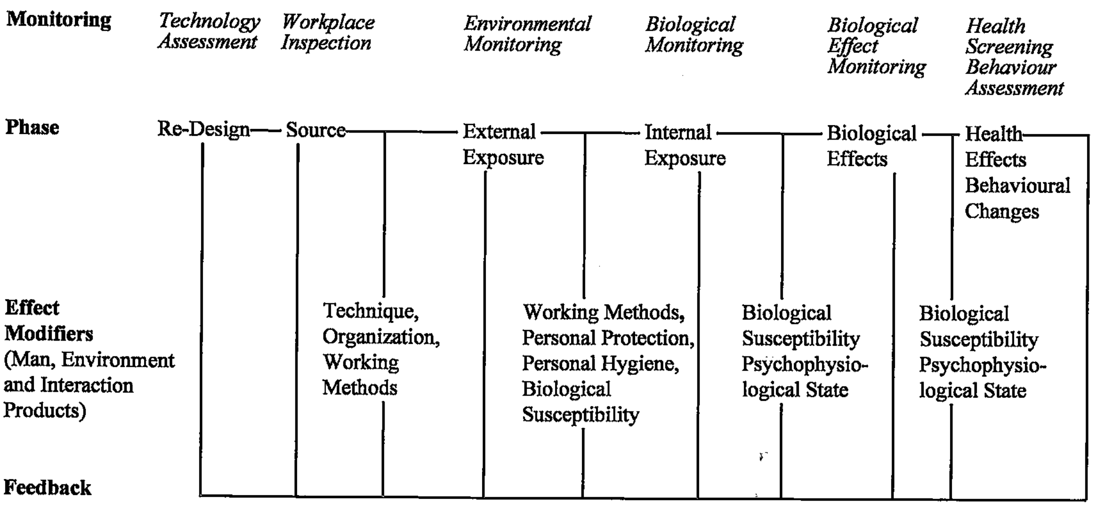


Figure 1.2 Dynamic model of exposure, susceptibility and effect including monitoring and feedback (from: van Dijk et al 1988)

The phases which are discerned are source, external exposure, internal exposure, biological effects, health effects, and behavioural changes. In this model the stages at which subsequent effects can be modified are clearly defined.
The focus of this thesis is on control measures which can be applied at the workplace, therefore attention will be restricted to the first stages of the model. The last phases and transitions described i.e. the detection of biological effects and possible health or behavioural effects due to practical considerations are left to the area of occupational toxicology and medicine, and sometimes occupational psychology.
Van Dijk et al consider the modifying factors that are relevant in the transitions between the various phases as tools for prevention and intervention. According to this model in the transition from source to external exposure control measures directed at changes in technique, organization and working methods could be used for prevention. Working methods, personal protection, personal

hygiene and biological susceptibility are supposed to play a modifying effect on the transition between external and internal exposure. In this phase control measures should be mainly directed towards improving work practices.
Occupational hygiene control will limit itself on ways to control sources and next external and internal exposure. The concept "external exposure" in occupational hygiene can be described as the process by which a substance becomes available for absorption by the worker. "Internal exposure" or "dose" is the total amount of a substance absorbed by a worker (Duffus 1993).
"Source" is not defined so unambiguously. A further description of the variable "source" is needed.

Buringh et al (1992) introduce the "multiple source model" for occupational hygiene. In this model they define source as a potential cause of exposure. Sources are attributed to four categories: agents, processes or appliances, the working environment and work practices. The latter source is considered to be a modifier of relations in the "dynamic model".

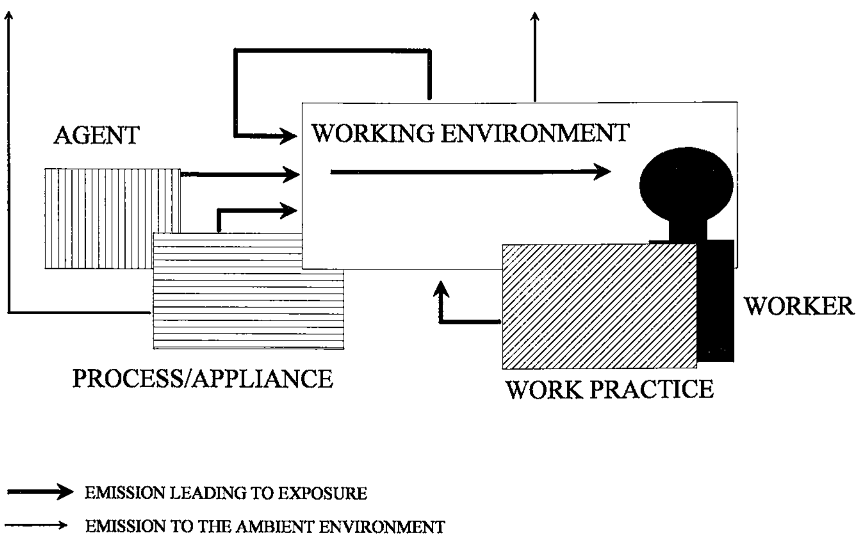


Figure 1.3 Multiple-source diagram for occupational hygiene (from: Boleij et al 1995)

The diagram illustrates the contribution of agent, process/appliance and work practice to the working environment concentration. This concentration determines the exposure level of the worker. Interrelations between agent and process, between process and working environment and the obvious relation between worker and his work practices are shown in this figure.
This model is developed to study the contribution of the different sources with the aim to facilitate the selection of control measures. The underlying idea is that tackling the source with the highest contribution is the most effective way to control exposure.
When the characteristics of the sources change, exposure will change. For example, the application of a more dust-generating substance will increase emission leading to exposure. And the introduction of an new production process equipped with local exhaust ventilation will reduce its emission to the workplace concentration. A clear distinction between the contribution of these causes of exposure will facilitate the optimal choice for effective control measures.
In a survey of wood working processes Scheeper et al (1995) successfully applied this “multiple source model” in setting priorities and developing a control strategy to reduce the average exposure of wood dust.
Kant (1995) used the multiple source approach in a number of distinct workplaces. Summarizing the results of these studies he states that this “multiple source model”, giving insight into the relation between sources and exposure is a prerequisite to the design of surveys allowing both evaluation and control of occupational hazards.

Both models are developed to describe the information needed to recommend the correct type of control measures. The “multiple source model” is more explicit in describing the sources of exposure, an aspect which is lacking in the “dynamic model”. The “dynamic model” in more detail discloses the subsequent stages from source to eventual health effect. With regard to the second objective of this thesis, determining the impact of work practices, especially the transition from external to internal exposure is of importance.
Both the “dynamic model” and the “multiple source model” pay attention to the impact of the employees’ behaviour. “Personal hygiene”,”the use of personal protection” and “working methods”, effect modifiers in the “dynamic model” can be summarized as the source “work practice” within the “multiple source model”. A distinct difference in approach of “work practices” can however be detected between the two models.

In the dynamic model a prominent role is given to the impact of work practices as *modifier*. Working methods are supposed to have a modifying effect in the transition from source to external exposure, and in the transition from external exposure to internal exposure. Personal hygiene and personal protection are effect modifiers on the transition from external to internal exposure. The modifying effect of personal hygiene and personal protection may be an explanation for differences in biological monitoring results between workers performing the same tasks in identical conditions, having similar external exposure.
In the "multiple source model" work practices are considered to be *source* of exposure, i.e. emission leading to external exposure of the worker. A possible impact of work practices on the transition from external to internal exposure is not described in this model.

Work practices: hygienic behaviour and working methods

In general, good hygienic behaviour can be defined as actions that are directed towards improving or maintaining a good health. Good hygienic behaviour at the workplace, within the context of chemical exposure, can be described as a set of individual actions that lower the uptake of chemical agents. Hygienic behaviour consists of three elements:

- personal hygiene, e.g. regularly washing hands and carefully changing of work clothes, refraining from eating and smoking at the workplace
- the use of personal protection equipment, e.g. wearing a mask in the prescribed way during riskfull operations
- working methods, the individual way in which tasks are being performed, e.g. correct application of local exhaust ventilation, choosing a good working posture.

When searching occupational hygiene literature for studies on the impact of hygienic behaviour and working methods, information on this subject proves to be limited. In some studies subjective classifications are used to assess the impact of work practices.
Williams et al (1969) investigated lead uptake in an accumulator factory. The lead exposures of men doing almost identical jobs differed by a factor four. According to the authors this could only be attributed to personal differences in working habits. Qualitative not standardized ranking by the researchers for "cleanliness at work" correlated well with the results of personal air sampling

for persons performing similar jobs.
Hassler (1983) attributed differences in cadmium and nickel exposure of workers doing the same type of jobs to their individual hygienic behaviour. Together with an occupational nurse she classified the workers' appearance on a scale for 1 to 4, from extremely dirty to very clean. This crude estimate predicted the variance in exposure level rather well.
Based on the conviction that a change in work practices may have a positive impact on exposure levels and dose, a number of training programs was developed and applied. A training program for improving working methods was proven useful in reducing both lead in urine and lead in blood levels (Maples et al 1982).
Kentner and Fischer (1994) and Kentner et al (1994) report a significant decrease in both exposure and dose (internal lead load) in a ten year period. They attribute this decline among others to their efforts to change the hygienic behaviour of the workers. Unfortunately they do not disclose what methods they used.
Rosén and Lundstrom (1987) tried to visualize the impact of working methods on exposure levels by combining the readout of direct reading instruments with concurrent video filming and invented the PIMEX (picture mixed with exposure). They proved to be successful in illustrating the impact of working methods on external exposure and applied this equipment to make instruction films for several branches of industry, clarifying to workers the impact of certain working methods on the level of exposure (Rosén 1993, Anthonsson and Rosén 1995).
Not all methods were equally successful. Robins et al (1990) found that the working methods and hygienic behaviour of workers had an impact on their exposure level. They implemented a training program to influence their work practices. After two years the program was evaluated. A subjective progression could be detected, people indicated that they learned how to behave at the workplace. Objective changes however were not found: actual workplace behaviour remained the same.
Differences in work practices however seem to have an impact on external exposure levels and dose. Some authors attempted to determine their causes.
In a project on hygienic behaviour at workplaces field measurements in an electric accumulator factory and a secondary lead smelter were carried out. The impact of hygienic behaviour on the relationships between environmental and biological monitoring measures of lead was high (Ulenbelt et al 1990a). Next to assessing the impact of hygienic behaviour, Ulenbelt et al (1989) tried to ex-

plain what caused the differences in behaviour. In order to explain these differences they applied the Karasek job strain model (1979). The model, consisting of a scale for job demands and for job decision latitude, is used to describe job characteristics; the scale "job demands" measures work load and time pressure. The scale "job decision latitude" measures potential control of the loading factors, i.e. aspects of task contents, working conditions, social relationships and conditions of employment. The level of these scales is determined by a standardized questionnaire. Workers are asked after their own perception of the characteristics of their jobs. Job characteristics seemed to modify hygienic behaviour at the work place. It was shown that workers who considered themselves to have a high job decision latitude focus more on source oriented control measures. The source oriented approach might decrease future exposure levels; for the present, their exposure levels were higher than those of workers with little job decision latitude. The latter workers relied on the use of personal protection devices for controlling their exposure. This difference in approach determined their hygienic behaviour (Ulenbelt et al 1990b).
Most of these findings suggest an important contribution of work practices, i.e. hygienic behaviour and working methods on the relation between external and eventual internal exposure. In the above mentioned studies the impact of work practices is assessed merely by qualitative measures.
After estimating the quantitative contribution of the multiple routes of uptake of lead exposure Chavalitnitikul (1981) also concluded that hygienic behaviour must be a major modifier in the relation between external and internal lead exposure.
In this thesis the impact of work practices on the exposure to and uptake of chemical agents will be elaborated.

Structure of the thesis

In order to place the results of these studies within the larger framework of this thesis each chapter on the separate studies will be preceded by a short introduction in which reference will be made to the objectives of this thesis.
In chapter 2 a study in a chromium exposed population is described. The impact of individual hygienic behaviour in determining eventual uptake of chromium is investigated. Next to this the role of hygiene of the general working environment on exposure levels is described.
Chapter 3 deals with the impact of hygienic behaviour and working methods on

the uptake of lead. In a lead smelter variation in biological monitoring values (lead in blood levels) is studied, both by comparing variation in environmental lead levels and studying possible relevant behavioural determinants.
The results of four studies, two in lead factories and two in chromium industries are described in chapter 4. The impact of hygienic behaviour and working methods on eventual internal uptake is compared to the impact of external exposure.
Chapter 5 describes the results of a study to quartz exposure in construction industry. A problem that is little recognized by both occupational hygienists and those concerned in construction trades. In this research the "multiple source model" approach is applied to detect the contribution of the several sources and to find indications as to which control measures to implement in order to decrease quartz exposures as effectively as possible.
In chapter 6 a theoretical attempt is made on how to deal with the subject of control measures in the construction industry. The highly dynamic characteristics of this type of industry, e.g. the ever changing work locations and work situations indicate the need for a special approach in developing control measures.
In chapter 7 a general discussion on the implications of the results will be given. The conclusions to be drawn from this thesis will be described.

References

Anderson LA (1993) Developing an effective lead detection and abatement industry: the role of the industrial hygienist. Am Ind Hyg Ass J 54:331-334

Andersson IM, Rosén G (1995) Detailed work analysis for control of exposure to airborne contaminants in the workplace. Appl Occup Environ Hyg 10:537-544

Blanc PD, Galbo M, Balmes JR, Olsom KR (1994) Occupational factors in work related inhalations: inferences for prevention strategy. Am J Ind Med 25:783-791

Boleij JSM, Buringh E, Heederik D, Kromhout H (1995) Occupational hygiene of chemical and biological agents. Elsevier, Amsterdam, the Netherlands

Buringh E, Noy D, Pouwels H, Swuste P (1992) A systematic implementation of control measures for airborne contaminants in workplace air. Staub. Reinhaltung der Luft 52:347-351

Chavalitnitikul C (1981) A study of the quantitative contribution of the multiple sources of lead exposure in the industrial environment. Drexel University, Philadelphia, USA, thesis

Dijk van FJH, Meijman TF, Ulenbelt P (1988) Towards a dynamic model of exposure, susceptibility and effect. In: Notten WRF, Herber RFM, Hunter W, Monster AC, Zielhuis RL (eds) Health surveillance of individual workers to chemical agents. Springer, Heidelberg, Berlin, New York

Duffus JH, Brown SS, Fernicola N de, Grandjean P, Herber RF, Morris CR, Sokal JA (1993) Glossary for chemists of terms used in toxicology. Pure and APL Chem 65:2003-2122

EEC European Directive 80/1107/EEC (1980): Council directive on the protection of workers from the risks related to exposure to chemical, physical and biological agents at work. Official Journal of the European Communities, L-327

EEC European Directive 89/391/EEC (1989): Council directive on the introduction of measures to encourage improvements in the safety and health of workers at health. Official Journal of the European Communities, L-183

EEC European Directive 90/394/EEC (1990): Directive on carcinogenic substances. Official Journal of the European Communities, L-374

Ellenbecker MJ (1996) Engineering controls as an intervention to reduce worker exposure. Am J Ind Med 29:303-307

Goldenhar LM, Schulte PA (1996) Methodological issues for intervention research in occupational health and safety. Am J Ind Med 29:289-294

Hamilton A (1995) Forty years in the poisonous trades, Cummings Award Lecture 1948. Am Ind Hyg Ass J 56:423-431

Hansen DJ, Whitehead LW (1988) The influence of task and location on solvent exposures in a printing plant. Am Ind Hyg Ass J 49:259-265

Hassler E (1983) Exposure to cadmium and nickel in an alkaline battery factory. Karolinska Institute, Stockholm, Sweden, thesis

Kant IJ (1994) Evaluation and control of occupational health risks, an integrated strategy applied to chemical, physical and ergonomic stressors. University of Maastricht, the Netherlands, thesis

Karasek RA (1979) Job demands, job decision latitude, and mental strain: implications for job redesign. Admin Sci Quart 24:285-308

Kentner M, Fischer T (1994) Lead exposure in starter battery production: investigation of the correlation between air lead and blood lead levels. Int Arch Occup Environ Hlth 66:223-228

Kentner M, Fischer T, Richter G (1994) Changes in external and internal lead load in different working areas of a starter battery production plant in the period 1982-1991. Int Arch Occup Environ Hlth 66:23-31

Kubr M (1977) Management consulting: a guide to the profession. International Labour Organization, Geneva

Maples TW, Jacoby JA, Johnson DE, TerHaar GL (1982) Effectiveness of employee training and motivation programs in reducing exposure to inorganic lead and lead allyls. Am Ind Hyg Ass J 43:692-694

Millar JD (1991) AIHCE keynote address: 10% inspiration. Appl Occup Environ Hyg 6:742-746

Ministry of Social Affairs and Employment (1990) Kabinetsstandpunt naar aanleiding van de interim rapportage van de Tripartiete Werkgroep Volumebeleid Arbeidsongeschiktheid (Cabinet position in response to the interim report of the Tripartite Working Group on Volume Policy Disablement Regulations) The Hague, The Netherlands

Morgan WKC (1984) Historical and legal aspects of industrial diseases. In: Occupational lung diseases. WKC Morgan and A Seaton (eds) WB Saunders Company, Philadelphia, USA

NIOSH (1988) Comments on the Occupational Safety and Health Administration request for comments and information on general safety and health programs. 20 CFR Parts 1910, 1915 and 1918, NIOSH, USA

Robins TG, Hugentobler MK, Kaminski M, Klitzman S (1990) Implementation of the Federal Hazard Communication Standard: Does training work? J Occup Med 32:1133-1141

Rosén G, Lundstrom S (1987) Concurrent video filming and measuring for visualization of exposure. Am Ind Hyg Ass J 48:688-692

Rosén G (1993) PIMEX Combined use of air sampling instruments and video filming: experience and results during six years of use. Appl Occup Environ Hyg 8:344-347

Scheeper B, Kromhout H, Boleij JSM (1995) Wood-dust exposure during woodworking processes. Ann Occup Hyg 39:141-154

Schulte PA, Goldenhar LM, Connally LB (1996) Intervention research: Science, skills, and strategies. Am J Ind Med 29:285-288

Spee T, Swuste P, Burdorf A (1990) Control of occupational exposure to toxic substances. Staub-Reinhaltung der Luft 50:361-363

Swuste P, Hale A (1993) Databases on measures to prevent occupational exposures. Ministerie van Sociale Zaken en Werkgelegenheid, SDU, The Hague, The Netherlands

Swuste P, Buringh E (1994) Sharing knowledge on preventive measures, summary of the workshop. Appl Occup Environ Hyg 9:74-76

Swuste P, Corn M, Goelzer B (1995) Hazard prevention and control in the work environment, report of a WHO meeting. Occupational Hygiene 1:325-328

Swuste P (1996) Occupational Hazards, risks and solutions. Technical University Delft, The Netherlands, thesis

Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM, Meijman TF (1989) Combined effects of job demands and job decision latitude on hygienic behaviour and on lead in blood. In: Manninen (ed) Recent advances in researches on the combined effects of environmental factors. International Society of Complex Environmental Studies, Tampere, Finland

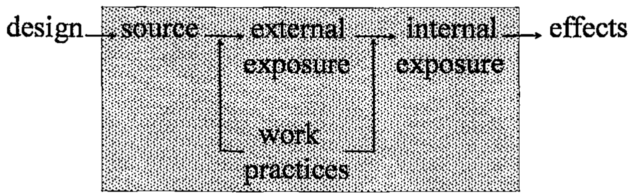
Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM, Broersen S, Zielhuis RL (1990a) Work hygienic behaviour as modifier of the lead air - lead blood relation. Int Arch Occup Environ Hlth 62:203-207

Ulenbelt P, Lumens MEGL, Meijman TF, Herber RFM (1990b) Job control, job demands, hygienic strategies and exposure to lead. Proceedings 4th International Conference on the Combined Effects of Environmental Factors, Baltimore, USA

Ulenbelt P (1991) Omgaan met blootstelling aan chemische stoffen: grenswaarden, hygiënisch gedrag en regelmogelijkheden (Handling exposure to chemical agents: threshold values, hygienic behaviour and decision latitude) University of Amsterdam, the Netherlands, thesis (partly in Dutch)

Williams MK, King E, Walford (1969) An investigation of lead absorption in an electric accumulator factory with the use of personal samplers. Br J Ind Med 26:202-216

Zielhuis RL, Henderson PT (1986) Definitions of monitoring activities and their relevance for the practice of occupational health. Int Arch Occup Environ Hlth 57:249-257



Introduction to Chapter 2:
Hygienic behaviour in chromium plating industries

Chapter 2 of this thesis focuses on the impact of hygienic behaviour on the uptake of chromium. Differences in individual personal hygiene and in the way workers perform their tasks are supposed to be modifiers on the relation between external and internal exposure. The impact of these work practices is acknowledged in both the "dynamic model" of van Dijk et al (1988) and the "multiple source model" (Buringh et al 1992). The design of this study is based on the "dynamic model", in which the modifiers of the transition between the subsequent stages from design to health effects are clearly indicated.
The field study is performed in two plateries, where essentially the same production process takes place, i.e. parts of ship engines are chrome plated in large baths. During the preparation and the plating process exposure to chromium can occur.
Although the two factories in this study belong to the same holding, a clear distinction can be drawn between the general working conditions at the workplaces. Therefore the impact of modifiers could be studied. In factory I hardly any provisions were made to lower exposure, whereas in factory II various precautions were taken.
Information on other factors, next to work practices, modifying exposure became available as well, and can be used in explaining differences in results between the two factories. Within the larger framework of this thesis the results of this study will be used to further investigate the applicability of a model approach in the search for control measures.
The information that became available because the field studies were performed in two distinct factories will be used to judge the applicability of the "multiple source model". This implies that e.g. the general neatness of the working environment and characteristics of the chemical agents applied will be considered as sources of exposure.

Chapter 2: Hygienic behaviour in chromium plating industries[1]

Mieke E.G.L. Lumens, Paul Ulenbelt, Henri M.A. Géron, Robert F.M. Herber

Summary

The impact of hygienic behaviour on the uptake of chromium has been studied in two small chromium plating industries. The correlation between the environmental monitoring measure (Cr-A) and the biological monitoring measure (Cr-U) varied between the two factories. In one factory (I) the correlation between Cr-U and Cr-A was 0.68 ($p<0.001$), while in the factory (II) it was negative ($r=-0.64$, $p=0.03$). However, in both populations a significant impact of hygienic behaviour on the variance in Cr-U levels could be detected. In factory I, explained variance could be enhanced to $R^2=0.94$ ($p<0.001$), when considering expressions of hygienic behaviour. In factory II, a strong relation proved to exist between Cr-U and dermal uptake. For the various questions referring to skin problems and possible dermal uptake, the correlation with Cr-U is up to 0.70 ($p=0.03$). When comparing the results for the two factories, it is shown that in addition to individual differences in hygienic behaviour, general hygienic conditions also have an impact on uptake of chromium. In factory II, where many efforts were made to prevent exposure to chromium, Cr-U was significantly lower than in factory I ($p<0.0001$).

Introduction

The background to this study is the rather low correlation that is often found between environmental and biological monitoring measures. It is supposed that differences in hygienic behaviour and working methods may influence this relation (Williams et al. 1969, Hassler 1983); however, no quantitative studies have been performed. Despite the assumption that hygienic behaviour might be

[1]Int Arch Occup Environ Health (1993) 64:509-514

a modifier of the relation between environmental and biological monitoring, until recently little research has been done on the actual impact of hygienic behaviour.

In studies conducted in lead processing plants (in a electric accumulator plant and a secondary lead smelter) it could be proved that factors relating to hygienic behaviour have a marked impact on lead levels in blood (Ulenbelt et al 1990, 1991). In order to investigate whether the impact of hygienic behaviour also applies to a chemical that differs from lead with respect to routes of uptake and biological half-time, chromium has been studied. Chromium enters the body mainly by inhalation. Of ingested chromium, only 0.5-3% is gastro intestinally resorbed (WHO 1988), whereas in the case of lead a relatively large part is resorbed after (secondary) ingestion. Therefore in the case of chromium, ingestion related behaviour may be expected to have only a minor impact.

Hygienic behaviour connected with dermal uptake may be important: some studies have shown already injured skin can be penetrated by chromium (Lindberg and Vesterberg 1983; Liden and Lundberg 1979). Skin contact with chromium can cause skin injuries, e.g. chromic ulcers, and in turn these skin injuries may enhance the uptake of chromium.

Chromium can be present in the body as Cr(III) and Cr(VI). The toxic effects are mainly caused by Cr(VI). In tissues water-soluble Cr(VI) may pass the cell membranes and is intercellularly reduced to Cr(III)(Langård 1982). Determination of chromium in urine of workers exposed to chromium has been successfully used in biological monitoring (Alessio et al 1984). The concentration of chromium in urine (Cr-U) is a reflection of recent exposure; the biological half-life of chromium is between 15 and 41 hours (Tossavainen et al 1980). Bukowski et al (1991) have reported that a number of confounding variables have an important effect on Cr-U. In general, however, the contribution of non-occupational sources of exposure is negligible compared to occupational exposure (Lundquist 1981). Lewalter et al (1985) stated that since only Cr(VI) can penetrate into erythrocytes, a single determination of chromium in erythrocytes will provide a way of determining exposure to Cr(VI). As the objective of this study is to determine the impact of hygienic behaviour on the relation between Cr(total) in air and body, it is considered more convenient to determine chromium in urine and total chromium on PAS filters (Blomquist et al 1983) as measures of biological and environmental contamination.

In other field studies the correlation between Cr in the air (Cr-A) and Cr-U has been high: correlation coefficients of up to 0.85 (Tola et al 1977) have been reported.

On the basis of early studies on the effects of chrome plating, Royle (1975a, b) concluded that health risks can be avoided by preventing the chromic acid from contaminating the workplace, thereby lowering the Cr-A level. It is, however, still to be expected that part of the variation in Cr-U can be ascribed to differences in hygienic behaviour. In fact working methods that lead to lower exposure can be considered as expressions of hygienic behaviour as well.
In order to check these suppositions, field studies were performed in two chromium plating factories. The field studies consisted of environmental monitoring, biological monitoring, questionnaire, and workplace observations.

Materials and methods

Description of the workplaces
Field studies were performed in two chrome plating factories in which parts of ship engines are chrome plated and ground. Plating takes place in large baths. The primary constituent of these chrome plating baths is chromic acid (CrO_3). The major source of chromium pollution in the air of chromium plating plants is the droplet spray caused by the bursting of hydrogen bubbles produced at the electrodes due to electrolysis of the bath (Stern 1982). Exposure at the workplace is (mainly) to water soluble Cr(VI). In factory I, cylinder liners are plated; they often measure up to 8 metres long and have a diameter of 1.5 metre. In factory II the piston heads are plated; these are much smaller, measuring up to 1 metre across, but many more manipulations are involved in the process. The differences in the size of the objects to be plated meant that the sizes of the chrome baths in the two factories were very different.

Chromium in air
From each employee, personal air samples were taken over about four working days. Cr-A samples were taken with custom-made PAS-6 filter holders attached to duPont P2500 pumps (van der Wal 1983). The PAS-6 samplers are designed in such way that at a flow rate of 2 l/min the air velocity at the opening of the sampler is 1.25 m/s. The filters on which the chromium was deposited were vinyl metrical membranes (Gelman USA). The available personal air sampling equipment was assigned each day at random to the workers selected for that day. The workers wore the personal air sampling equipment during a working day (± 8 h). The filters were changed during the lunch hour in order to prevent overload of the filters.

Due to the absence of some workers and to sampling errors (squeezed or disconnected tubes), the number of air samples was not identical for all workers, The majority of the workers, however, were sampled over 4 working days. The determination of the chromium on the filter was performed by a wet ashing procedure in quartz tubes. Concentrated nitric acid (Suprapur, Merck, Germany) was used as the digestion solution. Subsequently the digested samples were determined by Zeeman atomic absorption spectrometry (Varian SpectrAA-30 with GTA96 graphite furnace, Australia).
Due to the unavailability of commercial standard reference materials for quality assurance, an indoor filter standard was prepared. This was done by depositing onto the membrane surface a fixed volume of a 50 µl chromium solution in diluted nitric acid (Suprapur, Merck, Germany). Blank filters were prepared by depositing onto the filter 50 µl of blank solution, 2% (v/v) nitric acid. The internal inaccuracy amounted to 6%. Calibration was carried out with a chromium nitrate stock solution (Merck, Germany). From this solution working standards were prepared covering the range from 0 to 15 µg Cr/l.
All reagents used were of analytical grade. Laboratory ware, including pipette tips and micro vials were soaked several times for at least 24 h in 5% nitric acid v/v (p.a.) and thoroughly rinsed with aqua bidest. Subsequently the materials were checked randomly. All used glass and containers were checked for chromium contamination.

Chromium in urine
After the work shift urine was gathered in acid-rinsed polyethylene containers. All used glass and containers were checked for chromium contamination. Workers were strongly urged to wash their hands in order to prevent contamination.
The urine was kept in a refrigerator at 4°C until determination was performed. Determination of Cr-U was performed by first pretreating the urine samples. All urine samples were ultrasonificated for 15 min and centrifugated. 0.5 ml of the pretreated urine was diluted with 0.5 ml 2% (v/v) nitric acid.
The apparatus used for determination was the same as in the case of the Cr filter determination. For internal quality control a urine reference standard (Seronorm, Nyegaard, Norway) was used. The inaccuracy amounted to 4%. Calibration with spiked pool urine covering the range 0-10 µg chromium/l was found to be an adequate method.

Observations

Observations of actual hygienic behaviour and of tasks being performed were made by three observers, independently and randomly. All workers were observed about 14 times (13.7 and 14.2 times respectively, in factory I and II) and each observation period lasted about 10 min (10.1 and 10.5 min, respectively, in factory I and II). Event recorders (Institute for Experimental Psychology, The Netherlands) were used to store the scored hygienic events.

Workplace observations were performed to ascertain actual hygienic behaviour at the workplace. The observations concerned: (a) workplace and tasks performed during the observation period; (b) wearing of gloves at the start of the observation period; (c) frequency of putting on/taking off gloves; (d) frequency of eating, drinking, smoking and spitting.

Questionnaire

All workers were asked to complete a questionnaire composed of several parts: general information, a personality scale, questions about job demands and decision latitude. and questions on attitudes to chemicals, use of protection devices, and knowledge of potential risk of working with chemicals. Specifically for these chromium workers, some questions concerning exposure of the skin of the hands and arms were added. These questions referred to the yellow spots, chromic ulcers, and perforated nasal septum that are the typical expressions of dermal contact with Cr(VI) (WHO 1988).

Results and discussion

Questionnaire

The response to the questionnaire was 85% in factory I and 100% in factory II. The mean age of the workers was 40 years. Their mean job tenure was about 7 years. This did not differ significantly between the two factories and groups.

In Table 2.1 the results of the questions referring to skin complaints are shown. The results showed that none of the workers in the two factories were without skin complaints. In factory I, 13 out of 17 workers answered affirmatively to three or more questions, while in factory II, five out of nine workers did likewise.

	Factory I (n=17)	Factory II (n=9)
Skin irritations	10 (59%)	3 (33%)
Bleeding nose	6 (35%)	5 (55%)
Chromic ulcers	11 (65%)	2 (22%)
Yellow spots	9 (53%)	2 (22%)
Irritated nasal septum	10 (59%)	4 (44%)
Recent skin irritations	4 (24%)	0 (0%)

Table 2.1 Number of workers in the two factories who responded affirmatively to questions on skin complaints

Royle (1975a,b) states that without clinical examination the value of posing questions to platers about skin and nasal ulceration is limited. Skin ulceration and its scars are visible, but many platers have nasal ulceration and even septal perforation without being aware of it. Consequently the answers to the questionnaire may even represent an underestimation of the real problem.
These results suggest that working in a chromium-contaminated environment poses a threat to the skin. It can constitute a significant health risk not only because of the skin problems themselves, but especially due to the possible extra uptake of chromium by the affected skin. This extra uptake may affect the relation between environmental and biological monitoring

Chemical determinations
The results of the chromium determinations in the factories are in Table 2.2.

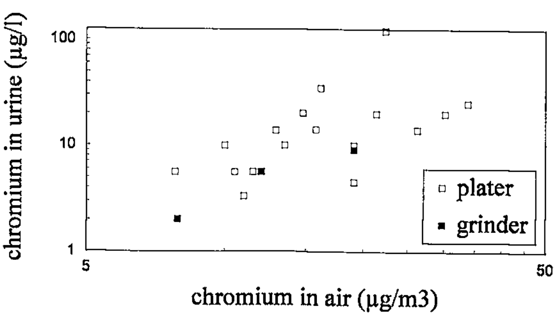
	Factory I (n=20)	Factory II (n=9)
Cr-A (µg/m^3)	15.5	14.7
range	(4.2-73.8)	(5.1-49.6)
Cr-U (µg/l)	12.3	5.0
range	(1.6-212.9)	(0.3-21.8)

Table 2.2 Levels (geometric mean and range) of airborne chromium (Cr-A) and chromium in urine (Cr-U)

The distributions of both Cr-A and Cr-U proved to be log-normal according to Kolmogorov-Smirnov tests. In all statistical analyses, log-transformed values were used. The results of the determinations showed that the Cr-U levels varied between the two factories ($p<0.001$). Moreover, clear-cut differences existed between platers and grinders. Levels of Cr-U were considerably higher than in persons not occupationally exposed to chromium (Verschoor et al 1988). More surprising, however, were the results of the Cr-A determinations: there was hardly any difference in the mean outcome between the two factories. The mean Cr-A was well below the Dutch maximum allowed concentration of 50 μg/m^3; only at three days some Cr-A levels higher than 50 μg/m^3 were recorded.

Correlations between Cr-A and Cr-U

A straight correlation was calculated between Cr-U and Cr-A. Figures 2.1 and 2.2 show the plot of these correlations. The results of these correlations differed between factories I and II. In factory I a positive correlation of $r=0.68$ ($p<0.001$) was found, whereas in factory II a negative correlation of $r=-0.64$ ($p=0.03$) was detected.



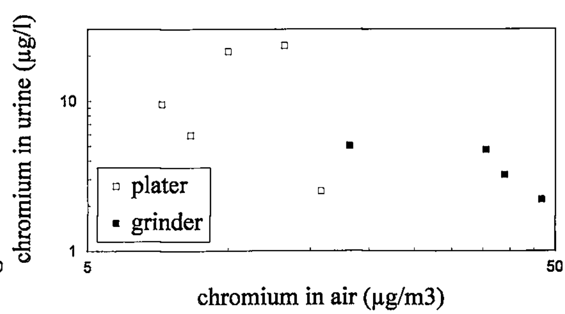


Figure 2.1. Scatterplot of Cr-A/Cr-U for factory I

Figure 2.2 Scatterplot of Cr-A/Cr-U for factory II

The impact of hygienic behaviour: general notes

Hygienic behaviour at the workplace may be considered as a set of strategies aimed at decreasing health risks caused by exposure to toxic agents. This means that hygienic behaviour consists both in preventing the uptake of chemicals by the body and in preventing them from contaminating the workplace. An example of the former might be wearing of personal protection devices.

Certain working methods, e.g. working exactly below the exhaustion equipment, may be considered an example of the latter.
In this study biological monitoring was used as a measure to study the impact of hygienic behaviour. Eventual uptake, which is measured by biological monitoring, is the sum of the contributions of all routes of uptake. Variation in biological monitoring reflects variation in the relative importance of the different routs of uptake. Hygienic behaviour is often directed at reducing uptake via an extra route besides inhalation. Whereas it is not possible to exclude uptake by inhalation (except by constantly wearing of respiratory protective equipment), it may be possible to reduce or even prevent the uptake of chemicals through ingestion and dermal absorption. The extent to which hygienic behaviour contributes to the variation in biological monitoring depends on certain characteristics of the chemical under study. In comparison to the results of our lead studies, a more moderate impact of hygienic behaviour was expected in this chromium study.

Differences between factory I and II
Although the two factories in this study belong to the same holding, a clear distinction can be drawn between the general appearances of the workplaces. Whereas in factory I the few precautions aimed at ensuring lower exposure were merely provisional and scarcely seemed effective in preventing exposure to chromium, the general impression of factory II was much better and neater, with exposure to chromic acid prevented as much as possible. All kinds of preventive measures had been taken: good suction equipment had been installed, a foam layer covered the surface of the chromium baths, and well-fitting coverings were used to cover the chromium baths when the plating was in progress. So it could be postulated that in factory II exposure through inhalation had been reduced as much as possible. The mean Cr-A in factory II was, however, similar to that in factory I. This was mainly due to the high Cr-A levels of the grinders (see Figure 2.2). Since this is not reflected in their Cr-U, most probably this Cr-A is in a non-soluble form. In a survey of the Swedish chrome plating industry, in which both Cr(VI) and total Cr in air were determined, Lindberg et al (1985) stated that polishing was the task that resulted in the smallest amount of Cr(VI). On the other hand, this work produced high total Cr values owing to the metallic chromium in the air. Since in our study only total Cr-A was determined, this explanation may apply to our results as well.
Since both the general impression of the workplaces and the level of exposure and uptake differed considerably, it could be expected that these factors had an

impact on the hygienic behaviour of the employees. For this reason the populations of factory I and II were further analysed separately. As a result both populations became rather small, which has some consequences for the reliability of the statistical models.

Factory I

The impact of other variables besides variation in air concentration on the variation in Cr-U was first studied in factory I. Entering hygienic and smoking variables into a regression model designed to explain variance in Cr-U levels between employees proved to be successful. A regression model consisting of the variables "Cr-A level", "putting on/taking off gloves frequently", "smoking", "having recent skin injuries" and "washing hands before going to the toilet" explained 94% of the variance in the Cr-U level ($P<0.001$)(Table 2.3).

Factor	Regression coefficient
Cr-A level	1.58 **
Putting on/taking off gloves frequently	1.85 **
Smoking	0.33 **
Washing hands before going to toilet	-0.32 **
Recent skin injuries	0.45 *
Constant	-1.53 *

* $p<0.05$, ** $p<0.001$
$R^2=0.94$, $p<0.0001$

Table 2.3. Results of a multiple regression model (stepwise analysis) designed to explain variance in Cr-U levels among employees (n=20) in factory I

The model shows that when the frequency with which the gloves are put on and taken off is increased, Cr-U is higher as well. When people in the questionnaire replied that they did not smoke, their Cr-U tended to be lower.
Another factor which proved to have some impact on the Cr-U level was "washing hands before going to the toilet". Failure to do so could cause external contamination of the urine, this being not so much a direct health risk as a way in which the correlation between Cr-U and Cr-A might be affected. Recent skin injuries are a reason for increased Cr-U as well: chromium may be absorbed by injured skin.

The correlation between Cr-U and Cr-A was 0.68. This means that only 46% of the variation in Cr-U is explained by Cr-A. When considering other factors, as described in Table 2.3, up to 94% of this variation may be explained. These factors can be considered as expressions of hygienic behaviour since they reduce the uptake of chromium and thereby lower the risk associated with exposure to chromium. Athough the results of the statistical analyses need to be treated with some caution because of the relatively small number of employees studied, results prove that in this chrome plating plant, hygienic behaviour did have an important impact.

Factory II
When the aforementioned regression model was tested on the data for the smaller factory II, the results for factory I were not replicated. The negative correlation between Cr-U and Cr-A, however, hints at quite another relationship. Therefore, other factors were tested for their impact on the variation in the Cr-U level in employees in factory II. A model in which questions about skin injuries were stressed gave some striking results. In factory II dermal contact seems to play a more important role than uptake by respiration. The results of the analysis are shown in Table 2.4.

Type of injury	Factory II (n=9)
Nosebleed	0.34
Skin irritations	0.68 *
Chromic ulcers	0.95 **
Yellow spots	0.70 *
Irritated nasal septum	0.65 *

Table 2.4. Correlations between skin injuries and Cr-U levels in workers employed in factory II

The correlation indicate that the less workers reported having skin irritations, the lower were their Cr-U levels.
No relation exists between the prevalence of skin problems and Cr-A levels. This was also concluded by Langård and Norseth (1979), the explanation presumably being that the development of these lesions depends on local

deposition of the chromium compound on the skin and the presence of any preexisting cutaneous lesions and not on the concentration of chromium in the air.

The impact of factors pertaining to dermal absorption on Cr-U is very large. In factory II measures are taken to lower Cr-A as much as possible, so that the only way of coming into contact with chromium is by dermal uptake: in the process certain manipulations have to be performed in which manual contact can occur. After surveying 54 chrome plating plants, Royle (1975a, b) stated that even if the air concentration is low, exposure to chromium can still take place by dermal contact. As a consequence of this contact, skin irritations and injuries can arise, thereby enhancing uptake of chromium. This is confirmed by the correlations that were found between the occurrence of skin irritations and injuries and the Cr-U levels. In factory II, hygienic behaviour aimed at reducing the possibility of dermal uptake lowered the Cr-U level, thereby decreasing the health risks. Workers who were observed to wear their gloves more often, reported less skin complaints than did other workers. Consequently, more consistent wearing of gloves and better protection of the skin against the etching effects of chromium could decrease the impact of this route of uptake.

Conclusions

In chromium platers and grinders an impact of hygienic behaviour on the eventual uptake of chromium can be detected. In this study, as in others, the correlation between environmental and biological monitoring was rather small or even negative.

In one factory hygienic behaviour, i.e. refraining from smoking, frequency of putting gloves on and taking them off, washing hands before going to the toilet, and recent skin injuries, had a major impact on Cr-U compared to variation in Cr-A. In the other factory, where a negative correlation was found between Cr-U and Cr-A, Cr-U could be explained to a large extent by the impact of personal hygiene. In both factories there was a strong relationship between skin problems and Cr-U level . Since especially in factory II no positive relationship existed between Cr-U and Cr-A, it is probable that raised Cr-U are at least partially caused by dermal uptake. Dermal uptake can only take place after dermal contact. This dermal contact causes the skin irritations, and, at a later stage, the chrome ulcers, which in turn enhance the uptake of chromium.

In both factories stressing the importance of hygienic behaviour, e.g. protecting

the skin against the etching effects of chromium, might have a positive effects on Cr-U levels.
Since this study was performed in two different factories with different workplace hygiene, it can be concluded that not only individual biological monitoring but also general hygienic conditions can have an impact on chromium uptake. In factory II, where air contamination was decreased as much as possible, dermal uptake apparently started to play an important role.
As an overall conclusion based on our findings in these two factories it can be stated that however much stress is placed on the necessity of lowering external exposure, there will always be some variables, expressions of individual hygienic behaviour, that remain to be considered in the interaction between the worker and the workplace (van Dijk et al 1988).

Acknowledgements

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References

Alessio L, Berlin A, Roi R, Boni M (eds) (1984) Human biological monitoring of industrial chemicals series. Commission of the European Communities, Brussels

Blomquist G, Nilsson CA, Nygren O (1983) Sampling and analysis of hexavalent chromium during exposure to chromic acid mist and welding fumes. Scand J Work and Environ Health 9:489-495

Bukowski JA, Goldstein MD, Korn LR, Johnson BB (1991) Biological markers in chromium exposure assessment: confounding variables. Arch Environ Health 46:230-236

Dijk FJH van, Meijman TF, Ulenbelt P (1988) Towards a dynamic model of exposure, susceptibility and effect. In Notten WRF, Herber RFM, Hunter W, Monster AC, Zielhuis RL (eds) Health surveillance of individual workers to chemical agents. Springer, Heidelberg, Berlin, New York

Hassler E (1983) Exposure to cadmium and nickel in an alkaline battery factory - as evaluated from measurements in air and biological material. Thesis, Karolinska Institute Stockholm

Langård S (1979) Absorption, transport and excretion of chromium in man and animals. In: Langård S (ed) Biological and environmental aspects of chromium. Elsevier Biomedical Press, Amsterdam

Langård S, Norseth T (1979) Chromium. In: Friberg L, Nordberg GF, Vouk VB (eds) Handbook on the toxicology of metals. Elsevier, Amsterdam

Lewalter J, Korallus U, Harzdorf C, Weidemann H (1985) Chromium bond detection in isolated erythrocytes: a new principle in biological monitoring of exposure to hexavalent chromium. Int Arch Occup Environ Health 55:304-318

Liden S, Lundberg E (1979) Penetration of chromium in intact skin. J Invest Dermatol 72:42-54

Lindberg E, Vesterberg O (1983) Monitoring exposure to chromic acid in chromeplating by measuring chromium in urine. Scan J Work Environ Health 9:333-340

Lindberg E, Ekholm U, Ulvarson U (1985) Extent and conditions of exposure in the Swedish chrome plating industry. Int Arch Occup Environ Health 56:197-205

Lundquist MA (1981) An evaluation of combined dietary and airborne contribution to human lead absorption (abstract). Am Ind Hyg Conference, Portland, Oregon

Royle H (1975a) Toxicity of chromic acid in the chromium plating industry (1). Environ Res 10:39-53

Royle H (1975b) Toxicity of chromic acid in the chromium plating industry (2). Environ Res 10:141-163

Stern RM (1982) Occupational exposure in the chrome plating industry. In Langård S (ed) Biological and environmental aspects of chromium. Elsevier Biomedical Press, Amsterdam

Tola S, Kilpio J, Virtamo M, Haapa K (1977) Urinary chromium as an indicator of the exposure of welders to chromium. Scand J Work Environ Health 3:192-202

Tossavainen A, Nurminen M, Mutanen P, Tola S (1980) Application of mathematical modelling for assessing the biological half-times of chromium and nickel in field studies. Br J Ind Med 37:285-291

Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM, Broersen S, Zielhuis RL (1990) Work hygienic behaviour as modifier of the lead air - lead blood relation. Int Arch Occup Environ Health 62:203-207

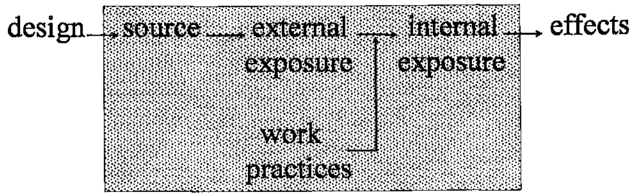
Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM (1991) A negative lead air - lead blood relationship: the impact of respiratory protection. Int Arch Occup Environ Health 63:89-95

Verschoor MA, Bragt PC, Herber RFM, Zielhuis RL (1988) Renal function of chrome plating and welders. Int Arch Occup Environ Health 60:67-70

WHO (1988) Environmental Health Criteria 61: Chromium. WHO, Geneva

Wal J van der (1983) Vergleichsmessungen mit verschiedene Geräten zur Bestimmung der Gesamtstaubkonzentration am Arbeitsplatz Teil 1 (Comparison measurements with several samplers for total dust measurements at the workplace, part 1) Staub-Reinhaltung der Luft 43:291-294

Williams MK, King E, Walford J (1969) An investigation of lead absorption in an electric accumulator with the use of personal samplers. Br J Ind Med 26:202-216



Introduction to Chapter 3:
An inverse lead air - lead blood relation: the impact of air stream helmets

In this chapter the impact of hygienic behaviour and working methods on the uptake of lead is studied. Direct cause for this study was the fact that in former investigations indications were found that variations in individual behaviour, both in working habits and personal hygiene, may cause differences in the uptake of lead. As in chapter 2 the design of the study is derived from the "dynamic model of exposure, susceptibility and effect" of van Dijk et al (1988). According to this model work practices are supposed to play a modifying role in both the transition from source to external exposure, and the transition from external to internal exposure.
The study took place in a secondary lead smelter. Although lead in air levels were known to be elevated, hardly any source oriented control measures were taken at the workplaces. The most important way in which the smelters were protected was by providing them personal protection equipment, a.o. coveralls, safety shoes, goggles and a air stream helmet as respiratory protection. The actual use of this equipment differed between the workers, partly due to the content of their individual activities, partly due to their attitude towards the lead exposure. The quantitative effect of these differences between workers on their uptake of lead will be studied in this chapter.
In the general discussion on the applicability of a model approach in the occupational hygiene practice the results of this lead study will provide information on the value of the "dynamic model". The relevance of this model for workplaces other than lead industries will be discussed.
The impact of working methods and hygienic behaviour are summarized as the source "work practices" in the "multiple source model". The results of this lead study will be used to compare the way these two models handle the impact of personal behaviour at the workplace, either as a modifier or as a source of exposure.

Chapter 3: An inverse lead air - lead blood relation: the impact of air stream helmets[1]

Paul Ulenbelt, Mieke E.G.L. Lumens, Henri M.A. Géron, Robert F.M. Herber

Summary

At a secondary lead smelter data on exposure to lead were collected by systematic observation of hygienic behaviour, a questionnaire, personal sampling of lead dust in ambient air (Pb-A) and determination of lead in blood level (Pb-B). 26 Smelters were studied.
The smelting workers showed a negative relation between Pb-A and Pb-B. Of the variance in Pb-B-levels 53% can be explained by Pb-A, the percentage of time an air stream helmet is worn, the frequency of cigarette smoking at the workplace and spitting. Air-stream helmets and spitting cause a lower Pb-B, whereas smoking contributes to a higher Pb-B. Moreover expected Pb-B-levels are computed by using several regression equations for the relation between Pb-A and Pb-B. As the percentage of time an air-stream helmets is worn increases, the deviation from the expected Pb-B grows substantially.
It can be concluded that some aspects of hygienic behaviour are a major factor modifying the relation between Pb-A and Pb-B. Incorporation of hygienic behaviour in the Pb-A-Pb-B model substantially improves the accuracy of predicting Pb-B-levels and makes unexpected outliers and/or systematic deviations from the expected relation understandable.

Introduction

Despite many occupational studies on the relation between lead in air concentration (Pb-A) and lead in blood levels (Pb-B), a strong relation is seldom observed (Chavalitnitikul 1981; Alessio et al 1983; Booher 1988). In 1969

[1]Modified from: Ulenbelt et al (1991) An inverse lead air lead blood relation: the impact of air stream helmets. Int Arch Occ Environ Health 63:89-95

Williams et al suggested that differences in Pb-B-levels of workers doing almost identical jobs in a battery factory should be attributed to personal differences in working habits that cause differences in Pb-A and not only to differences between these workers in metabolic effects of lead absorbed. A study in another battery factory concluded that personal hygiene, work attitudes and individual working methods appear to play a role in affecting Pb-B (Chavalitnitikul 1981).
Hygienic behaviour at the workplace can be defined as a set of individual actions that lower the uptake of chemical agents.
Recommendations for better general and personal hygiene are widely promoted in lead processing industries. However, these recommendations are based more on sound judgement than on empirical findings, and little is known about the effectiveness of the different types of hygienic behaviour at the workplace to prevent lead uptake.

The objective of the present study is to establish the impact of aspects of hygienic behaviour on the actual intake of lead.

Material and Methods

General
At a secondary smelter, data on exposure were collected during 14 working days by observation of the hygienic behaviour at the workplace, a questionnaire, personal air sampling of ambient lead dust (Pb-A) and determination of lead in blood levels (Pb-B). The population studied comprised 26 male smelting workers.
The main task of the smelting workers was to load the smelting furnace with lead containing scraps, to open the tap hole and to drain the melted lead into pots. The smelting furnace operated continuously. The smelters worked in a five shift system of 8 hours each.
The different tasks rotated more or less between the members of a shift. Air stream helmets were available to all workers.

Blood samples
One blood sample was collected from all 26 workers using lead-free vacuum containers with EDTA as the anti-clotting agent. Pb-B was determined by graphite furnace atomic absorption spectrometry using a simple dilution

method (Herber and van Deyck 1982). The apparatus used was the Varian (Australia) SpectrAA 300 Zeeman Spectrometer with a GTA 96 furnace and sample dispenser.

Air samples

Each worker was measured on four days, the measurements lasted about eight hours. The air sampling equipment was randomly assigned to the workers. The total lead dust sampling equipment consisted of custom-made PAS-6 equipment according to van der Wal (1982) and ter Kuile (1984), coupled to Dupont P2500 pumps (USA).

Determination of the lead absorption on filter was performed by grinding the filters, followed by GFAAS (Schothorst et al 1987). The apparatus used was a Grün (FRG) SM20 solid sampling Zeeman spectrometer.

Observations

All workers were observed at random with an average of 16 times for about 10 minutes. The observations were made by three observers in view of the workers. The task being performed during the observation time was recorded. The type of protection worn was checked at the beginning of each observation period: wearing an air-stream helmet with the face screen down, wearing gloves, wearing a helmet: either an ordinary helmet or an air-stream helmet with the face screen either down or up.

During the observation period the frequency of the following hygienic variables was recorded: spitting, eating, drinking, smoking, putting face screen up or down, putting gloves on or off, putting helmet on or off, hand head shunt, hand mouth/nose shunt.

All hygienic variables were observed only at the workplace. The observations were recorded by Event Data Collectors (IEP the Netherlands).

Questionnaire

All workers were asked to complete a questionnaire, which contained 124 items concerning personal data, organizational aspects and characteristics of general and individual hygiene. 25 out of 26 questionnaires were returned.

Estimation of the expected Pb-B

In order to assess the impact of hygienic behaviour on the relation between Pb-A and Pb-B, information is needed about the level of Pb-B at a certain level of Pb-A, if no special precautions are taken to prevent lead uptake. For the estimation of Pb-B levels from the determined Pb-A level, several of the suggested relations between Pb-A and Pb-B by OSHA (1978) were used (Table 3.1). In the Final Standard for Occupational Exposure to Lead, the results of regression analyses developed for empirical studies on the relation between Pb-A and Pb-B were summarized. Also regression equations were presented to describe these relation at different levels of job tenure (CPA model). From the CPA model only the 9 year job tenure variant was used to compute the expected Pb-B, because it was closest to the average job tenure of the workers in this study.

Source	Pb-B = a + b * Pb-A	
	a	b
King (smelting)	52	0.053
Globe-Union	39.7	0.1229
Asarco	32	0.185
Williams	30.1	0.201
CPA9	29.8	0.2404

Table 3.1 Some of the suggested linear Pb-A-Pb-B relations by OSHA (1978) (Pb-B in μg/100 ml; Pb-A in $\mu g/m^3$)

In the study by Williams et al (1969), workers wearing respiratory protection were not selected for the investigation. It is assumed that in all other empirical studies, as reported in the Final Standard (OSHA 1978) the impact respiratory protection was not taken into account.

Results

The smelting workers showed a negative trend between Pb-A and Pb-B. Figure 3.1 presents the scattergram and the trend of Pb-A and Pb-B for the smelting workers ($r=-0.29$, $0.05<p<0.10$, $n=26$).

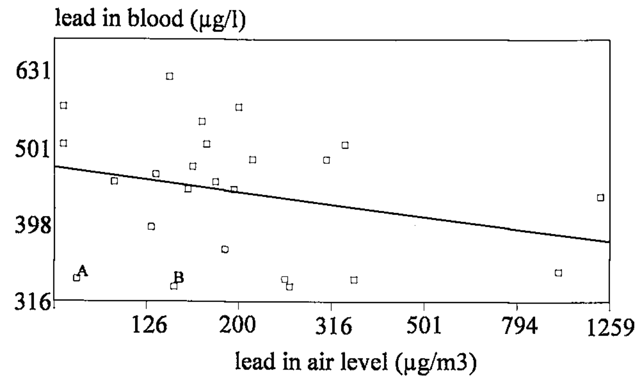


Figure 3.1 Scattergram and regression line of Pb-A and Pb-B for smelting workers (N=26)

It was hypothesized that the interindividual difference in Pb-B, as far as not caused by the Pb-A level, might be explained by interindividual differences in hygienic behaviour. To test this hypothesis a multiple regression of Pb-A and the observed hygienic variables on Pb-B was carried out.

38% of the variance in Pb-B can be explained by the combination of Pb-A, the percentage of time the air-stream helmet was worn with face screen down, the frequency of smoking at the workplace and of spitting ($p<0.05$, $n=26$). The greatest relative contribution (standardized regression coefficient ß) comes from the percentage of time the air-stream helmet was worn (ß=-0.39), followed by the frequency of spitting (ß=0.26). Smoking contributes to a higher Pb-B, whereas more use of the air stream helmet and spitting contribute to a lower Pb-B than expected.

Statistical analysis (z-scores of residue) identified the two cases (A,B) closest to the origin as outliers. Outliers A and B differed from their fellow workers with respect to the tasks performed. Workers A and B spent much more time of their working week operating the smelting furnace, if compared to the other 22 smelting workers (25% vs 4.4%, $p<0.01$).

The correlation coefficient between Pb-A and Pb-B after excluding these cases became $r=-0.46$ ($p<0.05$). After excluding the outliers A and B the percentage explained variance in Pb-B became 53% ($p<0.01$, $n=22$).

It was hypothesized that the inverse relation between Pb-A and Pb-B for these workers may be caused by increased use of the air-stream helmets in high exposure situations. However, a relationship between the use of air-stream

helmets and Pb-A was not found. To test the impact of the use of air-stream helmets Pb-B-levels were needed that correspond to a certain level of Pb-A if no respiratory protection would be used. The expected Pb-B levels were computed by using the regression equations developed by several empirical studies on the relation between Pb-A and Pb-B and by using the regression equation of the CPA model for 9 years on the job, all published in the Final OSHA Standard for Occupational Exposure to Lead (OSHA 1978). Correlation coefficients were computed between the percentage of time the air-stream helmet was worn and the congruity of expected and observed Pb-B. Congruity is observed Pb-B/ expected Pb-B. Expected Pb-B is computed by substitution of Pb-A by the observed Pb-A in the regression equations suggested by OSHA (Table 3.1).
The results for the different estimations were quite similar. As the percentage of time the air-stream helmet is worn increased, the congruity diminished (Table 3.2). The more the air-stream helmet was worn, the more the observed Pb-B deviated from the expected Pb-B.

Time spent wearing mask (%)	n	King	Globe-Union	Asarco	Williams	CPA9
> 0	22	-0.34	-0.29	-0.26	-0.26	-0.25
> 6	21	-0.36*	-0.32	-0.29	-0.28	-0.28
> 8	19	-0.56**	-0.56**	-0.55**	-0.55**	-0.54**
> 10	18	-0.47*	-0.48*	-0.47*	-0.47*	-0.47*
> 20	17	-0.41*	-0.45*	-0.46*	-0.46*	-0.47*

* $p<0.05$
** $p<0.01$

Table 3.2 Correlation coefficients between percentage time wearing masks with the congruity between expected Pb-B and observed Pb-B.

In order to establish the magnitude of the downward deviation from the expected Pb-B, the mean Pb-B of the group of workers (n=9) wearing the air-stream helmet for more than 50% of the time have been compared to the mean Pb-B of the group of workers (n=10) wearing these helmets less than 51% but more than 8%. The magnitudes of the downward deviation from the expected Pb-B did differ, depending on the suggested relation between Pb-A and Pb-B.

	Time spent wearing respiratory protection > 8% and < 51% (n=10)	>50% (n=9)	F
King	117	263	7.700**
Globe-Union	93	281	6.896*
Asarco	103	320	6.393*
Williams	106	330	6.289*
CPA9	159	408	6.161*

* $p<0.05$
** $p<0.01$

Table 3.3 Magnitude (in µg/l) of the deviation from the expected Pb-B for smelting workers.

Discussion

The cross-sectional analysis of these smelting workers points to a major contribution of hygienic behaviour. The percentage of time air-stream helmets were used, spitting and smoking at the workplace all explain the interindividual differences in Pb-B. Air-stream helmets are constructed with a built-in fan that sucks air from behind the worker, filters it, and blows the filtered air in front of the face of the worker. A face screen that can be moved up and down is fastened on the helmet. If the face screen is down, overpressure is created in front of the face. This overpressure prevents the intake of contaminated ambient air. It is assumed that only if the face-screen of the air-stream helmet is down this type of respiratory protection is effective (Que Hee and Lawrence 1983; Greenough 1988). If the air-stream helmet is used equally by all workers in all situations, one still should expect a positive relation between Pb-A and Pb-B, but with a lower intercept. The inverse relation between Pb-A and Pb-B, while results indicate the absence of a relation between Pb-A and the use of air-stream helmets, may be explained if the air-stream helmet is used more during the time that work is performed in high exposure situations. Because the Pb-A-levels are measured as a Time Weighted Average for 8 hours, changes in the use of the air-stream helmet during the day and during different tasks could not be studied in relation to variation in Pb-A.
The impact of spitting on the differences in Pb-B can be understood by the

physiological features of the respiratory tract. Large airborne particles are trapped in the upper respiratory tract, moved upwards by ciliary action up to the nasopharynx and subsequently swallowed or expectorated. If swallowed, the particles may be absorbed in the intestinal tract; if expectorated, the particles are not absorbed. In the average adult it is stated that about 40% of inhaled lead is deposited in the lungs and, depending on the particle size and solubility, it is then absorbed into the blood (Drill et al 1979). The rest of the inhaled dust is partly exhaled and partly collected in the nasal mucous. Thus the contribution of spitting may be important to prevent lead uptake.
The contribution of smoking can be explained by contamination of the tobacco and cigarette paper by rolling cigarettes with dirty hands and by keeping the tobacco in the working clothes. Moreover, the clearance mechanism of the respiratory tract is affected by smoking. Therefore more particles will be deposited in the lung compared to non-smokers.
To our knowledge it is the first time that an inverse relation has been reported between Pb-A and Pb-B. If one compares this finding with results from Table 3.2, it is highly suggestive that the use of air-stream helmets explains the inverse relation between Pb-A and Pb-B. The more time the air-stream helmets are worn, the greater the deviation downward from the expected Pb-B.

In recent years there seems to have been a general tendency for occupational lead exposure and lead in blood levels to slowly decrease (Kononen et al 1989). From their study on the development of Pb-A and Pb-B levels in about 2,000 workers in the USA from 1980 to 1986, it can be assumed that the decrease in Pb-A is less than the decrease of Pb-B. The major reason probably is that in lead-processing industries, in addition to improving technical control measures for lead emission, more and more emphasis is placed on safe work practices, on the use of personal protection devices and hygienic behaviour and provisions.
If individual workers can exercise power over individual prevention of lead uptake by either or not using protection devices, it is likely that interindividual differences in work practice and hygienic behaviour will gain impact and substantially modify the "true" relation between Pb-A and Pb-B. The contribution of the "human factor" on external - internal exposure relations may have two main effects. The first effect is the occurrence of cases that do not fit properly in regression equations. Strong positive of negative deviation from the plants' hygienic standards or workplace standards by a worker may cause less or extra uptake, although the Pb-A-level is similar. In our previous study in a battery factory we have already observed this effect (Ulenbelt et al 1990). The

correlation coefficient between Pb-A and Pb-B increased from 0.42 to 0.88 after excluding one worker with extremely poor hygienic behaviour and another worker with extremely good hygienic behaviour. The second effect is a systematic upward or, more likely, downward deviation from the "true" relation. If all workers in a plant apply high hygienic standards, they will have lower Pb-B-levels if compared to workers in another plant with low hygienic standards at the same Pb-A-level. In empirical studies both effects may occur together and may therefore confound the relation between internal and external exposure. In the present study a mixture of the two effects occurs. In high-exposure situations a higher hygienic standard (more use of air-stream helmet) is applied compared to low-exposure situations. At the same time two outliers are detected. Further analysis of the relations between the performed task, exposure and hygienic behaviour reveals task related hygienic behaviour (Ulenbelt et al 1990).

The OSHA standard is based on empirical studies. However, although OSHA claims that the results of the studies are quite similar, large differences occur. The regression equations mentioned result in substantial differences in Pb-B-level at zero exposure (from 300 to 520 µg/l) and also in the slope of the regression line (from 0.053 to 0.201) (Table 3.2). As possible sources of these different outcomes OSHA indicates some limitations of the studies. The exchange of lead in tissue and lead in bone to blood are not taken in consideration. High Pb-A levels may be due to a relatively large proportion of large particles, that are poorly absorbed and may have biased the relation between Pb-A and Pb-B. Workload, defined as gross-ventilation may differ between workers and between plants and may modify the relation between Pb-A and Pb-B. From a toxicokinetic point of view, one can hypothesize that the physico-chemical properties of the agent and the personal kinetics of workers may affect the relation. However the present study and our previous study indicate that a behavioral approach to explain the bias in the relation between Pb-A and Pb-B (and perhaps other external-internal exposure relations) may make even more sense.

Conclusions

From this study it can be concluded that:

- hygienic behaviour is a major factor modifying the relation between Pb-A and Pb-B,

- incorporation of hygienic behaviour in the Pb-A - Pb-B model improves the accuracy of predicting Pb-B-levels,
- differences in hygienic behaviour may make unexpected outliers and/or systematic deviations from the expected relation understandable.

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References

Alessio L, Foa V (1983) Lead. In: Alessio L, Berlin A, Roi R, Boni M (eds) Human biological monitoring of industrial chemicals series. Commission of the European Communities, Luxembourg. Report EUR 8476

Booher LE (1988) Lead exposure in a ship overhaul facility during paint removal. Am Ind Hyg Assoc J 49:121-127

Brunekreef B (1985) The relationship between environmental lead and blood lead in children. Wageningen Agricultural University, Wageningen, thesis

Chavalitnitikul C (1981) A study of the quantitative contribution of the multiple sources of lead exposure in the industrial environment. Drexel University, Philadelphia, thesis

Drill S, Konz J, Mahar J, Morse M (1979) The environmental lead problem: an assessment of lead in drinking water from a multi-media perspective. Office of drinking water, United States Environmental Protection Agency: Washington DC. EPA-570/9-79-003

Greenough GK (1988) Industrial dust control - the problems and some suggestions for improvement. Ann Occup Hyg 32:45-57

Herber RFM, Deyck W van (1982) On the optimization of blood lead standards in electrothermal atomization atomic absorption spectrometry. Clin Chim Acta 120:313-320

Herber RFM (1990) The World Health Organization study on health effects of exposure to cadmium. Tox Environ Chem 27:1-10

IEP Institute for Experimental Psychology (1988) Event data collector. Institute for Experimental Psychology, Groningen. Users Manual

Kononen DW, Kintner HJ, Bivol KR (1989) Air lead exposures and blood lead levels within a large automobile manufacturing workforce, 1980-1985. Arch Environ Health 44:244-251

Kuile WM ter (1984) Vergleichsmessungen mit verschiedenen Geräten zur Bestimmung der Gesamtstaubkonzentration am Arbeitsplatz: Teil 2 (Comparison measurements with several samplers for total dust measurements at the workplace, part 2) . Staub Reinhalt Luft 44:211-216

Lynam DR (1975) Lead Industries Association position. J Occup Med 17:84-90

Norusis MJ (1986) SPSS/PC+ Users Manual. SPSS Inc, Chicago

OSHA (1978) Occupational Safety and Health Standards. Occupational Standard to lead - final standard. Department of Labor, United States: Federal Register. Tuesday, November 14

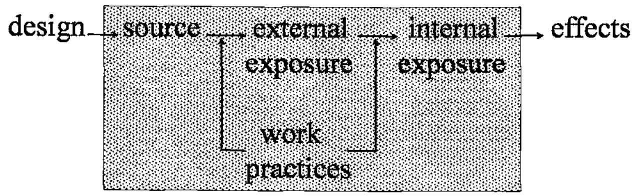
Que Hee SS, Lawrence P (1983) Inhalation exposure of lead in brass foundry workers: the evaluation of the effectiveness of a powered air purifying respirator and engineering controls. Am Ind Hyg Assoc J 44:746-751

Schothorst RC, Géron HMA, Herber RFM (1987) Determination of heavy metals in filter material by solid sampling direct Zeeman AAS. Fresen Z Anal Chem 328:393-395

Staubforschungsinstitut (1973) Empfelungen zur Messung und Beurteilung von gesundheitsgefährlichen Stauben (Recommendations for the measurement and evaluation of toxic dusts). Staub Reinhalt Luft 33:1-3

Wal J van der (1983) Vergleichsmessungen mit verschiedenen Geräten zur Bestimmung der Gesamtstaubkonzentration am Arbeitsplatz: Teil 1 (Comparison measurements with several samplers for total dust measurements at the workplace, part 1) . Staub Reinhalt Luft 43:291-294

Williams MK, King E, Walford J (1969) An investigation of lead absorption in an electric accumulator factory with the use of personal samplers. Br J Ind Med 26:202-216



Introduction to Chapter 4:
The impact of hygienic behaviour and working methods on the uptake of lead and chromium

This chapter provides with an overview of the results of four studies. These studies were performed within the scope of one project. The objective of this project was to assess the impact of work practices on the uptake of chemical agents. Within the dynamic model of van Dijk et al characterization of the different phases involved is one of the main prerequisites. When attempting to assess the impact of work practices both external exposure and internal exposure/dose must be quantifiable. This can be done by environmental and biological monitoring respectively. Field studies in lead and chromium workplaces were chosen because reliable measures are available for these metals.
This chapter focuses on the question whether this approach proves to be suitable in assessing the impact of work practices on the exposure to and uptake of chemical agents, one of the objectives of this thesis. Furthermore the summarized results of these four workplace studies are used to find indications if there is an impact of hygienic behaviour and working methods on the uptake of chemical agents. Next to the environmental and biological measurements the workplace surveys consisted of a questionnaire and structured workplace observations. Both observations and questionnaire mainly focused on the impact of hygienic behaviour and working methods. This focus limits the applicability of the results with regard to the "multiple source model".
This chapter summarizes the results of four field studies. A comparison of these results will give information not only on the impact of hygienic behaviour and working methods on the uptake of lead and chromium but also on the feasibility of a model approach in this type of studies.
Further the question will be answered whether work practices should be considered as a modifying factor in the transition source - external exposure - internal exposure, or as a source of exposure in themselves.

Chapter 4: The impact of hygienic behaviour and working methods on the uptake of lead and chromium[1]

Mieke E.G.L. Lumens, Paul Ulenbelt, Robert F.M. Herber, Theo F. Meijman

Summary

Hygiene-related behaviour and working methods are believed to be important parameters in the relationship between environmental and biological monitoring measures. In order to study the impact of hygienic behaviour and working methods on the uptake of toxic agents, field studies were performed in two lead and two chromium processing factories. Field studies consisted of environmental and biological monitoring of lead or chromium(VI) levels. Besides these measures, hygienic behaviour and working methods were described by means of both a questionnaire and workplace observations. The impact of hygienic behaviour was studied by comparing the explained variance of the biological monitoring measure when the environmental monitoring measure is introduced in a regression analysis either with or without hygienic behaviour.
In all four factories variation in the biological monitoring measures could be explained to a much larger extent when acknowledging the impact of hygienic behaviour. Explained R^2 at least doubled. From the results of these four factories it can be concluded that hygienic behaviour and working methods are a major factor in the relation between environmental and biological monitoring. It may be expected that stressing the impact of hygienic behaviour and working methods will be an important factor in decreasing the uptake of toxic agents.

Introduction

Hygienic behaviour is aimed at preserving good health. At the workplace this can be interpreted as behaviour aimed at keeping exposure and eventual uptake as low as possible. This goal can be achieved in several ways, by using personal protective equipment, by personal hygiene and good working methods.

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[1] Appl Occup Environ Hyg (1994) 9:53-56

The impact of hygienic behaviour and working methods on the uptake of chemicals has been the subject of a number of studies performed at our institute. The direct cause for starting these studies was questions which arose because of the often found rather low correlation between environmental monitoring measures (EM) and biological monitoring measures (BM), even when several confounding variables were taken into account. In general, the contribution of non-occupational sources of exposure, such as hobbies or eating and drinking habits, is negligible compared with occupational exposure (Lundquist 1981). Several studies have indicated that individual differences in hygienic behaviour and working methods might be of importance in explaining differences between employees. Hardly any quantitative research on this subject exists. A few studies have tried to describe the impact of hygienic behaviour qualitatively. Both Hassler (1983) and Williams (1969) made a division of hygienic behaviour based on external appearances of employees. Hassler rated personal hygiene on a 1 to 5 scale. In the Williams study a foreman ranked employees with respect to a "cleanliness at work" scale. The content of these scales was not reported. Even this crude classification could explain some variance in uptake between workers.

The objective of this study is to describe the impact of hygienic behaviour and working methods more quantitatively. The results of researches in four factories will be described. Lead and chromium were chosen to be the agents studied, because of their different route of uptake and biological half-lives. Lead enters the body by inhalation and for a relatively large part by ingestion. In the case of lead the extra uptake is caused to a certain extent by personal behaviour, e.g. refraining from smoking and eating at the workplace with contaminated hands. Chromium(VI) is mainly taken up by inhalation and for a much smaller part possibly by dermal contact. In the case of chromium(VI) the possible extra uptake is caused by either or not preventing skin contact. Different types of hygienic behaviour may play a role when considering these different agents. In the case of lead exposure a larger impact of hygienic behaviour is expected, because for lead the relative amount of uptake by (secondary) ingestion is larger than the uptake of chromium(VI). Lead and chromium are thought to be exemplary agents.
Field studies consisted of biological monitoring (BM), environmental monitoring (EM), a questionnaire and workplace observations.

Methods and Materials

Environmental monitoring

From each employee personal air samples (PAS) were taken over approximately four days. The PAS device consisted of PAS-6 filter holders (van der Wal 1983) attached to duPont P2500 pumps. At a flow rate of 2 l/min the air velocity at the opening of the sampler is 1.25 m/s. The worker wore the PAS equipment during a working day (8 hours). The filters were changed around the lunch-hour, in order to prevent overload of the filters. Time weighted eight hours averages were calculated from these measurements. These TWAs are used in further calculations.

The determination of chromium(VI) on filter (Blomquist et al 1983) was performed by GF-AAS. The apparatus used is the same as for the BM determinations. The determination of Pb on filter (Schothorst et al 1987) was performed by direct solid sampling GF-AAS with a Grün M20 apparatus. Quality control was performed by determination of reference samples.

Biological monitoring

Lead: One blood sample of each worker was collected, using lead-free vacuum containers with EDTA as anti-clotting device. Pb-B was determined by GF-AAS. A simple dilution method (Herber and van Deijck 1982) was used. The equipment used was the Varian (Australia) 1275 spectrometer with GTA 95 furnace and sample dispenser.

Chromium: after-shift urine of each employee was gathered on all days they wore a PAS equipment. Determination of chromium in urine (Cr-U) was performed after pretreating the samples by ultrasonificating, centrifuging and diluting them with 2% nitric acid and subsequent analysis by GF-AAS. The apparatus used for determination was identical as for lead. Quality control was performed by determination of reference samples and participation in intercomparison studies.

Observations

Workplace observations were made to learn more about actual hygienic behaviour at the workplace. These observations consisted of describing the workplace, tasks performed and use of protective equipment at the start of the observation. Subsequently the frequency of putting on/taking off gloves and respiratory protective equipment, finger shunt and smoking, drinking, eating and spitting at the work place was counted. All workers were observed about 11 times, each observation period lasting about 10 minutes. Event-recorders (IEP 1988) were used to store the observed hygienic events. For each worker the mean of each scored behavioural characteristic over the observation periods was used as a descriptor for certain types of hygienic behaviour.

Questionnaire

All workers were asked to complete a questionnaire at home. It contained 124 items concerning personal data, smoking and alcohol consumption habits, leisure time activities, job demands, job decision latitude, working hours, shift work, autonomy, work-organization, job satisfaction, sanitary conditions, availability of personal protective equipment and aspects of hygienic behaviour. In total 57 out of 61 questionnaires were returned. Ulenbelt et al (1990) gave a description of this questionnaire.

Results

The results of the chemical determinations are summarized in Table 4.1. All distributions were log-normal. In all statistical analyses, log-transformed values were used.

	Lead		Chromium	
	EM (μg Pb/m³)	BM (μg Pb/l)	EM (μg Cr/m³)	BM (μg Cr/l)
	Battery factory		Plating factory 1	
Number of samples	25	10	75	76
GM	90	475	15.5	13.9
GSD	2.2	1.4	1.9	2.7
	Lead smelter		Plating factory 2	
Number of samples	99	26	35	35
GM	214	441	14.7	5.5
GSD	2.1	1.2	1.9	2.0

GM = Geometric Mean; GSD = Geometric Standard Deviation

Table 4.1 Results of environmental and biological monitoring of exposure to lead and chromium

For the two lead plants lead in blood levels were in the same range, whereas lead in air levels differed considerably. For the plating plants the inverse applied: similar chromium(VI) in air levels lead to dissimilar chromium(VI) in urine concentrations. Most probably part of the airborne chromium(VI) in factory 2 is in a non-soluble or non-respirable form. Since in this study only total Cr-A was determined, this cannot be verified.

Correlations between personal air sampling results and the uptake in the body, measured by BM, were calculated. Correlation coefficients for the battery factory and the lead smelter were 0.42 and -0.45 respectively. In plating plant I r=0.67 and in plant II r=-0.64. In all cases p was less than 0.05. These results indicated that other factors besides the level of air contamination have their impact on eventual uptake.

Multiple regression analyses were performed in order to study the impact of hygienic behaviour on the variance in uptake. Because of different routes of uptake for lead and chromium(VI), and because of differences in general workplace layout and the availability of personal protective equipment in these four plants different sets of factors were introduced into the regression analyses. Hygienic behaviour was described by variables obtained partly by the workplace observations and partly by means of the questionnaire.
Ulenbelt et al (1990, 1991) and Lumens et al (1993) described these regression analyses quantitatively. At this place they will be summarized by stating the regression coefficients in parentheses. Only significant variables ($p<0.05$) were retained in the final models.

In the battery factory a higher frequency of putting on and taking off gloves (b=0.081) and a higher frequency of hand-mouth contact (b=0.094) increased the uptake of lead in blood.
In the secondary lead smelter air stream helmets were available for all workers. The Pb-B level was mainly determined by the percentage of time the air stream helmet was worn correctly (b=0.067), i.e. with the face screen down. Next to this factor, the frequency of spitting (b=0.051) and smoking (b=0.043) during working hours correlated with Pb-B.
In chromium plating plant 1 a higher frequency of smoking(b=0.33), putting on and taking off gloves (b=1.85) and having recent skin injuries (b=0.45) caused a higher Cr-U level. Frequently taking off gloves combined with injuries may lead to dermal uptake of chromium. Next to this, less washing of hands before

visiting the toilet (b=-0.32) caused a higher chromium in urine level. Probably this caused external contamination of the urine.
In plating plant 2 dermal contact seems to play a more important role than uptake by respiration. In this plant higher Cr-U is related with a higher occurrence of skin injuries.
The final results of these regression analyses, i.e. the change in explained variance (R^2) of the biological monitoring measure, are summarized in Table 4.2. A correction for the number of variables was applied; in Table 4.2 adjusted explained variances are given.

	N	R^2 %BM by EM	R^2 %BM by EM + behaviour
Battery factory	10	18	92
Lead smelter	26	21	53
Plating factory 1	20	46	94
Plating factory 2	9	41	75

Table 4.2 Summary of regression analyses in 4 factories, either with or without including hygienic behaviour as factor

The results show that in all cases R^2 is increased considerably when adding hygienic behaviour to the model.

Discussion

The contribution of hygienic behaviour to the explanation of variance in individual uptake is higher in the lead factories than in the chromium plants. Probably this is due to the fact that in lead the uptake by other routes, besides inhalation, is larger than for chromium.
In the lead plants behaviour related to (secondary) ingestion of lead, i.e. smoking with contaminated hands, frequent hand-mouth contact and spitting, has a large impact on the individual uptake.
In the plating plants activities connected to dermal contact with chromium seemed to be of importance in increasing Cr-U levels. In both plants the

uptake of chromium was higher when the gloves were taken off regularly and when skin injuries occurred more often.
In chromium plating plant 2 all kinds of prevention measures were taken to lower airborne exposure as much a possible. In this factory dermal uptake seemed to be of greater importance compared with respiratory uptake.
These results seem to suggest that personal hygiene-related behaviour mainly exerted its influence on the routes of uptake other than by inhalation. This may be caused by the fact that behaviour related to oral or dermal uptake is easier to observe than behaviour related to inhalation. Only in the case of the lead smelter, where the proper use of the air stream helmet (face screen down) could be easily observed, the impact of inhalation related personal behaviour could be demonstrated.

Conclusions

These results prove that hygiene-related behaviour is an important modifier in the relation between EM and BM.
It is acknowledged that these results stem from four factories. Still the change in R^2 caused by taking into account variations in hygienic behaviour is always in the same direction and always very large. This implicates that uptake and consequent health effects cannot be predicted only by EM measurements. Stressing the impact of hygienic behaviour may lead to a better understanding of variations in BM between different workers.
It may be expected that promoting more hygienic behaviour will lead to less uptake and in that way to better health.

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References

Blomquist G, Nilsson CA, Nygren O (1983) Sampling and analysis of hexavalent chromium during exposure to chromic acid mist and welding fumes. Scan J Work Environ Hlth 9:489-495

Hassler E (1983) Exposure to Cadmium and Nickel in an alkaline battery factory - as evaluated from measurements in air and biological material. Karolinska Institute Stockholm, thesis (1983)

Herber RFM, Deyck W van (1982) On the optimization of blood lead standards in electrothermal atomization atomic absorption spectrometry. Clin Chim Acta 120:313-320

IEP (1988) Event data collector -users manual-. Institute for Experimental Psychology: Groningen

Lumens MEGL, Ulenbelt P, Géron HMA, Herber RFM (1993) Hygienic behaviour in chromium plating industries. Int Arch Occup Environ Hlth 64:509-514

Lundquist MA (1981) An evaluation of combined dietary and airborne contribution to human lead absorption. In: Proceedings of American Industrial Hygiene Conference: Portland, Oregon

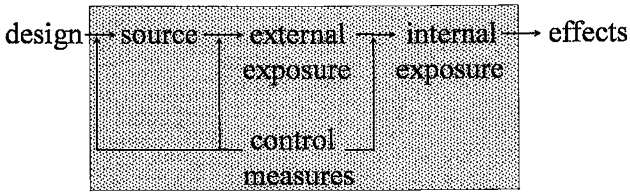
Schothorst RC, Géron HMA, Herber RFM (1987) Determination of heavy metals in filter material by solid sampling direct Zeeman AAS. Fresenius Z Anal Chem 328:393-395

Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM, Broersen S, Zielhuis RL (1990) Work hygienic behaviour as modifier on the lead air- lead blood relation. Int Arch Occup Environ Hlth 62:203-207

Ulenbelt P, Lumens MEGL, Géron HMA, Herber RFM (1991) An inverse lead air-lead blood relation: the impact of air-stream helmets. Int Arch Occup Environ Hlth 63:89-95

Wal J van der (1983) Vergleichsmessungen mit verschiedenen Geräten zur Bestimmung der Gesamtstaubkonzentration am Arbeitsplatz: Teil 1 (Comparison measurements with several samplers for total dust measurements at the workplace, part 1) . Staub Reinhalt Luft 43:291-294

Williams MK, King E, Walford J (1969) An investigation of lead absorption in an electric accumulator factory with the use of personal samplers. Br J Ind Med 26:202-216



Introduction to Chapter 5:
Quartz in the construction industry: sources of exposure

The research described in this chapter is aimed at quartz exposure at construction sites, and at detecting ways to control elevated exposure. Focus will be on measures controlling source and external exposure. In this study the multiple source model is applied to assess the impact of all possible sources in order to gather information on exposure levels and possible means to control this exposure. The results of this approach are elaborated in this chapter.
The field studies in both industry and construction trade had one important feature in common: in all cases workplace conditions and working methods were observed in a structured way in order to be able to detect the impact of the various factors that may have a contribution to the level of exposure, either external or internal. In this study observations were aimed at describing the sources contributing to the external exposure.
The "dynamic model" illustrates that work practices also are a modifier of the relation between external exposure and dose. In contrast to the lead and chromium studies, in this quartz study however the impact of this modifier can not be quantified: the level of the quartz dose can not be measured, because a biological monitoring measure for quartz does not exist. Further, quartz is taken up into the body only by inhalation. This implies that individual hygienic behaviour will only be effective when it is aimed at preventing or decreasing inhalatory uptake of quartz. Apart from the use of respiratory protection it is difficult to discern this type of hygienic behaviour. Therefore some derived conducts are taken into consideration to determine the extent of hygienic behaviour displayed by the workers.
One of the objectives of this thesis is to determine the feasibility of a model approach in the selection of control measures. The results of this study will be used to determine whether this "multiple source model" provides a valuable mean to choose the optimal control measures.

Chapter 5: Quartz in the construction industry: sources of exposure[1]

Mieke E.G.L. Lumens and Ton Spee

Summary

Because most masonry building materials contain quartz and because these materials are subjected to a variety of treatments during the building process, quartz is encountered everywhere in building operations. The level of exposure to quartz has been measured for some highly exposed groups of employees. At 30 construction sites PAS measurements of respirable dust and quartz have been performed. We have taken 171 samples. Both respirable dust and quartz levels were high. Respirable quartz exposures of more than ten times the Dutch MAC value were common, but exposures up to 200 times the Dutch MAC-value were also found.
By statistical analysis the contribution of multiple sources to the total exposure has been identified. With this model approach indications for an effective control measures programme can be given.

Introduction

Dust is omnipresent at construction sites. During almost all activities exposure to dust can occur; from excavation for the foundations up until the final sweeping before delivering a new building. Exposure to dust is very much part of every days practice. Depending on the nature of the building material being used this dust can contain a considerable amount of silica. Crystalline free silica (silicon dioxide, SiO_2) can occur in three phases: quartz, cristobalite and tridymite. The most important and prevailing type is quartz.
Reports about exposure to quartz in the building industry are scarce and the problem has by no means attracted as much attention as exposure to quartz in

[1]submitted to: Annals of Occupational Hygiene

the mining industry and the iron and steel industry (Tomb et al 1995, Amandus et al 1995). Susi and Schneider (1995) propose a database for task-based exposure assessments in construction. Moser (1992) has determined exposure levels to quartz during demolition and reconstruction of a large building. Almost eighty percent of 44 measurements were above the Swiss MAK of 0.15 mg/m^3. The highest levels were encountered when renovating a sand stone wall (4.7 mg/m^3) and during the milling of recesses within the building (1.2 mg/m^3). According to Riala (1988) the exposure of Finnish construction site workers to quartz can be as high as 0.53 mg/m^3 during dry sweeping.

Although construction workers seem to regard exposure to dust as natural and inevitable, the amount of complaints, both of nuisance and of health effects, is considerable. All Dutch construction workers can, on a voluntary basis, take part in a regulatory health monitoring programme. Results of the health monitoring are regularly examined at a group level, thus giving some idea of the amount of health complaints in the Dutch construction industry [Arbouw]. Some of the results are summarized in Table 5.1.

kind of complaint	percentage of people involved (male) in construction industry	other industries
nuisance by dust	45	20
clogged nose	18	13
regular coughing	19	12
short of breath		
in general	25	16
at light exercise	6	3
treated for bronchitis		
or asthma	6	5

Table 5.1 Some results of health examinations of Dutch construction workers compared to a reference population of the general industry.

Occupational exposure to quartz may cause considerable damage to the lungs, among others obstruction of the lungs and lung emphysema. Moreover there are indications that exposure to freshly milled quartz may increase the risk of developing pulmonary injury. Fubini et al (1995) found that dusts obtained by grinding crystalline minerals exhibited a propensity to originate surface radicals. Shoemaker et al (1995) exposed rats to both freshly milled and aged

alpha-quartz and found that inhalation of freshly cleaved quartz resulted in dramatically greater increases in all pulmonary responses. These findings suggest that freshly machined quartz, generated during certain construction activities, may result in a greater risk of occupational disease.
Chronic exposure to high concentrations of quartz may lead to silicosis (Parkes 1985), well known from the mining industry. Exposure to exceptionally high concentrations may lead to acute silicosis and death (Parkes 1985). In Germany, where silicosis is a compensable occupational disease, 80 new compensations due to silicosis have been assigned in 1995 to construction workers. Due to underreport the real number of cases of silicosis will probably much higher (HVBG 1996). Hodel et al (1977) described the occurrence of two cases of silicosis among construction workers. They wanted to attract attention to this hitherto little recognized health hazard.
In the autumn of 1996 the International Agency for Research on Cancer (IARC) has reviewed recent data on the carcinogenicity of quartz. As a result of this review quartz is placed in IARC Group 1, implicating that "there is sufficient evidence of carcinogenicity in humans" (Borm 1997).
The Dutch government has placed respirable, crystalline silica on her list of proven human carcinogens (Arbeidsinspectie 1994).
Where data about exposure to quartz in the construction industry are scattered, papers about control measures are even more scarce. To our best knowledge, only Hallin (1983) has reported on this subject. This author determined quartz exposure during a number of construction jobs. He found very marked differences between working with and without local exhaust ventilation (LEV). The highest concentration was 32.8 mg/m^3 quartz when milling recesses for inserting conduits for electric cables in sand-lime bricks without LEV. The use of LEV decreases the quartz exposure to an average 0.2 mg/m^3, so the exposure was still well above the Dutch TLV of 0.075 mg/m^3.
There were various factors which induced us to draw renewed attention to the exposure to quartz in building:
- There is a world wide increase in interest for work related quartz exposure. Recently both the Scandinavian Journal of Environmental and Occupational Health and the Journal of Applied Occupational and Environmental Hygiene devoted a special issue to this subject.
- The farming out of work to subcontractors is a well-known phenomenon in the building industry. The increasing rationalisation of the building process means that this phenomenon is on the increase, and there are now companies which have a single specialisation. If such specialisation concerns an occupa-

tion with a high exposure to quartz, then we are dealing with a long term exposure problem.
- In the Netherlands the MAC (a limit value comparable to the British OEL) for silica has been reduced from 0.150 mg/m^3 to 0.075 mg/m^3 as from 1st May 1996. For the construction industry this MAC value will apply from April 1st 1997.
- The Dutch government has placed respirable crystalline quartz at the list of carcinogenic substances. So the EU Directive on carcinogenic substances, which was embodied in 1994 in the Dutch legislation, also applies to quartz (EEC 1990).
- Despite of the large numbers of workers possibly exposed and the severe risks involved data on exposure levels at construction sites are hardly available.

This combination of factors together formed the direct cause for this study.

The objectives of this study were:
- to investigate the level of silica exposure for several jobs at construction sites,
- to determine the contribution of different sources to total exposure.

A field study was carried out, in which 171 air samples were collected. Before the field study was started a literature survey was performed. In this survey information was gathered on 29 occupations within the construction industry in the Netherlands. The literature search focused on information on the frequency and level of respirable dust and quartz exposure for these jobs. Specific control measures aimed at decreasing these exposures were searched as well. The results of this literature survey are summarized in Table 5.2 (after Tjoe Ny and van Amelsvoort 1993).

It can be concluded that in the Netherlands at least 7000 workers in the construction industry are excessively exposed to quartz. As the working population in the Dutch construction industry amounts to 200,000 employees, we deal with at least 3.5 % of the population. This applies only to the employees that are officially registered to these occupations. A lot of other construction workers perform the tasks named in Table 5.2 as part of their job, and may be exposed to equally high exposures.

Table 5.2. An overview of highly exposed occupation groups within the construction industry with an assessment of frequency and level of quartz exposure

Occupation	number of employees	frequency of quartz exposure[1]	level of quartz exposure[2]
concrete driller	400	++	+
(concrete) blaster	?[3]	++	++
bricklayer carcass	300	++	+
bricklayer completion	500	+	-
stone cutter	1000	++	++
carpenter	?	+	+/++
plumber/electrician	200 ?	++	++
demolisher	1500	+/++	++
terrazzo worker	550	++	++
cement finisher	600	++	-/++
road paver	?	++	+
labourer	150	++	++
roofer	?	-/+	++
jointer	2500	++	++

[1]: += often (> 15 h/week), ++=very often (> 20 h/week)
[2]: - =<< 0.15 mg/m^3, +=about 0.15 mg/m^3, ++=>> 0.15 mg/m^3
[3]: uncertain

The specific tasks, meant by the above-mentioned occupations, are as follows:

bricklayer:	person who piles up gypsum or lime-sandstone blocks to form inner walls.
stone cutter:	person who processes natural stone, e.g. for outer wall cladding or for the pavement of floor buildings.
carpenter:	person who mounts false ceilings, e.g. in office buildings.
plumber/electrician:	person who makes recesses in walls, to conceive water pipes and electricity mains.
plasterer:	person who sprays a fluid plaster (called "spack" in Dutch) on walls.
cement finisher:	person who levels floors (e.g. by sanding) before the floor finishing is applied.
labourer:	person who cuts off the heads of concrete foundation piles.
roofer:	person who lies roof tiles on roofs.

Based on these results a ranking of occupations with a high exposure to dust can be made. The current study is focused on these highly exposed employees, working as recess millers, demolition workers and inner wall constructors. Since construction job titles vary in different countries, a short description of these occupations will be given.

- recess millers. Recesses are made in materials for the purpose of concealing utility lines and pipes for water and electricity. Instead of being mounted on the wall, the pipe or conduit is located inside the wall. This is neater and more practical if further finishing has to be carried out. The usual technique for making recesses is to use a recess miller.
- demolition workers. By the concept demolition the dismantling of walls, floors and ceilings, but also for example, the removal of plaster or tiles from walls is indicated. The demolition usually therefore precedes renovation and improvement. The tools used for this type of demolition are hammers. Sometimes these are simple hand hammers, but frequently also electrically or pneumatically driven hammers. This study does not concern with the demolition of complete buildings. Such work is carried out by totally different techniques such as crushing, the use of explosives or a crane. In this work the demolition experts are usually located in a cab, screened from the proceedings.
- inner walls constructors. Inner walls are constructed by connecting elements with a special glue. These elements have to be made down to size. This can be done with a (electric) saw or with a specially designed pair of nippers.

The construction trade has specific properties which necessitate a special approach for measurements. Attempting to characterize exposures among construction workers is particularly challenging since most of the parameters that determine the exposure are perpetually changing. Construction is synonymous with change. Because hardly any house or building is similar to another, conditions are different all the time; the material varies, natural ventilation changes, the amount of work to be finished in one day varies as well. Much of the tasks to be performed at construction sites take only a few hours. This means that workers often work at different places during one day, a considerable time is spent preparing the work and travelling. Exposure hardly ever lasts a full shift of eight hours. Moreover because of the different construction sites where employees have to work supervision may also be a problem. As well as contact with co-workers, which might enable them to discuss problems and exchange solutions with respect to the exposure to dust and silica. Control measures at construction sites almost exclusively are directed at personal protection devices (Reed et al 1987). The dynamics of the building industry complicate the development and application of control measures. Unfortunately, adequate "off-the-shelf" control technology is hardly available for many construction operations (Linch et al 1993).

Materials and Methods

Selection of construction sites

Construction sites where the research could be executed were acquired in two ways. By contacting both firms listed in the Yellow Pages and the Health and Safety coordinators of several big construction firms, describing the objectives of the study to them and asking whether they could supply addresses where the specified works were performed. It was tried to include into the selection not only the selected occupations but also a variation in the conditions in which the works were executed, e.g. variation in type of building material and level of control measures.

Measurements: task based PAS and source oriented measurements

A total of 30 relevant construction sites were identified. Some sites were studied on more than one day. At each site employees were asked to cooperate by wearing personal air sampling equipment for some hours. The large majority of them were willing to participate in the study. Only two of them refused because they considered it too much of a fuss. Measurements lasted as long as feasible. Because of the nature of the jobs (at different sites, ready-go-home system) hardly any measurement lasted a full shift of 8 hours. The average sampling time was about 3 to 4 hours.

Next to the personal air sampling source oriented ambient measurements were taken. A direct reading dust monitor was used both near the working environment of the worker and at the background to quantify the (relative) contributions of the different sources mentioned above.

Description of construction sites

A questionnaire and a checklist developed for this study were used to enable a qualitative description of the different workplaces where the measurements were conducted. In the questionnaire the workers at the construction sites are asked after their normal working habits, working hours, use of personal protection equipment, use of other control measures and possible improvement of the working conditions at the construction sites.

The checklist was used to systematically report on factors at the workplace, which might have an impact on the total exposure of the workers. Information was gathered on: type and (if available make) of building material, type and make of equipment, state of the building (lay-out, with or without glass in the windows), presence of other workers, use of LEV, general impression on the neatness of the workplaces and weather conditions at the day of the measurements.

Sampling and analysis

Samples were collected on Millipore mixed ester filters (type RA 1.2 µm, 25 mm) using Casella cyclones as sampling heads in combination with Dupont P-2500 or Gilian Gilair pumps with a flow of 1.9 l/min. Casella cyclones sample the respirable dust fraction, which is relevant in determining exposure to quartz. Filters were weighed before and after sampling with a Mettler balance (type AT 261 DeltaRange, Switserland).

Part of the filters were sent to an external laboratory (Ascor Analyse, The Netherlands) to measure the content of respirable crystalline silica of the respirable dust. The analysis was performed by X-ray diffraction (XRD) according to NIOSH method 7500. These filters were chosen for their representativeness. The quartz content of these filters is used to assess the quartz content of the respirable dust samples.

As a direct-reading aerosol monitor the MiniRAM (model PDM-3,USA) was used. The MiniRAM is a light scattering aerosol monitor which responds to particles in the range 0.1-10 µm. Consequently, the MiniRAM gives a good estimate of respirable dust concentrations. The MiniRAM is calibrated on Arizona Road Dust and not on "construction" dust: consequently the results of these measurements can only be used to compare different situations. The MiniRAM was connected to a data logger (Metrosonics, USA). The logged data were read into a personal computer using Metrosoft software. The results were plotted and interpreted by comparing the variation in exposure to the results of the observations made synchronously at the workplace.

All statistical analyses were performed with SAS software (SAS Institute Inc. 1994).

Multiple Source Model

In this study personal exposure is thought to be composed of the contributions of different sources. A source is defined as a possible cause of exposure. The concept "external exposure" in occupational hygiene can be described as the process by which a substance becomes available for absorption by the worker.

Sources can be divided into four different categories: agents, processes or appliances, work practices and working environment. This approach is called the "multiple source model" and is described by Buringh et al (1992). The impact of these four sources is determined in order to assess their individual contributions to eventual exposure. These separate contributions are calculated by statistical analysis. Analyses of the "multiple source model" were performed by analyses of variance within the framework of general linear models (GLM)(Draper and Smith, 1981).
The separate sources are composed of input of the following variables on which information was gathered during the field studies. On some of these variables quantative information could be obtained, others had to be assessed by workplace observations. For the four distinctive sources the information which was thought to be important to be included is described.
agents: type of building material used (quartz content);
processes and appliances: type of process applied, without or without use of local exhaust ventilation, make of equipment used;
working environment: layout of the building under construction, glass already present in the windows, presence of other workers causing extra exposure, weather conditions (rain/wind);
work practices: use of personal protection equipment and the general impression of neatness when working.

Results

In Table 5.3 and 5.4 the results of the respirable dust and quartz dust determinations are summarized.

	N	min	max	GM	GSD
total population	171	0	298.8	5.2	3.8
recess millers	53	0	18.9	3.1	2.7
inner wall constructors	36	0.2	10.6	2.1	2.9
demolition workers	82	0.5	298.8	10.8	3.5

GM: geometric mean
GSD: geometric standard deviation

Table 5.3 Personal respirable dust concentrations at construction sites (in mg/m^3)

	N	min	max	GM	GSD
total population	171	0	35.9	0.5	5.6
recess millers	53	0	6.9	0.7	3.3
inner wall constructors	36	0	0.2	0.04	2.6
demolition workers	82	0	35.9	1.1	4.0

GM: geometric mean
GSD: geometric standard deviation

Table 5.4 Personal respirable quartz dust concentration at 30 construction sites (in mg/m^3)

Both the results of the total populations and the three separate populations are lognormally distributed for respirable dust and quartz dust. Hence the geometric mean and standard deviation are reported.

Table 5.5 describes the results of the statistical analysis aimed at determining the impact and contribution of the four sources to total exposure.

	total population	recess millers	inner wall constructors	demolition workers
agents	10.12 (0.0001)	7.39 (0.0002)	4.63 (0.0037)	____
process/ appliances	6.70 (0.0001)	2.06 (0.14)	0.83 (0.37)	5.90 (0.0004)
working environment	0.98 (0.422)	8.20 (0.0001)	3.33 (0.05)	3.14 (0.080)
work practice	0.56 (0.572)	4.68 (0.015)	0.13 (0.72)	0.47 (0.49)
R^2 p>F	0.68 (0.0001)	0.66 (0.0001)	0.54 (0.0067)	0.26 (0.0009)

Table 5.5 Regression analyses of the multiple source model, with personal respirable quartz concentration as dependent factor

Discussion

General

By performing measurements in a large variety of construction sites, construction materials, working conditions and external conditions we have got a representative description of quartz levels for the three occupations under study. We selected the construction sites by thorough discussions with construction experts, to create ourselves a picture of the everyday practice for these occupations.

Even though the average measuring time did not cover a full workday, the results of these measurements probably represent average exposure.

The average level of exposure to quartz is higher than the Dutch MAC value of 0.075 mg/m^3. Especially for demolition workers and recess millers their exposure to quartz can pose a threat to their health.

As the large standard deviation indicates, variation between workplaces is rather large. A number of factors prove to have a negative or positive impact on the level of exposure. The use of a LEV system for instance decreases the concentration considerably. It should however be noted that even in case of this control measure average concentration still is too high, especially when compared with the future Dutch MAC value.

Workplace visits, checklists and personal interviews made it clear that dust at the construction site is regarded as unavoidable by those concerned. On the building sites almost no-one is aware of the potential health hazards of (quartz) dust. This is probably the reason why only limited measures are taken to combat the occurrence and propagation of dust. Even though measures are being taken in a number of areas to reduce the exposure, these are still not resulting in an acceptable exposure level.

Multiple source model

The results of the personal measurements indicate the need for control measures. Control measures can be applied most effectively, when the main sources of exposure are known.

In order to assess the contribution of the different sources to the total exposure the "multiple source model" is applied. The results of the statistical analyses show that the model can explain up to about 66% of the variation in the quartz exposure, depending on the occupation investigated.

The model as it is applied in this study is most appropriate for the occupation of recess millers. For this job title the four sources are best described, important

parameters at the workplace could be easily attributed to one of the four sources. For inner wall constructors and demolition workers less variance is explained by this "multiple source model". In case of the inner wall constructors this may be due to the low levels of quartz which were found during the measurement. Personal exposure of these workers may consist for a relatively large part of quartz present in background dust. The large variety in activities which together form the job title demolition workers probably make it more difficult to attribute the four sources to the eventual personal exposure. In the case of demolition workers a further division into the different activities may lead to better results.
As to the contribution of the four separate sources the following can be concluded.
Not surprisingly the *agent*, i.e. the type of building material (either or not with a high silica content) plays an important role in determining eventual quartz exposure. This is most prominent for the recess millers. In this occupational group building material is well defined and separated, certainly as compared to the demolition workers, who almost always work in a mixed dust environment. Recess millers were usually well aware of the type of building material they were milling in, because they have to choose their grinding wheel in accordance to the hardness of the material. Moreover at most construction sites recess milling produces most dust, so that the personal exposure of the millers predominantly can be attributed to the quartz content of the construction material at hand. For demolition workers the building material usually is not so well defined; this makes it difficult to investigate the impact of material at hand to quartz exposure. Inner wall constructors know the type and make of elements they are joining to construct inner walls. Since however the dust emission with this task is not very high, the quartz content of the dust samples may be composed of other quartz sources next to the material the inner wall constructor is handling at the time the sample is taken. This is shown in the results of the model, which indicate that the impact of the agent is large in determining the quartz exposure of recess millers, not very strong for the inner wall constructors and absent for the demolition workers.
With regard to the contribution of the *process and equipment* used the results also indicate differences between the three selected occupations. For demolition workers a significant impact is detected: when considering the large variety in tasks and materials used in this occupation, ranging from using hand held hammers for removing small remnants of stone to using a small bulldozer to throw over walls, the relatively large impact is understandable. The variation in total dust emission between these extremes is clearly visible.
To a certain extent this also applies to the recess millers. The way they perform

their tasks varies from using "conventional" recess millers to using diamond saws with LEV. The use of either of these methods has large implications for the respirable dust exposure and quartz exposure.

For inner wall constructors two different types of apparatus are used to cut the elements to the correct size. The elements can either be sawn or cut. The impact of these methods however is not visible in the results of the modelling. A possible explanation may be the fact that making the elements to the right size takes a relatively small part of the working time. The impact of the appliance of either a saw or a special pair of nippers may therefore be diluted by the exposure during the rest of the workday, which will be comparable for the two methods.

The source described as *working environment* is composed of a number of parameters. Considering the large variety of building and construction sites it will be clear that, in comparison with agents and processes, the variation in the working environment is almost unlimited. The presence of certain features in the working environment of the three occupations is merely coincidental, moreover because weather conditions are also included in this source. Still it can be argued that climate is an integral part of the working environment at construction sites, since a large part of the building activities takes place in the open air.

For all three occupations the working environment plays a more or less important role in explaining exposure. An example of the importance on exposure can be found with the recess millers. Their exposure proved to be highly dependent on the fact whether or not glass was already present in the windows. If this was the case exposures were significantly higher than without glass ($p<0.05$), the effect being enlarged by strong winds which add to the natural ventilation.

Work practices contribute to the personal quartz exposure of recess millers. For demolition workers probably the overall exposure is so high that the contribution of personal behaviour can hardly be discerned. In this study work practices are described by the subjective impression of neatness and the use of personal protection of the airways. The use of personal protection equipment is chosen as an indicator for a positive attitude towards safe working. In this case respiratory protection equipment is not considered to have a direct impact on the personal exposure as measured. We did not try to place the sampling head behind the protection device. Moreover both the frequency of use of protection and the quality of the masks used was very poor, so the reduction caused by this equipment is only marginal. The use of personal protection devices is incorporated in the source "work practice" only as an indicator of awareness of potential danger connected to quartz dust exposure, as a potential contributor to safer work practices.

The results of this "multiple source model" are partly supported by the results of the direct reading instrument with data logger, which enabled us to investigate the contributions of the separate sources.

Calculations based on this model provided us with relevant information on the contributions of the four sources. This information can be used to order and prioritize these sources to their individual contribution on personal exposure. When designing control measures for high exposure situations or occupations it is important to determine what type of control measures on what source will have the highest impact. The model shows a different hierarchy for the three occupations.
For each occupation the problem of high quartz dust exposures can now be tackled in a structured way. We are now working on an overview of possible control measures.

Conclusions

Under the present conditions limits for quartz exposure are frequently being exceeded for occupants of certain jobs in the construction industry.
The "multiple source model" used in this investigation gives a clearer idea of the impact of different factors on the level of the exposure. As the contributions made by the sources become better known, a more systematic approach can be adopted to formulating corrective preventive measures.
The most important and urgent conclusion however is that there is a clear need to raise the awareness to the possible dangers of high exposure to quartz dust.

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References

Amandus HE, Shy C, Castellan RM, Blair A, Heineman EF (1995) Silicosis and lung cancer among workers in the North Carolina dusty trades. Scand J Work Environ Health 21 suppl 2:81-84

Amelsvoort, L van, Tjoe Ny E, Arbeidsomstandigheden in de Bouw, in het bijzonder (silica)stofblootstelling; een literatuuroverzicht (Working conditions in the construction trade, with regard to (silica) dust exposure: a literature review) Wageningen, Department of Air Quality Landbouwuniversiteit, internal report IV-187, March 1993 (in Dutch)

Arbeidsinspectie (1994) Werken met kankerverwekkende stoffen en processen (Working with carcinogenic agents and processes) (P-187, in Dutch), SDU, Den Haag, The Netherlands

Arbouw Foundation, Werk en Gezondheid in de bouwnijverheid (Work and Health in the construction Industry, in Dutch), Arbouw Foundation, Amsterdam, The Netherlands.

Borm P (1997) personal communication

Buringh E, Noy D, Pouwels H, Swuste P (1992) A systematic implementation of control measures for airborne contaminants in workplace air. Staub Reinhaltung der Luft 52:347-351

DECOS (Dutch Expert Committee on Occupational Standards) (1992) Health based recommended occupational exposure limits for crystalline forms of silicon dioxide (free silica), DGA, Den Haag, RA 5/92

Draper N, Smith H (1981) Applied regression analysis, 2nd Edition, John Wiley and Sons Inc, New York

EEC European Directive 90/394/EEC (1990): Directive on carcinogenic substances. Official Journal of the European Communities, L-374

Fubini B, Bolis V, Cavenago A, Volante M (1995) Physicochemical properties of crystalline silica dusts and their possible implications in various biological responses. Scand J Work Environ Health 21 supp 2:9-14

Hallin, N (1993) Occurrence of quartz in the construction sector, an investigation of the occurrence of quartz dust in connection with various operations in the construction sector. Bygghalsan

Hodel T, Schegel H, Ruttner JR (1977) Backstein- und Betonbohrersilikose (Brick and concrete drillers silicosis). Schweiz. med. Wsch 107:1896-1899

HVBG (Hauptverband der gewerbliche Berufsgenossenschaften) (1996) Geschafts- und Rechnungsergebnisse der gewerblichen Berufsgenossenschaften '95, (Business and numerical results of industrial accident assurances, in German) HVBG Sankt Augustin

IARC (1987) IARC Monographs on the Evaluation of the carcinogenic risks of chemicals to humans: Silica and some Silicates, vol 42, IARC Lyon

Linch, KD, Groce DW, Cocalis JC, Parker JE (1994) Silica exposure surveillance in the construction industry. In: Proceedings of the Second International Symposium on Silica, Silicosis and Cancer, October 1993 San Francisco, Western Consortium for Public health

Moser HA (1992) Staubgefaehrdung bei Arbeiten im Hochbau (Risk of dust exposure when working at construction sites). Staub 52:163-167

Parkes, WR (1985) Occupational lung disorders. Butterworths, London

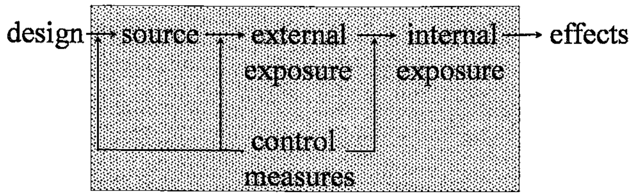
Reed LD, Lenhart SW, Stephenson RL, Allender JR (1987) Workplace evaluation of a disposable respirator in a dusty environment. Appl Ind Hyg 2:53-56

Riala, R (1988) Dust and quartz exposure of Finnish construction site cleaners. Ann Occup Hyg 32:215-220

Shoemaker DA, Pretty JR, Ramsey DM, McLaurin JL et al (1995) Particle activity and in vivo response to freshly milled and aged alpha-quartz. Scand J Work Environ Health 21 suppl 2:15-18

Susi P, Schneider S (1995) Database needs for a task-based exposure assessment model for construction. Appl Occup Environ Hyg 10:394-399

Tomb TF, Gero AJ, Kogut J (1995) Analysis of quartz exposure data obtained from underground and surface coal mining operations. Appl Occup Environ Hyg 10:1019-1027



Introduction to Chapter 6:
Control strategy for the construction trade

Described in this chapter is a strategy how to determine the most effective control measures in a specific branch of industry, the building industry. This industry has some characteristics which require a special approach of the situation.
As the figure at the top shows the strategy proposed in this chapter is not restricted to the workplace itself. The construction industry has a dynamic character, i.e. circumstances at building sites change constantly and the variety in processes applied is very large. Moreover, in contrast to other industrial settings where products are being made by one company, in the building industry usually a number of companies are assembling one final product. This type of organization complicates the exchange of information on control measures and their implementation.
Especially in this chapter a model approach would provide valuable indications on how to structure the search for control measures. In this case the "multiple source model" is applied to determine the possibilities for controlling exposure. With regard to the objectives of this thesis, it will be discussed to what extent the use of this "multiple source model", and possibly extension of the model approach with the "dynamic model", contributes to the development of a strategy to develop and implement control measures in the construction industry.

Chapter 6: Controlling exposure in the construction trade

Mieke E.G.L. Lumens

Summary

From an occupational hygienic point of view the construction industry can be characterized by its dynamic nature. With regard to chemical exposure, the variety in agents, tasks and working conditions is large and they are subject to constant change.
Working conditions in the construction industry are known to be severe. In a large number of situations control measures are needed to prevent adverse health effects. However, the dynamic nature of this industry hampers the implementation of controls.
A control strategy for chemical exposure at construction sites is described with both its opportunities and limitations. The need for further control measures for the construction industry is indicated and recommendations are given for the development and implementation of these control measures.

Introduction

From an occupational hygienic point of view, the construction industry is notably different from other industries in many respects. These differences come down to one major aspect: the dynamic character of the construction industry with regard to working conditions. Both within one construction site and between construction sites there is a constant variation in workplace conditions. In the process of building numerous tasks have to be performed in order to arrive from scratch at a completed building. Many different processes and equipment are applied to perform the different tasks. Moreover a wide range of chemical substances is used in the construction process. Exposure may occur to e.g. wood dust, quartz dust, different types of paints containing solvents and metals, man made mineral fibers and roofing substances. Next to the large range of agents being applied, the level of exposure can vary considerably. Workers can be exposed not only due to their own activities but also by their coworkers.
Within the construction trades a high level of specialization has developed in

recent years. Workers often perform one main task at the construction site. Even though the content of this task may be equal at all construction sites, e.g. being a painter, carpenter or a recess miller, exposure to chemical agents may vary considerably due to the following factors:

- Building materials applied change depending on the part of the building to be built, e.g. inner walls are made of other materials than outer walls.
- The equipment used may differ considerably from one site to another. For example the use of local exhaust equipment fixed on the apparatus may be obligatory at some workplaces.
- The layout of the workplaces in the building process is constantly subject to change.
- The number of other workers present is also subject to variation. Depending on the type of job, one or more colleagues performing the same tasks may be present. Next to these, workers performing completely different works may be doing their job at a nearby workplace, causing extra exposure to the same or another agent.
- Since a large part of all work is carried out in the open air, the ever changing weather conditions are an important source of variation in working conditions at construction sites.

In general, construction workers work in worse conditions than the general workforce . Their sick leave and work related disablement is higher than in most trades. Although in recent years a steady decline in sick leave and disability rates can be discerned, working conditions still cause a lot of problems. One of the causes of these problems is the exposure to a variety of chemical agents. Health complaints related to chemical exposure occur more than with workers in other industries (Broersen and Weel 1991).

Although the impact of this exposure is gradually being acknowledged, in the construction trade the implementation of control measures to decrease exposure to chemical agents is still limited (Linch 1994).

There may be various reasons why the application of controls has not yet reached a high level:

- High costs may be involved in the introduction and maintaining of control measures.
- Solutions will only be searched when a problem is being recognized. Some exposures are so much part of everyday 's practice, that hardly anyone considers them to be a problem. Exposure to dust for example is considered merely a nuisance. Dust at construction sites may consist for up to 40% of respirable quartz, implicating a serious health threat (Lumens and Spee, 1995).

- The exchange of information on control measures may be limited, because the importance and general applicability are not evident to the users. When asking working condition coordinators in 50 construction firms after their experience with control measures and solutions, most of them came forward with the implementation of personal protection equipment. Only after visiting some of their workplaces it became clear that other control measures such as wet processes were being applied. These were not recognized as effective control measures.
- The low availability of useful control technology. Linch et al (1994) found that adequate "off-the-shelf" control technology does not exist for many construction operations.
- Reed et al (1987) found that control measures at construction sites almost exclusively were directed at personal protection devices. Providing workers with personal protection equipment is supposed to be sufficient. Other control measures were not considered necessary by either employers or employees.

With regard to the development and implementation of control measures still other characteristics of the construction industry are relevant.
A hindrance in the implementation of controls is the lack of a constant working structure. Although at most larger sites a works foreman coordinates the tasks to be carried out, most workers work autonomously. Often workers are present at a specific site for only a short time, sometimes they even work at several sites during one day. It is logistically difficult to organize supervision for most jobs. One of the results of this way of working is the relatively limited contact between colleagues. This implies that there is little exchange of information on adverse healths effects and on ways to prevent these health effects by application of control measures. Education and instruction by occupational health services suffer from the same problem.
Although it does not exclusively apply to the construction trade, another typical feature of this industry is the fact that it consists of many small firms, which are subcontractors for other larger firms. Often the owner of the firms is the only or one of few employees. These small firms lack knowledge in the field of occupational health and safety. Moreover, because they are so many and they work scattered on a large number of sites the transfer of information by occupational health services is limited.
These characteristics will present an occupational hygienist with practical problems when trying to assess the exposure levels of construction workers, and subsequently in the stage where improvements for the working conditions are being proposed, implemented and evaluated.

Based on the information given in this introduction it can be stated that attention for the improvement of working conditions is necessary.
The objectives of this study are:
: to describe ways to assess exposure aimed at developing control measures in the construction industry
: to discuss a control strategy and its applications in the construction industry

Exposure assessment

Although construction workers suffer elevated disease and death rates, little exposure data have been documented in literature (Susi and Schneider 1995). More information on exposure levels is needed.
In the regular occupational hygiene practice measurements are often carried out to characterize average exposure levels, in order to compare these to occupational exposure limits. Although elevated exposure levels often are the direct cause for control measures to be developed the results of these measurements usually do not supply all relevant information. Certainly for construction work, where conditions are ever changing, full shift measurements will probably not supply sufficient information on the causes of elevated exposure levels. Since control measures directed at the source with the highest contribution to exposure are most effective, exposure assessment should be directed towards the characterization of the separate sources.
Although it is not developed especially for the construction trade the "multiple source model" provides a useful approach when seeking control measures. Buringh et al (1992) suggest this "multiple source model" to differentiate between the four factors contributing to total exposure. The factors they discern are: agent, process/equipment, working environment and work practices. This multiple sources approach clarifies the relations between these factors and enables one to take all workplace variation at the workplace in consideration. By careful observation of the determinants and statistical analysis the impact of these factors on the total exposure can be determined. This type of information facilitates the choice for certain control measures.
The same approach is followed by Susi and Schneider (1995). However instead of determining the impact of the four sources afterwards, they choose task-oriented measurements to gather information on the exposure. Subsequently information on these separate levels enables a prioritizing of sources and a further choice for the most effective control measures. According to them a careful description of the conditions in which a certain task is being performed

should consist of: process, make and brand of equipment used, material being worked at, workplace lay-out, presence of other workers performing tasks possibly contributing to total exposure, and weather conditions. Variation in exposure levels is supposed to be due to the impact of these factors.
Next to performing field studies at construction sites to acquire information on exposure levels and ways of controlling them, other routes could be used to assess exposure. Measurements performed under conditioned circumstances for instance could give valuable information on the impact of a specific factor or of an intervention. However, at construction sites measurements can not easily be repeated under equal conditions, as these conditions are constantly subject to change. Mock up workplaces can offer a solution and are available at some of the education centers for construction workers. Of course they differ from real life construction sites with respect to for instance weather conditions. Still these instruction workplaces provide with good opportunities for measuring the impact of e.g. building material, equipment used and work practices. Before introducing alternative materials and equipment or working regulations to the construction practice the efficacy of these control measures could be tested under those conditioned circumstances.
In practice, the estimation of exposure levels could also be based on already existing exposure data. Susi and Schneider (1995) propose the founding of a database with known exposures of processes in the construction industry, plus a careful description of the conditions at which these exposures were measured. They specify the information to be gathered in order to use this database for a task-based exposure assessment model (T-BEAM). Should this information become available on a large scale for a wide variety of construction tasks, then the occupational hygienist will have a valuable tool in estimating exposure. The proposed database on construction site exposure levels (Susi and Schneider 1995) would possibly make a valuable contribution to ranking exposures to chemical agents at construction sites. This database however still is in its planning stage. A drawback of this database is that a vast amount of professionally performed measurements is needed to fill this database in order to give a complete overview of exposure levels to be expected under specific conditions.

Control strategy and its applications

In the USA a control strategy is proposed in which it is stated that engineering controls are preferred above organizational controls, which in turn are to be preferred above controls depending on behaviourial changes (NIOSH 1988). The

same principles are applied in the European control strategy. In Council Directives 80/1107 and 89/391 these principles are elaborated (European Union 1992) In compliance with European legislation in the Netherlands in 1997 the Resolution on Working Conditions (Arbobesluit) has come into force. This Resolution indicates that a systematic approach has to be followed in which the types of measures must be considered in a hierarchic order. Basically, measures should be taken as close as possible to the source of emission. Only if a solution of the highest step can not be implemented, it is allowed to continue with solutions of the following step.
This occupational hygiene strategy, as it is called, ranks solutions in order of preference.
The four levels of measures are:

1. reduction of the source of emission
2. extraction of polluted air from the workplace atmosphere
3. separation of worker and source
4. application of personal protective equipment (Arbobesluit §4.1.11)

An interpretation of this strategy in the construction trade will be given, based on control measures and actions already taken in the industry. The applicability of these control measures and the needs for further developments will be discussed. Level 1 control measures aim at substituting the source of emission. Substitution of potentially dangerous building materials or replacing dangerous working processes by safer processes can be considered level 1 measures. For example switching to water based paints will take away most exposure to organic solvents of painters and other construction workers (Wolford 1996). The application of construction materials with a lower quartz content may decrease quartz exposure to an acceptable level (Arbouw 1995a). Pre-fab elements can be prepared under controlled conditions at the place of production. The use of these pre-fab elements prevents all sorts of treatments, e.g. grinding or milling of the material at the construction site.
Often the choices for these solutions however are not made at the work floor. These types of decisions are in most cases taken in a much earlier stage of the construction process and can hardly ever be turned back afterwards. Usually the architect makes the choices for the building materials to be applied, thereby largely restricting the possibilities for project managers and construction workers. Hinze et al (1993) researched the role of designers in construction workers' safety and concluded that even though in the development of a project a significant role is played initially by the designers of the project, construction workers'

safety is regarded as the sole responsibility of the construction contractor. They developed a rationale for supporting the thesis that designers should consider workers' safety in their design. Arbouw Foundation (1995b) in one of their leaflets directly addresses the architects by pointing out to them the possible risks of exposure to quartz and providing alternatives and solutions to be applied in future designs. Also European Union legislation requires incorporation of safety and health considerations into architectural and engineering designs. This necessitates the commitment of architects, project managers and manufacturers of building materials who are rather unfamiliar with the effect of their designs and plans on the working conditions at construction sites. In order to increase the number of source oriented solutions, more attention needs to be given to the education of architects in the field of workers' health and safety. This approach will only be successful when the financial implications of alternative buildng materials and processes are being considered and compensated.

Level 2 control measures are directed towards the extraction of polluted air. On construction sites general exhaustion of workplace air is hardly ever possible. Local exhaust ventilation (LEV) is the most logical way of extracting polluted air. The equipment available for this aim however is inadequate. More research is needed on controls aimed at extraction of polluted air at the workplace (Linch 1994). Too few machines used for building purposes can be equipped with LEV, even though this can lower exposure considerably. The simple translation of equipment used in industrial settings however will lead to frustration and not using the equipment because it usually is not adapted to the conditions at construction sites (Arbouw 1995a). Attention should be given to practical aspects, e.g. how to clean filters and dust gathering bags. Otherwise these activities may in turn become sources of exposure. The equipment should be sturdy, capable of performing in the severe conditions of a construction site. Next it should be transportable, and preferably portable. It should be easy in use, not taking too much extra time in applying it. Too much extra costs in learning time and time in use would seriously hinder a successful introduction (Ellenbecker 1996).

Competition is tough on the market for construction industry. In most cases the budget for material and equipment is fixed, which implies that the budget for workforce is the main aspect to economize on. Work needs to be carried out in a tight schedule. This leaves little opportunity for experimenting with (and in a later stage applying of) new working methods and other control measures (Wolford 1996). The "time is money" argument is a major reason for deciding not to use local exhaust ventilation. The use of this equipment would cost extra time and would therefore make a tender for a new construction project uncompetitive.

For level 3 workers have to be separated from the sources. In large demolishing works where techniques such as crushing, the use of explosives or a crane are applied the demolition experts are usually located in a cab, screened from the proceedings.
For most construction activities however organizational measures are needed to achieve this separation. A careful consideration of the order in which some activities are being performed can lead to new insights. Sometimes the simple reversal of tasks will decrease exposure. When several tasks have to be performed in one room, first performing the low exposure task and then the higher exposure task, will mean a decrease in exposure, because the time workers are exposed to the high exposure will be shorter. This can also be achieved by performing high exposure tasks at the end of the working day when most employees have left and dust or other pollution can be removed afterwards without bothering all employees.
The disadvantage of this organizational control measure is that it involves a lot of logistics, which may be hard to achieve at a construction site. Moreover it relies more heavily on the motivation of the workers. Increasing the knowledge of construction workers by education and instruction on occupational health and safety may be considered as a both organizational and behavioral control measure. Probably increased knowledge induces more awareness, intentions to change behaviour and at last safer work practices. For instance at one construction site a recess miller was encountered, who was conscious of quartz exposure and therefore insisted on using a type of equipment that could only be used with LEV (Arbouw 1995).
Even though it is the control measure of the lowest level 4, as in most other industries (Spee et al 1990, Swuste and Kromhout 1996) personal protection equipment is the control measure most often applied in construction industry (Reed 1987).
In order for personal protection equipment to be effective its use should comply with a code of practice. Only if the correct type of equipment is used, adequate protection can be achieved. Employees exposed to high levels of quartz were observed working with paper masks protecting only against coarse non-toxic dust (Arbouw 1995a). Not only the type of equipment should be correct, a complete code of practice needs to be followed: masks should be checked regularly on possible leaks, cleaning and substitution should take place at a regular base, as well as fit tests. Next to these conditions, repeated instruction and education on the correct use of this equipment is necessary as is supervision on the use of it. Only when these conditions are met, personal protection equipment will be an effective control measure. Especially at construction sites, with the characteris-

tics already mentioned, it will be hard to satisfy these requirements. Even more than in other branches of industry the use of personal protection equipment should be considered as a last resort, as a temporary solution (White et al 1988).

The implementation of control measures

Although the building industry has some characteristics that may hinder the application of control measures, opportunities exist to facilitate their implementation.

The high degree of specialization within construction workers offers opportunities to provide these specialized groups with specific and relevant information. In the Netherlands the roofers for instance form a well organized group: they organize their own training and distribute a specialized magazine. Even though the individual roofers may be difficult to approach because they work scattered around the country, as a group they are easily accessible. This type of channels can be applied to transmit information on occupational health and hygiene matters, especially about new solutions

A way to evade the argument that high costs are involved in the implementation of control measures and problems on the distribution and implementation of control measures is to have strict regulations on working methods. In the Netherlands, an example of successful implementation of such regulations can be found within the demolishers branch. In order to be authorized to demolish buildings possibly containing asbestos, demolition firms have to meet regulations on handling of toxic waste and safe working methods. In this branch of business, competition due to budgeting on safe working conditions has virtually disappeared. This approach may be employed for other hazardous operations.

Another example of stricter regulations that involves a large group of construction workers deals with construction work for the chemical industry. Only contractors that work according to the "VCA-certificate" (veiligheids checklist aannemers, safety checklist contractors) are permitted to work for chemical companies. In this way the care for safe working conditions and control of chemical exposure can be safeguarded (Arbouw 1997).

In order to facilitate the implementation of new control measures right from the start the people who have to apply the new controls should be involved in their development. In this way they can apply their own knowledge of the process, and controls will be developed in such a way that they can be integrated into actual work practices. In ergonomics (Vink et al 1992) this participatory approach in the design stage of control measures has proven to be most successful.

In order to promote the exchange of control measures already available and in order to facilitate the choice for effective control measures both Hinze et al (1992) and Swuste (1996) are working on databases with solutions for occupational (health) problems in the construction industry. The information available from these databases will provide the information which at the moment is so difficult to acquire.
The development of adequate strategies and new construction procedures in which both productivity and safe working methods are enhanced will of course satisfy all parties involved. The Netherlands Study Center for Technology Trends recently initiated such research and came forward with some successful projects in which both physical workload and total building costs decreased (Korbijn 1996). Implementation of these types of control measures, in which there is direct gain for all groups involved will probably be easiest.

Conclusions

Even though the application of control measures at construction sites is limited, a control strategy exists and to some extent control measures can be found at construction sites.
The results of the limited number of field studies and the current elevated morbidity rates are however an indication that exposures during some building activities are still too high.
In order to be applicable in a control strategy exposure assessment in the construction industry should be organized in such way that information on sources of exposure becomes available.
In the four leveled control strategy decisions with regard to level 1 measures are usually not within reach of the construction workers. In the longer term (5-10 years) improvements due to changes on this level may be expected. The protection offered by personal protection equipment (level 4) is observed to be hardly ever sufficient. Therefore construction workers for the time being are better off not counting too much on the protection provided by level 1 and level 4 in the control strategy. For the moment levels 2, local extraction, and 3, separation, can offer more protection within their reach. Further research is needed in these fields, e.g. on the application of local exhaust ventilation.
Successful implementation of measures to control exposure to chemical agents will only be possible when all groups involved in the construction industry, workers, managers, designers, and architects are committed to achieving a safe

and healthy working environment. Financial incentives are needed to overcome the extra costs involved with healthier and safer materials and processes. Covenants, like the recent covenant to improve the image of the construction trade, can give an impulse to cooperation in the field of occupational health and safety (Peperstraten 1992). Occupational hygienists can support the construction industry in achieving this goal by providing all of them with information on health hazards, exposure levels, alternative materials and processes and control measures.

Recommendations

- Construction workers need to be informed on the subject of occupational health and safety, with special attention to the characteristics of this branch of industry. Because of the high degree of specialization in construction jobs, specific information should become available for all distinct professional groups. This information should be provided to them firstly in their professional education and subsequently by their employers, occupational health services and branch organizations.
- More quantitative information on exposure levels should become widely available, both by extended measurement projects, and by the use of databases for task based exposure assessments.
- The implementation of already existing control measures should be promoted. Easy access should be available to databases with solutions for occupational (health) problems. Exchange of existing or newly developed controls between construction firms (and to the databases) must be stimulated by branch organizations. Demonstration of effective control measures at trade fairs, at meetings of the professional associations and of the trade unions may facilitate introduction at the workplace.
- Practical controls, e.g. local exhaust equipment for all types of building operations, need to be developed. These developments have to be stimulated by financial support and new regulations.
- Personal protection equipment should be provided only as long as no better solutions are available, instruction and documentation and supervision on correct use and maintenance need to come with it.
- Designers, architects and suppliers of building materials need to be informed on relevant subjects of occupational health and safety at construction sites, in order to get their commitment in designing for a safer work environment.

- Regulations for quality control should include prescriptions on safe work practices and working methods, as for example in the "safety checklist contractors" (VCA).
- In the development of new construction methods priority should be given to processes that enhance both productivity, healthy and safe working conditions and the general environment.

References

Arbouw (1995a) Grote stofbronnen in de bouw (Large dust sources in the construction industry) Arbouw Foundation, Amsterdam, the Netherlands (in Dutch)

Arbouw (1995b) Kwartsstof op de tekentafel (Quartz dust at the drawing table) Arbouw Foundation, Amsterdam, the Netherlands (in Dutch)

Buringh E, Noy D, Pouwels H, Swuste P (1992) A systematic implementation of control measures for airborne contaminations in workplace air. Staub 52:347-351

Ellenbecker MJ (1996) Engineering controls as an intervention to reduce worker exposure. Am J Ind Med 29:303-307

Hinze J, Wiegand F (1992) Role of designers in construction workers safety. J Construction Engineering and Management 118:677-684

Korbijn A (ed) (1996) Healthy production, innovation for improved working conditions. STT Netherlands Study Center for Technology Trends report STT 58, Den Haag, The Netherlands

Linch KD, Groce DW, Cocalis JC, Parker JE (1994) Silica exposure surveillance in the construction industry. In: Proceedings of the Second International Symposium on Silica,, Silicosis and Cancer, October 1993 San Francisco

Lumens MEGL, Spee T (1995) Silica exposure at construction trades. Proceedings Annual Conference of the British Occupational Hygienists Society, Blackpool, United Kingdom

Peperstraten J (1992) Brede arbo-afspraak in de bouw moet bezoedeld image oppoetsen (Covenant on working conditions in construction trade has to improve damaged image) Maandblad voor Arbeidsomstandigheden 68:605-606

Reed LD, Lenhart SW, Stephenson RL, Allender JR (1987) Workplace evaluation of a disposable respirator in a dusty environment. Appl Ind Hyg 2:53-56

Ringen K, Stafford EJ (1996) Intervention research in occupational safety and health: examples from construction. Am J Ind Med 29:314-320

Schneider S, Susi P (1993) An investigation of health hazards on a new construction site. CWPR Report OSH1-93. Center to Protect Workers Rights, Washington DC

Spee T, Swuste P, Burdorf A (1990) Control of occupational exposure to toxic substances. Staub-Reinhaltung der Luft 50:361-363

Susi P, Schneider S (1995) Database needs for a task-based exposure assessment model for construction. Appl Occup Environ Hyg 10:394-399

Swuste P (1996) Occupational hazards, risks and solutions. Technical University Delft, thesis

Swuste P, Kromhout H (1996) Improving working conditions in the rubber manufacturing industry in the Netherlands. Occupational Hygiene 3:341-349

Vink P, Lourijsen E, Wortel E, Dul J (1992) Experiences in participatory ergonomics: results of round table session during the 11th IEA congress, Paris, July 1991. Ergonomics 35:123-127

White MC, Baker EL, Larson MB, Wolford RD (1988) The role of personal beliefs and social influences as determinants of respirator use among construction painters. Scand J Work Environ Health 14:239-245

Wolford R (1996) Intervention research in construction: a hypothetical case study of painters. Am J Ind Med 29:431-434

Chapter 7: Discussion and conclusions

Introduction

The field of control measures is broad, it covers the whole range from detecting the need for control measures, the development of effective and efficient equipment and methods to control exposure, up to the eventual implementation of these measures.
The scope of this thesis is limited to two objectives:

- to determine whether a model approach is feasible in the selection of control measures, and
- to assess the impact of work practices on the exposure to and uptake of chemical agents.

The model approaches studied in this thesis were the "dynamic model of exposure, susceptibility and effect" and the "multiple source model".
In order to find out whether these models really contribute to the choice of control measures, a number of studies were used or reevaluated.
Originally these studies had their own specific objectives. They were performed in strongly different workplaces: in chrome plateries, in a secondary lead smelter, in a battery factory and at several construction sites, where exposure to quartz dust could occur.
Firstly the question will be answered if the applied models were usable to reach the specific objectives for the separate studies. Subsequently the general applicability of model approaches to arrive at optimal control strategies will be discussed.

Discussion per chapter

In the studies in plateries and the lead industries the main question was to what extent hygienic behaviour and working methods had an impact on the differences in the uptake of chromium and lead between workers. In the Van Dijk et al model (1987) it is explicitly posed that these factors can play a role in the path between source and external exposure, and between external exposure and eventual entry in the body. In the design of the studies this is taken into consideration by recording the impact of these factors on both routes during the observation of the working methods. The analyses of the results demonstrate that individual

differences in working methods and hygienic behaviour indeed are important modifiers.
As is demonstrated in Chapter 4, that summarizes the results of these four studies, the percentage of explained variation in dose (internal exposure) more than doubles when next to variation in external exposure individual work practices are taken into account. In the lead factories explained variance increases from 18 to 92% and 21 to 53% respectively. In the chrome plateries it changes from 46 to 92% and from 41 to 75%. These results suggest that the impact of work practices is higher in case of lead exposure than in chromium workplaces. This distinction is probably due to the differences in routes of uptake between the two chemical agents. Next to the respiratory uptake lead can enter the blood by primary and secondary ingestion to a relatively large extent. Chromium also has an extra route of uptake apart from inhalation; dermal absorption of chromium however plays a smaller role than the oral uptake of lead to the total dose. The impact of behaviour on dermal uptake mainly relates to appropriate skin protection, i.e. the correct use of protective clothing and gloves. Oral uptake can be decreased by preventing contamination of hands and face and further by preventing the finger shunt. The variation in work practices directly affecting oral uptake therefore is higher than in case of dermal absorption.
A possible objection to the approach followed in these lead and chromium studies could be that the study design was fully focused on the impact of hygienic behaviour and working methods in the complete exposure-effect chain. The impact of other modifiers on the relation between external exposure and dose, e.g. individual susceptibility to lead or chromium, is not taken into consideration, and can therefore not be quantified (Zielhuis and Henderson 1985).
The results of these lead and chromium studies show that workers are not passive beings, but can actively influence their exposure. This is an important conclusion with regard to control measure research. It indicates the inevitability to study the relation between the worker, i.e. the user and the control measure during and after the implementation of the control measure.

The original assignment for the investigation in the construction industry was to determine which activities in the building process possibly could lead to high quartz exposure, and further to indicate which control measures were already present at construction sites or could be taken to decrease these quartz exposure to an acceptable level. Furthermore an assessment of the efficacy of these control measures already present was needed.
Because of the ever changing conditions at construction sites, even more than in

other industries in the building industry it is of utmost importance to achieve a distinct description of the sources of exposure. In order to come to an accurate description of the sources of exposure the multiple source model is used in the research design of the quartz study. The supposition in this model is that the choice for control measures is facilitated when the separate sources of exposure are described clearly and quantified when possible.

The model is applied for three different job functions: recess millers, demolishers and inner wall constructors. In the analyses of the results for these construction activities variation in personal exposure is explained by variation in the four sources. The analysis results differ depending on the activity being studied. For the total population studied the four sources explained 68% of the variation in quartz concentration. The recess millers are a group with rather well defined tasks, using a limited number of building materials and equipment. For this subgroup explained variation amounted to 66%. For the inner wall constructors and demolition workers respectively 54% and 26% could be explained.

In general, the large variation in circumstances at construction sites complicates the correct description of sources. In this study in the analysis of the results a rather crude classification of building materials, applied equipment, working environment and work practices is used. The availability of more information on the characteristics of the modifying factors, e.g. exact quartz content of building material or efficiency of local exhaust ventilation filters, would further facilitate their classification and subsequently their introduction in the analysis model.

Although the description of the four sources can still be improved it can be stated that the use of the multiple source model has given this study a structure, which makes it possible to investigate the complex situation at the construction sites. Based on the research results it turned out to be possible to indicate a ranking in the sources that contribute to exposure. For the different job functions the sources are ranked in a different order. Based on this ranking for each job function measures can be chosen, directed towards controlling the most relevant source of exposure. For the recess millers in the quartz study for example the results of the analysis showed that the sources "agent" and "work environment" contributed most to the eventual exposure level. Construction workers usually are not allowed to substitute the building material applied. Influencing the source "agent" is not within their power of decision. They can however decrease the contribution of "work environment", e.g. by working neatly and keeping doors and windows open as much as possible.

General applicability of the models

The question posed in this thesis is which contribution the use of exposure models has in the occupational hygiene practice directed towards controlling health effects.

In order for a model to be valuable for practical applications it should give information on what aspects of the workplace situation give cause to the elevated exposure levels. Furthermore the model should propose points of actions where control measures should be applied.

The objective of both models described is to represent the exposure-effect situation in such way that indications where the control measures could be applied to be most effective can be given.

For the use of these models information is needed on the circumstances at the workplace.

The measurement strategy needed when using these models differs from the regular occupational hygiene strategy in which measurements often are performed in order to check compliance with occupational exposure limits. In these measurements focus usually is on characterization of exposure, and the measurements do not directly result in information that can be used in the choice for control measures. Information on sources or modifiers can be gathered in different ways, by statistical modelling of exposure data or by source oriented measurements (Kromhout 1994, Scheeper et al 1995, Kant 1994).

In the occupational hygiene strategy a source oriented control strategy is strongly favoured. In this respect the multiple source model, that is developed to describe the separate sources accurately, has advantages over the dynamic model. Application of this model will provide valuable information to be used in the selection of control measures. This has been shown already in Chapter 5, in the quartz study in the construction industry. Another application of the multiple source model can be given based on the data from the plateries.

The main objective of the chromium research was to assess the impact of hygienic behaviour in chrome plateries. Information on other factors modifying exposure however became available since even though the two factories in this study belong to the same holding, a clear distinction can be drawn between the general working conditions at the workplaces. In factory I hardly any provisions were made to lower exposure, whereas in factory II various precautions were taken. Use of this background information in the multiple source model provides with an overview of factors in the workplace contributing to exposure.

With respect to *agent* it was shown that the exposure in factory II partly consisted

of insoluble chromium, which did not contribute to the internal exposure of the workers.
Major differences could be found when comparing the *production processes* in the two factories. Whereas in factory I the few precautions aimed at ensuring lower exposure were merely provisional, in factory II the chromium baths were provided with good exhaust equipment, a foam layer covered the surface of the chromium baths, and well-fitting coverings were used to cover the chromium baths when the plating was in progress.
The general impression of the *working environment* also differed between factory I and II. In factory I the layout of the workplace was not efficient and floors were covered with spills of the baths, causing both a risk of slipping and an extra source of exposure. The working environment in factory II was much more tidy.
The impact of *work practices* for these plateries is already described in more detail in chapter 2.
All these factors to some extent explain the differences in exposure levels between the two factories. In this example this comparison is done in a qualitative descriptive way. A further quantitative analysis of these results would provide with a ranking of the four sources.
Both the quartz study and this example show that by considering exposure information in a structured way, as is proposed in the "multiple source model" more clarity can be gained on the possible control of exposure.

A comparison can be made between the applicability of the two models.
One difference between the dynamic model and the multiple source model is that the dynamic model describes the full chain from source to possible health effect, whereas the multiple source model focuses all attention to the external exposure. It has already been stated that with respect to the occupational hygiene strategy the multiple source model is to be preferred over the dynamic model because of its more accurate description of the sources of exposure. Another difference between the models is the way the circumstances at the workplace are being considered. In the multiple source model these are allocated to four distinct sources of exposure. In the dynamic model they are described as modifiers of the different transitions. Within the scope of this thesis special notice is given to the handling of "work practice". In the multiple source model work practices are considered to be one of the sources emitting to the work environment, i.e. external exposure. In the dynamic model work practices appear at two places in the scheme, both as modifier of the relation between source and external exposure and in the transition from external to internal exposure. The recognition that work practices may play

a role at different stages in the exposure-effect chain adds valuable information. Application of the multiple source model in the lead and chromium studies would only have acknowledged the impact of work practices to external exposure. Overlooking the possibility that work practices modify the relation between external and internal exposure may affect the effectiveness of control measures. This inadequacy is clearly illustrated by the results of the lead study. In this lead factory control measures were taken in the form of providing personal protection equipment. However the way the workers used this type of control had a large impact on their eventual uptake of lead. This impact only becomes clear when exposure is considered in a larger context than merely looking at the initial sources of external exposure, as is advocated in the multiple source model.

Employees performing the same tasks and being exposed to comparable contamination levels, as measured by personal monitoring are able to influence the eventual uptake as measured by biological monitoring by means of their individual hygienic behaviour.

The more extensive representation of the exposure situation, with stages following the external exposure, by the dynamic model therefore is more suitable when the impact of hygienic behaviour and working methods is being studied. Quantification of this impact however is limited to these agents for which a reliable biological monitoring method is available. Only in that case the relationship between external exposure and uptake in the body, dose, can be calculated. Since these biological monitoring methods are not available for a large number of substances, this is a serious restriction to the use of the dynamic model for this type of application.

The variation in hygienic behaviour can be higher when more routes of uptake are involved. Since biological monitoring methods mainly are developed for these agents for which other routes of uptake next to inhalation may play an important role, it can be stated that the dynamic model is apt for the most relevant substances.

The impact of respiratory protection can also be quantified by biological monitoring. Work practices related to the correct use of respiratory protection do not contribute to the external exposure of the worker and are therefore not visualized in the multiple source model. For quartz no biological monitoring method exists, in the study devoted to quartz exposure in the construction site the impact of work practices is only be quantified as far as it is related to external exposure.

In general designing a field study based on the multiple source model will provide with information on the four sources possibly contributing to external exposure. For most exposure situation based on the results, acquired in this structured way, it will be possible to choose the most efficacious type of control measures. In these cases where other routes of uptake, next to inhalation, may play an important role, or where the impact of hygienic behaviour is an important modifier the dynamic model supplies extra information.

Conclusions

Occupational hygiene research is directed towards the recognition, evaluation and control of, among others, chemical factors in the work environment. Until recently the focus of the activities of occupational hygienist was mainly on the recognition and evaluation of this exposure, nowadays a growing interest for the subject of control measures can be discerned.
In the design of workplace measurements the applicability of these measurements results for a control strategy should get more attention.
In this thesis the feasibility of a model approach is described with which to anticipate in occupational hygiene research on this search for control measures. Analysis of the results of several studies points out that application of the multiple source model supplies direct indications for the choice of control measures.

The results of the lead and chromium studies in this thesis clarify the impact of individual differences in behaviour and working methods on the eventual uptake of chemicals. Partly these differences modify the transition from external exposure to eventual uptake in the body, as is illustrated by the dynamic model. The findings of these studies clearly indicate that personal behaviour can influence the efficacy of control measures.

References

Buringh E, Noy D, Pouwels H, Swuste P (1992) A systematic implementation of control measures for airborne contaminants in workplace air. Staub. Reinhaltung der Luft 52:347-351

Dijk van FJH, Meijman TF, Ulenbelt P (1988) Towards a dynamic model of exposure, susceptibility and effect. In: Notten WRF, Herber RFM, Hunter W, Monster AC, Zielhuis RL (eds) Health surveillance of individual workers to chemical agents. Springer, Heidelberg, Berlin, New York

Kant IJ (1994) Evaluation and control of occupational health risks, an integrated strategy applied to chemical, physical and ergonomic stressors. University of Maastricht, the Netherlands, thesis

Kromhout H (1994) From eyeballing to statistical modelling: methods for assessment of occupational exposure. Wageningen Agricultural University, the Netherlands, thesis

Scheeper B, Kromhout H, Boleij JSM (1995) Wood-dust exposure during wood-working processes. Ann Occup Hyg 39:141-154

Zielhuis RL, Henderson PT (1986) Definitions of monitoring activities and their relevance for the practice of occupational health. Int Arch Occup Environ Hlth 57:249-257

Summary

Presently both professional developments in the field of occupational hygiene and legislative requirements are triggering the further research for control measures.
In this thesis attention is given to some aspects of control measures.
The main objectives of this thesis were:

1. to determine whether a model approach is feasible in the selection of control measures,
2. to assess the impact of work practices on the exposure to and uptake of chemical agents.

The model approaches studied in this thesis were the "dynamic model of exposure, susceptibility and effect" and the "multiple source model".
In order to analyse the research questions the results of occupational hygienic field studies are analysed (*chapter 1*).
These studies had their own specific objectives. They were performed in strongly different workplaces: in chrome plateries, in a secondary lead smelter, in a battery factory and at several construction sites, where exposure to quartz dust could occur.

Chapter 2 describes a research in two chrome plateries, where parts of ship engines were being plated. The conditions in these factories differed considerably: in factory 2 much more measures were taken to prevent the exposure to chromium than in factory 1.
In these companies the impact of hygienic behaviour on the uptake of chromium is studied. For this objective chromium in air (Cr-A) concentrations were determined by personal air sampling, and chromium in urine (Cr-U) levels were measured. Hygienic behaviour and working methods are characterized by structured observations of activities and by questionnaire.
In factory 1 variance in uptake (Cr-U) could be explained better when next to variation in chromium in air levels differences in hygienic behaviour were considered. In factory 2 the correlation between Cr-U and Cr-A was negative. Because of the measures already to decrease exposure to airborne chromium the contribution of dermal uptake of chromium could play a relatively large role in this factory.
The differences in general hygienic conditions between the two plateries

provided the possibility to apply the results of this research in the multiple source model in a later stage.

In *chapter 3* the results of a study in a secondary lead smelter are described. This research too was aimed at determining the impact of hygienic behaviour on the uptake of a chemical agent, lead. The study design was comparable to the chromium study. The external exposure to lead in air (Pb-A) was measured. In blood samples the lead level (Pb-B) was determined. In the workplace observations and in the questionnaire extra attention was being paid to behaviour related to the oral uptake of lead, because this has a relatively large contribution to the eventual uptake of lead into the body. To control exposure to lead all smelters were provided with personal respiratory protection by means of an airstream helmet.
For the smelters involved in this study an negative correlation existed between exposure to and uptake of lead. The deviation between Pb-B measured and Pb-B levels calculated based on lead in air levels became larger when the time the airstream helmets were worn correctly increased. Because of differences in function and hygienic behaviour this time period varied widely between workers.
One conclusion of this study is that differences in behaviour can interfere considerably with the effectiveness of control measures.

The results of four studies on the impact of work practices are compared in *chapter 4*. Lead and chromium exposures were chosen as subject of study, because reliable environmental and biological monitoring methods exist for these agents. Next to this these agents have different routes playing a role in the uptake in the body.
The impact of work practices is studied by comparing the explained variance in the biological monitoring measures either with or without including differences in work practices next to variation in workplace levels in the analysis.
In all four studies addition of the factor "hygienic behaviour and working methods" meant a significant increase of explained variance.

The research in *chapter 5* is concerned with quartz exposure in the construction industry. The objectives of this study were to determine which levels of quartz

exposure can occur at construction sites, to point out the sources of exposure and to assess the effectiveness of control measures already taken.
At 30 construction sites personal and stationary (quartz)dust measurements were carried out, and an inventory was made of workplace conditions: materials and equipment being used, layout of the workplace and work practices. Several activities, among others recess milling and demolishing, were shown to cause high quartz exposures. During the site visits it was observed that hardly any measures were taken to decrease this exposure: the employees and employers involved were hardly or not at all aware of the potential risks of quartz exposure.
The multiple source model is used to assess the contribution of the possible sources of exposure: agents, process/equipment, work environment and work practices. Depending on job title up to 66% of the variance in quartz dust concentrations could be explained by the contributions of these four sources of exposure. In the selection of control measures the relative contribution of these sources need to be taken into account.
The results of this study indicate that the application of the multiple source model provides points of actions for the choice of control measures.

Chapter 6 points attention to the specific situation in the construction industry with regard to control measures. As a workplace a construction site is more dynamic than most industrial workplaces. The construction process itself causes the constant change of the work environment. The range of materials and techniques applied is large and the composition of the worker population changes frequently. These factors must be considered when drawing a control strategy for the construction industry. The limited literature on measurement assessment and control measures in the construction trade is described. Based on these data a control strategy is proposed with its possibilities and limitations.
It is concluded that there is a need for further control measures adapted to the circumstances at construction sites, and recommendations for the development and implementation of these measures are given.

The general discussion and conclusions are given in *chapter 7*. It is concluded that a growing attention for control measures exists.
In the design of workplace measurements the applicability of these

measurements results for a control strategy should get more attention.
In this thesis the feasibility of a model approach is described with which to anticipate in occupational hygiene research on this search for control measures. Analysis of the results of the studies in this thesis points out that application of the multiple source model supplies direct indications for the choice of control measures.
The results of the lead and chromium studies in this thesis clarify the impact of individual differences in behaviour and working methods on the eventual uptake of chemicals. Moreover it is shown that personal behaviour can modify the effectiveness of control measures. In the design and implementation of these control measures their eventual user must be taken into account.

Samenvatting

Zowel professionele ontwikkelingen binnen de arbeidshygiëne als wijzigingen binnen de arbeidsomstandighedenwetgeving stimuleren het onderzoek op het gebied van beheersmaatregelen.
In dit proefschrift wordt aandacht besteed aan een aantal aspecten van deze beheersmaatregelen. De twee belangrijkste doelstellingen van het onderzoek waren:

1. onderzoeken of een modelmatige benadering bij arbeidshygiënisch onderzoek aanknopingspunten biedt voor de selectie van beheersmaatregelen,
2. vaststellen van de invloed van werkhandelingen (hygiënisch gedrag en manier van werken) op de blootstelling aan en opname van chemische stoffen

De modellen die in dit kader zijn toegepast, zijn het "dynamisch model van blootstelling, gevoeligheid en effect" en het "multiple source model".
Om de onderzoeksvragen te beantwoorden zijn de resultaten van een aantal arbeidshygiënische veldonderzoeken geanalyseerd (*hoofdstuk 1*).
Deze studies hadden hun eigen specifieke doelstellingen en vonden plaats in sterk van elkaar verschillende werkplekken: in verchromerijen, in een loodsmelterij, een accufabriek en op verschillende bouwplaatsen waar blootstelling aan kwarts kon optreden.

Hoofdstuk 2 beschrijft een onderzoek in twee verchromerijen, waar onderdelen van scheepsmotoren van een chroomlaag worden voorzien. De omstandigheden in de bedrijven verschilden sterk: in bedrijf 2 waren aanzienlijk meer maatregelen genomen om blootstelling aan chroom te voorkomen dan in bedrijf 1. In deze bedrijven is de invloed van hygiënisch gedrag op de opname van chroom onderzocht. Hiertoe zijn chroom in lucht (Cr-L) concentraties bepaald door persoonlijke luchtmonstername en zijn chroom in urine (Cr-U) niveaus gemeten. Hygiënisch gerdag en manier van werken zijn gekarakteriseerd door gestructureerde observaties van werkzaamheden en aan de hand van vragenlijsten. In bedrijf 1 bleek de variatie in opname (Cr-U) aanzienlijk beter te verklaren wanneer naast de variatie in luchtconcentratie (Cr-L) ook verschillen in hygienisch gedrag in overweging werden genomen. In bedrijf 2 was sprake van een negatieve relatie tussen Cr-L en Cr-U. Vanwege de reeds getroffen maatregelen om de chroomconcentratie op de werkplek terug te dringen kon de bijdrage van

dermale opname van chroom een relatief grote rol spelen.
De verschillen in algemene hygiënische omstandigheden tussen de twee verchromerijen maakten het mogelijk in een later stadium de resultaten van dit onderzoek te vertalen naar het "multiple source model".

In *hoofdstuk 3* worden de resultaten van onderzoek in een loodsmelterij beschreven. Ook dit onderzoek was gericht op het vaststellen van de invloed van hygiënisch gedrag op de opname van een chemische stof, in dit geval lood. De onderzoeksopzet was vergelijkbaar met die in de verchromerijen. De externe blootstelling aan lood in de lucht (Pb-L) is gemeten. In bloedmonsters is het loodgehalte (Pb-B) bepaald. Bij de werkplekobservaties en in de vragenlijst is extra aandacht besteed aan gedrag dat samenhangt met de orale opname van lood, omdat deze een relatief grote bijdrage levert aan de uiteindelijke opname van lood in het lichaam. Om de blootstelling aan lood te beperken hadden alle smelters de beschikking over persoonlijke adembescherming in de vorm van een air-streamhelm. Bij de 26 smelters, die aan het onderzoek meededen bleek een negatieve samenhang te bestaan tussen blootstelling aan en opname van lood. Het bleek dat de afwijking tussen gemeten en op basis van lood in lucht berekende lood in bloedconcentraties groter werd, naarmate de air-streamhelmen langer *correct* gedragen werden.
Vanwege verschillen in functie-inhoud en hygiënisch gedrag waren er grote verschillen in deze tijdsduur. Een belangrijke conclusie van dit hoofdstuk is dan ook dat verschillen in gedrag een bepalende rol kunnen spelen bij de effectiviteit van beheersmaatregelen.

De resultaten van vier studies over de invloed van werkhandelingen worden vergeleken in *hoofdstuk 4*. Lood- en chroomblootstelling zijn als onderwerp van studie gekozen, omdat voor deze stoffen betrouwbare omgevings- en biologische monitoringmethoden bestaan. Daarnaast spelen bij deze stoffen verschillende routes een rol bij de opname in het lichaam. De invloed van de werkhandelingen is bestudeerd door de hoeveelheid verklaarde variantie in de biologische monitoringmaat te vergelijken wanneer naast de variatie in werkplekconcentratie ook verschillen in uitvoering van het werk werden opgenomen. In alle vier de studies bleek toevoeging van de factor "hygiënisch gedrag en manier van werken" een aanzienlijke verhoging van de verklaarde variantie te betekenen.

Het onderzoek in *hoofdstuk 5* heeft betrekking op kwartsblootstelling in de bouwnijverheid. De doelstellingen van dit onderzoek waren vast te stellen welke niveaus van kwartsblootstelling op bouwplaatsen aangetroffen worden, aan te geven wat de belangrijkste bronnen van blootstelling zijn en een schatting te maken van de effectiviteit van reeds getroffen beheersmaatregelen. Op 30 bouwplaatsen zijn persoonlijke en stationaire (kwarts)stofmetingen verricht en zijn de werkomstandigheden: bewerkte bouwmaterialen, gebruikte apparatuur, inrichting van de werkplek en manier van werken in kaart gebracht. Bij verschillende werkzaamheden, onder andere bij het sleuven frezen en slopen, bleken hoge blootstellingen aan kwartsstof voor te kunnen komen. Tijdens de werkplekbezoeken bleken nauwelijks maatregelen getroffen te worden om deze bloostelling terug te dringen: de betrokken werknemers en werkgevers waren zich niet of nauwelijks bewust van de potentiele risico's van kwartsblootstelling.
Het "multiple source model" is gebruikt om de bijdrage van de verschillende bronnen van blootstelling: agentia, apparatuur/proces, werkomgeving en werkhandeling te schatten. Afhankelijk van het beroep kon tot 66% van de variantie in kwartsstofconcentratie verklaard worden uit de bijdrage van deze vier bronnen. Bij de selectie van beheersmaatregelen dient rekening te worden gehouden met de relatieve bijdrage van deze verschillende bronnen.
De resultaten van dit onderzoek geven aan dat door toepassing van het "multiple source model" goede aanknopingspunten geboden worden voor de keuze van beheersmaatregelen.

Hoofdstuk 6 besteedt aandacht aan de specifieke situatie in de bouwnijverheid met betrekking tot beheersmaatregelen. Als werkplek is een bouwplaats dynamischer dan de meeste industriële werkplekken. Door het bouwproces zelf is de inrichting van de werkomgeving voortdurend aan verandering onderhevig. Het scala aan gebruikte materialen en technieken is groot en de samenstelling van de werknemerspopulatie wijzigt in hoge frequentie. Met deze factoren dient rekening te worden gehouden bij het opstellen van een beheersstrategie voor blootstellingen in de bouwnijverheid. De slechts in beperkte mate aanwezige literatuur op het gebied van meetstrategieën en beheersmaatregelen in de bouw is besproken. Op grond hiervan wordt een voorstel gedaan voor een beheerstrategie met zijn mogelijkheden en beperkingen. In deze beheerstrategie is een centrale rol weggelegd voor het "multiple source model". Geconcludeerd wordt dat de noodzaak voor verdere beheersmaatregelen, aangepast aan de omstandigheden op bouwplaatsen bestaat, en aanbevelingen voor de ontwikkeling en implementatie van deze maatregelen worden gedaan.

De algemene discussie en conclusies van dit proefschrift staan in *hoofdstuk 7*. Geconcludeerd wordt dat er een groeiende belangstelling is voor het onderwerp beheersmaatregelen.
Bij de voorbereiding van werkplekonderzoek zou de toepasbaarheid van de meetresultaten in een beheersstrategie meer aandacht moeten krijgen. In dit proefschrift wordt een modelmatige aanpak beschreven, aan de hand waarvan in arbeidshygiënisch onderzoek geanticipeerd kan worden op de uiteindelijke toepassing voor beheersmaatregelen. Verschillende onderzoeken wijzen uit dat toepassing van deze model aanpak directe aanknopingspunten biedt voor de selectie van beheersmaatregelen.
De resultaten van de chroom- en loodstudies tonen de invloed van individuele verschillen in gedrag en werkwijze op de opname van chemische stoffen. Bovendien wordt duidelijk dat persoonlijk gedrag de effectiviteit van beheersmaatregelen beïnvloedt. Bij het ontwerp en de implementatie van beheersmaatregelen moet daarom rekening worden gehouden met de uiteindelijke gebruiker ervan.

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Curriculum Vitae

Mieke Lumens werd geboren op 18 april 1962 in Roermond. In 1980 behaalde ze haar VWO diploma aan de Scholengemeenschap Sint Ursula te Horn. Zij studeerde Milieuhygiëne aan de Landbouwuniversiteit te Wageningen van 1980 tot 1987, met als specialisatie Arbeidshygiëne. Ze deed doctoraalvakken bij de vakgroep Gezondheidsleer en de vakgroep Luchthygiëne- en verontreiniging. Daarnaast heeft ze stage gelopen bij het Instituut voor Zintuigfysiologie (IZF-TNO) te Soesterberg. Na het behalen van haar doctoraal examen kreeg ze een aanstelling als toegevoegd onderzoeker bij het Coronel Laboratorium van de Universiteit van Amsterdam. Van 1987 tot 1990 werkte ze op het Hygiënescore-project. Van 1990 tot 1993 was ze werkzaam op het project "Bevordering hygiënisch gedrag" bij het Studiecentrum Arbeid en Gezondheid, Universiteit van Amsterdam. In 1993 ging ze als toegevoegd onderzoeker werken bij de vakgroep Luchtkwaliteit van de Landbouwuniversiteit Wageningen op het project "Grote stofbronnen in de bouw". Vanaf 1994 is ze werkzaam als universitair docent Arbeidshygiëne, eerst bij de vakgroep Luchtkwaliteit, sinds april 1997 bij de leerstoelgroep Gezondheidsleer: Milieu, Arbeid en Gezondheid.