Historical exposure levels of inhalable dust in the Polish rubber industry compared to levels in Western Europe.

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Abstract. Although studies have been carried out to assess inhalable dust exposure levels in the rubber manufacturing industry, the levels of exposure in factories in Eastern Europe are less well documented. Routine stationary sampling for compliance testing of inhalable aerosols has however been conducted in a large factory producing tires and tubes in Poland between 1981 and 1996 (N=6,152). This study was conducted to assess historical inhalable aerosol levels in different departments in this rubber plant and to compare the results with estimates based on European data from the United Kingdom, Sweden, the Netherlands and Germany, and also Poland (EXASRUB project). Geometric mean (GM) concentrations in the factory ranged from 2.41 mg/m\textsuperscript{3} to 5.82 mg/m\textsuperscript{3} and were to a large extent associated to the actual production capacity of the plant and flow of the production process. Whereas 3-4 fold differences between departments existed prior to about 1985, stronger reduction of exposure in the raw materials and finishing departments (-12%/year) compared to other departments (range -5%/yr to -3%/yr), resulted in comparable levels in the 1990s. However, in the pre-treating departments, average concentrations were still about a factor 2-3 higher than in other departments, which could presumably be attributed to the use of anti-tacking agents. GM concentrations have been modelled using (1) stationary measurements collected in the Polish factory only, or (2) all European data collected in the EXASRUB project. Comparison of the estimates showed that these were fairly similar for both datasets. This analysis showed that the levels of inhalable aerosols in the Polish rubber industry have been at least a factor three to four higher than in Western European countries in the 1980s and 1990s, depending on the department, but that these differences were getting smaller in the 1990s. Furthermore, the
estimates based on all European data from EXASRUB provides valid estimates compared to factory-specific data.

1. Introduction
The rubber industry as a whole was classified as “entailing exposures that are carcinogenic to humans (group 1)” by the International Agency for Research on Cancer (IARC) as early as 1987 [1,2]. Employment in the rubber manufacturing industry exposes employees to a wide range of chemicals, including n-Nitrosamines, aromatic amines, rubber fumes, rubber process dusts, and more. One the important airborne exposures in this industry is exposure to rubber dusts, which have been shown to be mutagenic [3-5] as well as probably genotoxic [6].

Although studies have been carried out to assess inhalable dust exposure levels in rubber manufacturing [7,8], the levels of exposure in factories in Eastern Europe are less well documented. However, an exposure measurement survey was conducted in a large Polish tire manufacturing factory in the 1980s and ‘90s in which a large number of airborne chemicals, including inhalable aerosols, were measured [9]. These data were subsequently used to compare Polish exposure levels with those in other European countries in the EXASRUB project (http://exasrub.iras.uu.nl) [10,11] and have also been used to estimate a quantitative job-exposure matrix for this specific factory [12]. The present exercise was conducted to assess the validity of the estimates for average inhalable dust in a Polish factory extrapolated from a “European” statistical model based on data from five European countries compared to estimates from detailed “local” statistical analysis using only measurement data from the Polish factory.

2. Methods
The factory where the measurement survey [9] was conducted was involved in a large cohort study in the Polish rubber industry [13]. Its history and production has been described in detail [12], but in short the factory has been in production since 1950 and it consists of two mixing departments, a car tire production line, a production line for tubes for car tires, and agricultural vehicle tire production line, and a production line for bicycle tubes and tires. Except for the agricultural tires production line, assembly of all types of tires was done using “cold” processes.

Within the measurement survey routine stationary sampling for compliance testing of inhalable aerosols (N=6,152) was conducted between 1981 and 1996 (Table 1). Inhalable aerosol measurements were collected by means of a 42mm sampling head equipped with a 50mm AFPC filter (98%) or 50mm glass fiber filter (2%) at a flow rate of 2L/min (93%) or 3L/min (5%) (2% unknown). The sampling time was 3 hours (79%) or 4 hours (19%), with some 6 hour measurements (2%) as well.

Log-transformed concentrations were analyzed using linear mixed effects models to account for repeated sampling of locations to assess airborne levels and trends in time in the different departments in the factory. Deviations from log-linear trends in time in departments were assessed using penalized smoothing splines and these results were used to improve the estimates from the mixed effects models.

Inhalable dust exposure estimates extrapolated from the “European” analysis were obtained from analyses of the EXASRUB dataset [10]. This dataset included 4,284 personal and 8,463 stationary inhalable aerosol measurements collected in the Netherlands (N=2,285), United Kingdom (N=4,134), Sweden (N=415), Germany (N=185) and Poland (N=6,361) between 1969 and 2003. Estimates of average personal exposure levels for all countries were published previously [10], and these estimates were used to estimate average inhalable dust exposure levels based on stationary sampling using average differences between personal and stationary (57% to 68% lower) samples in different departments from those same statistical models.
3. Results
The results have been summarized in Table 1. Inhalable geometric mean (GM) concentrations in the factory ranged from 2.41 mg/m$^3$ in the finishing departments to 5.82 mg/m$^3$ in the mixing and milling departments. The inhalable aerosol levels were determined to a large extent by the production process. More specifically, inhalable aerosols were primarily generated in the first stages of the production process, where crude materials are handled, mixed and milled, and assembled before they are vulcanized in the curing process (GM=5.09 to 5.82 mg/m$^3$). After curing of products (GM=3.90 mg/m$^3$), average concentrations drop to 2.41 mg/m$^3$ in the finishing departments. High inhalable aerosol levels were also found outside the production process for non-process factory workers (GM=4.07 mg/m$^3$) and in the maintenance and engineering department (4.08 mg/m$^3$).

Estimated average inhalable dust levels in the different departments between 1980 and 1996 have been shown graphically in Figure 1. Whereas 3-4 fold differences between departments existed prior to about 1985, stronger reduction of exposure in the raw materials and finishing departments (-12%/year) compared to other departments (range -5%/yr to -3%/yr), resulted in comparable average inhalable aerosol levels throughout the factory in the 1990s. Only in the pre-treating departments however, average concentrations were still approximately a factor 2-3 higher than in other departments in the 1990s, which could presumably be attributed to the use of anti-tacking agents like talc and zinc stearate.

Figures 2.1 to 2.6 show the average inhalable dust concentrations in the different departments between 1980 and 1995 estimated using three different methods. Average personal exposure levels have been based on the results from the statistical models using all “European data” collected in the EXASRUB project [10,11] and published in [10]. Average concentration from stationary sampling were based on the same statistical models published in [10] but applying an additional correction factor to account for the difference between personal and stationary measurements, and the third “local data” method was to estimate average concentrations based on stationary measurements collected in the Polish factory only. The models and results of this third method have been published previously in [12]. As shown, personal exposure levels are on average a factor three higher than average concentrations from stationary measurements. However, the estimates of average inhalable dust concentrations based on stationary measurements from the European data are comparable to those based on “local” analysis using measurement data from that specific factory only.

Combining this with the results published in [10] suggests that the inhalable aerosol levels in the 1980s and 1990s in Poland were a factor 3 to 4 higher than in the Netherlands, UK and Sweden, but comparable to those in Germany. However, data from a small field-study assessing the relative performance of the different aerosol samplers to measure rubber dust in the different countries in the EXASRUB project showed that the sampling head used in this Polish survey under-sampled concentrations by approximately 35-50%, depending on the particle size, compared with samplers used in the other countries and to the EU-CALTOOL reference sampler [14]. This implies that in the 1980s and 1990s the differences between countries might even have been somewhat larger and that the average inhalable dust concentrations in Poland were more than twice as high as in western European countries.

4. Discussion
This exercise aimed to assess the validity of the estimates for average inhalable dust in a Polish factory extrapolated from a “European” statistical model, based on data from five European countries, compared to estimates from a detailed “local” statistical analysis using only measurement data from the Polish factory. In general, these data show that the processes across Europe are similar resulting in similar relative ranking of departments in terms of inhalable aerosol exposure levels. Furthermore, the predictions of average concentrations are comparable regardless of whether only “local data” was used or whether predictions are based on a large dataset containing measurement from different countries.
It should be noted that these analyses discuss average inhalable aerosol concentrations in departments and as such do not take into account measurements in specific low- or high-exposure tasks.

The measurement data does suggest that the levels of inhalable rubber aerosols in the Polish rubber industry have been at least a factor three to four times higher than in Western European countries in the 1980s and 1990s, depending on the department, but that the differences were getting smaller in the 1990s.

The reduction in average inhalable dust exposure levels, especially since half-way through the 1980s, can presumably be attributed to major changes in technology and the introduction of more effective exposure control measures in that time period [12]. In the Netherlands, it has been shown that these measures can reduce exposure to aerosols by 34-49% [8]. However, although specific information on local exhaust ventilation and other exposure reduction measures was collected for some locations within the factory but not for other locations, this information was not used in these analyses to further refine the factory-specific models. Additionally, a reduction in the production level of the factory around the period 1988-1992 [12] might have increased the trend towards lower average exposure levels.

As such, these data suggested that these estimates were comparable to and thus that the “European estimates” for average inhalable aerosol levels in different departments and years in European countries obtained in EXASRUB are also valid at a “local” level.

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Table 1. Characteristics of dataset (adapted from (de Vocht F. et al., 2008a). Number of different locations where stationary samples were taken, number of measurements, geometric mean (GM) concentrations and geometric standard deviation (GSD) for inhalable aerosols.

| Department                      | locations | samples | GM (mg/m³) | GSD  |
|---------------------------------|-----------|---------|------------|------|
| Crude materials                 | 2         | 242     | 5.68       | 1.75 |
| Compounding, mixing and milling | 17        | 2,734   | 5.82       | 1.76 |
| Pre-treating                    | 3         | 494     | 5.09       | 1.32 |
| Assembly (tires, Tubes or valves) | 7   | 1,999   | 5.54       | 1.60 |
| Curing                          | 2         | 9       | 3.90       | 1.48 |
| Finishing                       | 2         | 103     | 2.41       | 1.60 |
| Storage                         | 1         | 1       | 1.70       |      |
| Non-process working             | 12        | 567     | 4.07       | 1.49 |
| Maintenance & Engineering       | 2         | 3       | 4.08       | 1.18 |
Figure 1. Average (GM) concentrations in the different factory departments (miscellaneous departments includes curing, storage, non-process workers, and maintenance and engineering departments)
Figures 2.1-2.6. Comparison of estimated average (GM) personal and stationary exposure levels based on the full EXASRUB dataset and average exposure based on stationary measurements based on the Polish data only in different factory departments.
