National Institute for Public Health
and the Environment
*Ministry of Health, Welfare and Sport*

# Occupational health or occupational safety: which impact is larger?

RIVM report 620480001/2011

P.A.M. Uijt de Haag | L.J. Bellamy | A. Burdorf |
W. ter Burg | P. Eysink | D.J.J. Heederik |
R.H. Klein Entink | H.J. Manuel | I.A. Papazoglou |
A. Pronk | L.A. Smit | E. Tielemans |
J. Timmerman

National Institute for Public Health
and the Environment
*Ministry of Health, Welfare and Sport*

# Occupational health or occupational safety: which impact is larger?

RIVM Report 620480001/2011

# Colophon

P.A.M. Uijt de Haag, RIVM
L.J. Bellamy, White Queen BV
A. Burdorf, Erasmus MC, Rotterdam
W. ter Burg, RIVM
P. Eysink, RIVM
D.J.J. Heederik, IRAS, Utrecht University
R.H. Klein Entink, TNO
H.J. Manuel, RIVM
I.A. Papazoglou, Demokritos, Greece
A. Pronk, TNO
L.A. Smit, IRAS, Utrecht University
E. Tielemans, TNO
J. Timmerman, IRAS, Utrecht University

Contact:
P.A.M. Uijt de Haag
RIVM/Centre for External Safety
paul.uijt.de.haag@rivm.nl

This investigation has been performed by order and for the account of the Ministry of Social Affairs and Employment, within the framework of OHIA

# Abstract

**Occupational health or occupational safety: which impact is larger?**

Employees can be exposed to different risks at the workplace, for example chronic exposure to harmful substances, physical stress and accidents. In 2010, the Occupational Health Impact Assessment (OHIA) model was developed to compare occupational health and occupational safety. The comparison is done by calculating their contributions to the burden of disease of employees.

**Model expanded with burden of disease due to hand eczema**
In 2011, the OHIA model is expanded by the calculation of the burden of disease due to hand eczema. Furthermore, a few discussion points were resolved and the user requirements were specified for converting the model into a valuable software-tool. It is recommended to investigate the demand for the OHIA software-tool in industry sectors.

**Risks calculated with uncertainties**
The model takes uncertainty into account to make comparisons more meaningful. To highlight the importance of uncertainty, the risks are calculated for four job titles with and without uncertainty. The job titles selected were tiler, road paver, carpenter and concrete driller, based on their high contribution to the total burden of disease in the construction sector. The occupational risks considered were the risks of accidents, lifting of heavy objects and exposure to silica. For tilers and road pavers, the exposure to silica has the highest contribution to the burden of disease if best estimates are used without uncertainty. However, taking uncertainty into account, the contributions of lifting heavy loads and accidents becomes comparable to the contribution of exposure to silica. For carpenters and concrete drillers, the uncertainties do not change the results significantly.

The OHIA model is developed by RIVM in collaboration with experts from the University of Utrecht (IRAS), TNO, Erasmus Medical Center of Rotterdam and two consultants.

Keywords:
occupational safety, occupational health, risk model

# Rapport in het kort

## Arbeidsveiligheid of arbeidsgezondheid: wat weegt zwaarder?

Werknemers kunnen op hun werk blootgesteld worden aan verschillende soorten risico's, zoals schadelijke stoffen, fysieke belasting en ongevallen. In 2010 is het 'Occupational Health Impact Assessment' (OHIA)-model ontwikkeld, dat de arbeidsveiligheid kan vergelijken met de arbeidsgezondheid. Dit is mogelijk door de te berekenen in welke mate de risico's bijdragen aan het verlies van gezondheid van werknemers (ziektelast).

**Model uitgebreid met ziektelast handeczeem**
In 2011 is het model uitgebreid met een berekening van de ziektelast van handeczeem. Daarnaast zijn enkele onduidelijkheden ingevuld en zijn specificaties opgesteld om van het model een instrument te maken dat door meerdere partijen kan worden gebruikt. Aanbevolen wordt te onderzoeken in hoeverre er draagvlak is bij de sectoren om het OHIA-instrument te gebruiken.

**Risico's berekend met onzekerheden**
Het model houdt bovendien rekening met onzekerheden in de data, waardoor nauwkeurigere vergelijkingen kunnen worden gemaakt. Om het belang hiervan te illustreren, zijn de risico's voor vier beroepsgroepen berekend met én zonder deze onzekerheden. Gekozen is voor beroepsgroepen waarvoor het grootste verlies van gezondheid te verwachten is: tegelzetter, straatmaker, betonboorder en timmerman. Hierbij is gekeken naar de risico's van ongevallen, het tillen van zware voorwerpen en de blootstelling aan silica, een stof die bijvoorbeeld vrijkomt bij het bewerken van beton. Voor tegelzetters en straatmakers draagt de blootstelling aan silica zonder onzekerheden veruit het meeste bij aan het verlies van gezondheid; als onzekerheden worden inbegrepen blijkt het gezondheidsverlies als gevolg van silica daarentegen vergelijkbaar te zijn met dat van het tillen van zware voorwerpen en arbeidsgerelateerde ongevallen. Voor betonboorders en timmermannen hebben de inbegrepen onzekerheden geen invloed op de resultaten.

Het OHIA-model is ontwikkeld door het RIVM, in samenwerking met een consortium van deskundigen van de Universiteit Utrecht (IRAS), TNO, Erasmus Medisch Centrum Rotterdam, en twee consultants.

Trefwoorden:
arbeidsveiligheid, arbeidsgezondheid, risicomodel

# Contents

# Summary

## Introduction

The Occupational Health Impact Assessment (OHIA) model evaluates the burden of disease due to various working conditions, namely chronic exposure to harmful substances, work-related accidents and physical stress. This allows an integrated approach to occupational safety and occupational health, leading to an optimal use of risk reducing interventions and a cost-effective reduction of the burden of disease. The OHIA model is developed for end-users at the policy-decision level, at the inspection level and at industry sector level.

A feasibility study in 2010 demonstrated that it is possible to develop an integrated OHIA model in which risks of different working conditions can be calculated and compared for specific jobs within a branch of industry, resulting in a valuable prospect to a complete model. However, a number of issues were identified that should be investigated before an actual model could be put into practice. These issues have been resolved in the current project.

## Uncertainty analysis

In the feasibility study, the burden of disease was calculated using point estimates for the input parameters. As a result, the burden of disease due to exposure to silica appeared considerably larger than the burden of disease due to accidents and lifting. The uncertainty in the input parameters is large. Before using the model results for intervention strategies, an estimation of the uncertainty in the model outcome is necessary. Furthermore, an analysis of the most important sources of uncertainty is useful to direct further work. Therefore, an uncertainty analysis was carried out for the exposures and diseases used in the feasibility study, namely silicosis and lung cancer due to exposure to silica, low back pain due to lifting of heavy loads and injury and mortality due to accidents.

The analysis shows that the uncertainty in the outcome is large. The ratio between the upper estimate and the lower estimate of the burden of disease can be as high as two orders of magnitude (the burden of disease of drillers due to accidents). Due to this large uncertainty, the upper bounds for accidents and lifting become comparable to the lower bounds for silica exposure for the job titles carpenter, paver and tiler. Only for the driller we may still conclude that the occupational burden of disease due to silica is larger than due to the other exposures, even when the uncertainty is taken into account.

For the combinations of exposure and disease studied, the analysis shows that the uncertainty in exposure dominates the overall uncertainty. Further work should therefore be focussed on a better characterisation of the exposure.

## Dermal exposure resulting in skin effects

The OHIA model was initially constructed for diseases for which the risk factors are known from literature. To determine whether Periodic Occupational Health Survey (in Dutch abbreviated as PAGO) data suffice to derive OHIA model results, dermal exposure was selected as an extension of the phase 1 OHIA model. Furthermore, skin disease appears to be an important health impact in the construction industry.

The analysis shows that it is possible to include skin diseases in the OHIA model based on surveillance data. The cumulative burden of disease is calculated for hand eczema in the construction industry using the information of PAGO surveys. The analysis showed that it is possible to calculate the burden of disease in disability-adjusted life years (DALYs) associated with hand eczema,

based on relative risk factors for exposure to dust, smoke, gases/vapours and chemicals in the construction industry. The analysis shows that dermal symptoms were reported by a considerable number of construction workers. Self-reported symptoms and exposure during work explain a large part of the high prevalence of these symptoms.
Skin problems do contribute considerably to the total disease burden of the population: a first estimate for the population at risk indicates that the burden of disease per person-year due to hand eczema (exposed population in the construction industry) is a factor three larger than the burden of disease per person-year due to low back pain (scaffolders), but one order of magnitude lower than the burden of disease per person-year due to silicosis (concrete drillers, road pavers and tilers).

**DAWY as an alternative measure for the burden of disease**
The feasibility study used the DALY as relative measure to compare the different exposures and diseases. The DALY is a measure for the burden of disease and quantifies the loss of health due to premature death and due to life with illness over the total life expectancy. The DALY is therefore a good measure for public health. Alternative measures are possible, focusing on the loss of productivity of employees. An exploratory study was done to determine whether the DAWY, disease-adjusted working years, can be used within the OHIA project as a relative measure for the loss of productivity due to the presence of disease during (part of) a working career.
It is demonstrated that the DAWY can be used as alternative measure for the occupational burden of disease. The analysis showed that the relative importance of exposure-disease combination depends on whether DALY or DAWY is used as endpoint. The goal of the study therefore should determine what measure is appropriate.

**Priority of exposure-disease combinations**
The OHIA model will not cover all exposures and diseases: the range of substances for which exposure may occur is too large, and a quantitative relation between exposure and burden of disease is often missing. However, it is possible to develop an OHIA model that covers the most significant agents per sector. Based on literature, an overview was compiled of the most important agents/diseases combinations for the construction sector in order to prioritize further development of the OHIA model. Based on three criteria, namely disability weight, size of the exposed population and the feasibility of possible interventions, we determined the most important combinations of exposure–effect for the OHIA model. The exposure-effect relations of interest appear to be silica and COPD, epoxy resins and skin disease or asthma, cement and skin disease, wood dust and COPD, RSI/CANS and noise.

**Mock-up and requirements of the OHIA tool**
A mock-up of the OHIA tool was constructed to show how the OHIA tool would look like in practice. Furthermore, the mock-up was useful to determine which information should be included in the OHIA model and which information is to be supplied by the user.

**Recommendation**
The results of the feasibility study and this study show that an OHIA model is useful to compare occupational health and safety on an equal footing and to draw meaningful conclusions. The structure of the OHIA tool is well founded. It is therefore recommended to (1) investigate the demand for the OHIA tool in

industry sectors and, if the demand exists, (2) construct the OHIA tool and fill the model with the data for the exposures studied up to now.

# 1 Introduction

The Ministry of Social Affairs and Employment developed a risk model for occupational safety. This risk model, the Occupational Risk Calculator (ORCA), makes it possible to calculate the risk of injury or mortality to employees due to a job-related accident (Aneziris et al., 2008). However, it is estimated that accidents only account for 5 to 10% of the total occupational burden of disease in the Netherlands, whereas chronic exposure accounts for the rest (Eysink et al., 2007). To have an integrated approach to reduce the risk from work-related health effects, it is useful to develop a risk model, in which both accidents and chronic exposure are combined. The OHIA model, an acronym for Occupational Health Impact Assessment (OHIA) model, meets this need.

The OHIA model evaluates the burden of disease due to various working conditions, namely chronic exposure to harmful substances, work-related accidents and physical stress. This allows an integrated approach to occupational safety and occupational health, leading to an optimal use of risk reducing interventions and a cost-effective reduction of the burden of disease. The OHIA model is developed for different end-users:

- At the policy-decision level, the OHIA model can be used to gain an understanding of the industry sectors and working conditions leading to the largest burden of disease and possible improvements. The model thus allows prioritizing the policy efforts and introducing better improvement programs.
- At the inspection level, the most effective measures can be identified, thus helping in prioritizing the inspections.
- At industry sector, the jobs with the highest burden of disease can be identified and the combination of measures that is most cost-effective.

The development of a complete OHIA model, addressing all industry sectors and all working conditions, is a very demanding task in terms of time and money. Therefore, in 2010 a feasibility study was carried out by an international group of experts from the University of Utrecht, TNO, Erasmus MC of Rotterdam, White Queen B.V., Y. Papazoglou and RIVM. In the feasibility study, a model was developed for the construction industry to calculate the occupational burden of disease due to different exposures, namely silicosis and lung cancer due to exposure to silica, low back pain due to lifting of heavy loads and injury and mortality due to accidents. The feasibility study demonstrated that it is possible to develop an integrated OHIA model in which risks of different working conditions can be calculated and compared for specific jobs within a branch of industry, resulting in a valuable prospect to a complete model.

The OHIA model calculates the burden of disease for a job by starting with a fixed cohort of healthy employees of age 20, and following them through their working years and pension years. It is assumed that the employees keep the same job until retirement at age 65. This is in agreement with the concept of occupational exposure limits: an employee should not suffer detrimental health effects of life-time exposure to the limit value. To compare the different working conditions, the effects are reduced to one single measure, namely the disability-adjusted life years (DALY). The DALY is a measure for the loss of health and combines lost life years due to early death with loss of quality of life due to illness (Murray and Lopez, 1997). It can be used as a relative measure to compare different jobs and different exposures.

The OHIA model is the first demonstration that in one model different jobs and different working conditions can be compared in the same way, based on existing data. The burden of disease of accidents and chronic exposure is calculated in the same way and compared. This allows determining on a sector level which working conditions have the largest contribution to the burden of disease and which jobs are most exposed.

Although the feasibility study successfully demonstrated that it was possible to combine accidents and chronic exposure to chemical agents and physical load into one model, to compare them and draw meaningful conclusions, the study also revealed a number of issues that should be investigated further before the model could be put into practice. Therefore a follow-up project was defined, with two important objectives.

The first objective of the project is to resolve a number of issues that emerged in the feasibility study.

- In the feasibility study, the burden of disease was calculated using point estimates for the input parameters. As a result, the burden of disease due to exposure to silica appeared considerably larger than the burden of disease due to accidents and lifting. However, the uncertainty in the input parameters is large. If uncertainty is taken into account, it may be that the burden of disease of accidents or lifting becomes comparable to the burden of disease of silica. If we want to draw meaningful conclusions on the relative importance of exposures and jobs, and use this information for intervention strategies, an estimation of the uncertainty in the burden of disease is necessary. Therefore, an uncertainty analysis was carried out. The results are described in chapter 2.
- The OHIA model was initially constructed for diseases for which the risk factors and exposure-response relationships are well-known from literature. To find out whether it is possible to use PAGO health surveillance data to derive OHIA model results, dermal exposure was selected as an extension of the phase 1 OHIA model. Furthermore, skin disease appears to be an important health impact in the construction industry (see section 4.1). The results are shown in chapter 3.
- An OHIA model will never cover all exposures and diseases: the range of substances for which exposure may occur is too large, and a quantitative relation between exposure and burden of disease is often missing. However, it is possible to develop an OHIA model that covers the most significant agents per sector. Based on literature, an overview was compiled of the most important agents/diseases combinations for the construction sector in order to prioritize further development of the OHIA model. The overview is presented in section 4.1.
- The feasibility study was carried out for four different jobs in the construction industry, namely carpenter, tiler, road paver and concrete driller. For the classification of the jobs, the Arbouw code was used. One Arbouw code covers a large variety of jobs and/or tasks and thus a large variety of exposure. For example, the job title ‘road paver’ includes working with a large range of different materials resulting in different types of exposure. Therefore, the Arbouw code job descriptions were studied in more detail. The results are described in section 4.2.
- The feasibility study used the DALY as relative measure to compare the different exposures and diseases. We compared the health effects over the entire life of an employee, including the period after retirement. Alternative measures are possible, focusing on the loss of productivity of employees. An

exploratory study was done to determine whether the DAWY, disease-adjusted working years, can be used within the OHIA project as a relative measure for the loss of productivity. The result is shown in section 4.4.

The second objective of the study focuses on the software implementation of an OHIA model, more specific the user interface. In the feasibility study, the calculations are done with spreadsheets. To have an OHIA model that can be used by others, a user-friendly application must be developed. For this application, the requirements and specifications need to be formulated, e.g. the input and output. A mock-up of the OHIA model was constructed, allowing an in-depth discussion on the requirements of the OHIA software. The mock-up and the requirements are described in chapter 5.

# 2 Uncertainty analysis

## 2.1 Introduction

The Occupational Health Impact Assessment (OHIA) model currently calculates the occupational burden of disease of silicosis and lung cancer due to exposure to silica, low back pain due to lifting of heavy loads and injury and mortality due to accidents. The DALY is used as measure of the burden of disease. The functioning of the model is demonstrated by applying the model to a few combinations of exposure and diseases and a few selected jobs in the construction industry (Uijt de Haag, 2010). The result is summarized in Table 1, where the occupational burden of disease is shown for the actual number of employees in different jobs. It is assumed that they start their job at age 20 and work until age 65.

*Table 1 Occupational burden of disease (DALY) for different job titles and agents/diseases. The number of employees is given in brackets*

| | **Road pavers (4300)** | **Tilers (3200)** | **Carpenters (80,000)** | **Concrete drillers/ sawyers (1900)** |
|---|---:|---:|---:|---:|
| Total | 35,000 | 13,000 | 28,000 | 21,000 |
| *Exposure to silica* | | | | |
| – Silicosis | 31,000 | 10,000 | 7800 | 19,000 |
| – Lung cancer | 4000 | 2000 | 3400 | 1600 |
| *Lifting* | | | | |
| – Low back Pain | 400 | n.a. | 6500 | n.a. |
| *Accidents* | 300 | 200 | 10,000 | 400 |

n.a. = not available

The results indicate that the total occupational burden of disease is highest for the group of road pavers. However, the occupational burden of disease per employee is highest for concrete drillers/sawyers. Furthermore, exposure to silica is by far the highest contribution to the occupational burden of disease for road pavers, tilers and concrete drillers/sawyers, whereas for carpenters all agents contribute equally.

Before we jump to conclusions and initiate action plans, it should be noted that the model gives only a point estimate of the occupational burden of disease for each combination of exposure and disease. The uncertainty in the outcome point estimates as a result of uncertainty in the input variables may differ considerably. To make important decisions on risk reduction strategies and intervention plans, knowledge of the uncertainty in the model outcomes is needed. In addition, the model contains various assumptions and approximations. For prioritising further research, we need a clear view of the various uncertainties in the models and their effect on the model results.

Therefore, we conducted an uncertainty analysis of the OHIA model. For each submodel, we determined the most important sources of uncertainty and their effect on the model results.

## 2.2 Silica exposure

### 2.2.1 *Model and simulation approach*

In this section the model for silica exposure in relation to lung cancer and silica exposure in relation to silicosis and its assumptions are briefly described. Note that this report builds on work by Uijt de Haag et al. (2010), in which a more elaborate description can be found. The unknown model parameters that have to be estimated are discussed, since uncertainty in their estimates is reflected in the uncertainty in the model outcomes. The uncertainty around the estimated parameters is reflected in a probability distribution that is the input for a Monte Carlo simulation.

**Life tables**

The life table begins in a given year, starting with a fixed cohort of a certain size and age distribution, which is affected at every subsequent year by the mortality rates for that age. The life table continues until the last person dies. The life table is used to calculate age specific disease and/or mortality rates. With increasing age, increasing cumulative exposure is assumed and with this exposure a risk is associated for developing a specific disease. The mortality rate is adjusted for additional mortality caused by the exposure. The following relationships specify the model:

- Exposure is assumed to be constant over years and the total yearly exposure is given by: Total exposure = E = occupational background exposure + occupational exposure.
- A reduction factor for the intervention is assumed to only affect the mean occupational exposure, and not the possible uncertainty around the mean.
- Cumulative exposure (CE) is the cumulative exposure or dose as a function of age, where the cumulative age-specific exposure at age t equals CE(t) = CE(t-1) + 0.5 × E(t-1) + 0.5 × E(t), where CE(20) = CE0 is the cumulative exposure at the starting age of the study. Note that CE is a sum and thus a linear function of E.
- The life table contains the number of background disease cases ND for each year (age). With the assumed dose-response relationship it is assumed that the model predicts the number of cases in the presence of exposure: Nmodel = ND × RR, where RR is the relative risk, which is a function of exposure. For instance, when the exposure is not related to the disease, the RR = 1, resulting in the same number of expected cases. When the exposure is positively related to the disease rate, the RR > 1, resulting in more predicted cases. Consequently, the RR has a lower bound of zero, in which case the disease rate is zero as well.
- Relative risk for lung cancer: An exposure-response relationship between relative risk (RR) and exposure is assumed. This function is given by RR= 1 + CE × B, where B is a model parameter. The function is bounded to a maximum for CE >= 5, in that case RR = 1 + 5 × B.
- Because the general population is not exposed to silica, the background disease rate for silicosis is zero. Therefore, an absolute risk for silicosis is used: the number of silicosis cases is assumed to follow a Poisson regression model that predicts the number of cases as a function of CE and $CE^2$. Using CE, a prediction can be made for the number of silicosis cases. More details are provided in the next section. As for the RR, the absolute risk is bounded when CE > 5 to a value of 0.023.
- After applying those equations, the life table is updated and from the new table it is possible to calculate survival probabilities and incidence rates in the usual way.

**Distributional assumptions**

Uncertainty around the value of a variable X is best reflected by specifying a probability distribution for X, denoted by P(X). A probability distribution reflects which values X can possibly take, and which values are more likely than others. The following model parameters are included in the uncertainty analysis. For these parameters a distribution instead of a point estimate was used as input for the model. The assumed distributions are described here.

*Exposure*

In the model exposure is incorporated as the yearly mean exposure level. A mean has an approximate normal distribution $N(\overline{x}, s^2/n)$, with $\overline{x}$ the sample mean, and $s^2/n$ the sample variance divided by the sample size n. In Appendix B, descriptive statistics of exposure measurements can be found for the different activities. Note that for this uncertainty analysis all available exposure data were combined (a TNO exposure database was used in which data from the literature is combined with other available data), whereas for the feasibility study (Uijt de Haag et al., 2010), the exposure estimate for each activity was taken from a single study. Therefore the descriptive statistics may deviate from the previous report. With that information it is possible to describe the uncertainty around the yearly mean exposure. For example, for concrete drilling the mean exposure is 0.24, and the SD = 0.44 with N = 45. This results in a normal distribution for the mean exposure for concrete drilling with a mean of 0.24 and a standard deviation of 0.44/sqrt(45) = 0.066. This results in the distribution for the mean silica exposure for drilling as represented in Figure 1.

Since the sum of normal random variables is again a normally distributed variable, the uncertainty in the yearly exposure for a specific occupation can be represented by the sum of the exposure distributions of the different activities of that occupation, weighted by the time spent on each activity.

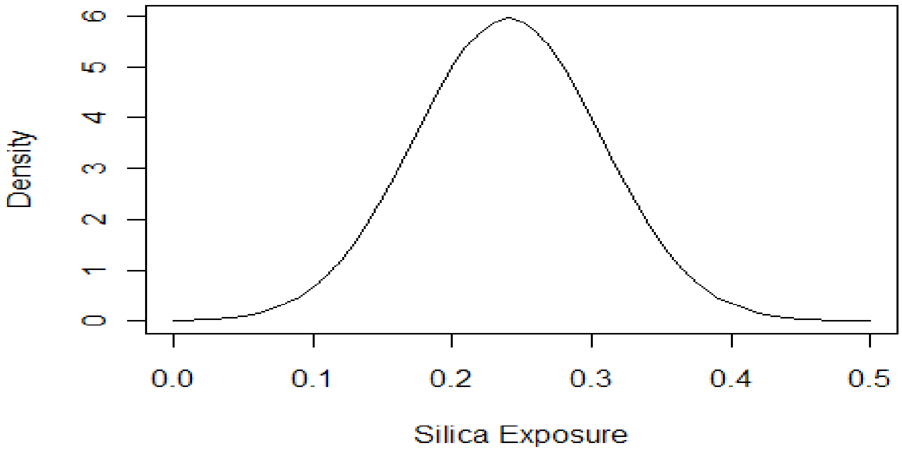


*Figure 1* *Distribution for the mean silica exposure for drilling (mg/m$^3$)*

*Relative risk for lung cancer*

For the exposure-response relationship between cumulative silica exposure and lung cancer risk (expressed as relative risk) the publication by Lacasse et al.

(2009) was used in Uijt de Haag et al. (2010). A meta-analysis including 9 dose-response studies of silica exposure and lung cancer roughly demonstrated a linear increase in lung cancer risk up to a RR of 1.8 for doses between 0 and 5 year.mg/m$^3$, which levelled off to a steady RR of 1.8 for doses above 5 year.mg/m$^3$ (Lakhal and Lacasse, 2009). The 95th percentage confidence interval around the RR is then best represented as the uncertainty around the parameter B in the equation for RR given in the previous subsection. From Lacasse et al. (2009) it follows that B is between 0.08 and 0.26, with an expected value of 0.16. To reflect this, a triangular distribution for B has been assumed, shown in Figure 2 below. It assigns the highest likelihood to values of B around the mean of 0.16, and declines linearly.

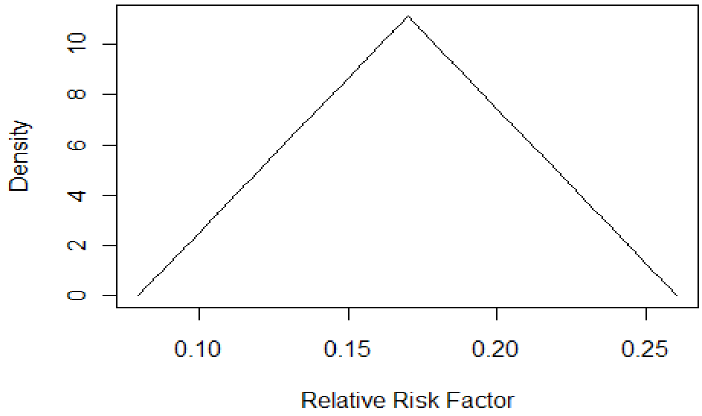


*Figure 2 Distribution of the relative risk factor for the lung cancer model*

*Absolute risk for silicosis*

For the absolute risk for silicosis, no meta-study results were available. Therefore, the uncertainty around this factor was estimated from data within one available study. Based on the data presented in the paper by Steenland and Brown (1995), a Bayesian Poisson regression model was fitted to the number of incident cases of silicosis as a function of CE and CE$^2$ (e.g., both a linear and a quadratic term were used in the regression model). The Bayesian approach has the advantage that the model coefficients have a posterior distribution, reflecting the uncertainty in the estimated regression coefficients. The coefficients are assumed to follow an approximate normal distribution with $B \sim N(\text{mean}, \text{sd}^2)$. The arm-package in the R-statistical environment was used for estimation, using the bayesglm() function. The posterior mean and posterior standard deviations are given in Table 2. The uncertainty in the absolute risk is now reflected by drawing a random sample from the posterior distribution of the regression coefficients, and then making a prediction for the number of silicosis incidents.

*Table 2* *Estimates of the posterior mean and posterior sd for the Poisson regression model of silicosis incidents as a function of cumulative exposure*

| Coefficient | Posterior mean | Posterior standard deviation |
|---|---|---|
| Intercept | -9.03 | 0.27 |
| CE | 2.16 | 0.24 |
| $CE^2$ | -0.22 | 0.051 |

*Intervention reduction factor*
The intervention measure considered was wet suppression of silica dust. For wet suppression, the exposure control efficacy library developed by TNO (Fransman et al., 2008) gives an expected reduction factor of 5 for dust, and a 95% confidence interval between 4 – 9. It can be seen that this distribution is strongly skewed to the right. To reflect this, the distribution shown in Figure 3 has been used. It assigns the highest likelihood to values between 4 – 6, and then declines to 10.

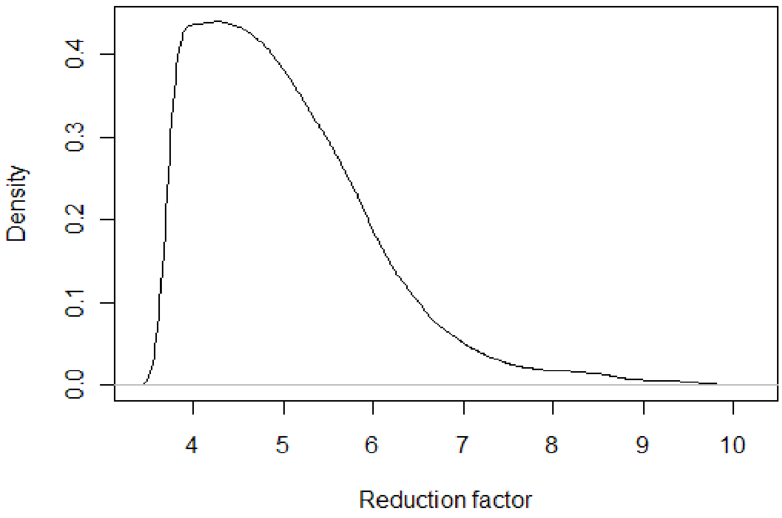


*Figure 3* *Distribution of the reduction factor for wet suppression*

**Monte Carlo approach**
To determine the uncertainty in the model output, we would need to consider all possible input values as given by the distributions of the model parameters. This amounts to integrating the model function over all the possible input values. However, due to product terms and multiple sources of uncertainty, an exact expression for this integral is hard to derive. Therefore, we rely on numerical algorithms known as Monte Carlo algorithms, which can approximate the integral with any desired accuracy. The method is straightforward but computationally intensive. The principle is simply to draw a random value from, for instance, the specified exposure distribution, and then calculate the model output given that draw for the exposure. When a large number of samples have been taken from the input distributions, one can aggregate the output results of the model. By taking random samples of sufficient size from the input distributions, the result is effectively the integration over that distribution. When the sample size goes to infinity, the integration approaches the exact solution of

the integral in the limit. The number of samples needed to approximate the distribution depends both on the specification of the model and its input distributions and the desired accuracy of the (numerical) result.

**Implementation**
The life table model has been implemented as a function in the free R-statistical environment (R Development Core Team, 2011).

### 2.2.2 *Results*

The results of the simulation studies are presented for lung cancer and silicosis with Disability Adjusted Life Years (DALY) as the outcome measure. First, the overall results are given, after which the separate effects of each model parameter are discussed. For all the simulations presented below, the model starts with a cohort of N = 10,000 workers at the age of 20 years. All results reported are based on 3,000 iterations. A sensitivity study to the number of iterations used showed that this number was sufficiently accurate for the results presented below.

**Lung cancer**
The simulation results for lung cancer are presented in Figure 4. The figure shows the median DALY, indicated by the dots, and a 90% confidence interval for each studied occupation. It represents the total uncertainty in the DALY estimates due to the variation in the relative risk, the intervention reduction factor and the exposure level.

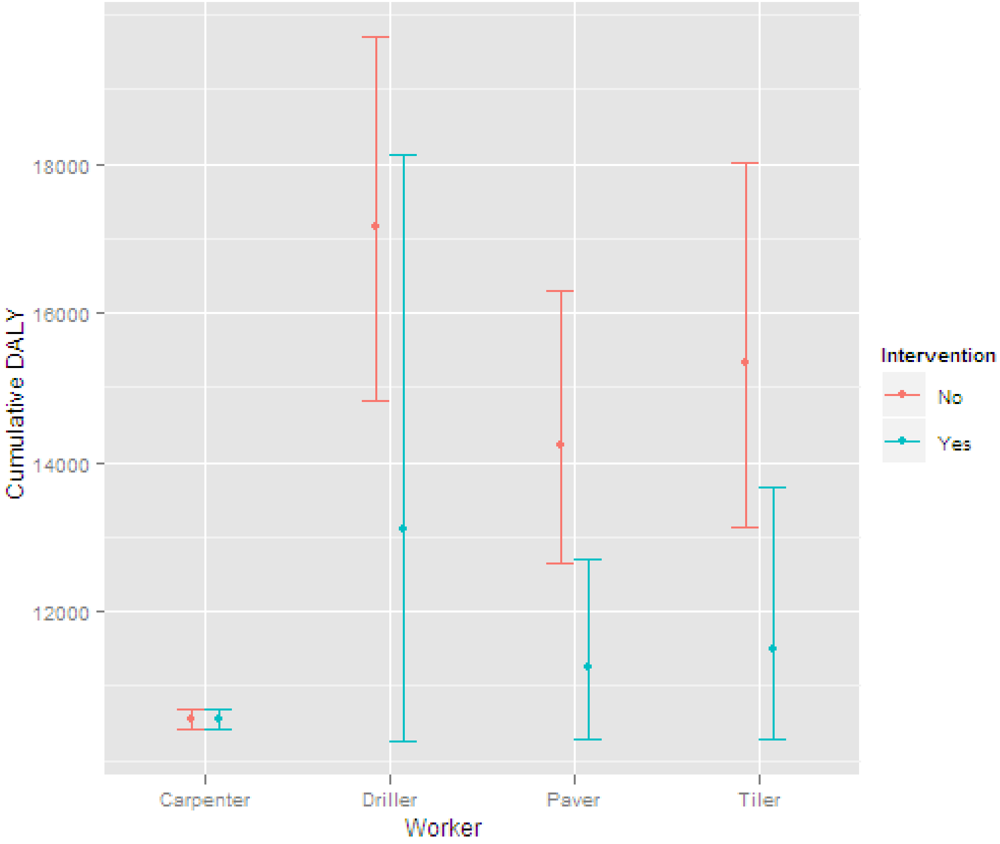


*Figure 4* *Cumulative DALY for lung cancer: median (dot) with 5th (lower) and 95th (upper) percentile*

From Figure 4 it is apparent that there is a reduction in the median DALYs as a result of the intervention. However, the uncertainty estimates show that for drillers the upper limit of the intervention situation still includes the median for the no-intervention situation. For the carpenter the variation is only due to variation in the estimated relative risk because the carpenter is only exposed to dust due to the prevailing background exposure to silica at the workplace (for which only a point estimate was used due to a lack of data). Note that the uncertainty for the DALY estimate for the driller is higher for the intervention scenario than for the scenario without intervention. This is due to a ceiling effect of the RR, which will be discussed in more detail now.

Besides the overall results some more detailed results will be presented for job title 'driller'. Figure 5 illustrates the development of the cumulative DALY as a result of lung cancer for drillers as a function of age of the cohort. The left figure shows the development of the cumulative DALY when only exposure is varied, the right figure shows the development when only relative risk is varied. A few things can be seen from Figure 5:

- The model shows that there are no lung cancer cases before the age of 40. This follows from the background lung cancer mortality data, which record lung cancer as a disease that occurs at a later age. Since the life table method is proportional (the relative risk), it does not allow for the development of lung cancer at earlier ages when the background rate is zero.
- The variation of exposure does not seem to have an effect for the no-intervention scenario. Varying relative-risk on the other hand has a substantial effect on the uncertainty in the DALYs. This can be attributed to the used function for relative risk that states that the rate is constant as soon as the cumulative exposure exceeds 5 mg/m$^3$. This threshold is reached after approximately 20 years, i.e. at the age of 40. In other words, the function for relative risk has a ceiling effect on the DALY for high exposure levels. Therefore, relative risk and exposure interact with each other.

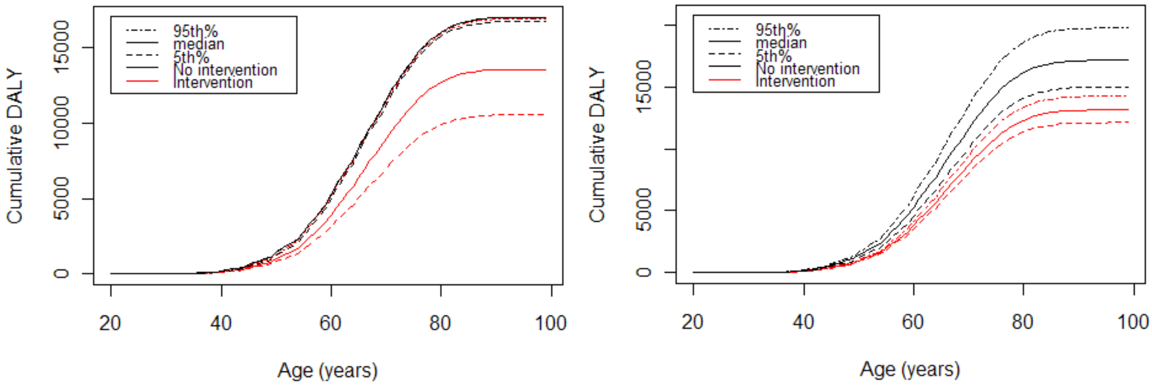


*Figure 5 The effect on Cumulative DALY as a function of age when varying exposure (left) or relative risk (right) for drillers*

A more detailed look at the effect of variability in all different parameters is presented in Figure 6. This table presents the results for drillers, since for drillers the highest amount of DALYs were found, as can be seen in Figure 4. To make the numbers comparable, the results in Figure 6 are for the situation with intervention.

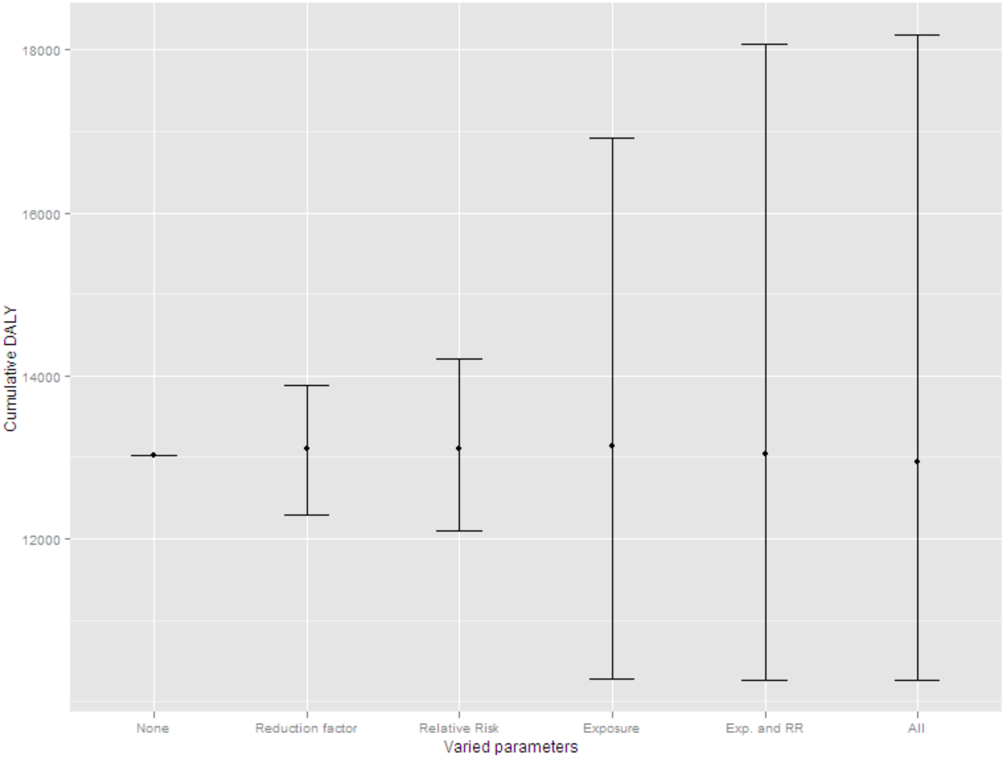


*Figure 6* *Median, 5th percentile and 95th percentile of the DALY estimate for drillers (with intervention) when different model parameters are varied*

It is apparent from Figure 6 that the biggest influence on the uncertainty in the DALY seems to be coming from the uncertainty in the exposure. However, it can be shown that an increase in sample size can easily reduce the uncertainty in the mean exposure. The distribution of the mean m of a normally distributed variable X is also normal, with $\mu \sim N(\bar{x}, s^2 / n)$, where $\bar{x}$ is the sample mean, and the variance is the sample variance divided by the number of observations n. It then follows that the uncertainty in the mean exposure is proportional to the sample size, and thus can easily be reduced by increasing the sample size. As an example, Table 3 shows the effect on uncertainty in the DALY when the sample size is increased with a factor 4, showing a substantial reduction in the 90% interval. Note that the 95th percentile does not change much due to the ceiling effect of RR (data not shown). Also note that the values do not seem to correspond with Figure 4. This is because other factors than exposure were held constant to isolate the effect of sample size for this demonstration.

*Table 3* *The effect of sample size on the uncertainty in the DALY due to uncertainty in the mean silica exposure*

| Condition | 5th percentile | 50th percentile | 95th percentile |
|---|---|---|---|
| Sample size N | 10618 | 15980 | 19285 |
| Sample size N×4 | 13525 | 16471 | 19238 |

## Silicosis

The simulation results for silicosis are presented in Figure 7. The figure shows the median DALY, indicated by the dots, and a 90% confidence interval for each studied occupation. It represents the total uncertainty in the DALY estimates due to the variation in the absolute risk, the reduction factor and the exposure level.

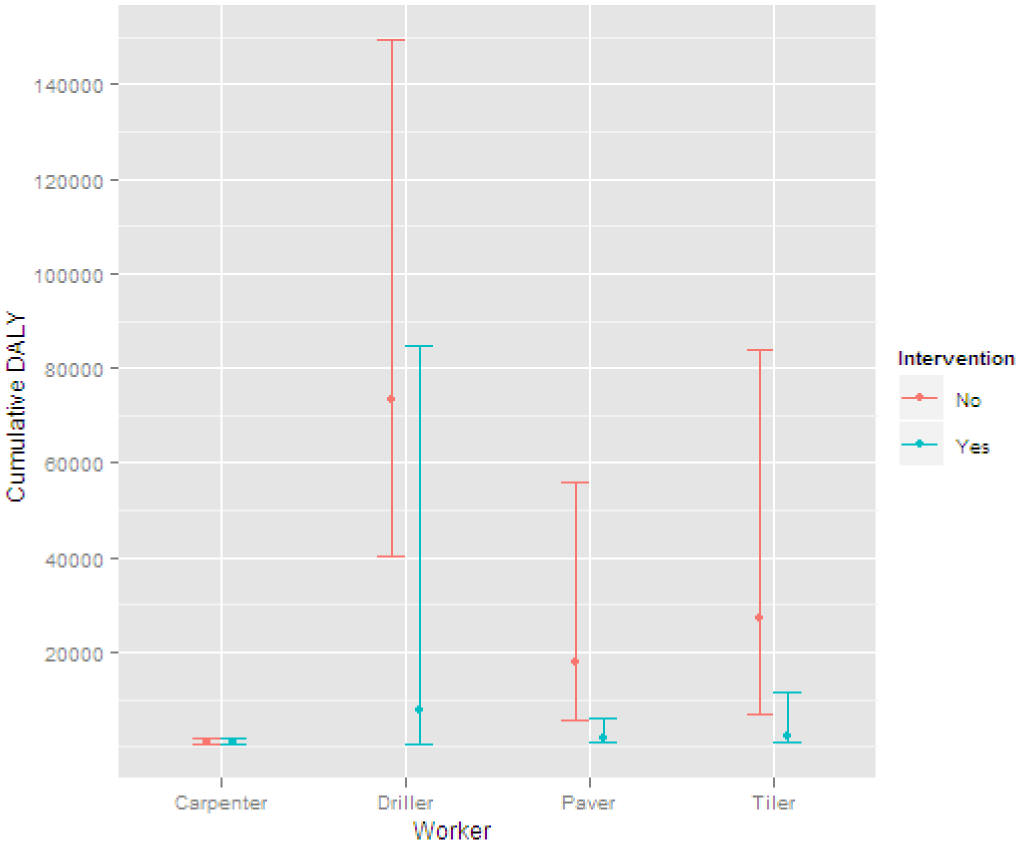


*Figure 7 Cumulative DALY for occupational silicosis: median (dot) with 5th (lower) and 95th (upper) percentile*

Figure 7 is very similar to Figure 4, and when studying the behaviour of the separate factors similar patterns were found as for lung cancer (data not shown).

In Figure 8, the effect of varying the coefficients in the Poisson regression model (Table 2) for the relationship between absolute risk and cumulative exposure on the cumulative DALY is shown. It can be seen that the model follows the general ‘smooth’ curve for the median, which corresponds to the expected values of the regression coefficients (i.e. the same as the coefficients assumed as fixed earlier). However, the behaviour in the tails is rather extreme. The sharp transitions occur at the point where the cumulative exposure is larger than 5, indicated with the vertical dotted line in the figure. It is the point after which the risk is assumed constant given exposure. The substantial variability can be attributed to the low number of data points that were available to estimate the absolute risk – cumulative exposure relationship, only 7, that resulted in substantial standard deviations for the regression coefficients. As a result, Figure 8 reflects that there is a lot of uncertainty about the coefficients’ values for the estimated function.

Another interesting difference with the use of absolute risk instead of relative risk is that the silicosis incidents do not depend on the expected incidents in the general population. It can be seen that there is already an increase in the cumulative DALY before the age of 40, whereas this would not be possible in the lung cancer model that depends on the base rate for lung cancer in the general population.

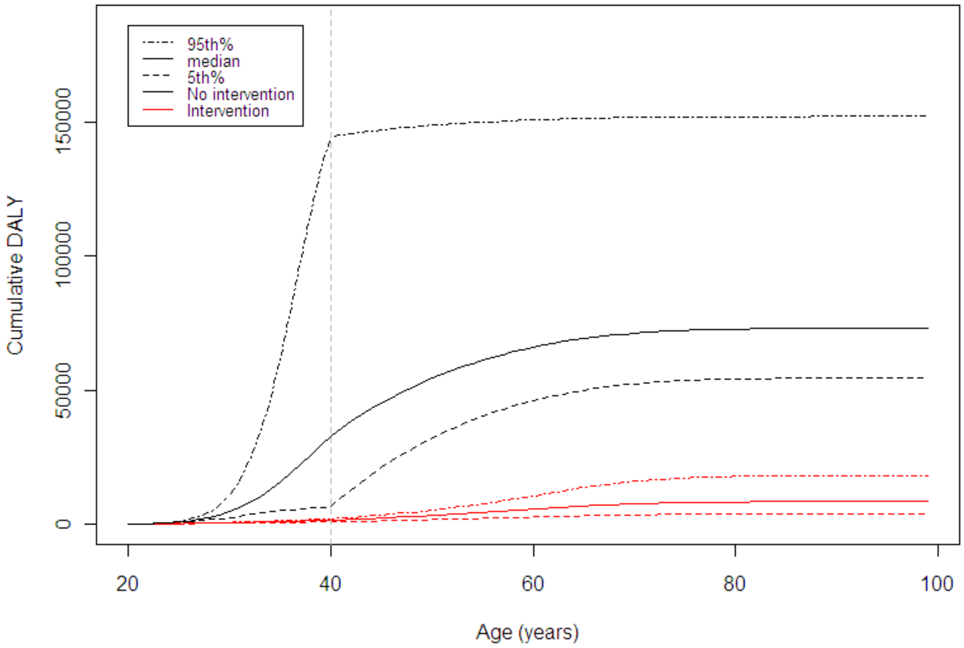


*Figure 8 Development of cumulative DALY for drillers when the absolute risk as a function of cumulative exposure is varied*

### 2.2.3 *Discussion*

**Available data**
The type and quality of data that was available for this uncertainty study differed per variable. Ideally, it reflects the uncertainty within as well as over different studies. For the relative risk for lung cancer a meta-analysis was available incorporating data from various epidemiological studies. However, for the absolute risk function for silicosis, only data of one study were available. In addition, the epidemiological studies based on which both risks were estimated were from studies among miners which may be exposed to a more potent type of silica than construction workers. The uncertainty arising from the potential difference in potency is not captured in the data that was used and the results from this study do not reflect this uncertainty. Incorporating this source of uncertainty is complicated by the lack of data for construction workers. Moreover, for some exposure factors (see Appendix B) the sample size was just six observations.

### Relative risk and absolute risk

A difference between the use of relative risk and absolute risk for estimating DALYs is that the first approach also depends on the incidence rate in the reference population. For example, if between the age of 20 – 40 there is just 1 case of lung cancer per year per 100,000, even a relative risk of 300% will raise this to just 3 per year per 100,000. On the contrary, an absolute risk function would allow a higher number of incidents since it does not depend on the reference population, but only on the exposure-response relationship and the exposure in the population.

### Impact on uncertainty in the DALY estimate

From the simulation results in Figure 6 it can be seen that the uncertainty in exposure has the biggest impact on the uncertainty in the DALY estimate for the intervention scenario for drillers. However, it cannot be concluded that uncertainty in the exposure is always the main factor. It was shown that there is an interaction between the level of exposure and relative risk. In the relative risk function it was assumed that for cumulative exposure larger than 5, the relative risk function is constant. Consequently, the level of exposure determines whether uncertainty in exposure has an effect on the uncertainty in the DALY. For example, as soon as the cumulative exposure (CE) is equal or greater than 5, the uncertainty in the CE has no effect, and the DALY is then determined by the Relative Risk (RR) function. The uncertainty in any of the input parameters can be reduced by increasing the sample size. However, an increased sample size is more easily obtained for an exposure study than for epidemiological studies. In addition, the absolute risk function for silicosis also has a substantial influence on the behaviour of the model, as was shown in Figure 8.

### Dynamic modelling

Currently, the model approach involved following a cohort over a specified time period. This approach is static, and not dynamic since natural inflow and outflow in the workforce were not accounted for. In addition the cohort in this life table analysis is assumed to be completely uniform in its age distribution (every individual has the same age at starting point) and assigned exposures (each individual gets the same annual exposure assigned if in the exposed population). These assumptions do not reflect the true situation of any real-life occupational cohort in which age, working life and exposure will vary between workers.

As a result, the estimates obtained from the life table analysis do not represent an estimate of the currently present burden of disease in a given population in the construction industry, since the approach chosen reflects a life course perspective. Thus, the estimates presented provide a good indication for the expected burden of disease among long-term employed workers, can be compared directly to each other in order to establish their relative importance and can be used to provide an indication of the intervention effect on disease burden that might be expected. Population characteristics and dynamics not taken into account might alter the true effect of an intervention especially when diseases with long latency, such as cancer, are involved. Here determinants like the true distribution of work time in a population or the average age of a working population plays an important role in the (change in) prevalence of disease.

A dynamic approach does take into account population dynamics and better reflects true prevalence and changes in prevalence. A drawback of the dynamic modelling approach is that model building is complex and requires quantitative information on a large number of (population) parameters. Therefore a trade-off should be made between the usefulness and representativeness of the results given the goal of the analysis (only indicative or as input, for example, for detailed cost-benefit analysis) and the available time and resources to perform the analysis.

## 2.3 Accidents

In Uijt de Haag et al. (2010) DALYs were calculated for occupational accidents that resulted in death or serious injuries. In the calculations a number of parameters were used, each introducing uncertainties into the result. The parameters, with a short explanation, are given in Table 4.

*Table 4 Parameters used in calculation with uncertainty effects*

| | |
|---|---|
| Limited sampling | Estimation of the annual probability of occupational accident is based on statistical sampling. Consequently there is always an uncertainty associated with the estimated parameters owing to the limited size of the sample. |
| Underreporting | One of the sample statistics is the number of observed accidents. Serious accidents are to be reported to the Labour Inspectorate. Some accidents, however, may not be reported resulting in uncertainty of the number of accidents. |
| Number of employees | The number of employees providing the statistical evidence is one of the parameters that determine the total exposure of the sampled population. The number of employees for each type of job analysed here is determined by PAGO studies and introduces uncertainty in the calculation method. |
| Individual annual exposure time | The annual probability of an accident depends on the number of hours an individual is exposed to the corresponding hazard. This time exhibits variability within a working population since not all workers work for the same number of hours per year. This variability is extended to the annual probability of an accident and hence to the DALY calculation. |
| Injury severity | Injuries in the DALY weighing factor list were not equal to the injuries from the accident analysis. A method was used to make them comparable, thus introducing uncertainty. |
| Minor injuries | Only serious accidents are reported to the Labour Inspectorate. The larger amount of daily occurring occupational accidents with minor effects are thus neglected and uncertainty is introduced. |
| Static vs dynamic population | Calculations assume a static population: no influx of new workers replacing injured or deceased workers and no workers leaving the cohort for other work. |

In the subsequent sections the possibility to quantify the amount of uncertainty related to the parameters is discussed.

### 2.3.1 *Parameter: Limited sampling*

In the database that is part of the ORCA model about 12,000 accidents are recorded from 1998 – 2004 (6.17 years) in the Netherlands. The database was queried for accidents that occurred with the four job types. This query is equivalent to a Poisson type of sampling where the duration of the observation is fixed in advance and the number of accidents to occur during this period is random. After the sampling process the sufficient statistics of the sample (Number of accidents, Total exposure) can be used to estimate the hazard rate and hence the annual probability for an accident. Even when these two quantities are precisely measured there is an uncertainty in the estimated quantities owing to the limited size of the sample. As shown in Appendix A this uncertainty can be quantified to give the annual probability for death, permanent injury and recoverably injury for an individual in each of the job types, exposed for the average yearly working time. The 5% and 95% values from Tables A3, A4 and A5 from Appendix A are used to recalculate the DALYs due to occupational deaths and injuries. No Monte Carlo simulation has been done but instead 2 recalculations with the 5% and 95% values. With this procedure the amount of calculation work is minimized and gives a first estimate to rank the parameters against one another. The results are given in Table 5.

*Table 5 DALYs associated with occupational deaths and injuries for the 4 jobs with uncertainty due to limited sampling (cohort of 10,000 workers, starting age 20).*

| **Job** | **From Uijt de Haag et al. (2010)** | **Recalculation with 5% and 95% values** | **Factor of difference** |
|---|---|---|---|
| Tiler | 722 | 263 – 3690 | 0.4 – 5.1 |
| Road paver | 710 | 258 – 3045 | 0.4 – 4.3 |
| Carpenter | 1244 | 1007 – 1578 | 0.8 – 1.3 |
| Concrete driller | 2027 | 1350 – 7086 | 0.7 – 3.5 |

As can be seen from Table 5 the difference between the previously calculated values from Uijt de Haag et al. (2010) is substantially lower for the carpenters than for the other jobs. This reflects the fact that the uncertainty in the annual probability of accidents (deaths and permanent injuries) is much larger for the other jobs than that in the corresponding probabilities for carpenters (see Tables A3, A4 and A5 of Appendix A). This in turn is due to the fact that the number of observed deaths and permanent injuries for the carpenters is relatively high leading to smaller statistical variations (see section 2.3 of Appendix A).

### 2.3.2 *Parameter: Underreporting (given limited sampling uncertainty)*

Serious accidents must be reported to the Labour Inspectorate. It is known that not all accidents are reported and thus the accident rate in practice will be higher than those calculated if the numbers of accidents in the GISAI data base are used. It has been estimated that there is an underreporting of serious accidents of around 54% by Giesbertz et al. (2007). It is assumed that this is applicable only to injuries as it is unlikely that deadly accidents will not be reported on. In Appendix A this uncertainty is quantified given the uncertainties due to limited sampling. The 5%-5% and 95%-95% values from Table A8 in Appendix A are used to recalculate the DALYs due to occupational deaths and injuries. For deaths the 5% and 95% values from Table A3 of Appendix A are used as we assume there is no further uncertainty due to underreporting. The results are given in Table 6.

*Table 6 DALYs associated with occupational deaths and injuries for the 4 jobs with uncertainty due to underreporting, given uncertainty due to limited sampling (cohort of 10,000 workers, starting age 20).*

| **Job** | **From Uijt de Haag et al. (2010)** | **Recalculation with 5%-5% and 95%-95% values** | **Factor of difference** |
|---|---|---|---|
| Tiler | 722 | 263 – 4209 | 0.4 – 5.8 |
| Road paver | 710 | 259 – 3419 | 0.4 – 4.8 |
| Carpenter | 1244 | 1051 – 2480 | 0.8 – 2.0 |
| Concrete driller | 2027 | 1353 – 10,326 | 0.7 – 5.1 |

From Table 6 it can be seen that the uncertainty in the underreporting increases the uncertainty further, given the uncertainty due to limited sampling. The uncertainty due to limited sampling is the largest factor in the overall uncertainty provided that underreporting is limited as assumed within 100% of the reported accidents.

### 2.3.3 *Parameter: Number of employees (given limited sampling uncertainty)*

The estimated hazard rate and hence the annual probability of an accident depends on the total exposure of the sample which in turn depends on the number of employees in the sample. This number of employees has been determined by PAGO studies and has several uncertainties:

- uncertainty in the determination of this number from PAGO studies by itself;
- the number from the PAGO studies is from a different year than the years in which the accidents reported in the database took place;
- the number may have fluctuated over the years.

In Appendix A the uncertainty owing to the number of employees is quantified given the uncertainties due to limited sampling. The 5%-5% and 95%-95% values from Table A10 in Appendix A are used to recalculate the DALYs due to occupational deaths and injuries. The results are given in Table 7.

*Table 7 DALYs associated with occupational deaths and injuries for the 4 jobs with uncertainty due to the number of employees, given uncertainty due to limited sampling (cohort of 10,000 workers, starting age 20)*

| **Job** | **From Uijt de Haag et al. (2010)** | **Recalculation with 5%-5% and 95%-95% values** | **Factor of difference** |
|---|---|---|---|
| Tiler | 722 | 205 – 5081 | 0.3 – 7.0 |
| Road paver | 710 | 193 – 4404 | 0.3 – 6.2 |
| Carpenter | 1244 | 630 – 2562 | 0.5 – 2.1 |
| Concrete driller | 2027 | 912 – 10,984 | 0.4 – 5.4 |

From Table 7 it can be seen that the uncertainty in the number of employees increases the uncertainty further, given the uncertainty due to limited sampling. The uncertainty due to nr of employees is slightly larger than for underreporting, mostly due to the assumption that there is no underreporting in the number of fatal accidents (because the fatal accidents are the largest contributing factor to the DALYs). The uncertainty due to limited sampling is the largest factor in the overall uncertainty.

### 2.3.4 *Parameter: Individual annual exposure time (given limited sampling uncertainty)*

To quantify the ORCA model, surveys were held asking a part of the working population for how much time they were exposed to hazards. This exposure can vary substantially between professions and particularly between individuals in the same profession. This uncertainty has an impact on the DALY calculation. In Appendix A the uncertainty owing to the individual annual exposure time is quantified given the uncertainties due to limited sampling. The probability density function (pdf) assumed is a best fit of the data collected in the surveys for the ORCA model (Aneziris et al. 2008). The 5%-5% and 95%-95% values from Table A12 in Appendix A are used to recalculate the DALYs due to occupational deaths and injuries. The results are given in Table 8.

*Table 8 DALYs associated with occupational deaths and injuries for the 4 jobs with uncertainty due to individual annual exposure time, given uncertainty due to limited sampling (cohort of 10,000 workers, starting age 20)*

| **Job** | **From Uijt de Haag et al. (2010)** | **Recalculation with 5%-5% and 95%-95% values** | **Factor of difference** |
|---|---|---|---|
| Tiler | 722 | 53 – 8004 | 0.07 – 11 |
| Road paver | 710 | 57 – 6250 | 0.08 – 8.8 |
| Carpenter | 1244 | 214 – 3286 | 0.2 – 2.6 |
| Concrete driller | 2027 | 37 – 8786 | 0.02 – 4.3 |

Table 8 shows that the uncertainty in the individual annual exposure time increases the uncertainty further, given the uncertainty due to limited sampling. The uncertainty due to individual annual exposure time is substantially larger than for underreporting and number of employees. The uncertainty due to individual annual exposure time also is bigger than the uncertainty due to limited sampling if we divide the 95%-95% over the 5%-5% values. The DALYs for occupational accidents were much lower than those attributed to the other factors as lung cancer, silicosis and low back pain (except for the carpenter). Therefore we feel that the 95%-95% values are more relevant as they might increase the number of DALYs into the region of the other factors. When we look at the 95%-95% values only the limited sampling is still the biggest factor that has the most influence on increasing the mean number of DALYs.

### 2.3.5 *Parameter: Injury severity*

To calculate DALYs for injuries the procedure described in Appendix C of Uijt de Haag et al. (2010) was used. This procedure necessitated the introduction of an extra ‘severity factor’ to correlate the injury types that are known from the observed accidents in the database to the types that have an actual DALY weighing factor. As discussed in the appendix this is an assumption that needs to be validated or replaced by a better method.

One possibility to do so is by not using the severity factor (or use a severity of 1), repeating the calculation and determining the influence on the DALY calculation. As an example, this would mean that burns of the 1st, 2nd and 3rd degree would get the same calculated weight, which represents a conservative (exaggerated) approach. This approach can be compared to weight factors that were collected in Haagsma et al. (2010). They collected data on the burden of disease in the Netherlands in 2007 on personal accidents, traffic accidents, occupational accidents and sporting accidents. To calculate the burden of disease, average DALY weights for recoverable injuries after first aid treatment and after hospitalization and for permanent injuries were used that were assembled or calculated from different sources. In Table 9 the DALY weights from Uijt de Haag et al. (2010) are compared to the recalculated OHIA weights without the severity factor and compared to the data of Haagsma et al. (2010).

*Table 9 Comparison of DALY weights from different sources.*

| | Uijt de Haag et al. 2010 | Recalc. without severity factor | Haagsma et al. 2010 |
|---|---|---|---|
| Avg DALY weight after first aid treatment (first year) | - | - | 0.018 |
| Avg DALY weight after hospitalization (first year) | 0.14[a,b] | 0.21[a] | 0.192 |
| Avg DALY weight for permanent injuries | 0.15 | 0.21 | 0.207 |

[a] *This is the average DALY weight of the 4 jobs for recoverable injuries from occupational accidents.*

[b] *A value of 0.10 was reported earlier, based on an avg time of absence of 0.7 year; corrected for 1 year this becomes 0.14.*

The recalculated DALY weights are comparable to the values determined by Haagsma et al. (2010). Thus we think that the recalculated weights are more reliable than the ones used in Uijt de Haag et al. (2010) and they were used for a recalculation of the DALYs associated with occupational deaths and injuries for the four jobs. The results are given in Table 10.

*Table 10 DALYs associated with occupational deaths and injuries for 4 jobs with recalculated DALY weights (cohort of 10,000 workers, starting age 20, in brackets: DALYs due to deaths and injuries are given respectively).*

| Job | Mean | With recalculated DALY weight | Factor of difference |
|---|---|---|---|
| Tiler | 722 (708 + 14) | 727 (708 + 19) | 1.0 |
| Road paver | 710 (529 + 181) | 775 (529 + 246) | 1.1 |
| Carpenter | 1244 (423 + 821) | 1568 (423 + 1145) | 1.3 |
| Concrete driller | 2027 (0 + 2027) | 2842 (0 + 2842) | 1.4 |

From Table 10 it can be seen that the recalculated DALY weight has almost no effect on the resulting DALY calculation for the tiler and has the biggest impact on the concrete driller. This reflects the fact that the ration of injuries is lowest in the tiler and highest for the concrete driller, where all DALYs were contributed by injuries. The highest factor of 1.4 found directly reflects the ratio between the recalculated DALY weight and the weight used in Uijt de Haag et al. (2010), which was also a factor of around 0.21/0.15 = 1.4.

### 2.3.6 *Parameter: Minor injuries*

DALYs were calculated, based on the accidents reported to the Labour Inspectorate. On a yearly basis about 2000 accidents are reported, that are severe enough to be inspected (in case of death or when the health damage leads to hospitalisation within 24 hours after the occurrence of the accident for reasons of observation or treatment, or when injuries are reasonably considered permanent). The total number of accidents that occur is much larger: around 200,000 occupational accidents occur yearly (Venema et al., 2010). By neglecting these accidents uncertainty in the DALY calculation is introduced.

Haagsma et al. (2010) looked at the burden of disease in the Netherlands in 2007 and compared the number of DALY for occupational accidents divided into deaths, permanent injuries, and recoverable injuries with and without first aid treatment or hospitalisation. The numbers obtained are given in Table 11.

*Table 11 DALYs for occupational accidents in the Netherlands 2007 (Haagsma et al., 2010)*

| | **DALY total** | **DALY breakdown** |
|---|---|---|
| **Death** | 2220 | |
| | | |
| **Permanent injury** | 4480 | |
| After first aid treatment | | 1880 |
| After hospitalisation | | 2600 |
| | | |
| **Recoverable injury** | 2120 | |
| After first aid treatment | | 1400 |
| After hospitalisation | | 720 |
| | | |
| **Minor injuries total** [a)] | 730 | |

[a)] *Data from general practitioners*

From Table 11, it can be concluded that 8% of the DALYs for occupational accidents is due to minor injuries. Therefore, the number of DALYs from minor injuries that is neglected in Uijt de Haag et al. (2010) is in the order of 8%. This means a factor of 1.08 in difference.

### 2.3.7 *Parameter: Static vs. dynamic population*

The DALY calculation in Uijt de Haag et al. (2010) uses a static population. This means that it is assumed that there are no movements of employees in or out of the cohort in the life tables. The number of workers in the cohort is decreased only with the fraction of people dying due to all causes (all possible natural causes, work-related diseases and accidents). For injuries the calculations do not take into account the fact that an injured person may be away from work and thus assume implicitly that an injured person could get another injury. In reality the population will be dynamic and the following deviations to the model will occur:

1. Fatalities will be replaced after some time by new workers.
2. Injured persons will likely be away from work for some period, and might not return to work at all depending on the injury. Those not returning will be replaced by new workers (though some permanently injured workers could get other jobs in the same sector where their injury is not problematic, but that would also mean a replacement by new personnel).
3. Even when no accidents occur workers will die due to all causes (which is accounted for in the static approach) or change jobs or move to other sectors.

Using a true dynamic model would require more time for reprogramming the model and could be part of a possible next phase, but it is possible to make some first order approximations to the deviations mentioned above:

On 1, 2 and 3: If fatalities, injured workers and workers that change jobs are replaced by new workers the total amount of workers would be higher than calculated in the static model and the total amount of fatalities would be higher. In fact the total number of workers in the cohort would stay at 10,000 if we assume that any worker would be replaced instantaneously in a dynamic model. The life tables in the static model sees a decrease in the number of workers due to all causes, ending with 8210 workers in the cohort at age 65. Summing the cohort over the 45 years between age 20 and retirement shows an average number of 9602 workers over the years. Repeating the calculation with 10,000 workers of a dynamic model would thus lead to a difference factor of 10,000/9602 = 1.04. We could also redo the calculation with tilers as an example: the risk of dying is 5.1e-5 $yr^{-1}$ (no distinction between ages over or under 50). In the static model this value results in 22.1 deaths for a cohort of 10,000 and in a dynamic cohort it would result in 5.1e-5 × 10,000 × 45 = 23.0 deaths, also a 1.04 factor of difference. This is a maximum value as a dynamic model would use some time for replacement, for acquiring new personnel and perhaps training.

On 2: If the number of people in the cohort is decreased with their time of absence, the calculated number of injuries and DALYs will be decreased, compared to the static approach. The average time of absence for injuries is 0.7 year (from the accidents recorded in the database for the 4 job types; the data give a factor of 0.77 year of absence for permanent injuries and 0.68 year for recoverable injuries; for approximation the average value of 0.7 year is used for both injury types). With this factor the calculation can be repeated. As an example: for concrete drillers 1122 workers were injured in the 45 years until retirement. This means about 25 workers per year were away from work for 0.7 years, thus decreasing the average cohort with 17.5 workers from 9602 to 9585, or a factor of difference 9585/9602 = 0.998. As this is less than 1 % difference this influence could be neglected considering the uncertainties in other parameters.

### 2.3.8 *Conclusions*

Table 12 summarizes the relative importance of the parameters.

*Table 12 Factor of difference found per parameter (per job or overall)*

| **Parameter** | **Job/Overall** | **Maximum factor of difference per parameter** |
|---|---|---|
| Limited sampling | Tiler | 0.4 – 5.1 |
| | Road paver | 0.4 – 4.3 |
| | Carpenter | 0.8 – 1.3 |
| | Concrete driller | 0.7 – 3.5 |
| Underreporting [a)] | Tiler | 1 – 1.1 |
| | Road paver | 1 – 1.1 |
| | Carpenter | 1 – 1.5 |
| | Concrete driller | 1 – 1.5 |
| Nr of employees [a)] | Tiler | 0.8 – 1.4 |
| | Road paver | 0.8 – 1.4 |
| | Carpenter | 0.6 – 1.6 |
| | Concrete driller | 0.6 – 1.5 |
| Individual annual exp. time [a)] | Tiler | 0.2 – 2.2 |
| | Road paver | 0.2 – 2.0 |
| | Carpenter | 0.3 – 2.0 |
| | Concrete driller | 0.03 – 1.2 |
| Injury severity | Tiler | 1.0 |
| | Road paver | 1.1 |
| | Carpenter | 1.3 |
| | Concrete driller | 1.4 |
| Minor injuries | Overall | 1.08 |
| Static vs dynamic population | Overall | 1.04 |

[a)] *For direct comparison the factors for underreporting, nr of employees and individual annual exposure time from tables were divided by the factors found for the limited sampling.*

From the table it can be seen that the biggest uncertainty arises from the individual annual exposure time. If we are only interested in the upper limit of the occupational burden of disease, limited sampling leads to the biggest possible increase in the number of DALYs, where the actual number of DALYs could be up to five times the mean value.

Thus we can conclude that the uncertainty in the limited sampling should be targeted first for a next phase when we want to improve on uncertainty. As described in Uijt de Haag et al. (2010) this could be done by determining the exposure of the jobs directly and derive the individual risks with the ORCA model. The exposure can be determined with surveys in the construction industry.

## 2.4 Lifting

### 2.4.1 *Core elements of the OHIA model*

The Occupational Health Impact Assessment for the influence of physical load on occurrence of low back pain (LBP) and associated burden of disease consists of six steps:

1. Description of the exposure profile in the occupation of interest.
2. Estimation of the expected occurrence of low back pain based on the exposure profile.
3. Assessment of the disability-adjusted life years due to low back pain.
4. Evaluation of the effect of the intervention on the exposure profile in the occupation of interest.
5. Estimation of the adjusted occurrence of low back pain based on the reduced exposure due to the intervention.
6. Assessment of the disability-adjusted life years due the adjusted occurrence of low back pain.

Each step contains a specific uncertainty, whereby particular choices and assumptions are made that will impact on the estimated burden of disease, expressed in DALY. The first step consists of an evaluation whether the three main risk factors are present in a given occupation. This information will not be readily available from existing sources and, thus, measurements or expert judgement is required. Thus, the quality of the exposure assessment in a given job may contribute to uncertainty, but the magnitude of misclassification of exposure is currently unknown.

The second step estimates the expected occurrence of LBP among workers in the occupation of interest. In this step several critical assumptions have to be made: (1) the incidence of LBP among workers unexposed to risk factors of physical load, (2) the recurrence and recovery from LBP, and (3) the magnitude of association between risk factors of physical load and occurrence of LBP. From these assumptions, the recurrence and recovery seem the least critical, since several studies in different occupational and community populations have shown comparable recurrence and recovery rates (Burdorf and Jansen, 2006; Elders and Burdorf, 2004; Hoogendoorn et al., 2002; Van den Hoogen et al., 1997) and there is no evidence available that these epidemiological measures are influenced by physical load.

The third step applies a Markov model to the defined cohort and attributes the burden of disease to the calculated occurrence of LBP over time. Two critical assumptions will influence uncertainty: (1) distribution of severity of LBP, given the occurrence of LBP in a particular year, and (2) the likelihood of entering the absorbing state in the Markov model. With regard to distribution of severity, the OHIA model has used duration of complaints in reference to current guidelines in the Netherlands to distinguish acute, subacute and chronic LBP. This distribution seems to be fairly stable across different occupational populations and not influenced by the presence of physical load.

The fourth step contains the estimated influence of particular interventions on the exposure profile of the occupational group of interest. As mentioned earlier (Uijt de Haag et al., 2010), there is a severe lack of documented interventions in the open literature and for very few occupations evidence is available that a particular ergonomic improvement will result in a quantified reduction in physical load. Thus, the quality of the expert judgement on reduction in exposure to physical load due to implementation of an ergonomic improvement is crucial, but no evidence exists to incorporate this source of uncertainty in the formal uncertainty analysis.

The fifth step in the OHIA model for LBP mirrors step two and as such contains the same sources of uncertainty. The model for LBP does not allow a gradual decline in exposure and associated reduced burden of disease, since the risk estimates are based on a dichotomous expression of the risk factor (present or absent). The intervention can only completely eliminate a risk factor. Due to absence of exposure-response information for different levels of exposure (e.g. weights of loads manually handled), the OHIA model necessarily reflects the largest contrast possible, i.e. those workers with the risk and those workers without this risk. When more information will become available on exposure-response relationships, the current OHIA model may be expanded to better reflect the reality at the workplace.

The sixth step again applies a Markov model to the defined cohort and attributes the burden of disease to the calculated occurrence of LBP over time. The same assumptions are used as in step three.

In summary, with respect to the uncertainty analysis, the most important parameters to be included in the uncertainty analysis are:
1. incidence and prevalence of LBP in the workforce unexposed to physical load;
2. the magnitude of the association between risk factors of physical load and occurrence of LBP;
3. the likelihood of entering the absorbing state in the Markov model.

### 2.4.2 *Assumptions about uncertainty*

Among unexposed workers the annual incidence of LBP is set at 13% and the annual prevalence at 30%. In a large cohort study with three years follow-up among 1192 workers in various companies in the Netherlands the observed incidence of low back pain was 12.6% per year (Hoogendoorn et al., 2002). This study provides a reasonable assumption for the annual incidence of 13% among unexposed populations. However, it may be argued that this incidence will be an upper limit since a certain proportion of workers in the cohort study will have been exposed to physical load. Thus, in the uncertainty analysis the upper value of incidence was set at 13%. Studies in primary care practices in the Netherlands have estimated an annual incidence of LBP of 6.75% (Gommer and Poos, 2010). This incidence will most likely be an estimate at the lower end, since not all workers with LBP will seek medical evidence from their general practitioner (IJzelenberg and Burdorf, 2005). The estimated 12-months prevalence of 30% in unexposed workers aged between 35 – 45 years is based on a meta-analysis of international studies (Lötters et al., 2003). In the general Dutch population (men and women in paid employment as well as outside the workforce) the 12-month prevalence of LBP was estimated around 27% (Picavet and Schouten, 2003). The aforementioned registration in primary care practices estimates an annual occurrence of LBP of approximately 10% (see Table 13).

*Table 13 Assumptions in the uncertainty analysis*

| Assumptions | Estimate | Source |
|---|---|---|
| 1. Incidence and prevalence of LBP | | |
| – Prevalence of 12 months LBP in unexposed population | 30% | Lötters et al. 2003 |
| | 27% | Picavet and Schouten. 2003 |
| | 10% | Gommer and Poos. 2010 |
| – Incidence of 12 months LBP in unexposed population | 13% | Hoogendoorn et al. 2002 |
| | 6.8% | Gommer and Poos. 2010 |
| 2. Magnitude of association between risk factors of physical load and occurrence of LBP | | |
| – Frequent lifting of 5 kg or lifting > 25 kg more than once a day | OR=1.31 | Lötters et al. 2003 (lower limit) |
| – Frequent bending/twisting trunk > 20° and > 2 hours per day | OR=1.41 | |
| – Magnitude > 0.5 m/s$^2$ during 8 hr workday | OR=1.24 | |
| – Frequent lifting of 5 kg or lifting > 25 kg more than once a day | OR=1.74 | Lötters et al. 2003 (upper limit) |
| – Frequent bending/twisting trunk > 20° and > 2 hours per day | OR=2.01 | |
| – Magnitude > 0.5 m/s$^2$ during 8 hr workday | OR=1.55 | |
| 3. Likelihood of entering the absorbing state in the Markov model | | |
| – Current OHIA model for LBP | 0.011 | Statistics Netherlands |
| – Upwards adjusted estimate becoming permanently disabled | 0.044 | |

The magnitude of the associations between risk factors of physical load and occurrence of LBP are based on a meta-analysis underlying the guideline for registration of work-related LBP (Lötters et al., 2003). This meta-analysis presents 95% confidence intervals around the pooled estimates. The lower and upper 95% confidence intervals were chosen for the uncertainty analysis.

The Markov-model requires an absorbing state, whereby it is assumed that subjects cannot recover. In this model we have chosen for disability, expressed by having a formal disability pension. The average probability of becoming disabled in the Netherlands in a given year was based on data from Statistics Netherlands. This average probability for 2009 was 0.000685 per person-year. We have assumed that workers with LBP will have a fourfold increased risk, given the importance of LBP as cause for becoming permanently disabled. Since in the Markov model the absorbing state is linked to chronic LBP and chronic LBP is roughly 25% of all LBP, the transitional probability for a worker with chronic LBP to become disabled was estimated to be 0.000685×4×4 = 0.010959. Information on new disability cases per branch of industry is lacking, but a four-fold difference between branches with low vs high risk is easily expected. Thus, in the uncertainty analysis the transitional probability for a worker with chronic LBP to become disabled was set at 0.044.

### 2.4.3 *Influence of uncertainty on burden of disease*

The three identified crucial assumptions in the OHIA model for LBP will be evaluated for their respective influence on estimated DALYs. The baseline comparisons are the calculations of DALYs in four different occupational groups, as presented in the full report on the OHIA model (Uijt de Haag et al., 2010).

The first assumption was the change in incidence (from 13% to 6.8%) and prevalence (from 30% to 10%) in LBP. The decrease in DALYs was between 35% – 38%, which may be considered as a modest change relative to the drastic change in assumptions on incidence and prevalence. The calculations showed that for the occupation with highest exposure (i.e. scaffolder or road layer) the estimated annual incidence was 11.4 instead of 20.8 (a reduction of 45%), which largely drove the estimated DALYs downwards (see Table 14).

*Table 14 Influence of uncertainty on estimated DALYs for four occupational groups*

| **Occupation** | **DALY per 100 person-years*** | **Lower incidence and prevalence of LBP** | **Lower and upper limit of associations** | **Higher estimate becoming disabled** |
|---|---|---|---|---|
| Carpenter | 2.43 | 1.56 | 2.25 – 2.61 | 7.75 |
| Road layer | 2.56 | 1.67 | 2.39 – 2.75 | 8.17 |
| Scaffolder | 2.56 | 1.67 | 2.39 – 2.75 | 8.17 |
| Unexposed worker | 1.69 | 1.04 | 1.69 – 1.69 | 5.38 |

* Persons who started in their job at age 20, including those workers who remained in their jobs as well as those who became permanently disabled.

The second assumption on magnitude of associations changed the odds ratios between 5% and 35%, resulting in relative changes in estimated DALYs of approximately 7%. For road layers the calculations with the lowest and highest risk estimates resulted in an annual incidence of LBP of 18.7% and 23.3%, respectively.

The third assumption changed the transitional probability for a worker with chronic LBP to become disabled from 0.011 to 0.044, a four-fold difference. Since information on new disability rates per branch of industry is lacking, it remains to be seen whether this uncertainty is extreme or not. Anyhow, the uncertainty analysis clearly demonstrates the crucial impact of this particular parameter on the estimated burden of disease. This large influence may be explained by the fact that permanent disability contributes largest to the overall burden of disease, since a worker with disability cannot recover and, thus, will contribute to DALYs from onset of disability to the end of the 40[1] year hypothetical working career.

The level of uncertainty introduced in the uncertainty analysis must be discussed in the light of its possibility to reflect the reality of the workforce. Based on evidence from literature, the assumptions made on low incidence and prevalence in unexposed workers seem fairly strong. It is anticipated that the most valid

---

[1] In the DALY calculation of LBP, it is assumed that workers retire at age 60, whereas for the other exposures retirement is expected at age 65. This difference is small and does not affect the conclusions.

estimations will use values for annual incidence and prevalence that are much closer to the default settings in the OHIA model for LBP. Thus, it may be expected that the uncertainty in the estimated DALYs will be modest with respect to the assumptions on occurrence of LBP in the workforce.

The magnitude of the risk factors plays a certain role in the burden of disease. The introduced range for evaluation in the uncertainty analysis showed that this range has a moderate impact on the estimated incidence of LBP in the highest exposed occupation. With growing evidence in epidemiological studies the meta-analysis from 2003 should be updated in order to incorporate evidence published in the past 10 years. However, it is expected that such an update will indeed change the value of the pooled odds ratio, but that this change will have a modest impact on the estimated burden of disease. The uncertainty analysis clearly demonstrated the crucial impact of the transitional probability from chronic LBP to disability. Unfortunately, this particular parameter was estimated with the lowest precision, due to lack of publicly available information.

## 2.5 Discussion

The uncertainty analysis was carried out for the exposure to silica (lung cancer and silicosis), accidents (mortality and injury) and lifting (low back pain). In a first step, expert judgement was used to determine the parameters that are the most important for the uncertainty in the DALY calculation. The parameters are summarized in Table 15.

*Table 15 Parameters considered in the uncertainty analysis. Parameters in italic are considered qualitatively.*

| | **silica** | **accidents** | **lifting** |
|---|---|---|---|
| Exposure | – Mean silica exposure<br>– *effect of sample size*<br>– Reduction factor of intervention | – individual exposure time<br>– limited sampling<br>– number of employees | |
| Reporting | | – underreporting of injuries<br>– no reporting of minor accidents | |
| Dose-exposure response | – relative risk factor lung cancer<br>– absolute risk factor silicosis | | – incidence and prevalence of LBP in unexposed population<br>– association between risk factors of physical load and occurrence of LBP<br>– likelihood entering state of permanent disability |
| DALY | | – injury severity | |
| Population | – *dynamic population* | – *dynamic population* | |

The analysis shows that the uncertainty in exposure dominates the overall uncertainty for silica and accidents. For silica, this is only the case when exposure is below the ceiling exposure, i.e. in the case of an intervention. If the exposure is larger than the ceiling exposure, an increase in exposure does not lead to an increase in effects and consequently, the uncertainty in exposure is less relevant. For lifting, the uncertainty in exposure is not known and therefore not included in the analysis.

The uncertainty in the estimation of DALYs is summarized in Table 16 for the four job titles.

*Table 16 The occupational burden of disease in DALY for a cohort of 10,000 workers starting at age 20, no intervention. Given are the lower and upper values, estimated from the confidence levels.*

| **job title** | **silica lung cancer** | **silica silicosis** | **accidents** | **lifting LBP** |
|---|---|---|---|---|
| Carpenter | 0 | 700 – 1700 | 210 – 3300 | 2000 – 7000 |
| Driller | 4000 – 9000 | 40,000 – 150,000 | 40 – 11,000 | n.a. |
| Paver | 2000 – 5000 | 5000 – 60,000 | 60 – 6300 | 2400 – 11,000 |
| Tiler | 2000 – 7000 | 7000 – 80,000 | 50 – 8000 | n.a. |

n.a. = not available, not possible to calculate

Notes:

1. For lung cancer due to silica exposure, the occupational burden of disease is calculated from the total burden of disease by subtracting the burden of disease for unexposed, which is about 11,000 DALY (Uijt de Haag et al., 2010). For carpenters, the total burden of disease is comparable to the burden of disease for unexposed.
2. For accidents, the highest and lowest numbers in Table 4 - Table 7 are shown.
3. For lifting, the total number of DALYs is calculated by multiplying the DALY per person-years with the number of person-years in the cohort (see Table 23 in Uijt de Haag et al., 2010). For the lower value, the number corresponding to the lower incidence and prevalence is used, whereas for the upper value, the higher estimate of becoming disabled is used. The numbers given are the differences between the job title and unexposed.

We conclude that the uncertainty in numbers is large. Due to the uncertainty, the upper values for lung cancer (silica), accidents and lifting are now comparable to the lower values for silicosis for the job titles carpenter, paver and tiler. Only for the job title driller we may conclude that the occupational burden of disease due to silicosis is significantly larger than the other exposures, even when the uncertainty is taken into account.

It should be noted that there are other sources of uncertainty, which cannot be quantified yet, e.g. the use of miners’ dose-response data for construction workers.

# 3 Dermal exposure

## 3.1 Introduction

Hand eczema is a disease that can lead to severe restrictions in social and occupational life (Diepgen and Coenraads, 1999). To prevent sick leave and job change, it is important to identify risk factors for hand eczema. In this section the effect of occupational exposure on the prevalence of hand eczema is explored in a population of construction workers. In addition, we explored whether job titles within the construction industry existed where prevalence and incidence of hand eczema are significantly increased if compared with a control population.

A review by Thyssen and colleagues in 2010 estimated a point prevalence of hand eczema of 4% in the general population. This is an average across different countries over a long observation period (since the 1960s) (Thyssen et al., 2010). In 2008, 12.5% of Dutch construction workers was diagnosed and/or treated because of skin complaints (Arbouw, 2008). Although recent data on the prevalence of hand eczema in the Dutch general population were not available, construction workers are exposed to several risk factors for developing hand eczema including chemical agents, physical trauma, water and extreme weather conditions. Therefore, it is likely that hand eczema has a strong work-related component and can in some cases be considered an occupational disease in construction workers.

Hand eczema can start as a disease with only small discomfort but when left untreated, it can become a chronic and disabling illness. Hand eczema can be caused by both allergenic and irritant substances. The course of the disease is often one of remittance and relapse. Therefore it is difficult to diagnose hand eczema in an early stage, except when the patient reports symptoms to a physician in an early stage. In the Netherlands, construction workers are invited for a periodical medical check-up every 4 years when they are younger than 40 years. Construction workers older than 40 years are invited every 2 years. As a result of the remitting character of hand eczema, symptoms may be absent during or around the check-up. At the time of the next check-up, however, disease may have become chronic and treatment is difficult, possibly leading to sick leave or even job change.

To obtain more information about the health impact of hand eczema and its (early stage) symptoms, (longitudinal) medical surveillance data from the construction industry were evaluated. The prevalence, incidence and recurrence of skin symptoms were assessed. Relations with self-reported exposure to different workplace hazards were analyzed and the information obtained was used as input for a simple health impact analysis.

## 3.2 Methods

Data were obtained from Arbouw, the Netherlands. As stated above, construction workers are invited for periodical check-ups, the so called PAGOs (Periodiek Arbeidsgezondheidskundig Onderzoek, Periodical Occupational Health Survey). Data were obtained over a period of 6 years (2005 up to 2010). The data involve 239,425 questionnaires of 152,255 individuals with a relatively uniform distribution over the years. The questionnaire responses cover all employees in the construction industry covered by ARBOUW and involve for almost 96% males and just above 4% females. The questionnaires included items from standardized dermal symptom questionnaires (see Appendix C), respiratory symptoms, atopic status, job title, age, gender, and smoking habits.

Subjects were asked to report the following symptoms in the previous twelve months:

- red, swollen hands or fingers;
- red hands or fingers with crests;
- vesicles on hands or between the fingers;
- raw or scaly hands with crests;
- itching hands or fingers with crests.

In addition, subjects reported whether they were hypersensitive for substances or materials to which they were exposed during their work (work-related skin allergy). Subjects also reported nuisance due to dust, smoke, gases or vapours and chemicals, which was used as an indication of exposure.
The questionnaire allowed evaluation of the prevalence of dermal symptoms in relation to some (potential) work-related determinants after adjustment for potential confounders. Determinants evaluated were nuisance reported as a result of exposure to dust, smoke, vapours and gases, chemicals, further referred to as (self-reported) exposure.

Because data were available for a sizable population, which participated health surveys repeatedly over time, incidence, remission, and chronicity of symptoms in relation to self-reported exposure, were explored as well.
From the total of 152,255 responding persons, 110,024 were actually construction laborers. Of them, 49,149 had two or more PAGO visits. Supervisors and office workers (n = 33,502 so called UTA-personnel) were used as a reference population. UTA-personnel who appeared to be working on a construction yard at the second PAGO (n = 767) were excluded from the study population. Canteen personnel (n = 233) were excluded from the reference population as they frequently perform wet work, which is a major risk factor for developing occupational hand eczema (Diepgen and Coenraads, 1999). The relatively small group of women (n = 7729) was excluded from the analyses.

*Table 17 Composition of the study population*

| (sub)group | N | use |
|---|---:|---|
| Men, total construction laborers | 110,024 | Study population, cross-sectional |
| Men, UTA-personnel | 33,502 | Reference population, cross-sectional |
| Men, >1 PAGO | 49,149 | Study population, longitudinal |
| Men, UTA-personnel, >1 PAGO | 11,160 | Reference population, longitudinal |
| Women, total | 7729 | Excluded |

Multivariate analysis was performed with the various (binary) symptoms as dependent variables. Prevalence ratios were calculated using log-binomial regression according to Deddens and Petersen (2008). As independent variables, we used age (continuous), self-reported exposure to dust, self-reported exposure to smoke, self-reported exposure to gases or vapours, self-reported exposure to chemicals, and self-reported use of gloves.

## 3.3 Description

In our study population of 110,024 men working on construction yards, the mean age was 41 years (interquartile range 32 – 52 years). The mean age of the reference population of 33,502 men working as UTA personnel was 43 years (interquartile range 35 – 52 years). More than half of the construction yard workers reported nuisance due to exposure to dust (57.1%), 4.9% due to exposure to smoke, 6.7% due to exposure to vapours or gases and 8.8% due to exposure to chemicals during work. In total, 37.7% of the subjects reported to wear gloves at work.

## 3.4 Prevalence of dermal symptoms in the construction industry

The prevalence of symptoms in our study population of construction workers and the control population of UTA-employees at their first PAGO in our dataset is shown in Table 18.

*Table 18 Prevalence of dermal symptoms in 110,024 men working on a construction yard and 33,502 UTA-employees (reference population) during their first PAGO in our dataset.*

| | **Reference population** | | **Construction workers** | | |
|---|---|---|---|---|---|
| **Symptom** | **n** | **%** | **n** | **%** | **PR (age ajusted)** |
| Work-related skin allergy | 958 | 2.9 | 10,184 | 9.5 | 3.28 (3.07 – 3.48) |
| Red, swollen hands or fingers | 1242 | 3.7 | 4321 | 3.9 | 1.13 (1.06 – 1.20) |
| Red hands or fingers with crests | 1172 | 3.5 | 6855 | 6.2 | 1.81 (1.71 – 1.92) |
| Vesicles on the hands or between the fingers | 1369 | 4.1 | 4578 | 4.2 | 1.04 (0.98 – 1.10) |
| Raw or scaly hands with crests | 2569 | 7.7 | 17,534 | 15.9 | 2.06 (1.98 – 2.14) |
| Itching hands or fingers with crests | 1587 | 4.7 | 7410 | 6.7 | 1.47 (1.39 – 1.55) |

The prevalence of the different symptoms differed greatly between job titles. An overview of the prevalence per job title is given in Table 19.

*Table 19 Prevalence (in percentages) of the different self-reported symptoms at first PAGO among different job titles. Job titles with less than 50 subjects were not shown. **b0122**: work-related skin allergy, **s9060**: red, swollen hands or fingers, **s9061**: red hands or fingers with crests, **s9062**: vesicles on hands or between the fingers, **s9063**: raw or scaly hands with crests, **s9064**: itching hands or fingers with crests.*

| **Job title** | **n in job** | **b0122 (%)** | **n in job** | **s9060 (%)** | **s9061 (%)** | **s9062 (%)** | **s9063 (%)** | **s9064 (%)** |
|---|---|---|---|---|---|---|---|---|
| Carpenter | 41,112 | 11.3 | 42,218 | 3.5 | 6.2 | 3.5 | 16.6 | 5.9 |
| Road layer | 2296 | 4.2 | 2386 | 3.6 | 5.8 | 3.9 | 13.5 | 6.4 |
| Scaffolder | 884 | 8.4 | 903 | 4.1 | 5.4 | 5.3 | 12.3 | 7.3 |

## 3.5 Exposures in the construction industry

The self-reported exposure to dust, smoke, vapours or gasses and chemicals in the different job titles is shown below in Table 20.

*Table 20 Prevalence (in percentages) of the different self-reported exposures at first PAGO among different job titles.*

| **Job title** | **n in job** | **Self-reported dust exposure (%)** | **Self-reported smoke exposure (%)** | **Self-reported vapours/ gases exposure (%)** | **Self-reported chemicals exposure (%)** |
|---|---|---|---|---|---|
| UTA-personnel (reference) | 33,502 | 11.4 | 1.6 | 2.0 | 1.9 |
| Total construction workers | 110,124 | 57.1 | 4.9 | 6.7 | 8.8 |
| | | | | | |
| Carpenter | 42,218 | 59.5 | 2.7 | 2.3 | 4.0 |
| Road layer | 2386 | 50.8 | 6.4 | 7.9 | 1.6 |
| Scaffolder | 903 | 55.1 | 10.7 | 16.7 | 15.1 |

## 3.6 Incidence of dermal symptoms in the construction industry

Although prevalence numbers provide a good indication of the occurrence of symptoms within our study population, it is not informative about the course of a disease. Therefore we calculated incidence figures for subjects with at least two PAGOs. When subjects reported no symptoms at both their first and second PAGO, their symptom pattern was 'no symptoms'. When they reported symptoms at the second PAGO but not at their first PAGO, their pattern was classified as 'incident'. On the contrary, when they reported a symptom at the first PAGO but not at the second PAGO, it was classified as 'remittent'. Finally, when the symptom was reported at both PAGOs, it was considered to be chronic. As the percentages of these symptom patterns varied greatly between job titles, job titles within the construction industry were compared with UTA-personnel (who did not work on a construction yard).

*Table 21 Percentages of chronic, incident and remittent cases of work-related skin allergy per job title.*

| ***work-related skin allergy*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 22,273 | 6.0 | 5.6 | 6.0 |
| Road layer | 1372 | 2.1 | 3.2 | 2.1 |
| Scaffolder | 586 | 3.5 | 3.2 | 4.8 |

*Table 22 Percentages of chronic, incident and remittent cases of red, swollen hands or fingers per job title.*

| ***red, swollen hands or fingers*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 21,436 | 0.7 | 3.3 | 3.3 |
| Road layer | 1308 | 0.7 | 3.9 | 3.5 |
| Scaffolder | 574 | 0.0 | 3.4 | 3.4 |

*Table 23 Percentages of chronic, incident and remittent cases of red hands or fingers with crests per job title.*

| ***red hands or fingers with crests*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 21,436 | 1.4 | 5.5 | 5.1 |
| Road layer | 1308 | 0.6 | 5.1 | 5.5 |
| Scaffolder | 574 | 0.9 | 6.2 | 3.7 |

*Table 24 Percentages of chronic, incident and remittent cases of vesicles on the hands or between the fingers per job title.*

| ***vesicles on the hands or between the fingers*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 21,436 | 0.9 | 2.9 | 2.5 |
| Road layer | 1308 | 1.0 | 2.9 | 2.7 |
| Scaffolder | 574 | 0.9 | 2.2 | 3.7 |

*Table 25 Percentages of chronic, incident and remittent cases of raw or scaly hands with crests per job title.*

| ***raw or scaly hands with crests*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 21,436 | 7.8 | 10.2 | 9.7 |
| Road layer | 1308 | 5.7 | 9.9 | 7.8 |
| Scaffolder | 574 | 3.4 | 6.5 | 8.1 |

*Table 26 Percentages of chronic, incident and remittent cases of itching hands or fingers with crests per job title.*

| ***itching hands or fingers with crests*** | | | | |
|---|---|---|---|---|
| **job title** | **n in job** | **chronic (%)** | **incident (%)** | **remittent (%)** |
| Carpenter | 21,436 | 1.7 | 5.1 | 4.7 |
| Road layer | 1308 | 1.1 | 5.0 | 5.4 |
| Scaffolder | 574 | 1.5 | 5.3 | 4.0 |

For UTA-personnel, incidence figures are shown in Table 3.11 below.

*Table 27 Symptom patterns over the first two PAGOs in UTA-personnel subjects with at least two PAGOs (reference population, n = 11,160).*

| | **Work related skin allergy (%)** | **Red, swollen hands or fingers (%)** | **Red hands or fingers with crests (%)** | **Vesicles on the hands or between the fingers (%)** | **Raw or scaly hands with crests (%)** | **Itching hands or fingers with crests (%)** |
|---|---|---|---|---|---|---|
| Remittent | 1.5 | 2.9 | 3.0 | 3.0 | 5.4 | 3.7 |
| Incident | 1.7 | 3.6 | 3.0 | 2.9 | 4.9 | 4.0 |
| Chronic | 1.3 | 0.7 | 0.5 | 1.0 | 2.7 | 1.0 |
| No symptoms | 95.5 | 92.8 | 93.4 | 93.2 | 87.0 | 91.3 |

Remittent: symptom reported at first PAGO but not at second PAGO;
Incident: symptom reported at second PAGO but not at first PAGO;
Chronic: symptom reported at both first and second PAGO;
No symptoms: no symptoms reported at both first and second PAGO.

## 3.7 Multivariate regression analysis of risk factors

The results of the multivariate regression analysis are shown in Table 28. Age was clearly and positively associated with the occurrence of skin symptoms. In all models the effect was statistically significant. However, inclusion of age in models with all exposure variables did not change the coefficients for the exposure variables in any way. Thus, age does not seem to confound the association between exposure and skin symptoms.

*Table 28 Risk factors for dermal symptoms at first PAGO. Given are prevalence ratios with 95% confidence intervals. n=110,024*

| | **Work related skin allergy** | **Red, swollen hands or fingers** | **Red hands or fingers with crests** | **Vesicles on the hands or between the fingers** | **Raw or scaly hands with crests** | **Itching hands or fingers with crests** |
|---|---|---|---|---|---|---|
| Age (per ten years) | 1.09<br>(1.07-1.11) | 1.36<br>(1.33-1.40) | 1.12<br>(1.10-1.15) | 1.10<br>(1.08-1.13) | 1.02<br>(1.01-1.04) | 1.17<br>(1.15-1.19) |
| Exposure to dust | 1.93<br>(1.85-2.02) | 1.22<br>(1.14-1.30) | 1.64<br>(1.56-1.73) | 1.45<br>(1.36-1.54) | 1.76<br>(1.71-1.82) | 1.50<br>(1.43-1.58) |
| Exposure to smoke | 1.01<br>(0.93-1.09) | 1.41<br>(1.25-1.59) | 1.24<br>(1.13-1.37) | 1.20<br>(1.07-1.35) | 1.08<br>(1.02-1.15) | 1.27<br>(1.17-1.39) |
| Exposure to vapours or gases | 1.03<br>(0.96-1.10) | 1.25<br>(1.12-1.40) | 1.08<br>(0.98-1.18) | 1.31<br>(1.18-1.45) | 1.05<br>(0.99-1.11) | 1.09<br>(1.00-1.18) |
| Exposure to chemicals | 1.75<br>(1.66-1.84) | 1.31<br>(1.19-1.44) | 1.26<br>(1.17-1.36) | 1.60<br>(1.47-1.75) | 1.02<br>(0.97-1.07) | 1.62<br>(1.51-1.73) |
| Use of gloves | 0.58<br>(0.56-0.61) | 1.04<br>(0.98-1.10) | 0.93<br>(0.89-0.98) | 0.93<br>(0.88-0.99) | 0.96<br>(0.94-0.99) | 0.89<br>(0.85-0.93) |

The same model was applied in subjects with at least two PAGOs to reveal the effect of the risk factors on the prevalence of 'chronic' symptoms in the second PAGO - i.e., subjects who reported symptoms at the first and second PAGO were compared with subjects who did not report symptoms at both occasions. Most prevalence ratios were increased compared with the prevalence ratios found in the cross-sectional analysis of the first PAGO. See Table 29.

*Table 29 Risk factors for 'chronic' dermal symptoms at the second PAGO for subjects who had these symptoms at both PAGOs compared with subjects who never reported these symptoms. Associations are presented as prevalence ratios with 95% confidence intervals. n=49,149.*

| | **Work related skin allergy** | **Red, swollen hands or fingers** | **Red hands or fingers with crests** | **Vesicles on the hands or between the fingers** | **Raw or scaly hands with crests** | **Itching hands or fingers with crests** |
|---|---|---|---|---|---|---|
| Age (per ten years) | 1.16<br>(1.11-1.21) | 1.72<br>(1.50-1.98) | 1.14<br>(1.05-1.24) | 1.08<br>(0.98-1.18) | 1.02<br>(0.99-1.06) | 1.19<br>(1.10-1.28) |
| Exposure to dust | 2.19<br>(1.99-2.40) | 1.62<br>(1.29-2.03) | 2.23<br>(1.87-2.65) | 1.83<br>(1.52-2.20) | 2.09<br>(1.94-2.24) | 1.80<br>(1.56-2.08) |
| Exposure to smoke | 0.95<br>(0.79-1.13) | 1.75<br>(1.21-2.52) | 1.38<br>(1.02-1.85) | 1.09<br>(0.78-1.53) | 1.01<br>(0.88-1.17) | 1.21<br>(0.93-1.56) |
| Exposure to vapours or gases | 0.95<br>(0.82-1.10) | 1.58<br>(1.11-2.25) | 1.05<br>(0.78-1.40) | 1.47<br>(1.10-1.97) | 1.06<br>(0.93-1.21) | 1.15<br>(0.91-1.46) |
| Exposure to chemicals | 2.14<br>(1.92-2.39) | 1.56<br>(1.15-2.13) | 1.60<br>(1.27-2.01) | 1.80<br>(1.41-2.30) | 1.14<br>(1.02-1.27) | 2.10<br>(1.75-2.52) |
| Use of gloves | 0.50<br>(0.45-0.55) | 0.86<br>(0.69-1.07) | 0.78<br>(0.66-0.91) | 0.89<br>(0.75-1.06) | 0.94<br>(0.88-1.00) | 0.79<br>(0.69-0.91) |

## 3.8 Exploratory health impact analysis for dermal symptoms

We calculated the burden of disease similarly to the model for lifting as described in section 2.4 and in Uijt de Haag et al. (2010). As unexposed population we selected UTA-personnel, the exposed population were construction yard workers. As proxy for hand eczema we considered individuals who suffered at least one out of five skin symptoms. Considered exposures were reported nuisance related to exposures to dust, smoke, gases/vapours and chemicals; the PRs for having hand eczema for the different exposures from the table below were considered. We assumed that a worker was exposed to all factors simultaneously and this resulted in a PR of 2.1. Prevalence ratios were again calculated using log-binomial regression according to Deddens and Petersen (2008).

*Table 30 Exposures and associated prevalence ratios for having hand eczema.*

| **Exposure** | **PR** |
|---|---|
| Dust | 1.64 |
| Smoke | 1.06 |
| Gases/vapours | 1.06 |
| Chemicals | 1.14 |
| *All exposures combined* | 2.10 |

Prevalence of hand eczema in UTA-personnel were calculated from our data set (14.5%) as well as incidence for UTA-personnel and construction yard personnel (9.4% and 14.8%). Recurrence of hand eczema was estimated to be 35% – 80% (Diepgen and Coenraads, 1999) and we used 80% as a conservative estimate.

Hand eczema was categorized into acute and chronic hand eczema. On the basis of a breakdown by type of symptom we considered 77% of symptoms chronic (raw or scaly hands with crests, itching hands or fingers with crests), 23% were considered acute (red, swollen hands or fingers, red hands or fingers with crests, vesicles on the hands or between the fingers).The WHO published a generic DALY value of 0.056 for skin diseases (WHO, 2004). We used this value for the category of most severe limitation; chronic hand eczema. For the other category, acute eczema, we arbitrarily set the DALY estimate at 0.02. The rational for this value is that this is roughly equivalent to a one week recuperation or treatment period after an acute spell of the disease.

We assumed a hypothetical intervention effect of 100% for the different exposures considered; dust, smoke, vapours/gases and chemical exposures. The rationale is that for instance the use of gloves seemed able to counterbalance the risk for developing skin allergy almost completely. However, the aim of this analysis is not to provide exact estimates for intervention effects but to provide a proof of principle estimate which can be compared with similar estimates for other health endpoints considered for this population. We did not model the different occupations separately; the assumptions underlying this exercise do not allow such a more refined approach. This approach can only give an impression of the order of magnitude of DALYs involved. Moreover, the distribution of exposures is not greatly different between job titles.

In the unexposed population, application of the model resulted in a total of 5430 DALYs, which is 1.47 DALYs per 100 person-years. In the exposed population, a total of 8223 DALYs was calculated, which is 2.26 DALYs per 100 person-years. We considered each individual to be exposed to all factors considered simultaneously.
This results in a difference of 0.80 DALYs per 100 person-years between exposed and non-exposed. In the calculation on low back pain, a difference of 0.25 DALYs per 100 person-years was found between unexposed workers and exposed workers (scaffolders). For populations at risk for developing silicosis (concrete drillers, road pavers, and tilers) the difference between an exposed and an unexposed population was considerably larger: 12.36, 8.94 and 4.40 DALYs per 100 person-years, for the three jobs respectively.

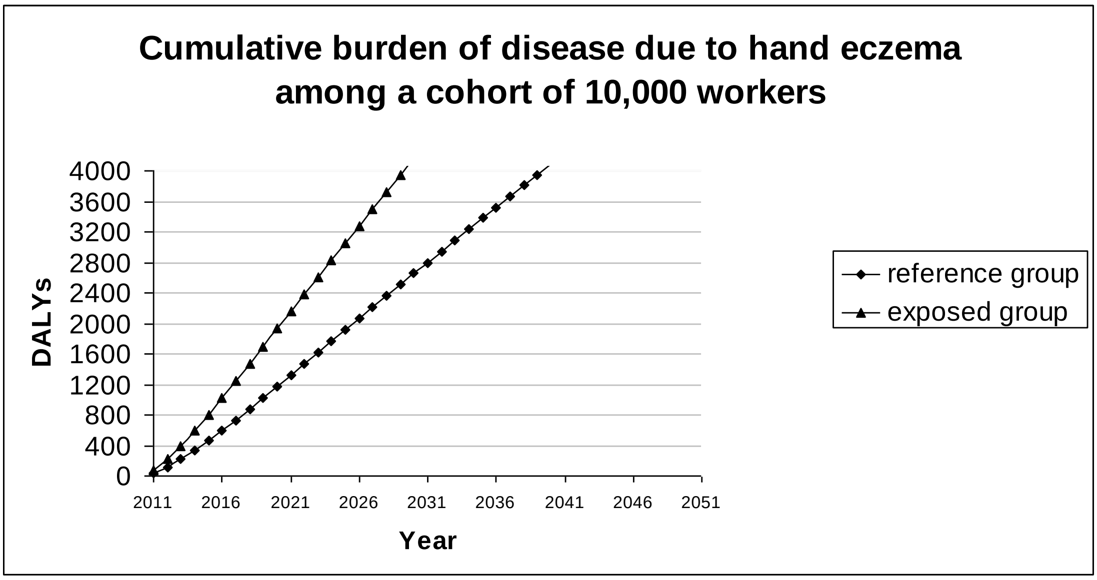


*Figure 9* *Cumulative burden of disease which is attributable to hand eczema in a cohort of 10,000 workers*

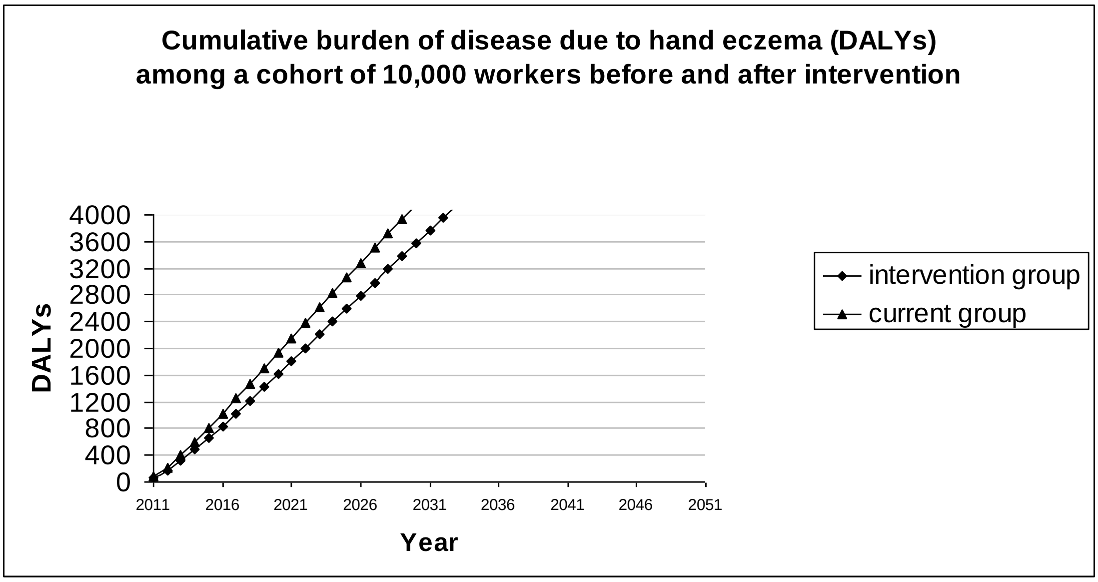


*Figure 10* *Cumulative burden of disease which is attributable to hand eczema in a cohort of 10,000 workers with and without intervention*

As can be seen from Figure 10, interventions have an immediate effect, because the PR is associated to both the acute as well as the chronic forms of eczema. Here is some room for refinement as the disease indeed flares up after an exposure incident but chronic hand eczema may persist after eliminating the exposure and will most likely lead to different disease patterns for acute eczema than for exposed individuals without chronic eczema.

## 3.9 Limitations

These analyses have several limitations. Detailed exposure data has not been collected and exposure data is self-reported and defined as nuisance resulting from exposure. An important issue is the variability in work and exposures within the various job titles. Within the same job titles, subjects may perform quite different jobs or have different working habits, working patterns etc. This may limit the relations found between job titles and dermal symptoms.
The level of detail for some questions was limited. For instance, 37% of construction workers report to use gloves, but it is unknown whether they use gloves all the time or maybe only part of the time. Other potential issues are recall and reliability of self-reported information. This might result in misclassification. This is also relevant for other variables, such as self-reported exposure, where misclassification can be considerable. Another complicating factor with glove use is that the use of a wrong type of glove can have an adverse rather than a protective effect.
Causal associations cannot be assessed in a cross sectional study. We conducted exploratory longitudinal analyses in subjects with more than one PAGO. However, ideally, information should be available from before start of employment for an accurate classification as incident case.

Little is known about estimated DALYs for hand eczema (see also Chren and Weinstock, 2004). It is not clear for the WHO disability weight of 0.056 for skin diseases to what extent hand eczema contributes to this value and whether a hand eczema value should be lower or higher in case of ongoing occupational exposures. The disability weight requires a more detailed underpinning.

Despite these limitations the main strength is the wealth of data available in the construction industry. These analyses indicate that dermal symptoms were reported by a considerable number of construction workers. Self-reported symptoms and exposure during work explain a large part of the high prevalence of these symptoms. Skin problems do contribute considerably to the total disease burden of the population.

# 4 Different aspects

## 4.1 Overview of important exposures and diseases

The OHIA model is currently constructed for a few job titles (tiler, road paver, concrete driller/sawyer and carpenter), and for a selected number of combinations of hazards and diseases. To extend the OHIA model with additional hazards and diseases relevant for the construction sector, a review of the most important hazards and diseases should be made.

In Appendix E, an overview is presented of the most relevant chemical agents used in the construction industry and their related endpoints. Three criteria are used to value the importance of a chemical agent/disease, namely disability weight, size of the exposed population and the feasibility of possible interventions.

The overview of exposure-effect relations in combination with their relevance for the different occupations and feasibility of interventions provides a valuable first step in the selection process as it includes the major building blocks for health impact assessments. Based on the gathered information and the set of criteria, the exposure-effect relations of interest appear to be silica and COPD (COPD as health effect was not considered in the feasibility study), epoxy resins and skin disease or asthma, cement and skin disease, wood dust and COPD, RSI/CANS and noise.

## 4.2 Risk groups

In the OHIA feasibility study, we looked at the job titles tiler, road paver, concrete driller/sawyer and carpenter, based on the Arbouw codes. In order to determine the variability of exposure within one job title, we looked in more detail at the job descriptions.

On the website of ARBOUW the following task descriptions for each job are given:

*Tiler*: A tiler removes old layers of tiles, prepares the surface by closing gaps, leveling and applying a primer, marks the area, transports material, prepares the mortar, cement or glue, applies the tiles using the mortar, cement or glue, and fills the joints. A report by ARBOUW on silica exposure gives some additional more detailed task descriptions which are relevant for silica exposure: grinding, sawing tiles, sweeping and sawing bricks (Onos and Spee, 2004).

*Road paver*: A road paver lays cobble stones, sets concrete curb stones and also works with road or pavement bricks and tiles. After laying he finishes the pavement by sweeping sand and compacting the soil by a plate compactor. Other tasks are removing old pavement stones and tiles, preparing the sand bed, the cutting of pavement stones and tiles, and the alignment of drains. Road paving using asphalt (‘asfaltwerker/asfaltwegenbouwer’) is not part of this group.

*Concrete driller/sawyer*: This is a collective term for the following job titles: concrete worker, concrete sawyer, diamond driller and concrete mixer driver. The following tasks are involved: making holes in concrete, natural stone, bricks and roads using electrical or pneumatic diamond drills or saws. Occasionally a hammer or percussion drill is used. Additional tasks are demolishing, and anchoring and gluing drawbars.

*Carpenter*: The carpenter manipulates, processes and replaces a range of wood and sheet materials and building materials.

In Uijt de Haag et al. (2010) the mean silica exposure was estimated based on:
- For tilers and road pavers: Task based exposure measurements (literature) and average time expenditure per task (based on the literature for tilers and based on expert judgment for road pavers).
- For concrete driller/sawyers: 8h exposure measurements (literature).
- For carpenters: This job was assumed to be non-exposed so background exposure (literature) was assigned.

Several potential sources of uncertainty can be identified:
- *Variability in exposure*. In the previous study the mean (as reported in the literature) was used. For the present study, available exposure data were pooled into one dataset and the distribution of the data is used to reflect the variability in exposure in the outcome.
- *Variability in daily activities*. Within a job some workers may spend more time on a specific task than other workers. For tilers and road workers the average time expenditure per task was used and this type of variability is not reflected in the uncertainty analyses. For tilers the time expenditure was available from an ARBOUW report (Onos and Spee, 2004). The range was reported (Table 31). Although this is not used in the uncertainty analysis in the present study, the ranges give an indication of the variability. For road pavers no information on the average time spent per activity was available and this was estimated based on one expert.

*Table 31 Task specific time expenditure for tilers*

| Relevant task | midpoint | range |
|---|---:|---:|
| Removing old stucco and tiles | 10% | 0 – 20% |
| Grinding and sawing of tiles | 7.5% | 5 – 10% |
| Sweeping | 1.3% | 0 – 2.5% |
| Sawing sand-lime bricks or cellular concrete | 7.3% | 2 – 12.5% |

For concrete driller/sawyer 8 hr TWA measurements were used. Variability in the 8 hr TWA measurements should reflect the variability in time spent per activity as well as the activity based exposure levels if measurements were taken for a representative sample of concrete drillers/sawyers.

- Lastly, not all relevant tasks may have been identified. For example, for road pavers sweeping was assigned background since it is outside in contrast to sweeping for tilers which was not assigned background. This type of uncertainty is not reflected in the uncertainty analyses.

In the present report only the effect of the first source of uncertainty is assessed in an uncertainty analysis since this is the only source for which enough data on variability was available.

## 4.3 Intervention

In OHIA, the effect of different intervention strategies are studied:
- the use of a stationary saw with water (silica exposure);
- the use of a hand saw (silica exposure);
- ergonomic interventions (low back pain);

- elimination of exposure to dust, smoke, vapours/gases and chemical exposures (eczema).

Up to now, the effect of an intervention strategy is studied per exposure and disease combination separately. The overall impact of an intervention on different diseases is not studied. However, it is clear that an intervention may have a positive effect on different diseases. For example, the reduction of silica exposure in the construction sector will probably also reduce the nuisance due to exposure to dust, a risk factor for eczema.

On the other hand, interventions may also have a counterproductive effect. It is possible that the use of a hand saw reduces the silica exposure, but increases the exposure to physical stress. Similarly, the use of a stationary saw with water may, depending on the particular set-up, lead to a slippery floor and therefore more accidents. However, data are currently missing to do a well-educated guess.

## 4.4 DAWY

### *4.4.1 Introduction*

An indicator for work-related health damage should combine mortality, illness and other health effects. The concept of DALY, disability-adjusted life-years meets this requirement and was successfully applied in the feasibility study. DALY is a measure for the burden of disease and quantifies the loss of health due to premature death and due to life with illness. The DALY is the sum of the number of lost years due to premature death and the (weighted) number of lost years due to illness, where the gravity of a specific illness is expressed in the weighting factor. In this way all types of diseases are converted into one single number.

The DALY measures the disability-adjusted life-years over the total life expectancy and is therefore a good measure for public health. However, the DALY does not provide information on the effects of (work-related) diseases on the productivity of employees: one year of illness of a pensioner is valued the same as one year of illness of a worker.

To determine the impact of diseases on the productivity of employees, the concept of DAWY, disease-adjusted working years, was developed (Eysink et al, 2010). In this concept, three different components contribute to the DAWY:

1. full-time or part-time absence of work due to the specific illness;
2. full or partial disability due to the specific illness;
3. loss of productivity at work due to the specific illness.

The DAWY concept was used to calculate the total loss of productivity for the Dutch working population for a period of one year for a limited number of disease classes. In this calculation, the loss of productivity due to absence of work was determined by the difference between the prevalence and average duration of absence of work between employees with a specific disease and employees without a disease. The DAWY concept has been developed only recently and additional data collection is required for a more detailed assessment of especially productivity loss at work due to different diseases among workers across a large variety of occupations.

The DAWY concept is applied to the agent disease combinations silica/lung cancer, lifting/low back pain, accidents/death and accidents/injury. For each combination of agent/disease, the calculation method of the DAWY is explained.

### 4.4.2 *Silica exposure*

In this section, the use of disability-adjusted working years, or DAWY, as an outcome measure to evaluate health impact for occupational diseases is studied (Eysink et al., 2010). Basically, the DAWY counts the number of lost work years due to disease. For example, assuming a retirement age of 65 a person who dies at the age of 30 results in a loss of 35 work years. Someone who dies at the age of 64 then results in a loss of just 1 DAWY.

This definition immediately hints to a problem for the use of the DAWY as a measure of occupational burden of disease. Diseases with a long latency occur at later age, and consequently contribute only a little or not at all. This is apparent from Figure 11 below, that shows the cumulative DAWY for lung cancer studied earlier in this report (cohort of N = 10,000 at starting age 20). Before the age of 40 there is almost no increase in the DAWY, because lung cancer appears mostly after that age. This is similar to the DALY development in Figure 5. Then there is an almost linear increase until the age of 65, after which there is no contribution to the DAWY anymore. Here, the difference with Figure 5 is clear, since the DALY measure for lung cancer keeps increasing for another 20 years.

It depends on the goal of the study what measure is appropriate, but clearly the DAWY does not account for the consequences of the total occupational disease burden when a long latency disease is studied.

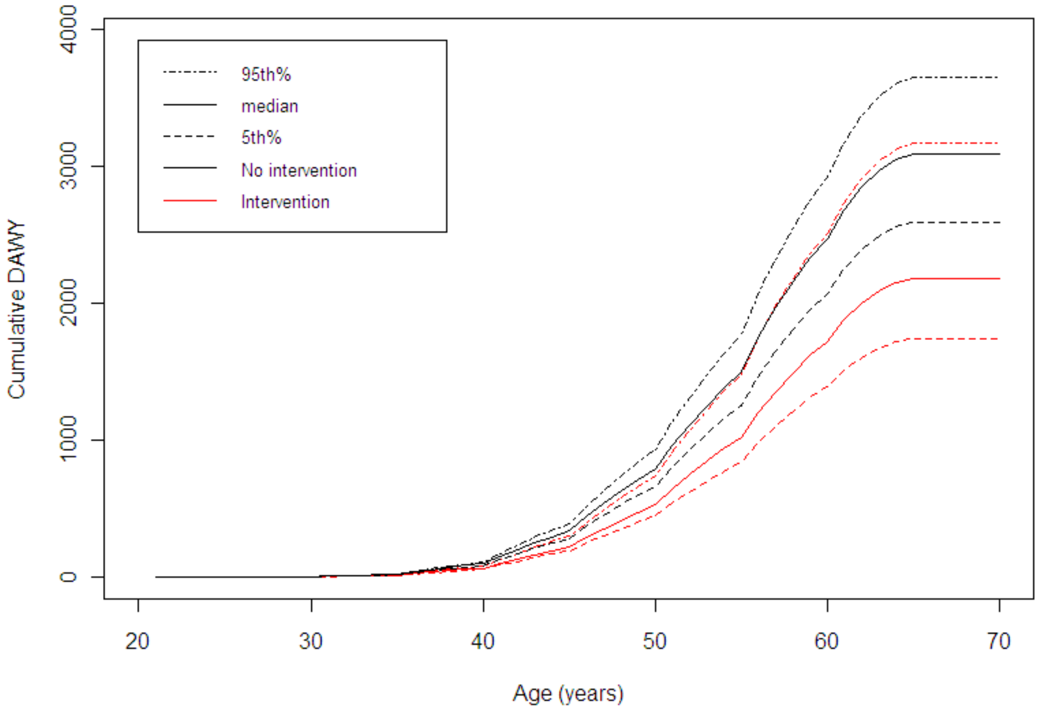


*Figure 11 Cumulative DAWY against age due to lung cancer for drillers*

### 4.4.3 *Accidents*

DAWYs can be calculated for accidents as follows:

1. Fatal accidents will result in loss of productive years. These are the years from a fatal accident until retirement and can be calculated with the life tables. The results are given in Table 32.
2. Recoverable injuries will lead to productivity loss due to the time it will take for the injury to heal and for the worker to return to work. We assume that there is no further loss of productivity after the injury is healed. The average time of absence for injuries is 0.7 year (from the serious accidents recorded in the database for the 4 job types). The calculated number of DAWYs will then be equal to the number of injuries that take place in the cohort in the 45 years until retirement, multiplied with 0.7 year. The results are given in Table 32.
3. Permanent injuries will result in productivity loss due to time of absence after the injury takes place and decreased employability after returning to work. Decreased employability is the sum of partial inability to work and decreased productivity while at work.
    - The productivity loss due to time of absence is calculated in the same way as for recoverable injuries, also by multiplying the number of (permanent) injuries with 0.7 year.
    - The productivity loss due to partial inability to work is calculated as given in Eysink et al. (2010): the number of permanently injured workers that are partially unable to work is multiplied with 0.425, the average percentage of working inability. As there are no known numbers for the percentage of permanently injured workers that are partially unable to work we have assumed 100% to give a first approximation, though this will be an overestimation.
    - In Eysink et al. (2010) the productivity loss due to decreased productivity while at work is given for a number of diseases (in table 4.3). As we do not have any data for occupational accidents, we used the average productivity loss of about 25% reported in Eysink et al. (2010).

    The results are given in Table 32.

*Table 32 DALYs and DAWYs calculated for deaths and injuries (cohort of 10,000 workers, starting age 20)*

| **Job** | **DALY** | | | | **DAWY** | | | |
|---|---|---|---|---|---|---|---|---|
| | Deaths | Perm. injury | Recov. injury | Total | Deaths | Perm. injury | Recov. injury | Total |
| Tiler | 710 | 0 | 10 | 720 | 500 | 0 | 100 | 590 |
| Road paver | 530 | 160 | 20 | 710 | 370 | 480 | 130 | 980 |
| Carpenter | 420 | 780 | 40 | 1200 | 300 | 2400 | 280 | 3000 |
| Concrete driller | 0 | 1900 | 80 | 2000 | 0 | 6100 | 530 | 6700 |

The following remarks can be made from Table 32:

- DALYs and DAWYs are just different endpoints for calculations and should not be compared amongst each other as they mean different things. As there is quite some uncertainty involved with the calculation itself only two significant digits are used in the table. For clarity sake they have been given here in one table to show the impact of the calculation on the different jobs.
- From the table we can see that for occupational accidents it does not matter much if we would rank the jobs according to the number of DALYs or DAWYs. DALYs would be used if we are interested primarily in bringing down the burden of disease, while DAWYs would be used primarily to improve on

the productivity of workers. From the table it can be concluded that the road paver should be targeted last if we look at the number of DALYs, while the tiler would be last if we look at the number of DAWYs, when comparing equal cohorts. However, there is quite some uncertainty in the calculation of DALYs, as mentioned in previous chapters. For the DAWY calculation we have made the assumptions given above that will need further investigation.

#### 4.4.4 *Lifting*

For chronic low back pain (LBP), a DALY allocation of 0.06 per year was used (Gommer and Poos, 2010). The DAWY per worker with chronic LBP is estimated to be 0.007191 (Eysink et al., 2010). This implies that it is assumed that a substantial proportion of workers with chronic LBP do not suffer a reduced work performance due to sickness absence or reduced productivity at work. Currently, there is only circumstantial evidence that the consequences of having chronic LBP for reduced productivity depends on the magnitude of physical load and especially on the planning and organisation at work. For example, it has been shown that workers with a reduced work ability may experience no or little effects on their work performance, when been given a high job control, i.e. ample possibilities to plan and execute the work activities at their own discretion. It may be hypothesized that in most construction jobs such possibilities are limited and, thus, chronic LBP may have more profound implications for work performance than in most other jobs. The DAWY-value may need an upward correction for workers with chronic LBP in jobs in the construction industry.

#### 4.4.5 *Discussion*

Two different measures for the occupational burden of disease were compared for exposure to silica (lung cancer), accidents and lifting, namely the DALY and the DAWY. Where the DALY was used to present the impact of the occupational disease on the health of the entire population, including pensioners, the DAWY was used to present the impact on the workforce only. This results in important differences. For ‘acute’ diseases, like injury or death due to accidents, the use of DAWY or DALY as measure does not change the relative importance of jobs. However, if we compare ‘acute’ diseases with a disease with a long latency period, like lung cancer, the relative importance of jobs and diseases may depend strongly on whether the DALY or DAWY is used as endpoint. It therefore depends on the goal of the study what measure is appropriate.

# 5 Towards an operational OHIA model

## 5.1 Introduction

In the feasibility study of the OHIA model, it was demonstrated that it was possible to calculate the impact of different exposures on occupational health and compare them in terms of DALYs. These calculations were done using research models, which are only available to the model developers and not intended to be used by a more general public.

For an operational OHIA model, we need to develop a software model that is available to the intended users and easy to use. In phase two of the project, the specifications of the OHIA model are defined. For this purpose, a mock-up is created.

## 5.2 Structure of the OHIA tool

A mock-up of a software model shows the input and output screens the user sees, without the build of the actual software engine. The mock-up is very useful in guiding the discussions on the content of the OHIA model. The final mock-up of the OHIA model is shown in Appendix D. The OHIA tool consists of eight tab screen types.

*Home page*
The Home page support (Figures D.1 – D.3) allows the user to either log in or request for an account. The Home page also shows links to databases and user help.

*Data sets*
When a user carries out a specific study with the OHIA tool, all the data information is stored as a data set. The Data sets page (Figure D.4) gives an overview of the data sets used. The user can either select an existing study (e.g. *My first dataset*) or start a new study (*New dataset*). If *New dataset* is selected, the jobs, activities and exposures have to be defined.

*Job definition*
For the definition of jobs, the user may either select a job name from the database (based on the ISCO code or the Arbouw code) or enter his own job name (Figure D.5). A Help-function is available (Figure D.6) with links to the relevant institutes such as Arbouw and the International Labour Organisation (ILO). He may also use his own database of job names or import a job name database from the data waiting room (see section 5.3 and Figure D.7). Per job, the number of employees should be supplied

*Activity definition*
For each job, the activities have to be defined (Figure D.8). Activities add up to 100%. The OHIA database contains default activities and default fractions of time per activity. However, the user can modify the list of activities and fractions of time. Furthermore, he can add activities that are not in the database yet.

*Exposure definition*
Exposure information can be available either on a job level ('the average exposure to silica dust is 1 mg/m$^3$ for a concrete driller') or on an activity level ('the average exposure to silica dust is 0.5 mg/m$^3$ for removing old stucco and

tiles'). Consequently, exposure data are entered either on a job level or activity (task) level (Figure D.9). For each job or activity, the hazard is defined (e.g. exposure to silica dust) and the level of the hazard (e.g. the concentration of silica dust). The hazard is not necessarily present for all the time of the activity. Therefore, the fraction of activity time for which the hazard is present can be filled in. A Help-function is available (Figure D.10) and the user may add own exposure data or use data from the data waiting room (Figure D.11).
Only hazards for which the model is available are included in the OHIA tool. This means that in version 1, the OHIA tool only contains the hazards associated with accidents and the hazards silica dust, lifting and 'dermal agent'. The user cannot add a hazard, since no validated model is available.
After selecting and/or providing the jobs, activities and exposures, the user can see an overview of the data at different levels (Figure D.12).

*Burden of disease result*
The job/activity/exposure information is sufficient to calculate the occupational health risk for the workforce defined at the Job tab. The results are shown in tabular form for the workforce and per individual at different levels of detail (Figure D.13). The results are expressed in DALYs, but in time other measures can be used. In addition, various graphs are generated, e.g. the number of DALYs per job and per hazard, the number of DALYs per employee and the relative contribution of different hazards (Figures D.14 – D.16).

*Measure definition*
To reduce the occupational burden of disease, an intervention strategy can be defined (Figure D.17). An intervention strategy consists of a set of control measures and can be applied to a job or an activity. The effectiveness (risk reduction factor) of the strategy must be defined (Figure D.18).

*Risk reduction*
The effect of the intervention strategy is calculated for the occupational health risk and presented in tabular form (Figure D.19) or in graphs (Figure D.20).

*Additional tabs*
In addition, tabs are present for user support (Figure D.21), the OHIA databases (Figure D.22), the Data waiting room (Figure D.23) and the library of measures (Figure D.24).

## 5.3 Specifications of the OHIA model

Based on the discussions during the construction of the mock-up, the following specifications were derived.

*Intended user of the OHIA tool*
The OHIA model is built to be a policy making instrument on national level and branch level. Expected users are therefore the following:
- government;
- branch organisations (HSE experts from ...);
- research institutes.

The OHIA model is not developed to be used by individual companies. However, the results can be useful for companies. They may therefore have access to the tool if they have a knowledgeable person.

*Web-based tool*

The OHIA tool is intended to be a tool to be used by various parties and not a research model for one or a few institutes. Therefore, interested parties should have easily access to the tool. Since access, management (including updating) and supervision is easier with a web-based tool, it is proposed that OHIA should be a web based tool. The OHIA tool may be hosted by RIVM, like the similar tool Web-Orca. RIVM will then give access to individual users or a group of users (like a branch organisation, or a university department).

If the tool is hosted by RIVM, the layout of the tool will match the national requirements, i.e. the use of the logo of the government. The source code of the model, including the sub-models, should be available to the host. However, the institutes contributing to the model should be clearly recognizable and the intellectual property of the models and data should be regulated.

*Data quality*

The OHIA tool contains a database with information on jobs, exposure, dose-effect relations and so on. The data in the database should be validated and referenced. The user can use specific data, but these data will not be available to other users, in order to keep the database consistent and validated.

In addition, the user can place his data in a ‘data waiting room’. Data in the data waiting room are to be validated by the model manager. After validation, the data are added to the model database. The data in the waiting room are also available to other users.

The OHIA tool links to other (non-validated) information, e.g. to a catalogue of measures. The level of the links (generic to the catalogue or specific to a particular measure) should be determined on a case by case basis.

*Dynamic or static population*

The OHIA tool calculates the occupational burden of disease for the number of people in the job, based on a (static) cohort of age 20. This makes the OHIA results useful for a relative comparison.

*Possibilities and limitations of version 1 of the OHIA tool*

It is envisaged that the first working version of the OHIA tool will be restricted to the construction sector (top 20 jobs from Arbouw, activities) and the hazards silica (lung cancer, silicosis), accidents, lifting (LBP) and eczema (dermal). This version will be useful to compare the occupational burden of disease due to different hazards in the construction industry and define cost-effective intervention strategies.

# 6 Conclusions

The OHIA model evaluates the burden of disease due to various working conditions. In the feasibility study, a model was developed for the construction industry to calculate the occupational burden of disease due to a limited set of exposures. However, a number of issues were identified that should be investigated before an actual model could be put into practice. These issues relate to the uncertainty in the model results, the possibility to use (longitudinal) medical surveillance data in the OHIA model and the consequences of the use of an alternative measure. Furthermore, the priority of exposure-disease combinations for an extension of the OHIA model is studied and the user requirements were assessed using a mock-up.

*Uncertainty analysis*
In the uncertainty analysis, the most important sources of uncertainty were identified and quantified for the exposures and diseases used in the feasibility study, namely silicosis and lung cancer due to exposure to silica, low back pain due to lifting of heavy loads and injury and mortality due to accidents.
The analysis shows that the uncertainty in the outcome is large. The ratio between the upper estimate and the lower estimate can be as high as two orders of magnitude (driller, accidents). Due to this large uncertainty, the upper bounds for accidents and lifting become comparable to the lower bounds for silica exposure for the job titles carpenter, paver and tiler. Only for the driller we may still conclude that the occupational burden of disease due to silica is larger than the other exposures, even when the uncertainty is taken into account.
For the combinations of exposure and disease studied, the analysis shows that the uncertainty in exposure dominates the overall uncertainty. Further work should therefore be focussed on a better characterisation of the exposure.

*Dermal exposure resulting in skin effects*
The cumulative burden of disease is calculated for hand eczema in the construction industry using the information of PAGO surveys. The analysis showed that it is possible to calculate the number of DALYs associated with hand eczema, based on relative risk factors for exposure to dust, smoke, gases/vapours and chemicals due to the wealth of data available in the construction industry. The analysis shows that dermal symptoms were reported by a considerable number of construction workers. Self-reported symptoms and exposure during work explain a large part of the high prevalence of these symptoms. Skin problems do contribute considerably to the total disease burden of the population: a first estimate indicates that the burden of disease per person-year due to hand eczema for the exposed population in the construction industry is a factor three larger than the burden of disease per person-year due to low back pain for the population at risk, scaffolders. Compared with hand eczema.  the burden of disease per person-year due to silicosis is about one order of magnitude lower for the population at risk, concrete drillers, road pavers and tilers.
There are however several limitations. Detailed exposure data have not been collected and exposure data is self-reported and defined as nuisance resulting from exposure. The use of protective devices, like gloves, is also self-reporting and open to misclassification; it is not known whether the correct protective devices were used all the time. Causal associations cannot be assessed in a

cross sectional study. Despite these limitations, the analysis shows that it is possible to include skin diseases in the OHIA model based on surveillance data.

*DAWY as an alternative measure for the burden of disease*

It is demonstrated that the DAWY can be used as an alternative measure for the occupational burden of disease. The analysis showed that the importance of exposure-disease combinations depends on whether DALY or DAWY is used as endpoint. It therefore depends on the goal of the study what measure is appropriate. It must be stressed that for most diseases the insight into DAWYs is still limited.

*Priority of exposure-disease combinations*

Based on three criteria, namely disability weight, size of the exposed population and the feasibility of possible interventions, we determined the most important combinations of exposure–effect for the OHIA model. The exposure-effect combinations of interest appear to be silica and COPD, epoxy resins and skin disease or asthma, cement and skin disease, wood dust and COPD, RSI/CANS and noise.

*Mock-up and requirements of the OHIA tool*

A mock-up of the OHIA tool was constructed to show how the OHIA tool would look like in practice. Furthermore, the mock-up was useful to determine which information should be included in the OHIA model and which information is to be supplied by the user.

*Recommendation*

The results of the feasibility study and this study show that a OHIA model is useful to compare occupational health and safety on an equal footing and to draw meaningful conclusions. The structure of the OHIA tool is well founded. It is therefore recommended to (1) investigate the demand for the OHIA tool in industry sectors and, if the demand exists, (2) construct the OHIA tool and fill the model with the data for the exposures studied up to now.

# References

Aneziris O, Baedts E de, Baksteen J, Bellamy LJ, Bloemhoff A, Damen M, Eijk V van, Kuiper JI, Leidelmeijer K, Mud M, Mulder S, Oh JIH, Papazoglou IA, Post JG, Sol VM, Uijt de Haag PAM, Whitehouse MA (2008). The quantification of occupational risk. The development of a risk assessment model and software. RIVM report 620801001. RIVM: Bilthoven.

Arbouw (2008). Bedrijfstakatlas 2008. http://www.arbouw.nl/pdf/tools/bedrijfstakatlas-2008.pdf.

Baars AJ, Pelgrom SMGJ, Hoeymans N, Raaij MTM van (2005). Gezondheidseffecten en ziektelast door blootstelling aan stoffen op de werkplek - een verkennend onderzoek. In Dutch. RIVM report 320100001. RIVM: Bilthoven

Burdorf A, Jansen J (2006). Predicting the long-term course of low back pain and its consequences for sickness absence and associated work disability. Occup Environ Med 2006;63:522-9.

CBS (2012). http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=71814ned&D1=0-2&D2=272,283,898&D3=l&VW=T (accessed at 16-1-2012)

Chren MM, Weinstock MA (2004). Conceptual issues in measuring the burden of skin diseases. J Investig Dermatol Symp Proc. 2004 Mar;9(2):97-100.

Deddens JA, Petersen MR (2008). Approaches for estimating prevalence ratios. Occup Environ Med 2008;65:481, 501-6.

Dekkers S, Baars AJ, Preller EA, Peters SM, Raaij MTM van (2006a). Historische versus recente blootstelling aan stoffen onder arbeidsomstandigheden als oorzaak van gezondheidseffecten en ziektelast. In Dutch. RIVM report 320506001; TNO report V7147. RIVM: Bilthoven

Dekkers S, Preller EA, Baars AJ, Marquart J, Raaij MTM van (2006b). Identificatie van belangrijke beroepsgroepen en stoffen bij het ontstaan van gezondheidseffecten en ziektelast door blootstelling aan stoffen onder arbeidsomstandigheden. In Dutch. RIVM report 320506002; TNO report V7148. RIVM: Bilthoven

Diepgen TL, Coenraads PJ (1999). The epidemiology of occupational contact dermatitis. Int Arch Occup Environ Health 1999;72:496-506.

Elders LAM, Burdorf A (2004). Prevalence, incidence, and recurrence of low-back pain in scaffolders during a 3 year follow-up study. Spine 2004;29:e101-6.

Eysink PED, Blatter BM, Gool CH van, Gommer AM, Bossche SNJ van den, Hoeymans N (2007). Occupational burden of disease in the Netherlands. In Dutch. RIVM report 270012001. RIVM: Bilthoven

Eysink P, Gommer A, Hoeymans N, Raaij MTM van (2008). Prioritering arbeidsrisico’s per sector. In Dutch. RIVM letter report. RIVM: Bilthoven

Eysink PED, Hamberg-van Reenen HH, Gool CH van, Hoeymans N, Burdorf A (2010). Meten van verloren arbeidsjaren door ziekte: Disease Adjusted Working Years (DAWY), Verkennen van een nieuwe maat. In Dutch. RIVM report 270244001.. RIVM: Bilthoven

Fransman W, Schinkel J, Meijster T, Van HJ, Tielemans E, Goede H (2008). Development and evaluation of an exposure control efficacy library (ECEL). Ann Occup Hyg. 2008;52(7):567-575.

Giesbertz P, Eykelestam J, Bloemhoff A (2007). Validatie meldingsplichtige arbeidsongevallen in het Occupational Risk Model (Validation of reportable occupational accidents in the Occupational Risk Model). In Dutch. Stichting Consument en Veiligheid (Consumer Safety Institute): Amsterdam.

Gommer AM, Poos MJJC (2010). Cijfers nek- en rugklachten (prevalentie, incidentie en sterfte) uit de VTV 2010. In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid. In Dutch. RIVM: Bilthoven.

Haagsma JA, Hoeymans N, Beeck EF van, Polinder S, Bonsel GJ, Gommer AM (2010). Ziektelast van letsels door ongevallen. In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid.In Dutch. RIVM: Bilthoven, <http://www.nationaalkompas.nl> (http://www.nationaalkompas.nl/gezondheid-en-ziekte/sterfte-levensverwachting-en-daly-s/ziektelast-in-daly-s/ziektelast-van-letsels-door-ongevallen)

Van den Hoogen HJ, Koes BW, Devillé W, Eijk JT van, Bouter LM (1997). The prognosis of low back pain in general practice. Spine 1997;22:1515-21.

Hoogendoorn WE, Bongers PM, Vet HC de, Twisk JW, Mechelen W van, Bouter LM (2002). Comparison of two different approaches for the analysis of data from a prospective cohort study: an application to work-related risk factors for low back pain. Occup Environ Med 2002;59:459-65.

IJzelenberg H, Burdorf A (2005). Risk factors for musculoskeletal complaints and ensuing use of medical care and sickness absence. Spine 2005;30:1550-6.

Lacasse Y, Martin S, Gagne D, Lakhal L (2009). Dose-response meta-analysis of silica and lung cancer. Cancer Causes Control. 2009;20(6):925-933.

Lakhal L, Lacasse Y (2009). Reply to: Dr. Peter Morfeld's Letter to the Editor (Manuscript Number: CACO2009): "Comment on Lacasse Y, Martin S, Gagne D, Lakhal L (2009) Dose-response meta-analysis of silica and lung cancer. Cancer Causes and Control; [e-pub ahead of print] doi: 10.1007/s10552-009-9296-0". Cancer Causes Control.

Lötters F, Burdorf A, Kuiper J, Miedema H (2003). A model for the work-relatedness of low back pain. Scand J Work Environ Health 2003;29:431-40.

Murray CJL, Lopez AD (eds.) (1996). The global burden of disease: a comparative assessment of mortality and disability from disease, injuries, and risk factors in 1990 and projected to 2020. Harvard School of Public Health, on behalf of the WHO and the World Bank.

Murray CJ, Lopez AD (1997). Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. Lancet. 1997 May 17;349(9063):1436-42.

Olsson A, Kromhout H, Agostini M, Hansen J, Lassen CF, Johansen C, Kjaerheim K, Langård S, Stücker I, Ahrens W, Behrens T, Lindbohm ML, Heikkilä P, Heederik D, Portengen L, Shaham J, Ferro G, Vocht F de, Burstyn I, Boffetta P (2010) A case-control study of lung cancer nested in a cohort of European asphalt workers. Environ Health Perspect. 2010 Oct;118(10):1418-24. Epub 2010 Jun 9.

Onos, T, Spee, T (2004). Samenvattend rapport stofbelasting in de afbouwsector. In Dutch. ARBOUW: Harderwijk.

Onos T and Spee T (2008). Stoffenmanager bouwnijverheid prioriteitstelling beroepsgroepen. In Dutch. ISBN: 9789077286777. ARBOUW: Harderwijk

Picavet HS, Schouten JS. Musculoskeletal pain in the Netherlands: prevalences, consequences and risk groups, the DMC(3)-study. Pain 2003; 102: 167-78

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Steenland K, Brown D (1995). Silicosis among gold miners: exposure-response analyses and risk assessment. Am J Public Health 1995; 85: 1372-7.

Van Thienen G and Spee T (2008). Health effects of construction materials and construction products. Journal of Applied Occupational Sciences 14(13):2-23.

Thyssen JP, Johansen JD, Linneberg A, Menné T. The epidemiology of hand eczema in the general population--prevalence and main findings. Contact Dermatitis 2010;62:75-87.

Uijt de Haag PAM, Bellamy LJ, Burdorf A, Heederik DJJ, Manuel HJ, Papazoglou IA, Portengen L, Pronk A, Tielemans E (2010). A model for comparing occupational Health and safety. RIVM report 620860001. RIVM: Bilthoven.

Venema A, Stam C, Bakhuys Roozeboom M, Nijman S, Ybema J F (2010). Monitor arbeidsongevallen in Nederland 2008. In Dutch. TNO Kwaliteit van Leven: Hoofddorp.

World Health Organization (WHO) (2004). Global burden of disease 2004 update: Disability weights for diseases and conditions. 2004. Online: http://www.who.int/healthinfo/global_burden_disease/GBD2004_DisabilityWeights.pdf. (accessed at August 25th 2010).

# Appendix A – Uncertainty assessment in accident risk

## Table of Contents of Appendix A

## 1 Executive Summary

The purpose of this Appendix is to present a methodology along with a demonstration for the assessment of the uncertainties in the annual probability of an occupational accident owing to the limitations of the available samples as well as the uncertainties in the estimated statistics of the samples. In particular the assessment of the uncertainties introduced by the uncertainty in the reported number of accidents, the working population supplying the data, and the annual working hours are assessed.

Four types of jobs, namely tilers, road pavers, carpenters and concrete drillers are considered along with accidents resulting in lethal, permanent and recoverable injuries. Data for the recorded accidents and the estimations of the corresponding populations have been taken from (Uijt de Haag et. al., 2010).

Uncertainties have been assessed using the principles of Bayesian Analysis.

Accidents have been assumed to occur according to a Poisson random process.

A non-informative prior distribution for the annual probability for all three types of accidents has been considered: A uniform pdf in the interval (0, 1).

This prior distribution has been updated with the provided evidence (number of accidents and total exposure) to provide the posterior distribution for the annual accident probability.

Four types of jobs and three types of accidents create twelve combinations resulting in twelve posterior distributions for the annual probability of accident. 90% probability intervals have been calculated for each case.

These probability intervals represent the uncertainty owing to the limited amount of information available through the sampling process. As the samples become larger and larger these intervals become smaller and smaller and in the limit they coincide to the single value of the annual accident probability. As expected the largest error factors (EF= R95%/R5%) are observed for cases with low numbers of observed accidents irrespectively of the size of the total exposure. The results are tabulated in Tables A3, A4 and A5.

It is noteworthy that although cases with few accidents present the larger error factors the role of the total exposure is important since it affects the position of the probability in the real axis and hence it eventually affects the number of DALYs.

Uncertainties owing to the fact that a number of accidents may be unreported have been quantified by assuming that the number of unreported accidents is a random variable uniformly distributed in the interval (0, k), where k is the number of the reported accidents. This is equivalent to assume that the underreporting can be as high as 100% of the reported accidents. The results are given in Table A6. It has been assumed that there is no underreporting in the number of occupational deaths. The effect of this uncertainty is relatively small but since it increases the number of accidents, it shifts the accident probability to higher than the base case values.

Uncertainties owing to potential inaccuracies in the estimated size of the working population constituting the sample have been quantified by assuming that the population is a random variable that can vary between 0 and 1600 working hours per year. The mean value of the assumed pdf is equal to the point estimate of the population given in Uijt de Haag et al. (2010). The results are tabulated in Table A7. The effect is of the same order of magnitude like the effect of the underreporting but since the range of population sizes includes values larger as well as smaller than the base case, the uncertainties span a region both larger and smaller than the base case.

A third important source of variability in the annual probability of an accident is due to the fact that the actual working hours per year in a working population are not identical for all the members of the population but rather exhibit a substantial variability. This variability has been quantified by considering the number of working hours per year, a random variable distributed according to a known pdf. The results of this analysis are given in Table A8 of this Appendix. Given the assumptions made in this work the uncertainties introduced by the variability of the exposed working hours per year are the most significant.

Finally the effects of the uncertainties in all three parameters considered simultaneously have been quantified and are given in Table A9.

The results of the analysis are given in chapter 2 of this Appendix. Chapter 3 of this Appendix presents the theoretical background for the approach followed and the techniques used.

## 2 Uncertainty assessment in the annual accident risk of four types of jobs

This section presents the results of an assessment of the uncertainty in the annual risk of an accident resulting in one out of three possible consequences (death, permanent injury, recoverable injury) and for four types of jobs.

### 2.1 Model and assumptions

- Accidents are assumed to arrive according to a Poisson random process.
- The fundamental parameter of this model is the intensity $\lambda$ of the process giving the conditional probability per unit of time that an accident will occur in the next short interval of time $(t, t+dt)$ given that there was no accident at time $t$.
- According to this model the time at which an accident occurs is a random variable exponentially distributed.
- The probability that an accident will occur during a period of time is then a function of the hazard rate $\lambda$ and the period in question (see section 3.1).
- Information about the actual value of the hazard rate $\lambda$ is obtained by observing the process for a while and obtaining samples of the times at which accidents occur. It turns out that not all specific values of the sampling of times are necessary for estimating $\lambda$ but only a summary of the collected evidence called sufficient statistics and consisting of two numbers:
    - the number of accidents observed $k$; and
    - the total time $T$.
- The total time of the observation is a quantity that has to be carefully determined (see section 3.1.3).
- In the case of occupational accidents the total time may be called total exposure and it depends on:
    - the Number of workers in the population ($N$) providing the data;
    - the actual times the $N$ individuals spent each year on the job exposed to the risk of an accident;
    - and the actual times at which the observed accidents occur.
- As it is shown in section 3.1.3 the total exposure $T$ can be approximated by the relationship

  $$T = N\tau x \tag{1}$$

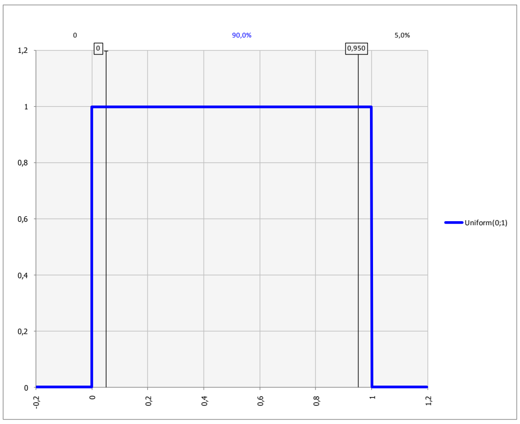
  where
    - $N$ is the population size;

  - ο $\tau$ is the average time a worker spends during a year exposed to the particular risk; and
  - ο $x$ is the number of years of the observation.

  This is a good approximation since the number of workers suffering accidents is extremely smaller than the size of the population $N$.

- In the particular case examined in this report data have been obtained by specifying the duration of the observation (x = 6.17 years) the working population to be observed (i.e. those reporting accidents to the GISAI data base) and observing the number of accidents during this fixed period. This means that the sampling method constitutes a Poisson Sampling where T is predetermined and k is left to chance.
- This report estimates a possible range and associated probabilities for the value of λ following the Bayesian approach (see section 3.2). This approach has a clear scientific basis particularly suited for the Poisson sampling method and with no difficulties when no accidents are observed (i.e. when k=0).
- Prior to observing the evidence (k,T) it is assumed that the hazard rate λ is a random variable distributed according to a gamma-1 pdf ( $f_{\gamma_1}(\lambda \mid \alpha', \beta')$ ).

  The parameters (α,β) express the extent of the lack of knowledge about the true value of λ.
- In this analysis the parameters (α,β) have been chosen such that the annual probability of an accident for an individual exposed for τ hours during a year is uniformly distributed over the range of possible values (0, 1) as shown in Figure A1. This is equivalent to expressing a total ignorance on the metric 'probability of an accident during a year'.
- As shown in section 3.2.1.1.1 of this appendix the previous assumption is equivalent to assuming that λ is distributed according to gamma1 distribution with parameters (α=1, β=τ) as shown in Figure A2.
- After obtaining the evidence (k,T), the posterior distribution of λ is also a gamma-1 distribution with parameters (α″=α′+k, β″=β′+T). An example of such an update is shown in Figure A2.
- From the posterior pdf of λ a posterior pdf for the annual probability of an accident can be derived. From the latter probability intervals for this probability are then derived.



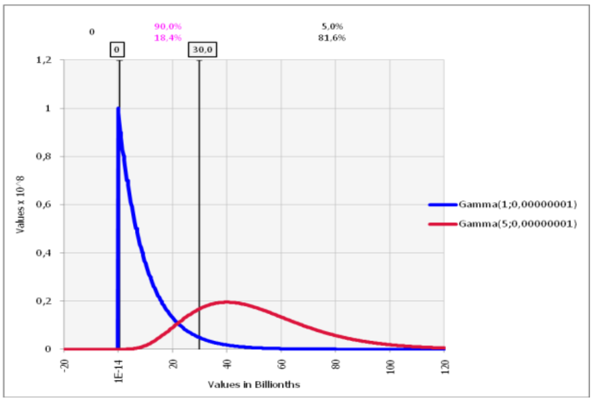


*Figure A1 Prior distribution for annual accident probability (left)*
*Figure A2 Prior and posterior distribution for λ (right)*

## 2.2 Sampling Evidence

From the OHIA project (Uijt de Haag et al., 2010) the following statistics have been obtained.

Table A1 provides the observed numbers of accidents (k) for the various types of accidents and the four types of jobs considered.

Table A2 provides the estimated populations of workers that provided the accidents of Table A1. It also gives the assumed average number of hours a worker works and is exposed to hazards over a year. It is noteworthy that the annual probability for an accident for an individual working exactly the average number of hours in a year does not depend on the assumed average annual working time. (see section 3.1.6 Eq.(23)). However the assumed distributions of the individual annual working times are important to establish the variability in the individual annual probability.

*Table A1 Number of accidents observed in the period of 6.17 years*

| Job | Deaths | Permanent injuries | Recoverable injuries |
|---|---|---|---|
| Tiler | 1 | 0 | 6 |
| Road paver | 1 | 2 | 11 |
| Carpenter | 15 | 184 | 454 |
| Concrete driller | 0 | 11 | 20 |

*Table A2 Populations of workers in the four types of jobs*

| Job | Population (N) | Average number of working hours exposed to hazards per year (τ) | Total exposure (T=N·τ·x) |
|---|---|---|---|
| Tiler | 3200 | 267 | 5.3E6 |
| Road paver | 4300 | 400 | 10.6E6 |
| Carpenter | 80,000 | 400 | 197.4E6 |
| Concrete driller | 1900 | 356 | 4.2E6 |

## 2.3 Uncertainty owing to limited sampling size

Given a particular evidence the Bayesian approach provides through the posterior distribution probability intervals for the hazard rate $\lambda$ and hence for the annual probability of an accident given a particular individual exposure.
The mean time of the posterior is equal to the point MLE of $\lambda$.
Owing to the specific nature of the assumed prior distribution the posterior is such that the random variable $2\lambda(T+\tau)$ is distributed according to a $\chi^2$ pdf. The 95% percentile of the posterior distribution is almost equal to an approximation given often in the literature as 'confidence limit'.(see section 3.2.6)
The results are given in Tables A3, A4, and A5 for an individual exposed for the average yearly working time.

*Table A3 Uncertainty in the annual probability for a lethal accident*

| **Job** | **Death** | | | |
|---|---|---|---|---|
| | R**5%** | R**50%** | R**95%** | **EF** (=R95%/R5%) |
| Tiler | 1.8E-05 | 8.5E-05 | 2.4E-04 | 13.3 |
| Road paver | 1.3E-05 | 6.3E-05 | 1.8E-04 | 13.3 |
| Carpenter | 2.0E-05 | 3.2E-05 | 4.7E-05 | 2.3 |
| Concrete driller | 4.4E-06 | 5.9E-05 | 2.6E-04 | 58.4 |

*Table A4 Uncertainty in the annual probability for a permanent injury accident*

| **Job** | **Permanent injury** | | | |
|---|---|---|---|---|
| | R**5%** | R**50%** | R**95%** | **EF** (=R95%/R5%) |
| Tiler | 2.6E-06 | 3.5E-05 | 1.5E-04 | 58.4 |
| Road paver | 3.1E-05 | 1.0E-04 | 2.4E-04 | 7.7 |
| Carpenter | 3.3E-04 | 3.7E-04 | 4.2E-04 | 1.3 |
| Concrete driller | 5.9E-04 | 9.9E-04 | 1.6E-03 | 2.6 |

*Table A5 Uncertainty in the annual Probability for a Recoverable-Injury Accident*

| **Job** | **Recoverable injury** | | | |
|---|---|---|---|---|
| | R**5%** | R**50%** | R**95%** | **EF** (=R95%/R5%) |
| Tiler | 1.7E-04 | 3.4E-04 | 6.0E-04 | 3.6 |
| Road paver | 2.6E-04 | 4.4E-04 | 6.9E-04 | 2.6 |
| Carpenter | 8.5E-04 | 9.2E-04 | 9.9E-04 | 1.2 |
| Concrete driller | 1.2E-03 | 1.8E-03 | 2.5E-03 | 2.1 |

It is noteworthy that the Error factor (EF) defined as the ratio of the 95% percentile to the 5% percentile gives a measure of the 90% probability interval and it depends only on the number of observed accidents. This is expected since the total exposure T is simply a scale parameter deterring the order of value of $\lambda$.

Perusal of Tables A1, A3, A4 and A5 indicates that the larger probability intervals correspond to cases where there was a limited or no number of accidents, as for example, the number of deaths for concrete drillers or permanent injuries for tilers.

The range where $\lambda$ takes values is also important. For example the annual probability for a permanent injury accident for tilers is characterized by a large uncertainty. However, we can say with a high degree of confidence that tilers are characterized by a lower annual probability for PI when compared with carpenters. This is true despite of the fact that the probability for the carpenters is known with relative accuracy.

## 2.4 Uncertainty owning to possible underreporting

The previous subsection examines the uncertainty on the real value of the hazard rate $\lambda$ given the sufficient statistics (k,T) of the sample. Exact knowledge of the sample results has been assumed. In large samples, like working populations and public reporting systems, the accuracy of the calculated statistics may be questionable. An indication of the effect to the annual individual risk for an accident of potential uncertainties in the sufficient statistics can be estimated if these uncertainties are quantified.

The number of accidents actually occurred may be larger than the number reported in the GISAI data base owing to possible underreporting. To assess the impact of such underreporting on the uncertainty of the annual probability for accident the number of non-reported accidents has been considered as a random variable distributed uniformly from zero to the number of the reported accidents. This allows for a potential underreporting up to 100% of the reported accidents or 50% of the actual accidents.

*No underreporting has been considered for the number of deaths.* For example underreporting in the number of permanent injuries for carpenters is modelled by assuming that in addition to the reported number of permanent injuries ($k_0$) there are additional unreported permanent injuries $\tilde{k}$ distributed according to a uniform distribution of integers between 0 and 200. Since $k_0$=184 the uniform distribution has been chosen to model an underreporting of about 50% of the actual accidents. Thus the actual number of permanent-injury accidents can vary between 184 and 384. The expected number of PI is 284, and the 90% interval is [194, 374], see Figure A3a.

Underreporting in the number of recoverable injuries of carpenters is modelled by assuming that in addition to the reported number of recoverable injuries ($k_0$) there are additional unreported recoverable injuries $\tilde{k}$ distributed according to a uniform distribution of integers between 0 and 500. Since $k_0$=454 the uniform distribution has been chosen to model an underreporting of about 50% of the actual accidents. Thus the actual number of recoverable-injury accidents can vary between 454 and 954. The expected number of PI is 704, and the 90% interval is [479, 929], see Figure A3b.

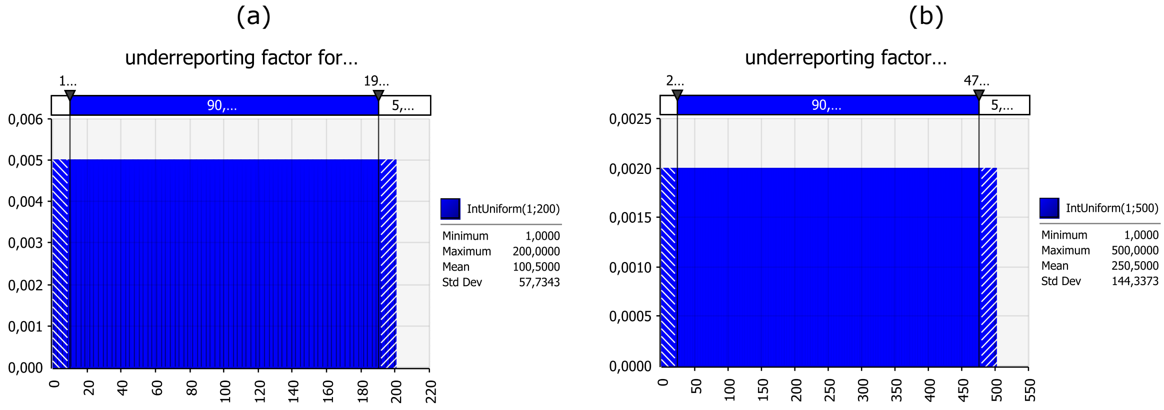


*Figure A3 Underreporting in accidents of carpenters: (a) Permanent injuries; (b) Recoverable injuries*

The assumptions about the pdfs of the underreported accidents for the various job types are given in Tables A6 and A7.

The results are given in Table A8. Double 90% probability intervals have been calculated, one quantifying the uncertainty owing to the limited information (less than perfect) that is contained in the sufficient statistics (k,T) and the other to quantify the uncertainty in the statistic k. In Table A6, for carpenters, the first row of the results for permanent injuries provides the 90% probability interval ($3.5\times10^{-4}$, $4.4\times10^{-4}$) for the annual risk owing to the limited information in the sample when the number of the underreported accidents is at its lowest 5% (i.e. $\tilde{k}$ =10 and k=184+10=194). The last row provides the corresponding 90% probability interval ($7\times10^{-4}$, $8.3\times10^{-4}$) when the number of the non-reported accidents has its upper 95% value (i.e. $\tilde{k}$ =190 and k=184+190=374). Overall, the combined uncertainty owing to the limited information in the sample and the uncertainty in the value of the number of accidents can be expressed by the overall 90% probability interval [$3.5\times10^{-4,}$ $8.3\times10^{-4}$] with an error factor of 2.4 while without uncertainty in k it was 1.3.

Comparison of the results in Tables A4, A5 and A8 indicates that the effect of possible underreporting is not significant given that it is confined within the 100% of the reported accidents.

*Table A6 Distribution characteristics for the number of non-reported* ***permanent injuries***

| **Job** | **Type of pdf** | **Min** | **Max** | **5%** | **95%** |
|---|---|---|---|---|---|
| Tiler | IntUniform | 0 | 3 | 0 | 3 |
| Road paver | IntUniform | 0 | 3 | 0 | 3 |
| Carpenter | IntUniform | 0 | 200 | 10 | 190 |
| Concrete driller | IntUniform | 0 | 15 | 0 | 15 |

*Table A7 Distribution characteristics for the number of non-reported* ***recoverable injuries***

| **Job** | **Type of pdf** | **Min** | **Max** | **5%** | **95%** |
|---|---|---|---|---|---|
| Tiler | IntUniform | 0 | 6 | 0 | 6 |
| Road paver | IntUniform | 0 | 22 | 1 | 21 |
| Carpenter | IntUniform | 0 | 500 | 25 | 475 |
| Concrete driller | IntUniform | 0 | 25 | 1 | 24 |

*Table A8 Uncertainty in the annual probability of an accident owing to possible underreporting*

| **Job** | | | **Death** | | | **Permanent Inj** | | | **Recoverable Inj.** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | |
| | | | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** |
| Tile setter | Uncertainty owing to the parameter k | 5% | N/A | N/A | N/A | 2,6E-06 | 3,5E-05 | 1,5E-04 | 1,7E-04 | 3,4E-04 | 6,0E-04 |
| | | 50% | N/A | N/A | N/A | 1,8E-05 | 8,5E-05 | 2,4E-04 | 2,7E-04 | 4,9E-04 | 7,9E-04 |
| | | 95% | N/A | N/A | N/A | 6,9E-05 | 1,9E-04 | 3,9E-04 | 3,9E-04 | 6,4E-04 | 9,8E-04 |
| Road paver | | 5% | N/A | N/A | N/A | 3,1E-05 | 1,0E-04 | 2,4E-04 | 2,9E-04 | 4,8E-04 | 7,3E-04 |
| | | 50% | N/A | N/A | N/A | 5,1E-05 | 1,4E-04 | 2,9E-04 | 5,9E-04 | 8,5E-04 | 1,2E-03 |
| | | 95% | N/A | N/A | N/A | 9,8E-05 | 2,1E-04 | 4,0E-04 | 9,1E-04 | 1,2E-03 | 1,6E-03 |
| Carpenter | | 5% | N/A | N/A | N/A | **3,5E-04** | 3,9E-04 | 4,4E-04 | 9,0E-04 | 9,7E-04 | 1,0E-03 |
| | | 50% | N/A | N/A | N/A | 5,2E-04 | 5,8E-04 | 6,3E-04 | 1,3E-03 | 1,4E-03 | 1,5E-03 |
| | | 95% | N/A | N/A | N/A | 7,0E-04 | 7,6E-04 | **8,3E-04** | 1,8E-03 | 1,9E-03 | 2,0E-03 |
| Concrete driller | | 5% | N/A | N/A | N/A | 5,9E-04 | 9,9E-04 | 1,6E-03 | 1,3E-03 | 1,8E-03 | 2,6E-03 |
| | | 50% | N/A | N/A | N/A | 1,1E-03 | 1,6E-03 | 2,3E-03 | 2,1E-03 | 2,8E-03 | 3,7E-03 |
| | | 95% | N/A | N/A | N/A | 1,6E-03 | 2,3E-03 | 3,1E-03 | 2,9E-03 | 3,8E-03 | 4,8E-03 |

## 2.5 Uncertainty owing to working population size

Uncertainties in the assessment of the actual population (N) that has produced the sample statistics have been quantified by considering N as a random variable assumed to be distributed according to a General Beta distribution with parameters (p,q,$N_{min}$, $N_{max}$).
For example the population of carpenters has been given a General Beta pdf with parameters (2, 6, 40,000, 200,000). This means that the minimum value for population size is 40,000, the maximum number is 200,000 workers and 2, 6 determine the shape of the distribution as shown in Figure A4. The 90% interval is [48,500, 123,300], the mean value is 80,000 and the standard deviation 23,094.

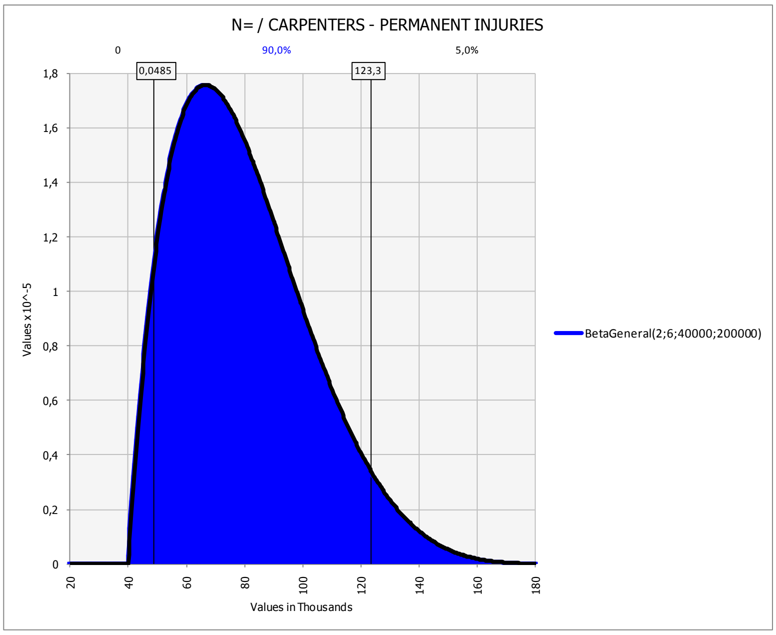


*Figure A4 Assumed uncertainty in the population of carpenters*

The assumptions about the pdfs of the size of the working population for the various job types are given in Table A9.

*Table A9 Distribution characteristics for the **working population** size*

| Job | Type of pdf | p | q | Min | Max | 5% | Mean | 95% |
|---|---|---|---|---|---|---|---|---|
| Tiler | Beta General | 2 | 3 | 2000 | 5000 | 2,293 | 3200 | 4254 |
| Road paver | Beta General | 2 | 3 | 2500 | 7000 | 2939 | 4300 | 5881 |
| Carpenter | Beta General | 2 | 6 | 40,000 | 200,000 | 48,500 | 80,000 | 123,300 |
| Concrete driller | Beta General | 2 | 4.66 | 1000 | 4000 | 1201 | 1900 | 2817 |

Table A10 tabulates the corresponding results providing generalised 90% probability intervals as explained in the previous subsection.

Table A10 Uncertainty in the annual probability of an accident owing to Population size (N)

| **Job** | | | **Death** | | | **Permanent Inj** | | | **Recoverable Inj.** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | |
| | | | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** |
| Tile setter | Uncertainty owing to the parameter N | 5% | 1,4E-05 | 6,4E-05 | 1,8E-04 | 2,0E-06 | 2,6E-05 | 1,1E-04 | 1,3E-04 | 2,5E-04 | 4,5E-04 |
| | | 50% | 1,8E-05 | 9,5E-05 | 2,4E-04 | 2,6E-06 | 4,1E-05 | 1,5E-04 | 1,7E-04 | 3,6E-04 | 6,1E-04 |
| | | 95% | 2,5E-05 | 1,2E-04 | 3,3E-04 | 3,6E-06 | 4,9E-05 | 2,1E-04 | 2,3E-04 | 4,7E-04 | 8,4E-04 |
| Road paver | | 5% | **9,8E-06** | 4,6E-05 | 1,3E-04 | 2,3E-05 | 7,4E-05 | 1,7E-04 | 1,9E-04 | 3,2E-04 | 5,0E-04 |
| | | 50% | 1,4E-05 | 7,1E-05 | 1,8E-04 | 3,1E-05 | 1,1E-04 | 2,4E-04 | 2,6E-04 | 4,6E-04 | 7,0E-04 |
| | | 95% | 2,0E-05 | 9,2E-05 | **2,6E-04** | 4,5E-05 | 1,5E-04 | 3,5E-04 | 3,8E-04 | 6,4E-04 | 1,0E-03 |
| Carpenter | | 5% | **1,3E-05** | 2,1E-05 | 3,0E-05 | 2,1E-04 | 2,4E-04 | 2,7E-04 | 1,9E-04 | 3,2E-04 | 5,0E-04 |
| | | 50% | 2,1E-05 | 3,4E-05 | 4,9E-05 | 3,5E-04 | 3,9E-04 | 4,4E-04 | 2,6E-04 | 4,6E-04 | 7,0E-04 |
| | | 95% | 3,3E-05 | 5,2E-05 | **7,7E-05** | 5,4E-04 | 6,2E-04 | 6,9E-04 | 3,8E-04 | 6,4E-04 | 1,0E-03 |
| Concrete driller | | 5% | 2,9E-06 | 4,0E-05 | 1,7E-04 | 4,0E-04 | 6,7E-04 | 1,0E-03 | 8,1E-04 | 1,2E-03 | 1,7E-03 |
| | | 50% | 4,5E-06 | 7,0E-05 | 2,6E-04 | 6,1E-04 | 1,1E-03 | 1,6E-03 | 1,2E-03 | 1,9E-03 | 2,6E-03 |
| | | 95% | 6,9E-06 | 9,3E-05 | 4,0E-04 | 9,3E-04 | 1,6E-03 | 2,5E-03 | 1,9E-03 | 2,8E-03 | 3,9E-03 |

## 2.6 Uncertainty owing to the individual annual exposure time

As it is discussed in section 2.1 and section 3.1.3 the overall exposure T depends in addition to the sampling population size (N) on the average individual working time τ. Again in section 3.1.6 it is shown that the annual risk of an accident for an individual *with annual working time equal to the average working time τ* does not depend on τ but only on (k,N). However the annual risk for a particular individual does depend on its own specific number of working hours per year. Thus if this time exhibits a variability, so does the corresponding annual risk. To quantify the effect of this variability the number of working hours per year for each of the 4 jobs considered in this report have been assumed to be random variables distributed according to given pdfs.

In particular the annual working times have been considered distributed according to General Beta pdfs B(p,q,0,1600). That is with maximum value 1600hours, minimum 0 hours and the parameters p, q determining the shape, the mean and the standard deviation of the distribution. For carpenters, for example, it has been assumed that p=2 and q=6 resulting in a pdf with mean equal to 40 0hours and a 90% probability interval of (85h, 833h). (see Figure A5)

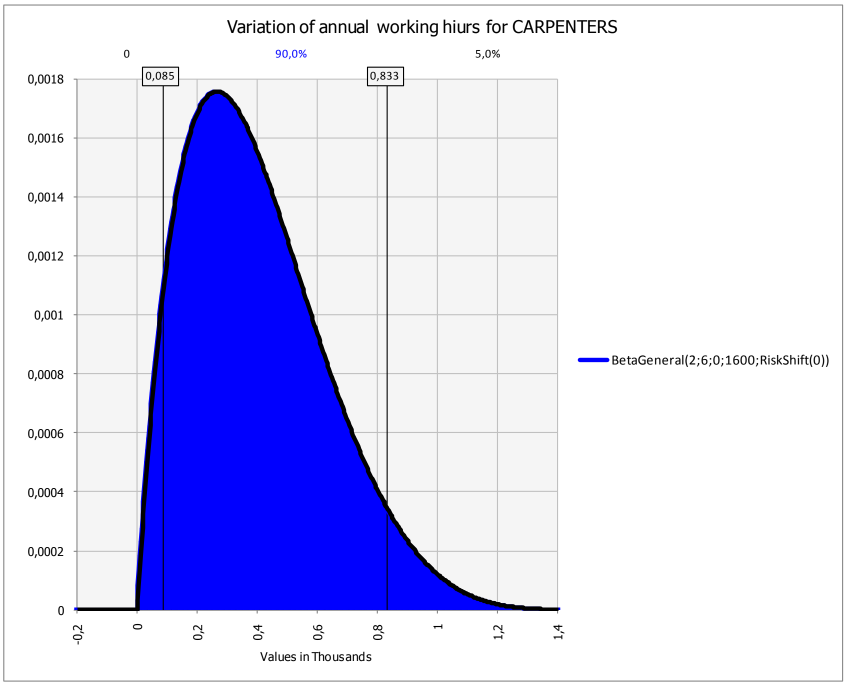


*Figure A5 Assumed uncertainty in the number of working hours per year of carpenters*

The assumed pdfs for the number of working hours for the job types are given in Table A11.

*Table A11 Distribution characteristics for the **annual exposure time** (hours)*

| Job | Type of pdf | p | q | Min | Max | 5% | Mean | 95% |
|---|---|---|---|---|---|---|---|---|
| Tiler | Beta General | 2 | 10 | 0 | 1600 | 53 | 267 | 583 |
| Road paver | Beta General | 2 | 6 | 0 | 1600 | 85 | 400 | 833 |
| Carpenter | Beta General | 2 | 6 | 0 | 1600 | 85 | 400 | 833 |
| Concrete driller | Beta General | 2 | 7 | 0 | 1600 | 74 | 356 | 753 |

Table A12 tabulates the corresponding results providing generalised 90% probability intervals as explained in section 2.4.

### 2.7 Overall uncertainty assessment

Finally a calculation that combines all three kinds of uncertainty (k,N,t) provides the results tabulated in Table A13.

*Table A12 Uncertainty in the annual probability of an accident owing to individual annual exposure $\tilde{\tau}$.* .

| Job | | | Death | | | Permanent Inj | | | Recoverable Inj. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | |
| | | | R5% | R50% | R95% | R5% | R50% | R95% | R5% | R50% | R95% |
| Tile setter | Uncertainty owing to the parameter $\tau$ | 5% | 3,6E-06 | 1,7E-05 | 4,8E-05 | 5,2E-07 | 7,0E-06 | 3,0E-05 | 3,3E-05 | 6,7E-05 | 1,2E-04 |
| | | 50% | 1,6E-05 | 7,5E-05 | 2,1E-04 | 2,3E-06 | 3,1E-05 | 1,3E-04 | 1,5E-04 | 3,0E-04 | 5,3E-04 |
| | | 95% | 3,9E-05 | 1,9E-04 | 5,2E-04 | 5,7E-06 | 7,7E-05 | 3,3E-04 | 3,6E-04 | 7,4E-04 | 1,3E-03 |
| Road paver | | 5% | 2,9E-06 | 1,3E-05 | 3,8E-05 | 6,6E-06 | 2,1E-05 | 5,1E-05 | 5,5E-05 | 9,3E-05 | 1,4E-04 |
| | | 50% | 1,2E-05 | 5,8E-05 | 1,6E-04 | 2,8E-05 | 9,2E-05 | 2,2E-04 | 2,4E-04 | 4,0E-04 | 6,3E-04 |
| | | 95% | 2,8E-05 | 1,3E-04 | 3,7E-04 | 6,4E-05 | 2,1E-04 | 4,9E-04 | 5,4E-04 | 9,1E-04 | 1,4E-03 |
| Carpenter | | 5% | 4,3E-06 | 6,8E-06 | 1,0E-05 | 7,0E-05 | 7,9E-05 | 8,9E-05 | 1,8E-04 | 1,9E-04 | 2,1E-04 |
| | | 50% | 1,9E-05 | 2,9E-05 | 4,3E-05 | 3,0E-04 | 3,4E-04 | 3,8E-04 | 7,8E-04 | 8,4E-04 | 9,1E-04 |
| | | 95% | 4,2E-05 | 6,6E-05 | 9,7E-05 | 6,9E-04 | 7,8E-04 | 8,8E-04 | 1,8E-03 | 1,9E-03 | 2,1E-03 |
| | | | | | | 9,8E+00 | | | | | |
| Concrete driller | | 5% | 9,1E-07 | 1,2E-05 | 5,3E-05 | 6,6E-06 | 2,1E-05 | 5,1E-05 | 2,5E-04 | 3,6E-04 | 5,1E-04 |
| | | 50% | 3,9E-06 | 5,3E-05 | 2,3E-04 | 2,8E-05 | 9,2E-05 | 2,2E-04 | 1,1E-03 | 1,6E-03 | 2,2E-03 |
| | | 95% | 9,2E-06 | 1,2E-04 | 5,4E-04 | 6,4E-05 | 2,1E-04 | 4,9E-04 | 2,5E-03 | 3,7E-03 | 5,2E-03 |

*Table A13 Combined uncertainty in the annual probability of an accident owing to the parameters* $k, N, \tilde{\tau}$

| Job | | | Death | | | Permanent Inj | | | Recoverable Inj. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | | Uncertainty owing to limited sampling | | |
| | | | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** | R**5%** | R**50%** | R**95%** |
| Tile setter | Uncertainty owing to the parameters $k, N, \tau$ | 5% | 1,6E-06 | 1,8E-05 | 5,0E-05 | 2,6E-07 | 1,4E-05 | 4,9E-05 | 3,9E-05 | 9,0E-05 | 1,4E-04 |
| | | 50% | 6,7E-06 | 7,6E-05 | 2,1E-04 | 9,8E-06 | 8,1E-05 | 2,3E-04 | 1,8E-04 | 4,3E-04 | 7,1E-04 |
| | | 95% | 1,8E-05 | 2,0E-04 | 5,8E-04 | 7,0E-05 | 3,3E-04 | 7,3E-04 | 5,4E-04 | 1,2E-03 | 1,9E-03 |
| Road paver | | 5% | 1,2E-06 | 1,4E-05 | 3,9E-05 | 6,1E-06 | 3,0E-05 | 6,0E-05 | 8,2E-05 | 1,5E-04 | 2,1E-04 |
| | | 50% | 5,1E-06 | 5,8E-05 | 1,6E-04 | 3,2E-05 | 1,4E-04 | 2,9E-04 | 4,3E-04 | 7,4E-04 | 1,1E-03 |
| | | 95% | 1,3E-05 | 1,5E-04 | 4,2E-04 | 1,2E-04 | 4,0E-04 | 7,8E-04 | 1,3E-03 | 2,1E-03 | 2,9E-03 |
| Carpenter | | 5% | 3,3E-06 | 6,4E-06 | 9,4E-06 | 9,5E-05 | 1,1E-04 | 1,2E-04 | 2,5E-04 | 2,6E-04 | 2,8E-04 |
| | | 50% | 1,5E-05 | 2,9E-05 | 4,3E-05 | 4,6E-04 | 5,3E-04 | 5,9E-04 | 1,2E-03 | 1,3E-03 | 1,4E-03 |
| | | 95% | 4,1E-05 | 7,9E-05 | 1,2E-04 | 1,3E-03 | 1,5E-03 | 1,6E-03 | 3,4E-03 | 3,6E-03 | 3,8E-03 |
| | | | | | | 1,3E+01 | | | | | |
| Concrete driller | | 5% | 8,5E-07 | 1,1E-05 | 5,0E-05 | 1,6E-04 | 2,9E-04 | 4,3E-04 | 3,2E-04 | 5,0E-04 | 6,8E-04 |
| | | 50% | 4,0E-06 | 5,4E-05 | 2,3E-04 | 7,9E-04 | 1,5E-03 | 2,1E-03 | 1,6E-03 | 2,6E-03 | 3,4E-03 |
| | | 95% | 1,1E-05 | 1,4E-04 | 6,3E-04 | 2,5E-03 | 4,2E-03 | 5,8E-03 | 4,8E-03 | 7,1E-03 | 9,3E-03 |

# 3 Theoretical background

Annual probability of an accident depends on the exposure of a worker to a number of hazardous agents and on the duration of these exposures. ORCA has assessed 63 such hazardous agents. Occupational risk of an accident depends on which of these agents are present during the performance of a job and for how long.

It has been decided by the OHIA project management and it was included in the terms of reference of this work that this detailed approach to the assessment of the occupational risk will not be followed. Instead an overall risk, specific to each of the four job types considered in the OHIA project, will be assessed on the basis of the overall available statistics. Available statistics are: the number of reported accidents per job type; and the assessed overall exposure of those in the particular job providing the accident statistics.

A fundamental assumption of the developed model is that accidents happen randomly as the worker performs the job and that the times at work before an accident occurs are exponentially distributed. That is, accidents arrive according to a Poisson random process.

Parameters of the Poisson model can be estimated on the basis of observations, i.e. the number of accidents and the times at which they arrive over a given population of workers. These statistics are obtained from the records of the Labour Inspectorate and other labour statistics.

There are, however, uncertainties associated with the various parameters of the model and the obtained statistics. These uncertainties are quantified according to the general principles and methodology of the Bayesian Analysis.

## 3.1 Annual probability of an accident

The fundamental quantity in the random process generating occupational accidents is the accident intensity rate $\lambda$. If $\lambda$ is known then the times of accident arrivals are exponentially distributed according to the exponential pdf or

$$f(t) = \lambda e^{-\lambda t} \qquad (2)$$

If a worker is exposed to accident hazards for $\tau$ hours during a calendar year then the probability that there will be an accident anytime during this period is equal to the probability that the time of accident arrival will be less than $\tau$ or

$$p = F(t \leq \tau) = 1 - e^{-\lambda \tau} \qquad (3)$$

### 3.1.1 Sampling and likelihood of sample

The parameter $\lambda$ is estimated from observations of the random process and recording of the times at which accidents occur.

This is usually done by observing a population of N workers, each for a given period of time $t_0$. Then the following results are obtained:

$t_1$ : the time of the 1st accident;
$t_2$ : the time of the 2nd accident;
.

$t_k$ : the time of the k$^{tht}$ accident;
$t_{k+1}$ = $t_0$ the (k+1)$^{th}$ worker completed the period of $t_0$ without accident;
$T_N$ =$t_0$ the Nth worker completed the period of $t_0$ without accident.

The likelihood of a sampling outcome like this is determined by the individual likelihoods of each outcome namely,

Probability of an accident occurring at time $t_k$ is

$$\Pr\{t = t_k\} = \lambda e^{-\lambda t_k} \qquad (4)$$

Probability of no accident occurring during $t_0$ is

$$\Pr\{t \geq t_0\} = e^{-\lambda \tau} \qquad (5)$$

Hence the likelihood *L* is given by

$$L = \prod_{i=1}^{k} \lambda e^{-\lambda t_i} \prod_{j=k+1}^{N} e^{-\lambda t_0} = \lambda^k \exp[-\lambda(\sum_{i=1}^{k} t_i - \sum_{j=k+1}^{N} t_0)] = \lambda^k e^{-\lambda T} \qquad (6)$$

Where *T* is the total exposure given by

$$T = \sum_{i=1}^{k} t_i + (N-k)t_0 \qquad (7)$$

From equation (6) it follows that the likelihood of the sample depends only on the statistics {k,T} and not on the individual observed times ($t_k$). For this reason the statistics {k,T} are called sufficient statistics of the sampling procedure.

### 3.1.2 Maximum likelihood estimation of the accidents rate λ given the sufficient statistics k and T

It can be shown that the estimation of the accident rate λ that maximizes the likelihood L given by Eq (6) is given by

$$\hat{\lambda} = \frac{k}{T} \qquad (8)$$

Equation (8) is widely used to obtain a point estimation of the accident rate λ. However, care must be taken on the correct calculation of the sufficient statistic T.

### 3.1.3 Estimation of exposure – approximations

The general expression for the sufficient statistic T of a sample taken from a Poisson random process is given by Eq. (7), there are, however, some special cases that facilitate some further analysis. The distinction of the various types of samplings has to do with the way the sample is taken and in particular on how the sampling procedure is terminated.

### 3.1.3.1 Fixed number of failure (k) to be observed (gamma sampling)

In the gamma type of sampling the sampling procedure stops immediately when the $k^{th}$ accident occurs. If a worker has an accident, he is not replaced or he is removed from the sample. The sufficient statistic k is in this case predetermined and the total exposure T is given by

*Gamma sampling without replacement* $T = \sum_{i=1}^{k} t_i$ (9)

If the population of the workers, N, is known and the times of accident arrival are recorded until the $k^{th}$ accident occurs, then the sufficient statistic T is given by

*Gamma sampling of size N without replacement* $T = \sum_{i=1}^{k} t_i + (N-k)t_k$ (10)

If the population of the workers is known, N, and a worker after having an accident is replaced, then the test is terminated again after the $k^{th}$ accident occurs at $t_k$ but the times ($t_k$-$t_i$) additional workers are added to the sample, thus the total exposure becomes

*Gamma sampling of size N with replacement* $T = Nt_k$ (11)

It is noteworthy that prior to gamma sampling the total exposure is always unknown (random) while the number of accidents to be observed is deterministically known.

### 3.1.3.2 Fixed exposure (T) to be observed (Poisson sampling)

In the Poisson type of sampling, the sampling procedure stops when a certain predetermined total exposure has been achieved and the number of accidents that have occurred has been recorded. In this case the number of accidents (k) to be observed is random.

*Poisson sampling without replacement* $T = \sum_{i=1}^{k} t_i + t$ (12)

Where $\{t_i\}$ are the k times to accident and t the remaining time (can be equal to zero) to complete the fixed time period T.

If there are N workers in the sample to be observed, then the duration of observation of each one is set to $t_0$.
If in addition there is no replacement of a worker having an accident, then

*Poisson sampling of size N without replacement* $T = \sum_{i=1}^{k} t_i + (N-k)t_0$ (13)

If there is replacement of a worker in the sample when he has an accident then

*Poisson sampling of size N with replacement* $T = Nt_0$ (14)

In all these cases the statistic T is predetermined and known and the statistic k is randomly determined after the sampling ends.

### 3.1.4 Variations of sufficient statistic T in gamma sampling and confidence intervals

Point estimations of the accident rate λ are given by Eq (8) when the sufficient statistics {k,T} are obtained from the sampling procedure. In certain cases it is also possible to obtain confidence limits for the true value of λ.

In the case of *gamma sampling without replacement* we get that prior to performing the sampling that k is known but T is randomly given by Eq. (9) as a sum of k individual random variables each distributed according to the exponential pdf which is simply a gamma pdf with parameters (1,λ).
It can be shown that the sum of k variables each distributed according to a gamma pdf with parameters ($r_i$,λ) or the convolution of k gamma pdfs is again a gamma pdf with parameters {($r_1+r_2+\ldots+r_k$), λ}. Hence since $r_1=r_2=\ldots+r_k=1$, the random variable T is distributed according to a gamma pdf with parameters (k,T) or

$$f(T)=f_{\gamma_1}(T\,|\,k,\lambda)=\frac{e^{-\lambda T}(\lambda T)^{k-1}\lambda}{\Gamma(k)} \qquad (15)$$

Or with a change of variable setting

$$x=2\lambda T \qquad (16)$$

It follows that

$$f(x)=f_{\gamma_1}(T(x))\frac{\partial T}{\partial x}=\frac{e^{-\frac{x}{2}}(\frac{x}{2})^{k-1}\lambda}{\Gamma(k)}\frac{1}{2\lambda}=\frac{e^{-\frac{x}{2}}(\frac{x}{2})^{\frac{2k}{2}-1}}{\Gamma(k)}\frac{1}{2}=f_{x^2}(x\,|\,2k) \qquad (17)$$

Or that the variable x has a $\chi^2$ pdf with 2k degrees of freedom.

Then the confidence interval α is given by

$$\Pr[\chi^2_{\alpha/2}(2k)\le 2\lambda T\le \chi^2_{1-\alpha/2}(2k)]=1-\alpha \qquad (18)$$

And hence

$$\Pr[\frac{\chi^2_{\alpha/2}(2k)}{2T}\le\lambda\le\frac{\chi^2_{1-\alpha/2}(2k)}{2T}]=1-\alpha \qquad (19)$$

But these confidence limits can be used only and only if the sampling is a gamma sampling where the statistic k (number of accidents) is predetermined there is no replacement and the sampling stops immediately after observing the $k^{th}$ failure.

The statistics available to the OHIA2 project are not from a gamma sampling since in this case the period of observation is fixed (the number of years, the size of worker's population is fixed) and the number of accidents is random. So equation (19) cannot be used to calculate confidence limits to the accident rate.

### 3.1.5 Variations of sufficient statistic k in Poisson sampling and confidence intervals

In the case of *Poisson sampling without replacement* the statistic T is fixed prior to performing the sampling and k is random. The pdf of the random variable $\tilde{k}$ can be determined by noting that the probability that there will be k or more failures is equal to the probability that the total time $\tilde{T}$ required to observe $\tilde{k}$ accidents is less or equal to the available total time *T*.

$$\Pr\{\tilde{k} \ge k \mid T,\lambda) = \Pr\{\tilde{T} \le T \mid k,\lambda\} = F_{\gamma_1}(T \mid k,\lambda) = F_{\gamma}(\lambda T \mid k) \quad (20)$$

The last part of the equation following from the fact that the total time of k failure is distributed according to a $\gamma_1$ pdf (see Eq.(15) in the previous subsection). But the cumulative distribution of a gamma distribution is equal to the complementary cumulative distribution of a Poisson mass function. Hence

$$f(k) = f_P(k \mid \lambda T) = \frac{(\lambda T)^k e^{-\lambda T}}{\Gamma(k+1)} \quad (21)$$

It is noteworthy that in this case k is an integer and hence Eq. (21) cannot be used to obtain confidence limits for λ.

### 3.1.6 Final expression of annual probability of accident as a function of k and N alone

In most cases of working population sampling to observe accidents the sampling is Poisson type. That is the observation period is fixed and the number of observed accidents is left to chance. This is certainly the case for the data in the OHIA2 project.

A number of N workers is observed for x years and the number of accidents is recorded. Then the total exposure T is given by one of the Equations (13) or (14). Given that k is usually small compared to N, equation (14) is a good approximation for T even when replacement is not assured.

Then by virtue of equations (8) and (14) the MLE of the accident rate is

$$\hat{\lambda} = \frac{k}{T} = \frac{k}{Nxt_0} \quad (22)$$

and from Eq. (3), it follows that the probability of an accident per year, *assuming that an individual worker is exposed to the risk for the whole period $t_0$*, is given by

$$p = F(t \le t_0) = 1 - e^{-\hat{\lambda} t_0} = 1 - e^{-\frac{k}{Nxt_0}t_0} = 1 - e^{-\frac{k}{Nx}} \quad (23)$$

Equation (23) is used to estimate the annual probability of an accident when a population of workers is observed for a fixed number of years x and the number of occurred accidents (k) is recorded. It is noteworthy that the average exposure $t_0$ does not appear in the equation for the annual accident probability.

## 3.2 Uncertainty assessment: the Bayesian approach

The accident rate is the fundamental parameter of the model. Every other quantity of interest, like the probability of an event occurring within a given period T, is expressed in terms of the accident rate *λ*. As a result the uncertainties are assessed in terms of this fundamental quantity.

### 3.2.1 Prior distribution of accident rate λ

Prior to obtaining the sampling results, the state of knowledge is described by assuming that the accident rate (λ) is distributed according to a gamma-1 pdf or

$$f'(\lambda) = f_{\gamma_1}(\lambda \mid \alpha, \beta) = \frac{e^{-\lambda\beta}(\lambda\beta)^{a-1}}{\Gamma(\alpha)}\beta \quad \alpha>0\ ,\ \beta>0 \qquad (24)$$

The gamma-1 distribution has been chosen simply for calculation convenience, since the gamma-1 pdf is the natural conjugate distribution to the likelihood of sample from a Poisson random process resulting in a gamma-1 posterior distribution.

Parameters (α,β) are chosen so that the mean and the standard deviation are getting desirable values.

#### 3.2.1.1 Choice of prior distribution

Even though the accident rate λ is the basic parameter of our model, the risk measure of interest is the annual probability for an accident.

It is more natural then to express the state of knowledge on the probability of an accident during the course of a year. Complete lack of knowledge on the value of this probability would imply a uniform pdf spanning the interval (0,1). See Figure A2.

Since the p and λ are connected through equation (3) the parameters (α,β) in the prior of f'(λ) can be chosen such that the prior of p is non-informative. This is done as follows.

The pdf of p is uniform over an interval (a,b) hence,

$$f(p) = \frac{1}{b-a} \qquad (25)$$

By virtue of equation (3) it follows that

$$\frac{\partial p}{\partial \lambda} = \tau e^{-\lambda\tau}$$

and since the pdf of λ g(λ) is given by

$$g(\lambda) = f[p(\lambda)]\frac{\partial p}{\partial \lambda}$$

it follows that the prior of λ is given by

$$f(\lambda)=\begin{cases}0 & if \quad \lambda \le \lambda_L = \dfrac{-\ln(1-a)}{\tau} \\ \dfrac{1}{b-a}\tau e^{-\lambda\tau} & if \quad \lambda_L \le \lambda \le \lambda_U \\ 0 & if \quad \lambda \le \lambda_U = \dfrac{-\ln(1-b)}{\tau}\end{cases} \qquad (26)$$

If (a,b) is the whole interval (0,1) then the prior of λ is

$$f'(\lambda)=\tau e^{-\lambda\tau} \quad = f_{\gamma_1}(\lambda \,|\, 1,\tau)$$

That is the prior of λ is a gamma-1 distribution with parameters

$$\alpha = 1 \quad \text{and} \quad \beta=\tau \qquad (27)$$

This prior is shown in Figure A3.

### 3.2.2 Sampling evidence sufficient statistics

The sufficient statistics of a sample generated by a Poisson process is the number of accidents observed (k) and the total exposure of the population (T) as described in section 3.1.3.

### 3.2.3 Posterior distribution of λ

Given the sufficient statistics of the sample (k,T) the posterior distribution of λ is also a gamma-1 distribution with parameters

$$\alpha'' = \alpha' + k \quad \text{and} \quad \beta'' = \beta' + T \qquad (28)$$

and

$$f''(\lambda) = f_{\gamma_1}(\lambda \,|\, \alpha'+k, \beta'+T) \qquad (29)$$

### 3.2.4 Unconditional distribution of an expected number of failures with fixed duration of sampling (Poisson sampling)

In subsection 3.1.5 it was shown that the conditional on (λ,T) pdf of the unknown, prior to sampling, statistic k is a Poisson distribution. When the accident rate λ is distributed according to a gamma-1 pdf with parameters (α, β) (see Eq. (24)), then it can be shown that the unconditional on λ distribution of the random variable k is a negative binomial distribution with parameters {(T/(β +T),α}

$$f(k \,|\, \alpha,\beta)=\int_0^\infty f_P(k \,|\, \lambda T) f_{\gamma_1}(\lambda \,|\, \alpha,\beta)d\lambda = f_{nb}(k \,|\, \frac{T}{\beta+T},\alpha) = \binom{k+\alpha-1}{k}\left(\frac{T}{\beta+T}\right)^k\left(\frac{\beta}{\beta+T}\right)^\alpha \qquad (30)$$

This means that when the accident rate is not known and is assumed to be distributed according to a gamma-1 pdf, then if the sampling process is Poisson type, that is the exposure T is set at a given predetermined value then prior to observe the process for the duration T and observe the number of accidents k, we expect k to have various values with associated probabilities given by the negative binomial pdf (30). If, furthermore, the prior pdf of λ has the form given in section 3.2.1.1.1, then the unconditional distribution of k becomes

$$f(k\,|\,1,\tau)=\left(\frac{T}{T+\tau}\right)^{k}\frac{\tau}{T+\tau} \qquad (31)$$

### 3.2.5 Distribution of the expected duration of sampling with a fixed number of accidents (gamma sampling)

In subsection 3.1.4 it was shown that the conditional on (λ,k) pdf of the unknown, prior to sampling, statistic T is a gamma-1 distribution. When the accident rate λ is distributed according to a gamma-1 pdf with parameters (α, β) (see Eq. (24)), then it can be shown that the unconditional on λ distribution of the random variable T is an inverted beta-2 pdf with parameters (k,α,β) or

$$f(T\,|\,k,\alpha,\beta)=\int_{0}^{\infty} f_{\gamma_1}(T\,|\,k,\lambda)f_{\gamma_1}(\lambda\,|\,\alpha,\beta)d\lambda = f_{i\beta 2}(T\,|\,k,\alpha,\beta)=\frac{1}{B(k,\alpha)}\frac{T^{k-1}\beta^{\alpha}}{\left(T+\beta\right)^{k+\alpha}}$$
(32)

This means that when the accident rate is not known and is assumed to be distributed according to a gamma-1 pdf, then if the sampling process is gamma type, that is, the number of accidents to be observed is set at a given predetermined value then prior to observe the k accidents, we expect the duration (exposure) of the sampling to have various values with associated probabilities given by the inverted beta-2 pdf (32). If, furthermore, the prior pdf of λ has the form given in subsection 3.2.1.1.1, then the unconditional distribution of T becomes

$$f(T\,|\,k,1,\tau)=\frac{1}{B(k,1)}\frac{T^{k-1}\tau}{\left(T+\tau\right)^{k+1}}=\frac{1}{k}\frac{\tau}{\left(T+\tau\right)^{2}}\left(\frac{T}{T+\tau}\right)^{k-1} \qquad (33)$$

### 3.2.6 Relationship with classical statistics

In subsection 3.1.4 it has been shown that if the random variable λ is distributed according to a gamma-1 pdf with parameters (α,β) then the rv $x=2\lambda\beta$ is distributed according to a $\chi^2$ pdf with $2\alpha$ degrees of freedom.

According to the Bayesian approach if the prior pdf of λ is a pdf with parameters (α,β) and the sufficient statistic of a sample are (k,T) then the posterior pdf of λ is also a gamma-1 with parameters (α+k, β+T). This means that the variable $x=2\lambda(\beta+T)$ is distributed according to a $\chi^2$ pdf with $2(\alpha+k)$ degrees of freedom, or using Eq (19) we get that

$$\Pr[\frac{\chi^2_{a/2}(2(k+\alpha))}{2(T+\beta)}\le\lambda\le\frac{\chi^2_{1-a/2}(2(k+\alpha))}{2(T+\beta)}]=1-a \qquad (34)$$

In the particular case when the prior of λ is the one defined in section 3.2.1.1.1 with (α=1, β=τ), then Eq. (33) becomes

$$\Pr[\frac{\chi^2_{a/2}(2(k+1))}{2(T+\tau)} \leq \lambda \leq \frac{\chi^2_{1-a/2}(2(k+1))}{2(T+\tau)}] = 1-a \qquad (35)$$

It is noteworthy that Eq.(19) and (35) are similar to the ones given in literature as derived along the lines of classical statistics (e.g. red book). Equation (19), however, is valid only if the sampling is of gamma type, i.e. if the number of accidents to be observed is predetermined and the duration of the observation $T$ is left to chance. Equations (34) and (35) on the other hand are valid and based on firmed theoretical basis for any type of experiment. They are also valid if there are no accidents observed i.e. if $k=0$.

## 3.3 Bayesian analysis with uncertain sufficient statistics

Up to this point it has been assumed that the results and hence the sufficient statistics (k,T) of the sampling process are known with certainty. In the case of occupational accidents, however, owing to the large population over which the sample is drawn, there are usually uncertainties about their exact values. The number of accidents (k) can be underreported, the exposure which depend on the number of workers (N) and the mean yearly exposure (τ) to the hazards are also fraught with uncertainties. In this case the posterior distribution of the accident rate λ is also not known precisely. Quantification of the uncertainties in the sufficient statistics allows the quantification of the uncertainties in the posterior pdf of λ.

To this end it is assumed that the parameters (k,T) are actually random variables distributed according to a pdf $g(k,T\,|\,\boldsymbol{\theta})$ where **θ** are the parameters of the distribution. Then the probability that the posterior pdf of λ will have a given form is given by

$$\Pr\{f''(\lambda) = f_{\gamma_1}(\lambda\,|\,\alpha+k,\beta+T)\} = g(k,T\,|\,\boldsymbol{\theta})dkdT \qquad (36)$$

The unconditional on the sufficient statistics (k,T) distribution of L is then given by

$$f''(\lambda\,|\,\boldsymbol{\theta}) = \iint f_{\gamma_1}(\lambda\,|\,\alpha+k,\beta+T)\}g(k,T\,|\,\boldsymbol{\theta})dkdT \qquad (37)$$

It is noteworthy that the accident rate λ is a monotonic increasing function of k and a monotonic decreasing function of T. Thus we can determine probability limits for λ on the basis of the pdf g(k,T|**θ**). If $k_0$ and $T_0$ are respectively the smallest k and larger T for which Pr{k<$k_0$ and T>$T_0$}=0.05 then the limit $\lambda_{05}$ is that for which

$$F_{\gamma_1}(\lambda \leq \lambda_{05}\,|\,k_0,T_0) = 0.05 \qquad (38)$$

Similarly if $k_0$ and $T_0$ are respectively the largest k and smaller T for which Pr{k>$k_0$ and T<$T_0$}=0.05 then the limit $\lambda_{95}$ is that for which

$$F_{\gamma_1}(\lambda \geq \lambda_{95}\,|\,k_0,T_0) = 0.05 \qquad (39)$$

### 3.3.1 Uncertainty in the number of accidents – underreporting

Uncertainty on the number of accidents taking place in a given period of time exists because of potential underreporting. To account for this uncertainty the number of accidents potentially not reported is considered to be a random variable distributed according to a given pdf. Thus the statistic k in the Poisson sampling is given by

$$k = k_0 + \tilde{k} \qquad (40)$$

Where $k_0$ is the number of the reported accidents and $\tilde{k}$ is the number of unknown non-reported accidents assumed distributed according to a known pdf f(k). It is noteworthy that since the number of accidents is an integer the pdf should be an appropriate one.

Since there are reports that the underreporting can be as high as 50%, it is reasonable to assume that the mean value of the non-reported accidents is equal to the number of the reported accidents.

### 3.3.2 Uncertainty in the population providing the sample number of accidents

Uncertainty about the actual size of the worker's population might exist owing to incompleteness in the assessment of the population, the source of the census information and mainly on the correspondence of the various population estimations and the population subject to the reporting requirements.

Reasonable uncertainty quantification would be to consider the number of population N as a rv normally distributed with known mean and standard deviation.

### 3.3.3 Uncertainty in the average yearly exposure

Uncertainty in the number of hours a worker is exposed to the risk of an accident while performing his job is mainly due to the actual variability of the working time of the various workers during a ca typical calendar year. If $\tilde{\tau}$ denotes the rv of the working hours per year of a worker, and $f(\tilde{\tau})$ the corresponding pdf then the total exposure of a population of size N is given by

$$T = \int_0^\infty N\tau f(\tau)d\tau = N\bar{\tau} \qquad (41)$$

where $\bar{\tau}$ is the mean value of $f(\bar{\tau})$ .

Surveys on the time various types of workers are exposed to different occupational risks for accidents have shown that the variability in the τ is substantial. Some professions show a high skewness in their yearly exposure towards small values some towards large values and others exhibit a dual mode one for small and one for large values. In all cases the use of mean value in Eq. (41) or the observation time t0 in Eq. (14) provides a good approximation for the sufficient statistic T. Consequently the point estimation (see section 3.1.2) or the Bayesian estimation (see section 3.2.3 and section 3.3) of the accident rate λ does not depend on the variability of τ but only on its mean value $\bar{\tau}$ . The probability that a specific worker will have an accident sometime during a calendar year (see Eq. (3)) does depend on the number of hours (τ) the worker works during the year and hence on the variability of this time.

# Appendix B - Task specific exposure measurements

*Table B.1 Measurements of silica exposure for different tasks. Shown are the task, before or after intervention (pre/post), the sample size (N), the average exposure (AM) and the standard deviation (SD)*

| **Task** | **Pre/ Post** | **N** | **AM (SD) in mg m$^{-3}$** |
|---|---|---|---|
| Concrete Drilling | Pre | 45 | 0.24 (0.44) |
| Grinding/sawing tiles with grinding machine (tiler) | Pre | 6 | 0.31 (0.36) |
| Grinding/sawing tiles with stationary saw with water (tiler) | Post | 6 | 0.01 (0.003) |
| Removing tiles (tiler) | Pre | 11 | 0.57 (0.48) |
| Sawing sand lime bricks or cellular concrete with circular saw/sawing machine (tiler) | Pre | 12 | 0.04 (0.04) |
| Sawing sand lime bricks or cellular concrete with hand saw (tiler) | Post | 6 | 0.001 (0.001) |
| Sweeping (tiler) | Pre | 25 | 0.10 (0.09) |
| Cutting/paving kerb (road paver) | Pre | 11 | 0.81 (0.67) |
| Compacting soil (road paver) | Pre | 15 | 0.24 (0.23) |

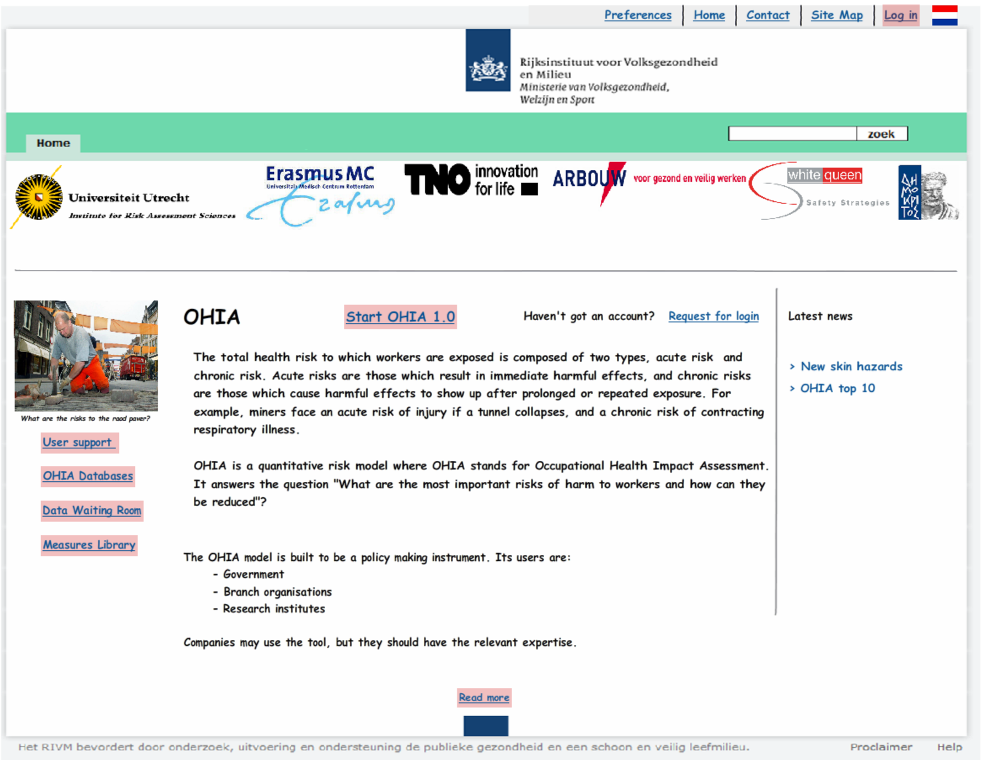
# Appendix C - Questionnaire for dermal complaints

Heeft u de afgelopen 12 maanden wel eens last gehad van:

- ☐ rode, opgezwollen handen of vingers (s9060)
- ☐ rode handen of vingers met kloofjes (s9061)
- ☐ blaasjes op de handen of tussen de vingers (s9062)
- ☐ ruwe of schilferende handen met kloofjes (s9063)
- ☐ jeukende handen of vingers met kloofjes (s9064)

Is uw huid overgevoelig voor een stof of materiaal waarmee u op uw werk in aanraking komt? [ja/nee] (b0122)

# Appendix D – OHIA mock-up



OHIA

The total health risk to which workers are exposed is composed of two types, acute risk and chronic risk. Acute risks are those which result in immediate harmful effects, and chronic risks are those which cause harmful effects to show up after prolonged or repeated exposure. For example, miners face an acute risk of injury if a tunnel collapses, and a chronic risk of contracting respiratory illness.

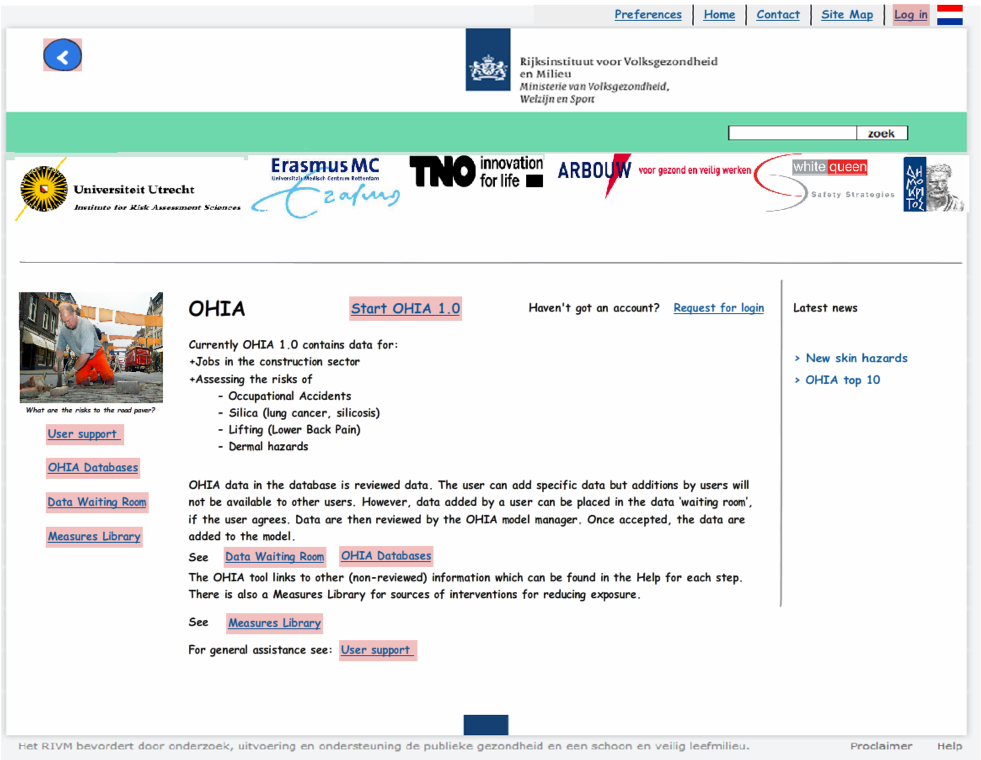
OHIA is a quantitative risk model where OHIA stands for Occupational Health Impact Assessment. It answers the question "What are the most important risks of harm to workers and how can they be reduced"?

The OHIA model is built to be a policy making instrument. Its users are:
- Government
- Branch organisations
- Research institutes

Companies may use the tool, but they should have the relevant expertise.

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

*Figure D.1 Start page*



OHIA

Currently OHIA 1.0 contains data for:
+Jobs in the construction sector
+Assessing the risks of
  - Occupational Accidents
  - Silica (lung cancer, silicosis)
  - Lifting (Lower Back Pain)
  - Dermal hazards

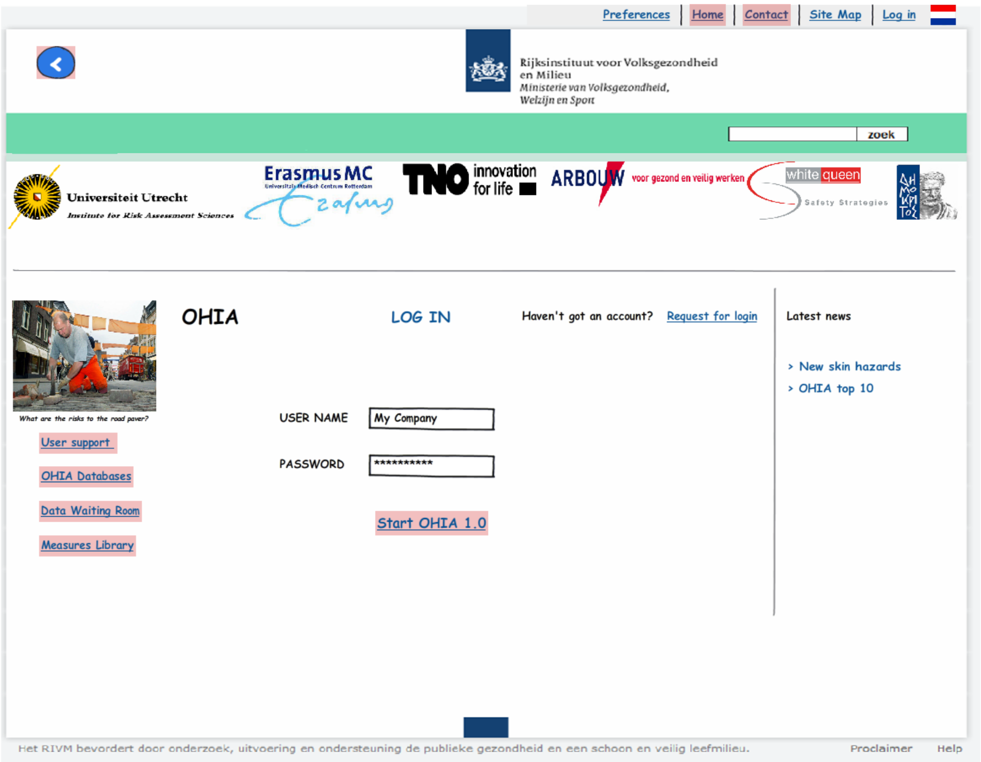
OHIA data in the database is reviewed data. The user can add specific data but additions by users will not be available to other users. However, data added by a user can be placed in the data 'waiting room', if the user agrees. Data are then reviewed by the OHIA model manager. Once accepted, the data are added to the model.
See Data Waiting Room OHIA Databases
The OHIA tool links to other (non-reviewed) information which can be found in the Help for each step. There is also a Measures Library for sources of interventions for reducing exposure.

See Measures Library

For general assistance see: User support

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

*Figure D.2 Read more*



Haven't got an account? Request for login

USER NAME: My Company

PASSWORD: **********

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

*Figure D.3 Log in*

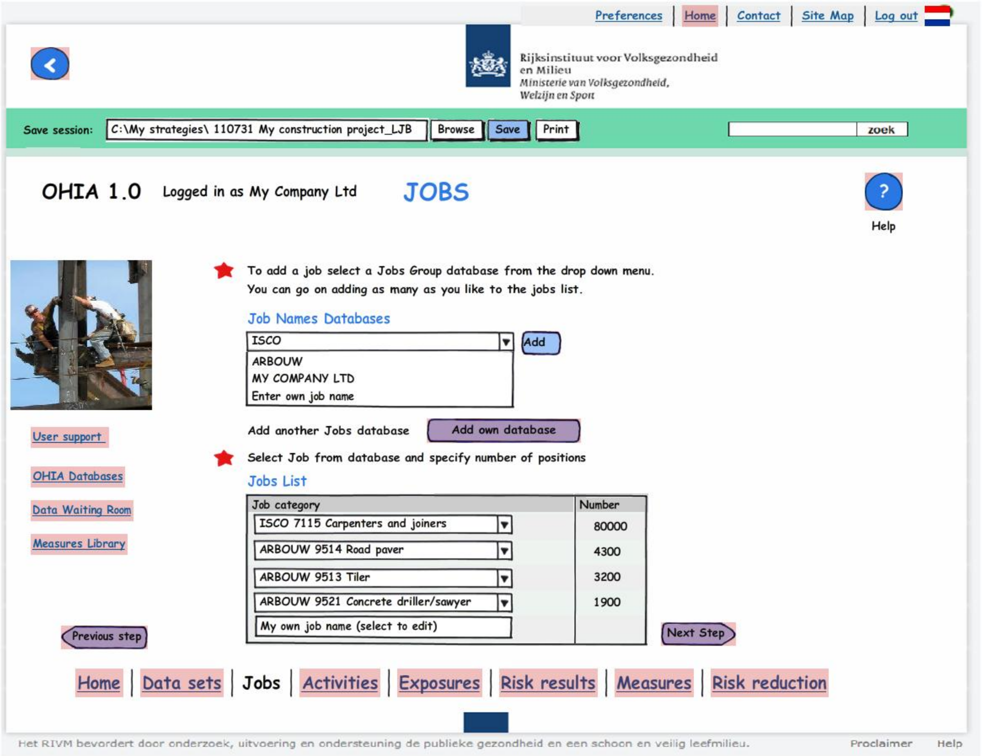
Logged in as My Company Ltd

DISCLAIMER
With regards to the use of the results from the Risk Calculation, the Kingdom of the Netherlands and/or its suppliers shall in no instance be held liable for any loss or damage suffered by you or third parties, including consequential damage, material damage or company loss. The exclusions above also apply if a representative of the Kingdom of the Netherlands and/or its suppliers was made aware in advance of the possible occurrence of such damage, costs or demands by third parties.

| Dataset Name | Date created |
|---|---|
| My first dataset | 1 March 2011 |
| My second dataset | 9 March 2011 |

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

*Figure D.4 Data sets*



Save session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd JOBS

To add a job select a Jobs Group database from the drop down menu.
You can go on adding as many as you like to the jobs list.

Job Names Databases

ISCO
ARBOUW
MY COMPANY LTD
Enter own job name

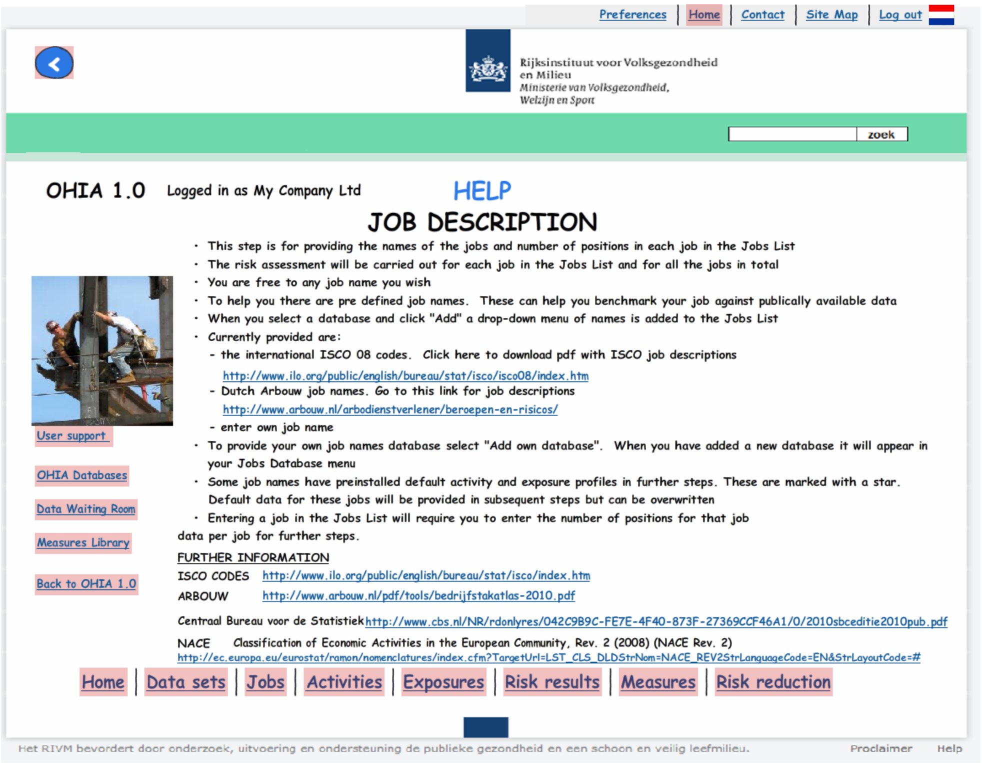
Add another Jobs database

Select Job from database and specify number of positions

Jobs List

| Job category | Number |
|---|---|
| ISCO 7115 Carpenters and joiners | 80000 |
| ARBOUW 9514 Road paver | 4300 |
| ARBOUW 9513 Tiler | 3200 |
| ARBOUW 9521 Concrete driller/sawyer | 1900 |
| My own job name (select to edit) | |

*Figure D.5 Job descriptions*



OHIA 1.0 Logged in as My Company Ltd HELP

JOB DESCRIPTION

- This step is for providing the names of the jobs and number of positions in each job in the Jobs List
- The risk assessment will be carried out for each job in the Jobs List and for all the jobs in total
- You are free to any job name you wish
- To help you there are pre defined job names. These can help you benchmark your job against publically available data
- When you select a database and click "Add" a drop-down menu of names is added to the Jobs List
- Currently provided are:
  - the international ISCO 08 codes. Click here to download pdf with ISCO job descriptions http://www.ilo.org/public/english/bureau/stat/isco/isco08/index.htm
  - Dutch Arbouw job names. Go to this link for job descriptions http://www.arbouw.nl/arbodienstverlener/beroepen-en-risicos/
  - enter own job name
- To provide your own job names database select "Add own database". When you have added a new database it will appear in your Jobs Database menu
- Some job names have preinstalled default activity and exposure profiles in further steps. These are marked with a star. Default data for these jobs will be provided in subsequent steps but can be overwritten
- Entering a job in the Jobs List will require you to enter the number of positions for that job

data per job for further steps.

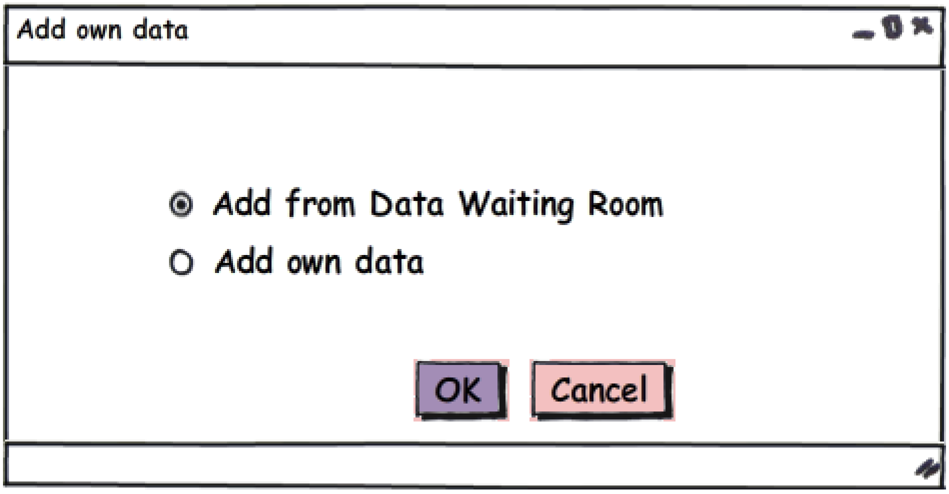
FURTHER INFORMATION

ISCO CODES http://www.ilo.org/public/english/bureau/stat/isco/index.htm
ARBOUW http://www.arbouw.nl/pdf/tools/bedrijfstakatlas-2010.pdf

Centraal Bureau voor de Statistiek http://www.cbs.nl/NR/rdonlyres/042C9B9C-FE7E-4F40-873F-27369CCF46A1/0/2010sbceditie2010pub.pdf

NACE Classification of Economic Activities in the European Community, Rev. 2 (2008) (NACE Rev. 2)
http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_CLS_DLDStrNom=NACE_REV2StrLanguageCode=EN&StrLayoutCode=#

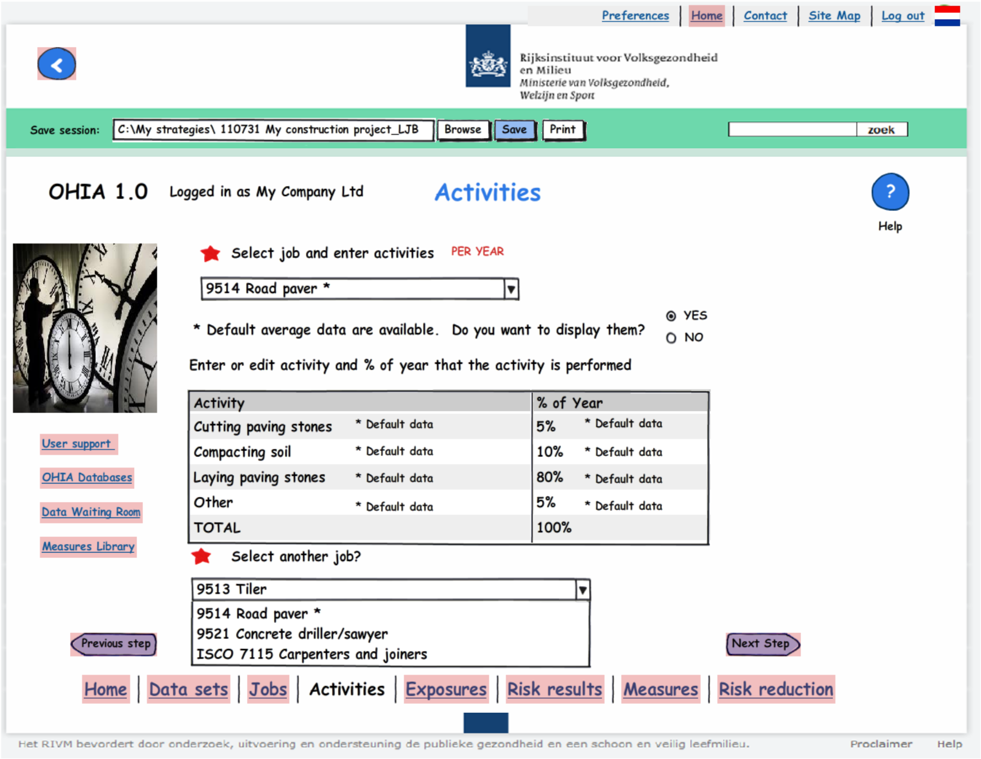
*Figure D.6 Help function Job descriptions*



● Add from Data Waiting Room

○ Add own data

Figure D.7 Data selection



Save session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd

Activities

Select job and enter activities PER YEAR

9514 Road paver *

* Default average data are available. Do you want to display them? ● YES ○ NO

Enter or edit activity and % of year that the activity is performed

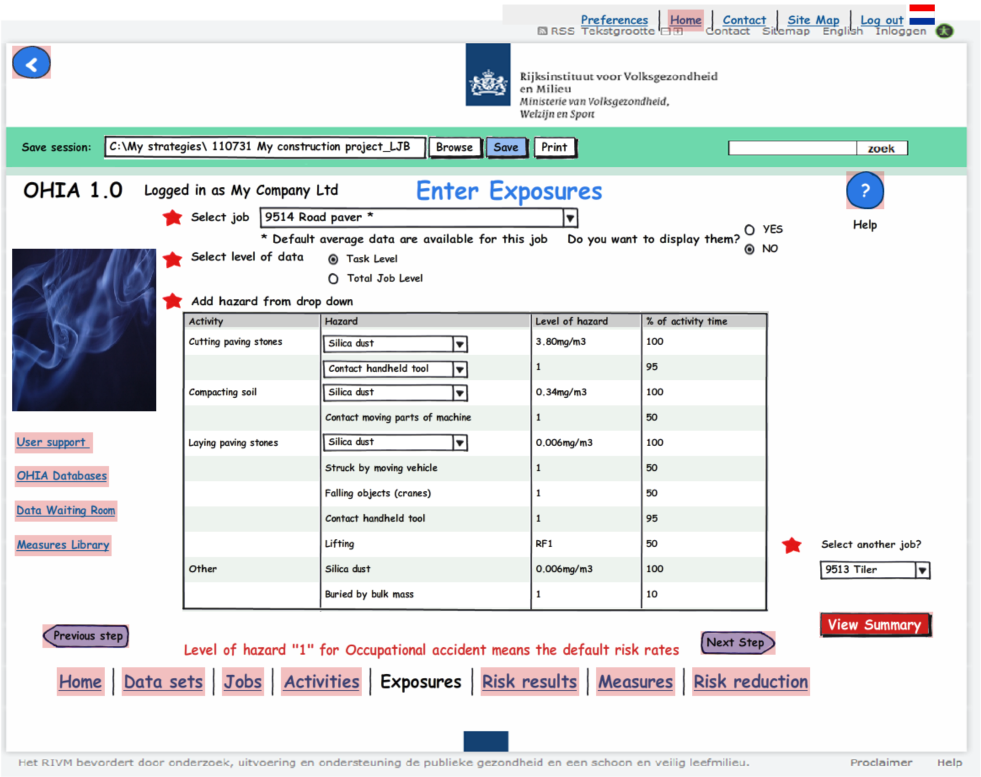
| Activity | | % of Year | |
|---|---|---|---|
| Cutting paving stones | * Default data | 5% | * Default data |
| Compacting soil | * Default data | 10% | * Default data |
| Laying paving stones | * Default data | 80% | * Default data |
| Other | * Default data | 5% | * Default data |
| TOTAL | | 100% | |

Select another job?

9513 Tiler
9514 Road paver *
9521 Concrete driller/sawyer
ISCO 7115 Carpenters and joiners

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

Figure D.8 Activities



Save session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd **Enter Exposures**

Select job: 9514 Road paver *

* Default average data are available for this job Do you want to display them? ○ YES ● NO

Select level of data: ● Task Level ○ Total Job Level

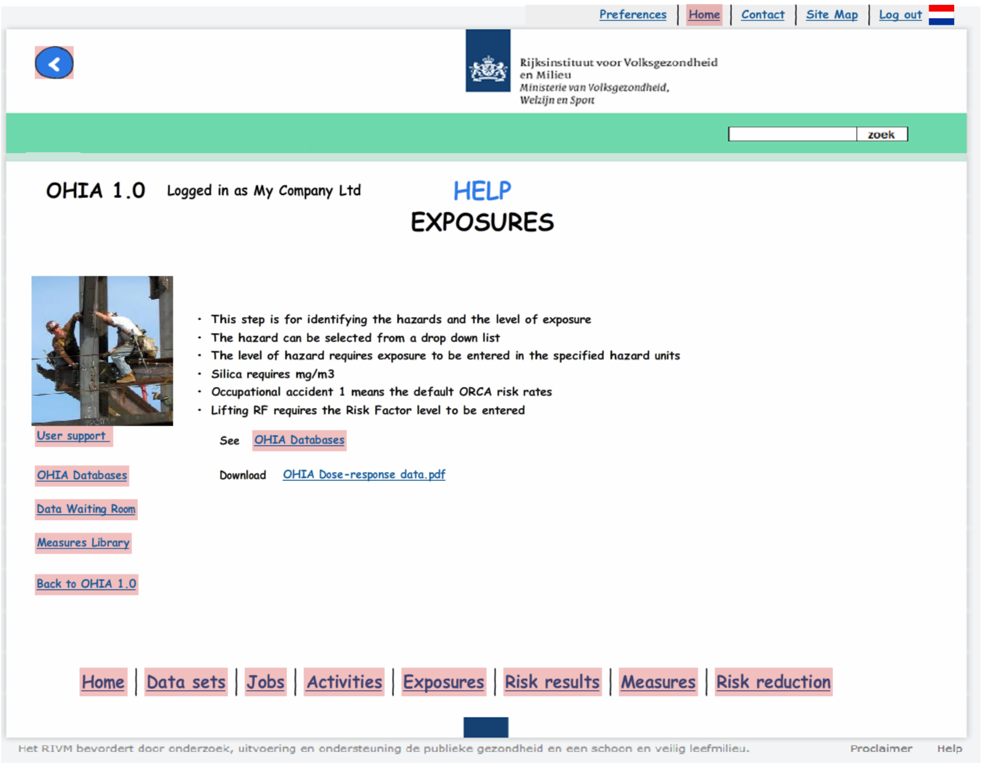
Add hazard from drop down

| Activity | Hazard | Level of hazard | % of activity time |
|---|---|---|---|
| Cutting paving stones | Silica dust | 3.80mg/m3 | 100 |
| | Contact handheld tool | 1 | 95 |
| Compacting soil | Silica dust | 0.34mg/m3 | 100 |
| | Contact moving parts of machine | 1 | 50 |
| Laying paving stones | Silica dust | 0.006mg/m3 | 100 |
| | Struck by moving vehicle | 1 | 50 |
| | Falling objects (cranes) | 1 | 50 |
| | Contact handheld tool | 1 | 95 |
| | Lifting | RF1 | 50 |
| Other | Silica dust | 0.006mg/m3 | 100 |
| | Buried by bulk mass | 1 | 10 |

Select another job? 9513 Tiler

Level of hazard "1" for Occupational accident means the default risk rates

Figure D.9 Exposure input



OHIA 1.0 Logged in as My Company Ltd

**HELP**

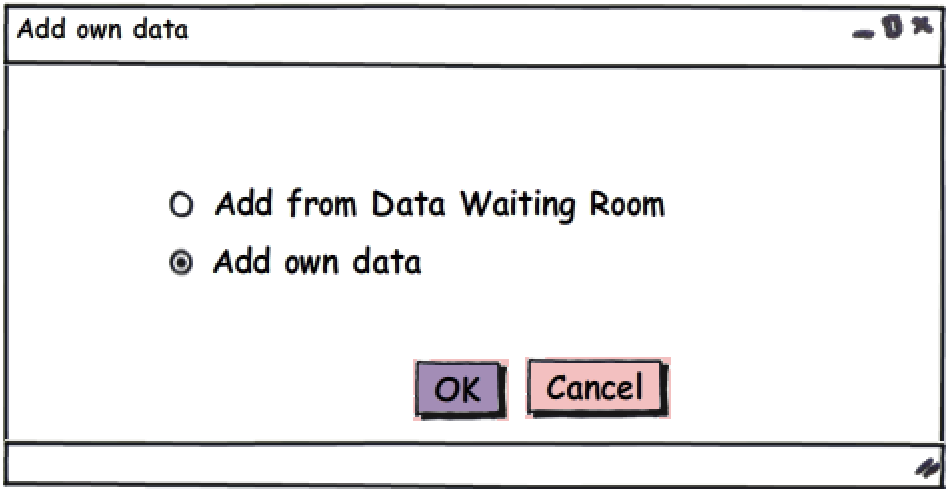
**EXPOSURES**

- This step is for identifying the hazards and the level of exposure
- The hazard can be selected from a drop down list
- The level of hazard requires exposure to be entered in the specified hazard units
- Silica requires mg/m3
- Occupational accident 1 means the default ORCA risk rates
- Lifting RF requires the Risk Factor level to be entered

See OHIA Databases

Download OHIA Dose-response data.pdf

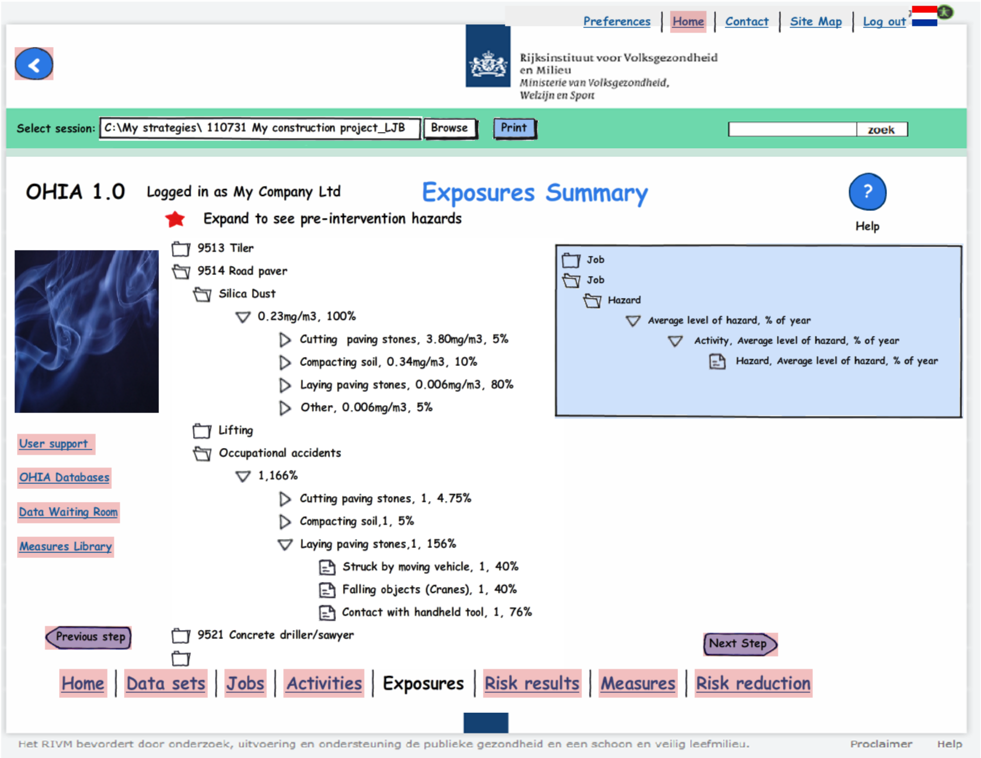
Figure D.10 Help function for exposure input



○ Add from Data Waiting Room

● Add own data

Figure D.11 Data selection



Select session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd

Exposures Summary

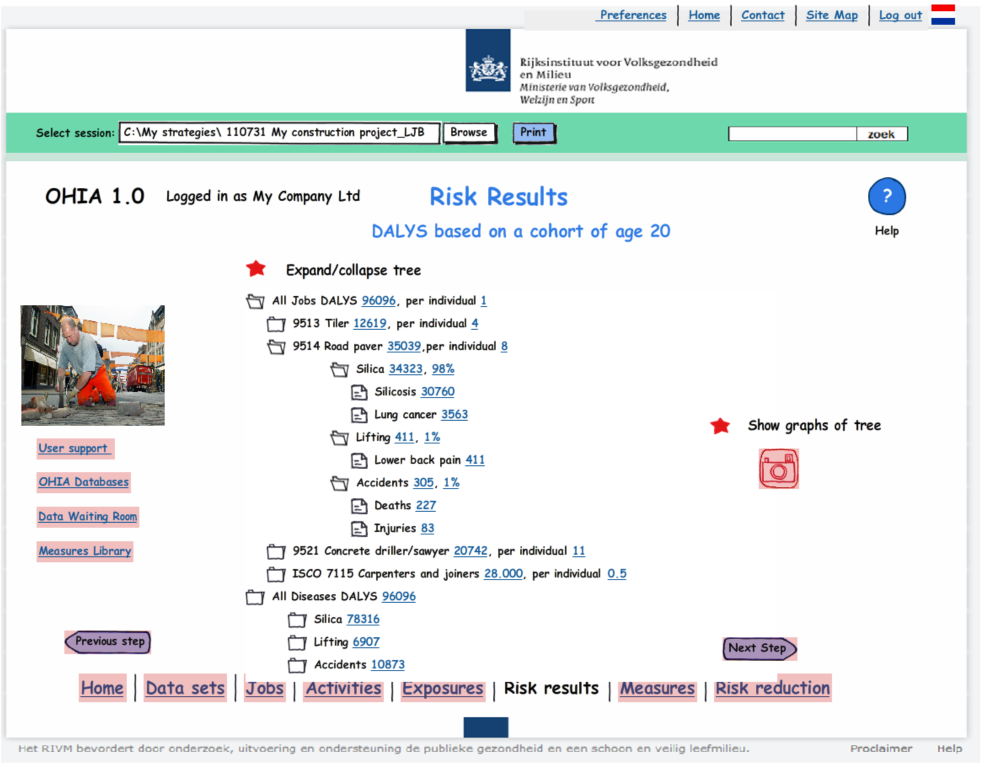
Expand to see pre-intervention hazards

- 9513 Tiler
- 9514 Road paver
  - Silica Dust
    - 0.23mg/m3, 100%
      - Cutting paving stones, 3.80mg/m3, 5%
      - Compacting soil, 0.34mg/m3, 10%
      - Laying paving stones, 0.006mg/m3, 80%
      - Other, 0.006mg/m3, 5%
  - Lifting
  - Occupational accidents
    - 1,166%
      - Cutting paving stones, 1, 4.75%
      - Compacting soil,1, 5%
      - Laying paving stones,1, 156%
        - Struck by moving vehicle, 1, 40%
        - Falling objects (Cranes), 1, 40%
        - Contact with handheld tool, 1, 76%
- 9521 Concrete driller/sawyer

- Job
- Job
  - Hazard
    - Average level of hazard, % of year
      - Activity, Average level of hazard, % of year
        - Hazard, Average level of hazard, % of year

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

Figure D.12 Exposure overview



Select session: C:\My strategies\ 110731 My construction project_LJB

Logged in as My Company Ltd

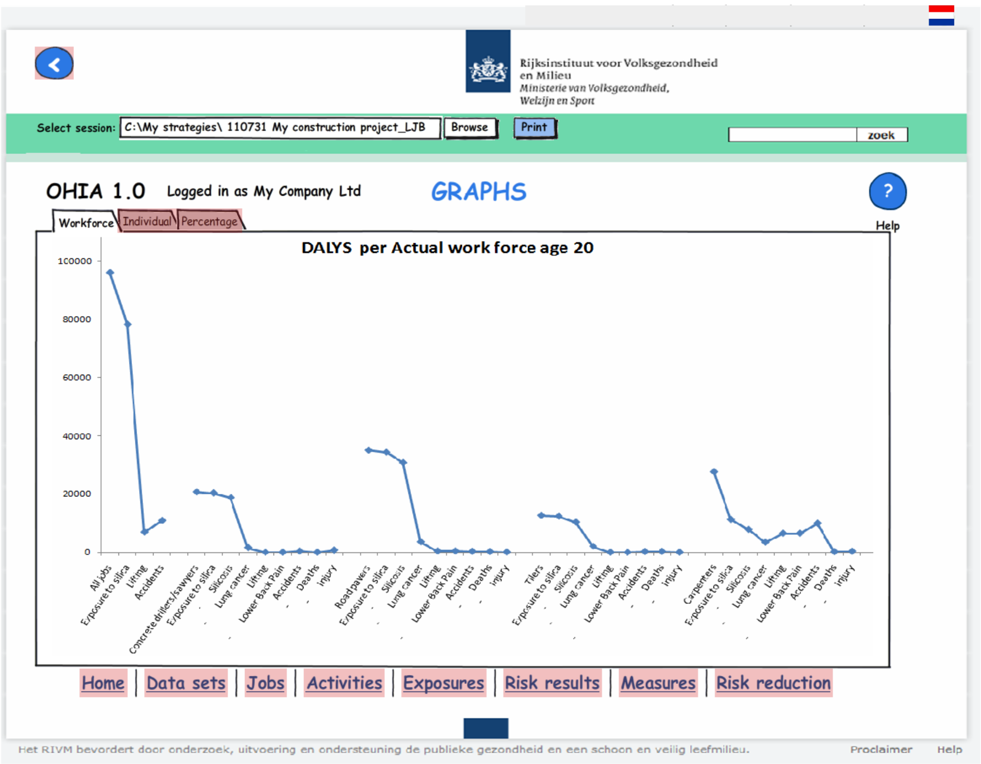
Risk Results

DALYS based on a cohort of age 20

Expand/collapse tree

- All Jobs DALYS 96096, per individual 1
  - 9513 Tiler 12619, per individual 4
  - 9514 Road paver 35039,per individual 8
    - Silica 34323, 98%
      - Silicosis 30760
      - Lung cancer 3563
    - Lifting 411, 1%
      - Lower back pain 411
    - Accidents 305, 1%
      - Deaths 227
      - Injuries 83
  - 9521 Concrete driller/sawyer 20742, per individual 11
  - ISCO 7115 Carpenters and joiners 28.000, per individual 0.5
- All Diseases DALYS 96096
  - Silica 78316
  - Lifting 6907
  - Accidents 10873

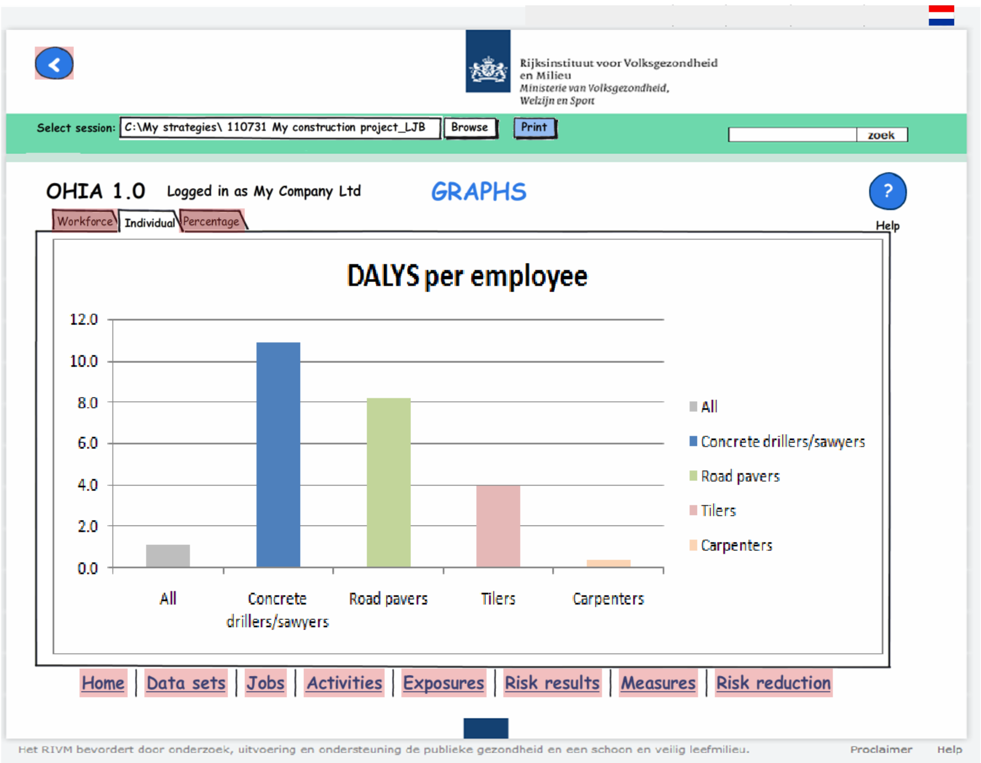
Figure D.13 Risk results



Select session: C:\My strategies\ 110731 My construction project_LJB

Logged in as My Company Ltd

Figure D.14 Graph - workforce



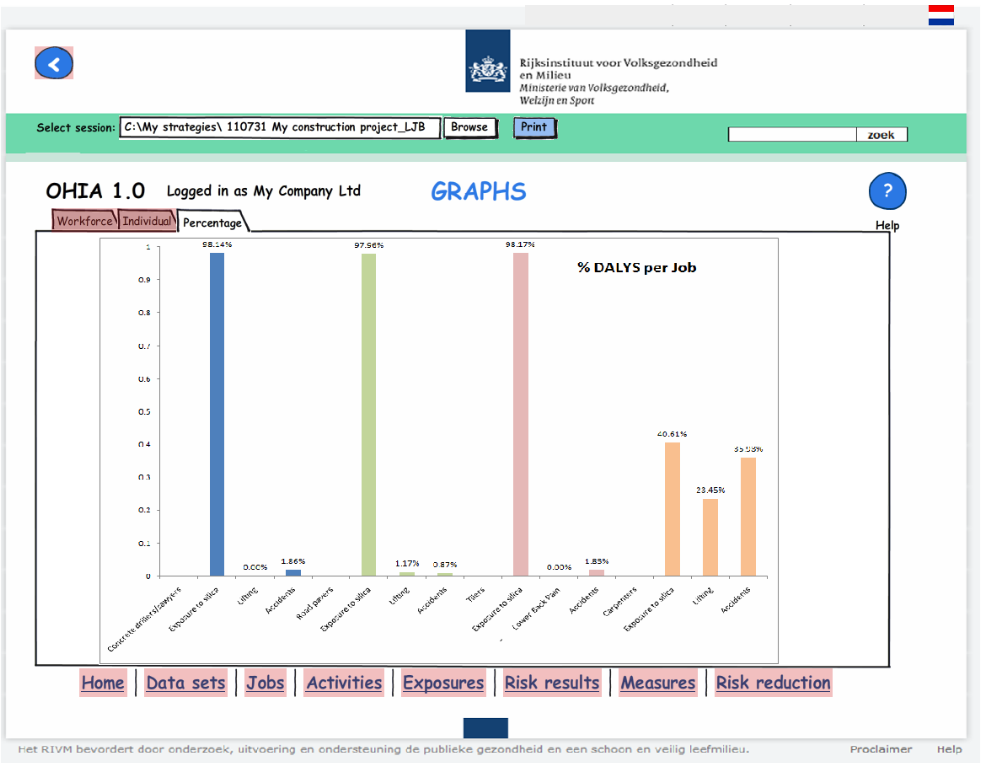
Rijksinstituut voor Volksgezondheid en Milieu
Ministerie van Volksgezondheid, Welzijn en Sport

Select session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

Figure D.15 *Graph - individual*



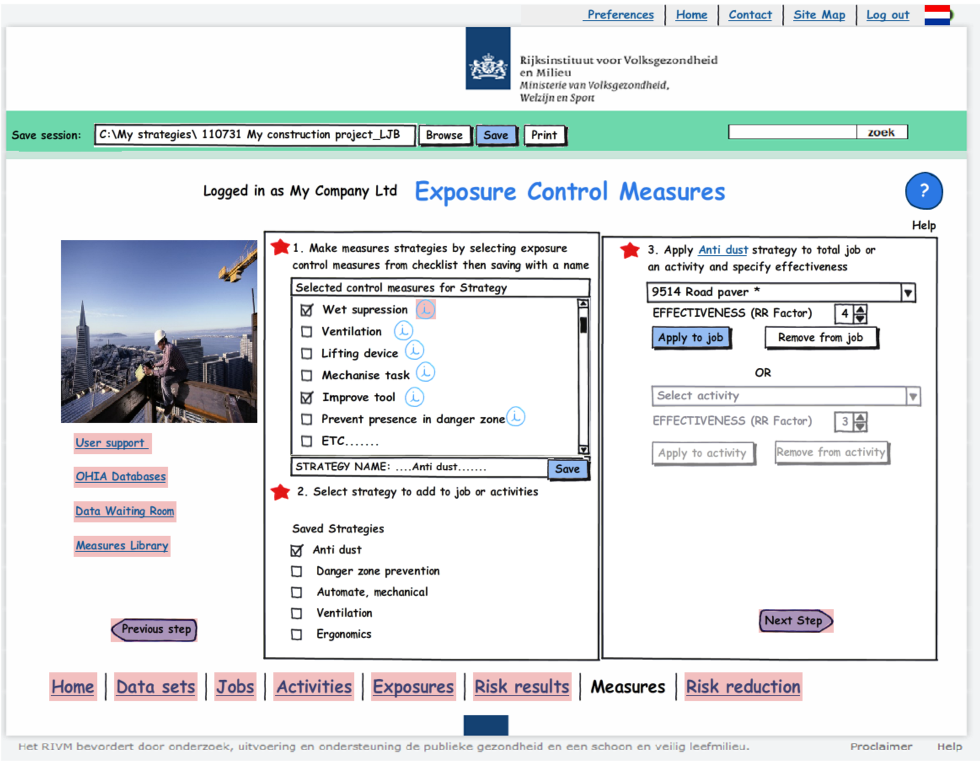
Rijksinstituut voor Volksgezondheid en Milieu
Ministerie van Volksgezondheid, Welzijn en Sport

Select session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

Figure D.16 *Graph – exposure contribution*



Save session: C:\My strategies\ 110731 My construction project_LJB

Logged in as My Company Ltd **Exposure Control Measures**

1. Make measures strategies by selecting exposure control measures from checklist then saving with a name

Selected control measures for Strategy
- ☑ Wet supression
- ☐ Ventilation
- ☐ Lifting device
- ☐ Mechanise task
- ☑ Improve tool
- ☐ Prevent presence in danger zone
- ☐ ETC.......

STRATEGY NAME: ....Anti dust.......

2. Select strategy to add to job or activities

Saved Strategies
- ☑ Anti dust
- ☐ Danger zone prevention
- ☐ Automate, mechanical
- ☐ Ventilation
- ☐ Ergonomics

3. Apply Anti dust strategy to total job or an activity and specify effectiveness

9514 Road paver *

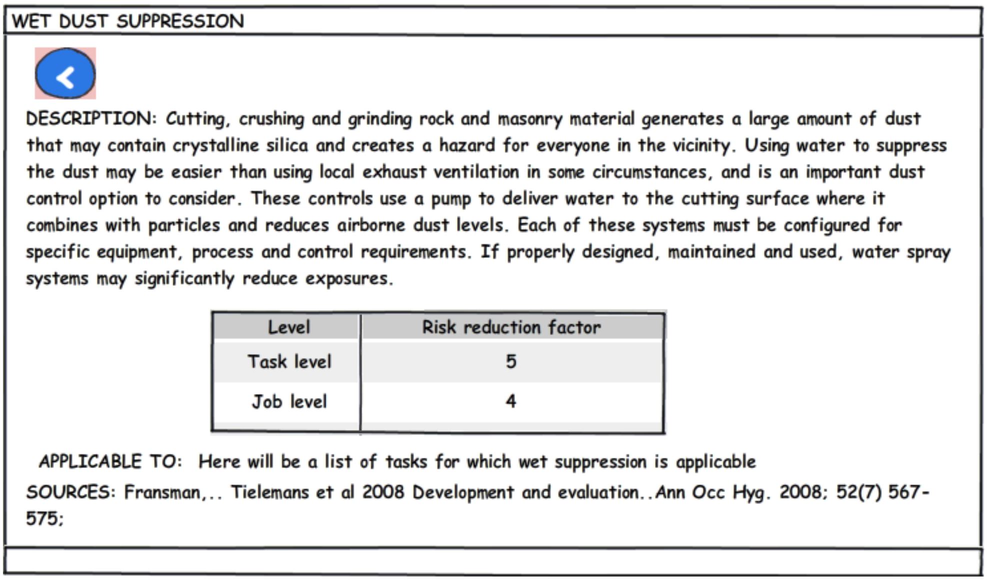
EFFECTIVENESS (RR Factor) 4

Select activity

EFFECTIVENESS (RR Factor) 3

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

Figure D.17 Measures



WET DUST SUPPRESSION

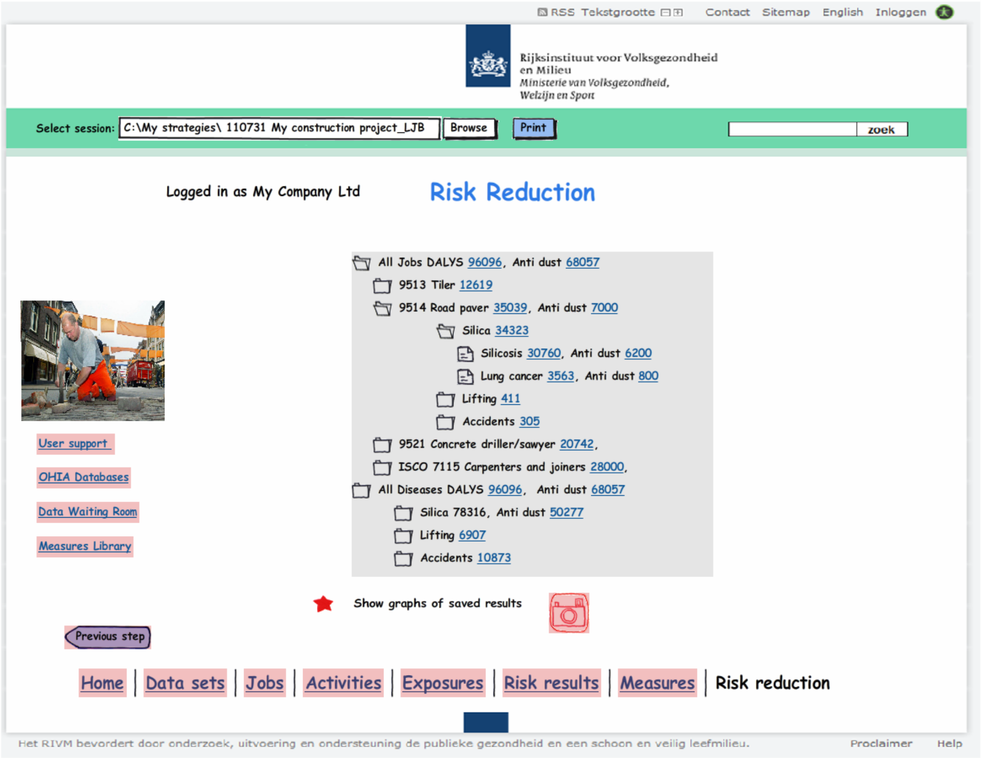
DESCRIPTION: Cutting, crushing and grinding rock and masonry material generates a large amount of dust that may contain crystalline silica and creates a hazard for everyone in the vicinity. Using water to suppress the dust may be easier than using local exhaust ventilation in some circumstances, and is an important dust control option to consider. These controls use a pump to deliver water to the cutting surface where it combines with particles and reduces airborne dust levels. Each of these systems must be configured for specific equipment, process and control requirements. If properly designed, maintained and used, water spray systems may significantly reduce exposures.

| Level | Risk reduction factor |
|---|---|
| Task level | 5 |
| Job level | 4 |

APPLICABLE TO: Here will be a list of tasks for which wet suppression is applicable

SOURCES: Fransman,.. Tielemans et al 2008 Development and evaluation..Ann Occ Hyg. 2008; 52(7) 567-575;

Figure D.18 Measure example – wet dust suppression



Select session: C:\My strategies\ 110731 My construction project_LJB

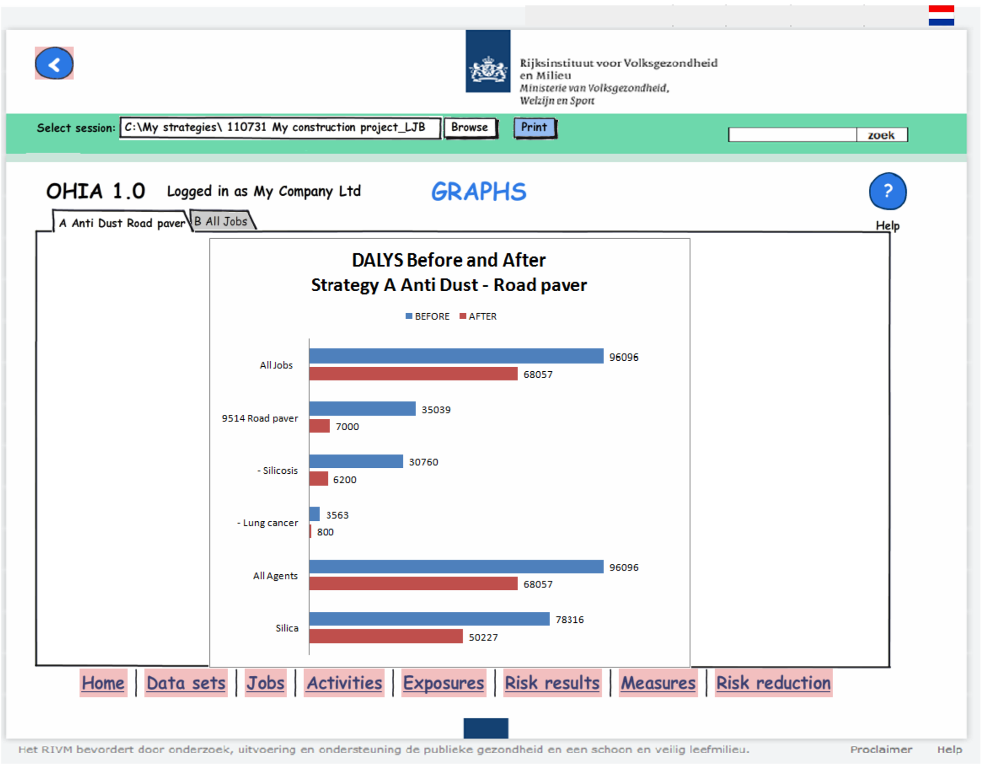
Logged in as My Company Ltd

Risk Reduction

All Jobs DALYS 96096, Anti dust 68057
  9513 Tiler 12619
  9514 Road paver 35039, Anti dust 7000
    Silica 34323
      Silicosis 30760, Anti dust 6200
      Lung cancer 3563, Anti dust 800
    Lifting 411
    Accidents 305
  9521 Concrete driller/sawyer 20742,
  ISCO 7115 Carpenters and joiners 28000,
All Diseases DALYS 96096, Anti dust 68057
  Silica 78316, Anti dust 50277
  Lifting 6907
  Accidents 10873

Show graphs of saved results

Figure D.19 Risk reduction due to intervention strategy

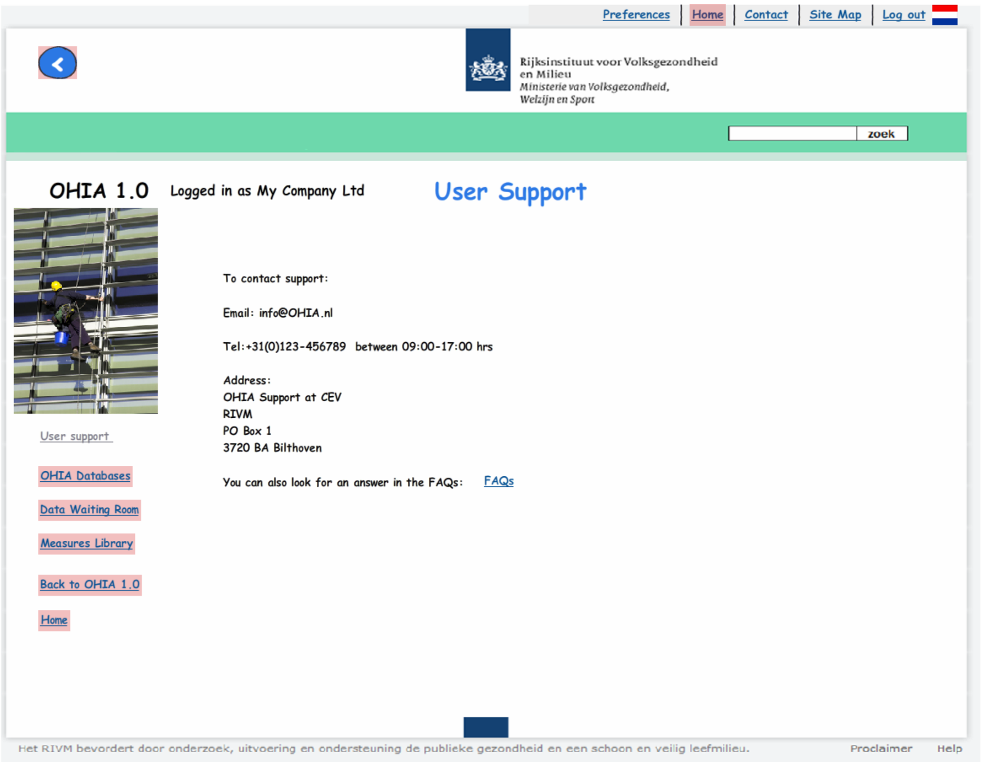


Select session: C:\My strategies\ 110731 My construction project_LJB

OHIA 1.0 Logged in as My Company Ltd

GRAPHS

Figure D.20 Risk reduction due to intervention strategy



Logged in as My Company Ltd

User Support

To contact support:

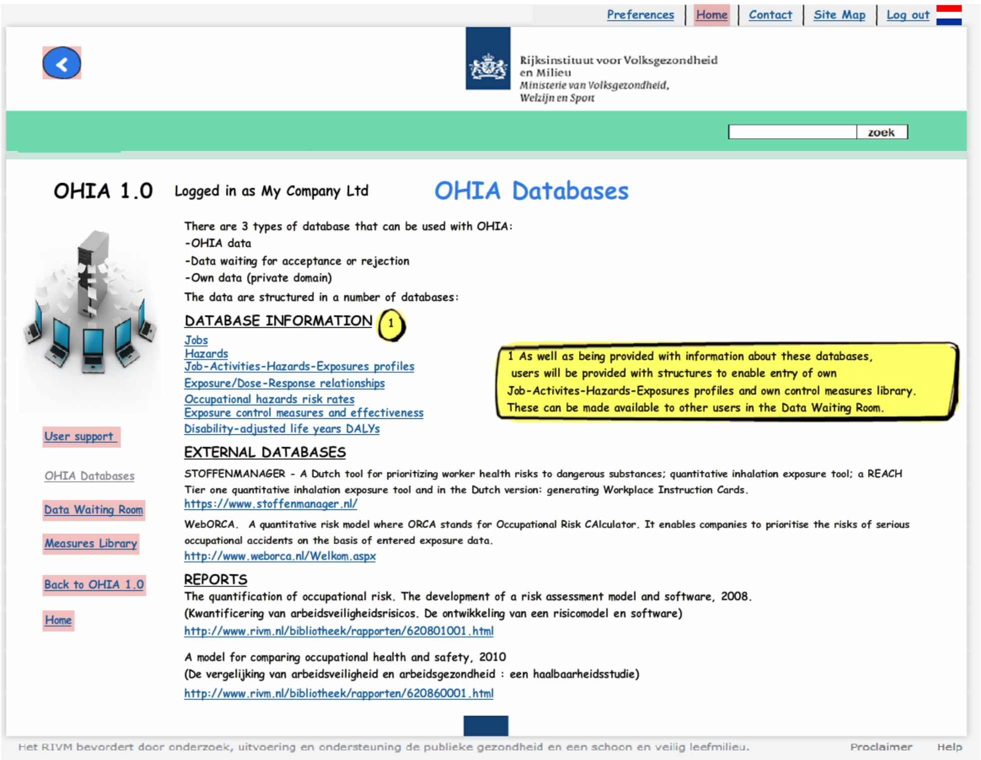
Email: info@OHIA.nl

Tel:+31(0)123-456789 between 09:00-17:00 hrs

Address:
OHIA Support at CEV
RIVM
PO Box 1
3720 BA Bilthoven

You can also look for an answer in the FAQs: FAQs

*Figure D.21 User support*



Logged in as My Company Ltd

OHIA Databases

There are 3 types of database that can be used with OHIA:
-OHIA data
-Data waiting for acceptance or rejection
-Own data (private domain)
The data are structured in a number of databases:

DATABASE INFORMATION ①

Jobs
Hazards
Job-Activities-Hazards-Exposures profiles
Exposure/Dose-Response relationships
Occupational hazards risk rates
Exposure control measures and effectiveness
Disability-adjusted life years DALYs

1 As well as being provided with information about these databases, users will be provided with structures to enable entry of own Job-Activites-Hazards-Exposures profiles and own control measures library. These can be made available to other users in the Data Waiting Room.

EXTERNAL DATABASES

STOFFENMANAGER - A Dutch tool for prioritizing worker health risks to dangerous substances; quantitative inhalation exposure tool; a REACH Tier one quantitative inhalation exposure tool and in the Dutch version: generating Workplace Instruction Cards.
https://www.stoffenmanager.nl/

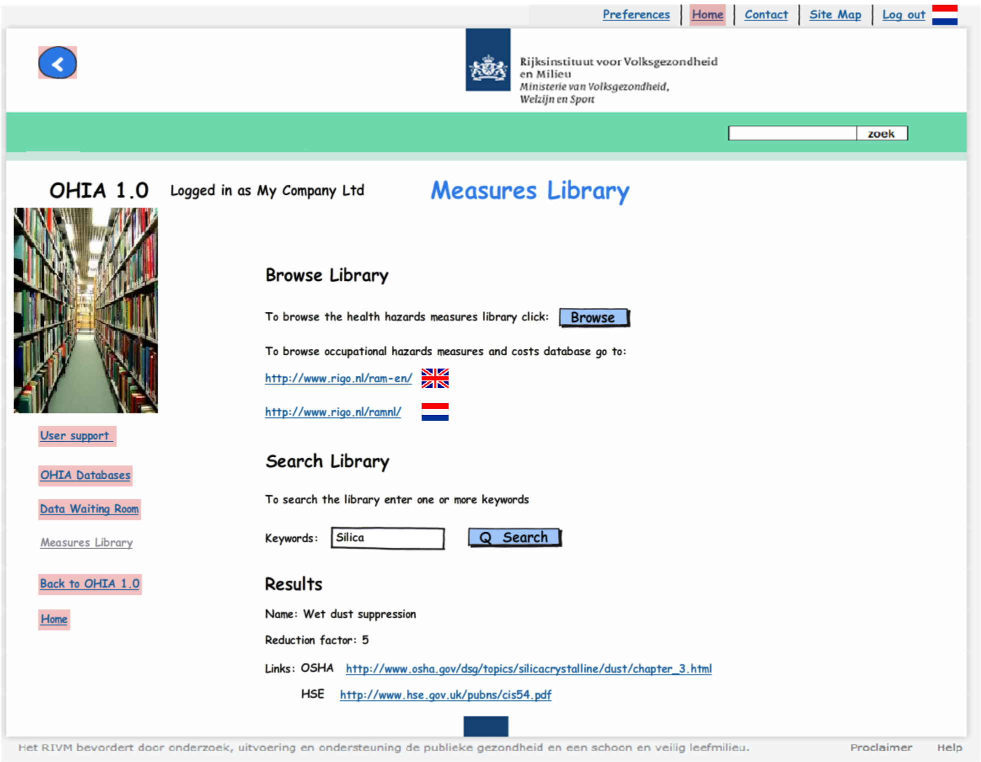
WebORCA. A quantitative risk model where ORCA stands for Occupational Risk CAlculator. It enables companies to prioritise the risks of serious occupational accidents on the basis of entered exposure data.
http://www.weborca.nl/Welkom.aspx

REPORTS

The quantification of occupational risk. The development of a risk assessment model and software, 2008.
(Kwantificering van arbeidsveiligheidsrisicos. De ontwikkeling van een risicomodel en software)
http://www.rivm.nl/bibliotheek/rapporten/620801001.html

A model for comparing occupational health and safety, 2010
(De vergelijking van arbeidsveiligheid en arbeidsgezondheid : een haalbaarheidsstudie)
http://www.rivm.nl/bibliotheek/rapporten/620860001.html

*Figure D.22 OHIA databases*



OHIA 1.0 Logged in as My Company Ltd

Measures Library

Browse Library

To browse the health hazards measures library click: Browse

To browse occupational hazards measures and costs database go to:

http://www.rigo.nl/ram-en/ 🇬🇧

http://www.rigo.nl/ramnl/ 🇳🇱

Search Library

To search the library enter one or more keywords

Keywords: Silica Search

Results

Name: Wet dust suppression

Reduction factor: 5

Links: OSHA http://www.osha.gov/dsg/topics/silicacrystalline/dust/chapter_3.html

HSE http://www.hse.gov.uk/pubns/cis54.pdf

Het RIVM bevordert door onderzoek, uitvoering en ondersteuning de publieke gezondheid en een schoon en veilig leefmilieu.

*Figure D.23 Measures Library*

# Appendix E – Overview of exposures in the construction sector

## Introduction

In the feasibility study (January to August 2010) to set up an Occupational Health Impact Assessment (OHIA) model, the choice was made to look at the construction sector. In this study, accidents, low back pain complaints, and health effects, i.e. lung cancer and silicosis, were included (Uijt de Haag et al., 2010). The OHIA model is to be extended with an additional exposure parameter and/or health endpoint to provide a more complete view of the overall health impact in the construction sector. It has been noted that construction workers are exposed to a large range of chemical substances, present in either building materials, tools, (professional) products, waste products (not considered) and contaminated soils (not considered), which may cause a significant contribution to the health impact in the construction sector. For the selection of an additional relevant exposure-related health endpoint, an overview of chemical agents used in construction and related health endpoints was prepared. Recent research (Eysink et al., 2008) showed that data are lacking for a selection based on a quantitatively estimated health impact. Therefore, a qualitative approach was used to envisage in some way the expected health impacts, using information on population size, severity and durations of associated health effects, and possibilities of interventions. This overview was intended to be used as background information for the selection process by the participants in the follow-up OHIA project.

## Method

A search was conducted through known websites on worker related health impacts with emphasis on chemical-related effects, i.e. publications by Arbouw, NCvB, and Ducth Labour Inspectorate. Reports by RIVM-TNO on occupational burden of disease studies (Baars et al., 2005; Dekkers et al., 2006a; 2006b) and a report and article by Arbouw (Onos and Spee, 2008; Van Thienen and Spee, 2008) were also considered. Furthermore, PubMed was searched for additional information.
The search focused on known, but not necessarily proven, exposure-effect relationships in the construction sector. Indicative parameters for the potential health impact, such as the occupation of workers involved, population size, the severity and duration of the effect, were considered in the search to indicate the possible importance of an exposure-effect relationship. Another useful criterion for addition to the OHIA tool is the feasibility and (possible) practical implementation of interventions on the specific chemical exposure. Besides chemical substances also some other sources of exposure and associated effects of interest are mentioned.

Please note that, although all the information was gathered with great care, the overview is not intended to be complete and in some cases might not be up to date as most exposure-effect relations in the abovementioned sources were not scientifically evaluated by us. In addition, exposure-effect relations are mostly given for chemical groups without specification of the responsible single compounds and therefore may not be specific enough.

**Results**

Within the construction sector there are numerous occupations and workers, who are exposed to a variety of chemical and non-chemical agents. In Onos and Spee (2008) a number of occupations were given highest priority for inclusion in the 'Stoffenmanager' for the construction sector, based on frequency and magnitude of exposure to agents (any agent) and a represented population size of at least 200 in a survey. These occupations were carpenters, brick layers, painters, tilers, demolishers, traditional plasterers, concrete sawyers and drillers, jointers and wood workers. Asphalt road workers were given a lower priority, but it was noted that within this occupation many complaints were made about vapours, gases, and smoke. Most of these mentioned job titles can also be linked to a variety of exposure agents. In Van Thienen and Spee (2008; Table 1 of the article) silica and dust are named most frequently per job title, followed by, amongst others, solvents, diesel exhaust, epoxy resins and mineral wool,.

The main health effects related to exposure in the construction sector are skin disease (irritation or allergic contact dermatitis), airway disorders (asthma and COPD), and (lung) cancer (Baars et al., 2005; Dekkers et al., 2006a; 2006b). Especially skin disease and airway disorders are found with a high number of complaints in the NCvB surveys. Next to the chemically related complaints, noise, back pains and CANS (complaints about arms, neck and shoulders) are often mentioned.

In Table E.1 an overview is given of chemical and non-chemical agents and related health effects. The setup of the table is agent based, showing the related health effects and their severity and occupations for which an indication was given if the exposure to the agent is considered to be relevant. It was decided to provide a qualitative indication of the exposure per agent for the occupations mentioned above in arbitrary terms of low, medium and high by personal judgment (for explanation of these arbitrary terms see Table E.1). It was decided to first focus on these occupations as they have previously been indicated by Onos and Spee (2008) to have high and frequent exposure to agents and comprise a relatively large number of workers (estimated population sizes per occupation are given in Table E.2). At this moment and given the information available, no distinction regarding the expected exposure was made within an occupation. Exposure in other occupations will be noted in the final column 'remarks'. The overview, however, does not indicate the actual risk or likelihood of obtaining the disability or disabilities. This would require an extensive quantitative literature search on the causative relations of the exposure-effect relationships, which goes beyond the scope of this document. It is noted that no further specification of the active compounds causing the effects is made for the agents, e.g. asphalt is not further specified to bitumen or PAH. Since the severity of the effects may also be relevant for the selection process, an indication of the severity of the effects are included (obtained from the National Public Health Compass http://www.nationaalkompas.nl/gezondheid-en-ziekte/sterfte-levensverwachting-en-daly-s/ziektelast-in-daly-s/verloren-levensjaren-ziekte-en-ziektelast-voor-56-geselecteerde-aandoeningen/). The severity in terms of disability weight is used in DALY calculations and ranges from 0 (no disability) to 1 (death). A disability weight of 0.07 means that a subject is affected by a disability with a weight of 0.07 on a scale of 0 to 1; for the duration of 1 year (Murray and Lopez, 1997).

*Table E.1 Overview of exposure response relationships of chemicals in the construction sector*

| **Chemical agent / other agents** | **Related disability: disability weight** [b] | **Occupations and expected exposure level** [a] | | | | | | | | | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Carpenter** | **Brick layer** | **Painters** | **Tilers** | **Demolisher** | **Plasterer** | **Concrete sawyer and driller** | **Jointers** | **Wood-workers** | |
| Volatile organic compounds (VOCs) | CSE: 0.50<br>Asthma: 0.08<br>COPD: 0.31<br>CD: 0.07 | high | low | high | high | low | high | low | low | low | Used as solvents.<br>Other jobs: floor layer,<br>sealant and PU foam applier. |
| Asphalt / bitumen | Bronchitis: 0.05<br>CD: 0.07<br>Lung cancer: 0.54[c] | low | low | medium | low | medium | low | low | low | low | Use as road pavement, roofing materials and paint ingredient.<br>High use in asphalt road worker, medium in roofer. |

| **Chemical agent / other agents** | **Related disability: disability weight** [b] | **Occupations and expected exposure level** [a] | | | | | | | | | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Carpenter** | **Brick layer** | **Painters** | **Tilers** | **Demolisher** | **Plasterer** | **Concrete sawyer and driller** | **Jointers** | **Wood-workers** | |
| Heavy metals | Tumor: 0.12 – 0.59 (skin cancer excluded)<br>CD: 0.07 | medium | medium | low | low | medium | low | medium | medium | medium | Used as raw material, preservatives (metal salts) and present in cement (metal oxides).<br>Used by metal workers, welders, solders. |
| Isocyanates | Asthma: 0.08<br>COPD: 0.31<br>CD: 0.07 | medium | low | high | high | low | high | low | low | medium | High in sealant and adhesive applier. |
| Polyurethanes | CD: 0.07 | high | low | high | low | low | low | low | low | high | High in PU foam applier. |
| Epoxy resins | Asthma: 0.08<br>CD: 0.07 | high | low | high | high | low | medium | medium | high | high | High in sealant and adhesive applier. |

| **Chemical agent / other agents** | **Related disability: disability weight [b]** | **Occupations and expected exposure level [a]** | | | | | | | | | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Carpenter** | **Brick layer** | **Painters** | **Tilers** | **Demolisher** | **Plasterer** | **Concrete sawyer and driller** | **Jointers** | **Wood-workers** | |
| Diesel exhaust | Lung cancer: 0.54<br>COPD: 0.31 | low | low | low | low | high | low | low | low | low | High in road workers and during use of machinery. |
| Asbestos | Lung cancer: 0.54 | low | low | low | low | high | low | low | low | low | High in asbestos removal and demolition. |
| Silica | Silicosis: 0.43<br>COPD: 0.31<br>Lung cancer: 0.54 | low | high | low | high | high | high | high | high | low | |
| Wood dust | COPD: 0.31 | high | low | high | low | high | low | low | low | high | |
| Mineral wool | CD: 0.07 | medium | high | low | low | medium | low | low | low | low | High in insulators |
| Cement | CD: 0.07 | low | high | low | high | medium | low | high | high | low | |

| **Chemical agent / other agents** | **Related disability: disability weight** [b] | **Occupations and expected exposure level** [a] | | | | | | | | | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Carpenter** | **Brick layer** | **Painters** | **Tilers** | **Demolisher** | **Plasterer** | **Concrete sawyer and driller** | **Jointers** | **Wood-workers** | |
| RSI, CANS | Neck/back complaints: 0.06<br>Artritis: 0.19 | | | | | | | | | | RSI and CANS apply to almost all construction workers. |
| Noise | Hearing defects: 0.11 | | | | | | | | | | Noise complaints applies to almost all construction workers. |

[a] Low means that exposure to that agent is considered not to be relevant for that job title; medium indicates that exposure to that agent can normally be expected albeit infrequent and relatively low, but not to be neglected, and high means that exposure is very relevant for that job title and therefore the exposure is expected to have a relatively high frequency and/or relatively high exposure levels (automatically ‘high’ is entered when Van Thienen and Spee (2008) have marked a relation between that occupation and agent).

[b] CSE = chronic solvent-induced encephalopathy, CD = irritative or allergic contact dermatitis, COPD = chronic obstructive pulmonary disease, RSI = repetitive strain injury, CANS = complaints about arms, neck and shoulders.

[c] In a recent nested case control study by Olsson et al. (2010), where additional information was obtained on smoking habits in the control group and lung cancer cases, no relation was found for asphalt and lung cancer after correction for smoking habits.

*Table E.2 Description of job titles within the construction sector with related PAGO numbers and estimated total number of employees (taken from Uijt de Haag et al., 2010)*

| **Arbouw code** | **Description** | **PAGO Number** | **Estimated number of employees (rounded)**[a] |
|---|---|---:|---:|
| 9541 | Carpenter (timmerman) | 11,704 | 80,000 |
| 9511 | Brick layer (metselaar) | 2892 | 18,800 |
| 9311 | Painter (schilder) | 2658 | 17,300 |
| 7021 | Supervisor (uitvoerder B & U) | 2253 | 14,600 |
| 9919 | Brick layer's assistant (opperman/bouwvakhelper) | 839 | 5500 |
| 9746 | Machinist (machinist GWW) | 764 | 5000 |
| 9514 | Road paver (straatmaker) | 666 | 4300 |
| 9913 | Excavation worker (grondwerker) | 644 | 4200 |
| 9551 | Plasterer (stukadoor traditioneel) | 577 | 3800 |
| 9546 | Carpenter (timmerman) | 572 | 3700 |
| 9513 | Tiler (tegelzetter) | 491 | 3200 |
| 9547 | Carpenter/brick layer (timmerman/metselaar) | 475 | 3100 |
| 9741 | Machinist mobile crane (machinist mobiele kraan) | 416 | 2700 |
| 9914 | Craftsman (vakman GWW) | 388 | 2500 |
| 9855 | Driver (chauffeur) | 375 | 2400 |
| 9595 | Cable pipeline layer (kabel- en buizenlegger) | 356 | 2300 |
| 9544 | Woodworker mechanized (machinaal houtbewerker) | 327 | 2100 |
| 9521 | Concrete driller/sawyer (betonboorder/zager) | 288 | 1900 |
| 8457 | Mechanic machine maintenance (monteur onderhoud machines) | 266 | 1700 |
| 9598 | Mechanic ceiling/completion (plafondmonteur/monteur afbouw) | 246 | 1600 |
|  | Total | 27,197 | 180,700 |

[a] the number of employees estimated per job title is obtained by multiplication of the PAGO (periodic medical examinations) registrations and a correction factor of 6.5 based on attendance percentages of employees. This approach was the same as reported in the RIVM report (Uijt de Haag et al., 2010) to obtain population sizes for DALY estimations. Please note that the total number of workers in the construction sector is estimated at 364,100 according to preliminary figures from CBS (2012) for the year 2009, which is approximately twice the total number in the table.

As an additional criterion for the selection process the possibility of interventions could be considered. The searched literature did not offer much information on possible interventions or alternatives regarding the substances used in the construction sector. In the past, a few regulative measures have been taken, e.g. VOC restrictions in paint products, a ban on asbestos, a ban on some metal salts in treated wood and restrictions of metal oxides in cement, amongst others. In the OHIA project, focus lies mainly on possible practical interventions that could be implemented by the employer (thus not policy measures). In Table E.3, possible interventions and their expected feasibility have been mentioned for each agent, which are predominantly based on personal judgment. The list of interventions is not considered to be complete as detailed technical information on alternatives and construction techniques is lacking.

*Table E.3 Possible policy measures or interventions for the respective substance groups and for their sources.*

| **Chemical agents / other agents** | **Possible intervention** [a] | **Feasibility** [b] |
|---|---|---|
| VOCs | Already taken for paints and VOC emitting systems<br>- max. concentration in products<br>- max. release into environment | not relevant |
| | Increase monitoring of interventions | + |
| Asphalt / bitumen | Replacement of bitumen | ? |
| Heavy metals | Use prefab materials from factory where exposure from metal construction can be better controlled. | + |
| | Ban of metal salts as preservatives | not relevant |
| Isocyanates | Replacement by other isocyanates that do not elicit effects. | ? |
| | Wearing gloves and respirators. | + |
| Polyurethanes | Use of gloves | + |
| Epoxy resins | Use containers that can mix the 2 components itself. Or use of syringes to add second component. | + |
| | Gloves | + |
| Diesel exhaust | Place particle filters on automotives | +, effectiveness is doubtful because exposure is mainly from traffic. |
| Asbestos | Banned, health effects are currently at their peak due to lag. | not relevant |
| | Improved protection during removal and monitoring thereof. | + |
| Silica | Keep silica dust wet | + |
| | Respirators | + |
| Wood dust | Respirators, use of prefab materials, use untreated wood, keep wood wet. | + |
| Mineral wool | Use of gloves | + |
| | Use of alternatives | + |
| Cement | Restrictions of metal oxides. | - |
| | Addition of ferrous sulfate. | + |
| RSI / CANS | Shorter work shifts, incl. physiotherapy | + |
| Noise | More silenced machinery | + |
| | Hearing protectors | + |

[a] Wearing of respirators, gloves and/or other personal protective equipment may reduce exposure but might not be ideal for the workers functionality.

[b] Feasibility is indicated with: -, not feasible, +, feasible and ?, if it is unknown whether or not the interventions will be feasible due to lack of information, and not relevant is stated when interventions have been taken.

Finally, a summary table (Table E.4) is provided, indicating per agent: the related health effects with their severity, the populations that scored 'high' in Table E.1 including a population size estimate from Table E.2, and the feasibility of interventions (Table E.3).

*Table E.4 Summary table of the set of criteria indicative for the potential health impact per agent.*

| **Chemical agent / other agents** | **Related disability: disability weight [a]** | **Exposed populations (size)[c]** | **Feasibility of possible interventions[d]** |
|---|---|---|---|
| Volatile organic compounds (VOCs) | CSE: 0.50<br>Asthma: 0.08<br>COPD: 0.31<br>CD: 0.07 | Carpenter (80,000)<br>Painter (17,300)<br>Tiler (3200)<br>Plasterer (3800) | Monitoring: + |
| Asphalt / bitumen | Bronchitis: 0.05<br>CD: 0.07<br>Lung cancer: 0.54[b] | Asphalt road worker | alternatives: ? |
| Heavy metals | Tumor: 0.12 – 0.59 (skin cancer excluded)<br>CD: 0.07 | | Use prefab material: + |
| Isocyanates | Asthma: 0.08<br>COPD: 0.31<br>CD: 0.07 | Painter (17,300)<br>Tiler (3200)<br>Plasterer (3800) | alternatives: ?<br>gloves and respirators: + |
| Polyurethanes | CD: 0.07 | Carpenter (80,000)<br>Painter (17,300)<br>Wood workers mechanized (2100) | gloves: + |
| Epoxy resins | Asthma: 0.08<br>CD: 0.07 | Carpenter (80,000)<br>Painter (17,300)<br>Tiler (3200)<br>Jointers<br>Wood workers mechanized (2100) | mixing equipment, gloves: + |
| Diesel exhaust | Lung cancer: 0.54<br>COPD: 0.31 | Demolisher | +, effectiveness is doubtful because exposure is mainly from traffic. |
| Asbestos | Lung cancer: 0.54 | Demolisher | improved removal and monitoring: + |

| Chemical agent / other agents | Related disability: disability weight [a] | Exposed populations (size)[c] | Feasibility of possible interventions[d] |
|---|---|---|---|
| Silica | Silicosis: 0.43<br>COPD: 0.31<br>Lung cancer: 0.54 | Brick layer (18,800)<br>Tiler (3200)<br>Demolisher<br>Plasterer (3800)<br>Concrete sawyer and driller (1900)<br>Jointers | keep dust wet, respirators: + |
| Wood dust | COPD: 0.31 | Carpenter (80,000)<br>Painter (17,300)<br>Demolisher<br>Wood workers mechanized (2100) | keep dust wet, use untreated wood, respirators: + |
| Mineral wool | CD: 0.07 | Insulators<br>Brick layer (18,800) | alternatives, gloves: + |
| cement | CD: 0.07 | Brick layer (18,800)<br>Tiler (3200)<br>Concrete sawyer and driller (1900)<br>Jointers | restrictions: -<br>additions: + |
| RSI, CANS | Neck/back complaints: 0.06<br>Artritis: 0.19 | All construction workers | shorter work shifts: + |
| Noise | Hearing defects: 0.11 | All construction workers | hearing protecting, silenced machinery: + |

[a] CSE = chronic solvent-induced encephalopathy, CD = irritative or allergic contact dermatitis, COPD = chronic obstructive pulmonary disease, RSI = repetitive strain injury, CANS = complaints about arms, neck and shoulders.

[b] In a recent nested case control study by Olsson et al. (2010), where additional information was obtained on smoking habits in the control group and lung cancer cases, no relation was found for asphalt and lung cancer after correction for smoking habits.

[c] Population and their sizes (Table E.2) were given if they scored 'high' in Table E.1. No estimation given if no information is available.

[d] Feasibility is indicated with: -, not feasible, +, feasible and ?, if it is unknown whether or not the interventions will be feasible

**Discussion and conclusion**

The tables above provide information on specific chemical and non-chemical exposures which are known, but not necessarily proven to cause health effects in construction workers. The overview of exposure-effect relations in combination with their relevance for the different occupations and feasibility of interventions provides a valuable first step in the selection process as it includes the major building blocks for health impact assessments. Based on the gathered information and the set of criteria, the exposure-effect relations of interest are silica and COPD (other endpoints of silica were previously included in the OHIA project), epoxy resins and skin disease or asthma, cement and skin disease, wood dust and COPD, RSI/CANS and noise. Other practical criteria in the selection process can further narrow down the selection.

We are aware of the fact that the present overview is incomplete and perhaps not always accurate or up to date. The overview contains information on chemical and non-chemical exposures per occupation in a qualitative way and therefore does not enable making distinctions between activities within a job, nor does it contain information on the likelihood of an exposed individual of obtaining the disability. In order to obtain this information an extensive literature search for representative epidemiological studies is required.

**National Insitute for Public Health**
**and the Environment**
P.O. Box 1 | 3720 BA Bilthoven
www.rivm.com