An assessment of time changes of the health risk of PM10 based on GRIMM analyzer data and respiratory deposition model

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Abstract

PM10 particles are considered as one of the most problematical pollutants affecting the human health, especially in the urban environment, where they are emitted primarily from the mobile sources. Particles entering human respiratory system are subjected to number of deposition mechanisms and the fraction deposited in different parts of respiratory tract depends on their aerodynamical diameter. Thus, identical PM10 concentrations measured by monitoring stations may cause different health effects depending on size distribution of particles whose concentration was detected.

Synchronous measurements of suspended particles fractions PM1, PM2.5 and PM10 were provided using GRIMM Model 180 analyzer in Prague (Czech Republic capital) and in Ostrava industrial region. These enable to assess the proportion of contribution of different fraction to the total PM10 concentration. Collocated PM10 concentration data gathered by the radiometric method was available as well.

The model developed by the International Commission on Radiological Protection (ICRP) to predict the particle deposition in human respiratory tract was applied at the measured data and possible particulate dose assessment has been found for different locations and time periods.

Keywords: PM10, size distribution, health effects, GRIMM analyzer

Introduction

Particles are considered as one of the most problematical pollutants affecting the human health. They comprise typical air pollution burden especially in the urban environment, where they are emitted primarily from the mobile sources and in the industrial regions as well. Health risk depends by particulate matter concentration and particles size, morphology and chemical composition (Pope III. C. A. and Dockery D. W. 2006). The air quality standards regulate PM10 concentrations first of all. In recent years, however, the PM2.5 and PM1 particles, depositing in the lower respiratory tract and being assumed as the main cause of increased morbidity and mortality among population, were studied with the increased intensity.

Methodology and data used

Measured data from GRIMM Model 180 analyzer (GRIMM Aerosol Technik, 2003), gathered at two places in the Czech Republic during the period September 2005 – October 2006, were analyzed. The GRIMM analyzers were installed at automatic monitoring stations located in Prague (Czech Republic capital) and in highly industrialized town Ostrava. PM10 concentrations measurements by means of Thermo ESM Andersen FH 62 I-R analyzers are provided at both stations at regular basis. Parallel meteorological data such as air temperature and humidity, wind and global solar radiation are available as well at these sites. The analysis has been provided for the hourly means of all measured quantities.

Particles suspended in the air enter human body by breathing. These particles include natural materials such as bacteria, viruses, pollens, sea salt, road dust as well as anthropogenic emissions. The hazard caused by these particles depends on their chemical composition as well as where they deposit within human respiratory system. Hence, the understanding of aerosol deposition in human respiratory system is critical to human health so that the deposition of “bad” aerosol can be reduced (http://aerosol.ees.ufl.edu).

The respiratory system is works essentially as a filter. The viscous surface of the airway walls almost guarantees the deposition without re-entrainment when a particle is in contact with it. The most important mechanisms are impaction, settling, diffusion and interception. A particle entering respiratory system is subject to all the deposition

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mechanisms mentioned previously. The actual deposition efficiency of a given particle size has been determined experimentally. Several models have been developed to predict the deposition based on experimental data. A widely used one was developed by the International Commission on Radiological Protection. For the purpose of this model, respiratory system is divided into 3 parts: head airways (HA), tracheobronchial region (TB) and alveolar region (fig. 1).

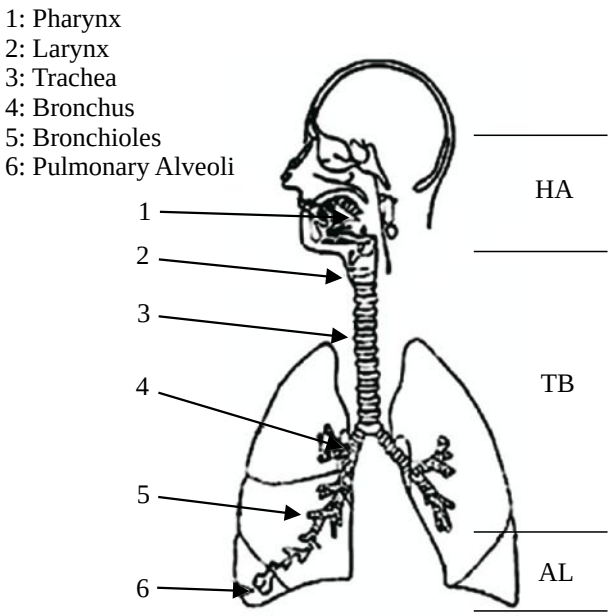

Figure 1:
Parts of human respiratory tract used in ICRP model

Equations describing the total deposition fraction (DF) in the whole respiratory system and regional deposition fractions in head airways (DFHA), tracheobronchial region (DFTB) and alveolar region (DFAL) were derived in this model (http://www.icrp.org). Regional deposition is of more interest because it is more relevant in assessing the potential hazard of inhaled particles.

In figure 2, dependences of particular deposition fraction on particle size diameter calculated according to ICRP model equations are depicted. It is obvious that particles with their diameter within the range 0.1 – 1 μm deposit with the lowest efficiency. The most dangerous, related to human health, are the fine particles with diameters ranging between 0.01 – 0.1 μm which are deposited in pulmonary alveoli without possibility to be removed from them for instance by cough.

Results and discussion

Hourly mean particle concentrations in fractions PM10 and PM2.5, measured by GRIMM analyzers, were compared with those from regular network.

Example of such comparison gives a scatter graph at figure 3, where comparison of PM10 data from Ostrava was depicted.

The good correlation of both methods is obvious, but GRIMM analyzer significantly underestimates PM10 mass concentration values. Similar results were obtained for locality in Prague and for the PM2.5 fraction. Obviously the

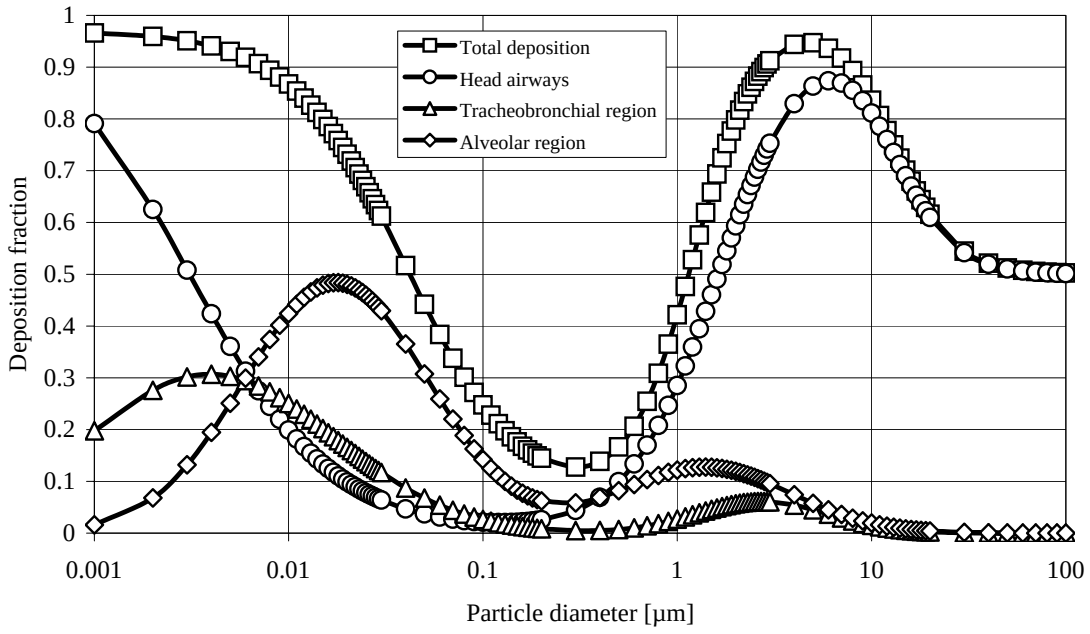

Figure 2:
Dependence of regional particle deposition fraction on particle diameter

calibration constants of GRIMM analyzer must be checked and set appropriately. As for the current data, we concluded that it would be reasonable to analyse proportions of particular fractions in PM10 instead their mass concentrations provided by GRIMM.

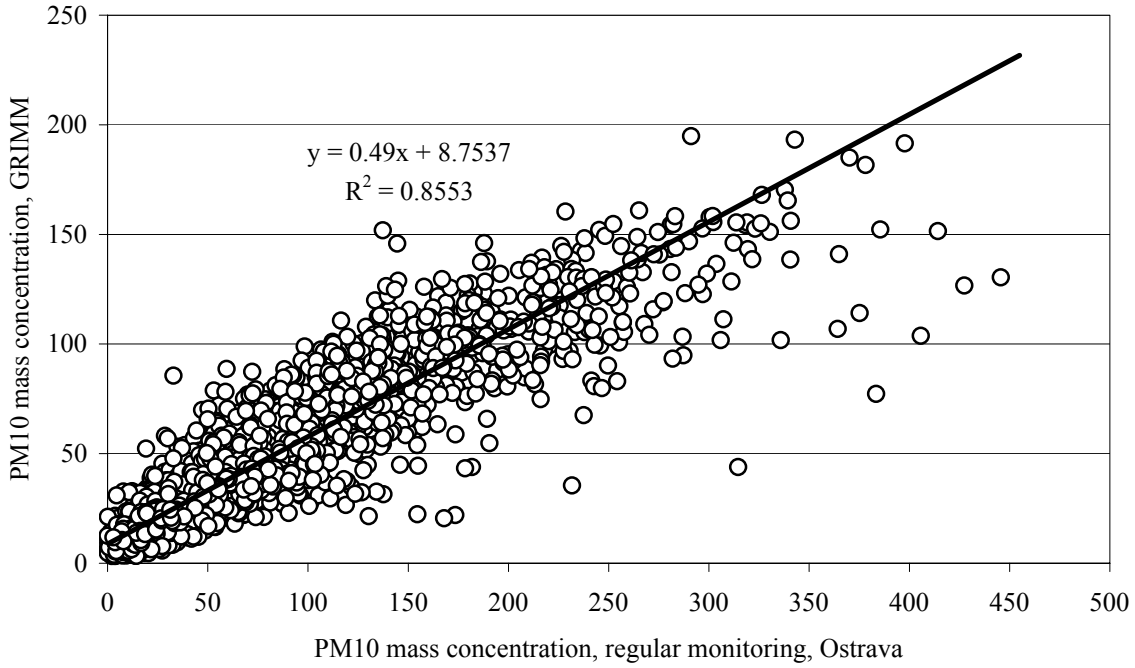

Figure 3:
Comparison of PM10 concentration measured by GRIMM and a standard network analyzer

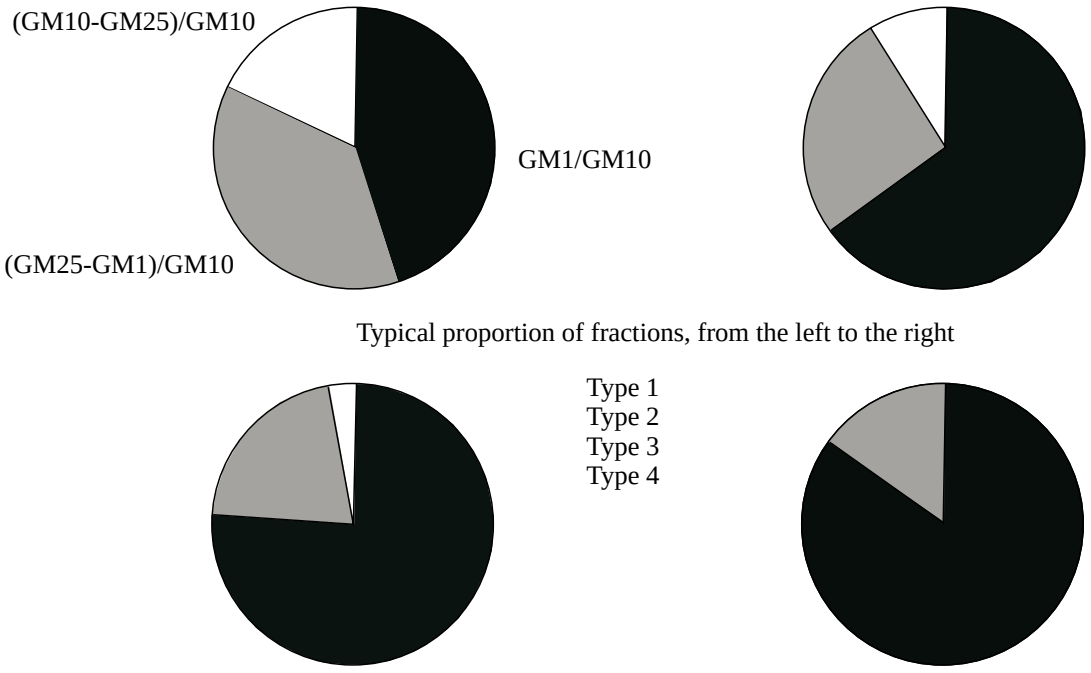

Figure 4:
Types of PM fractions proportions in PM10, Ostrava

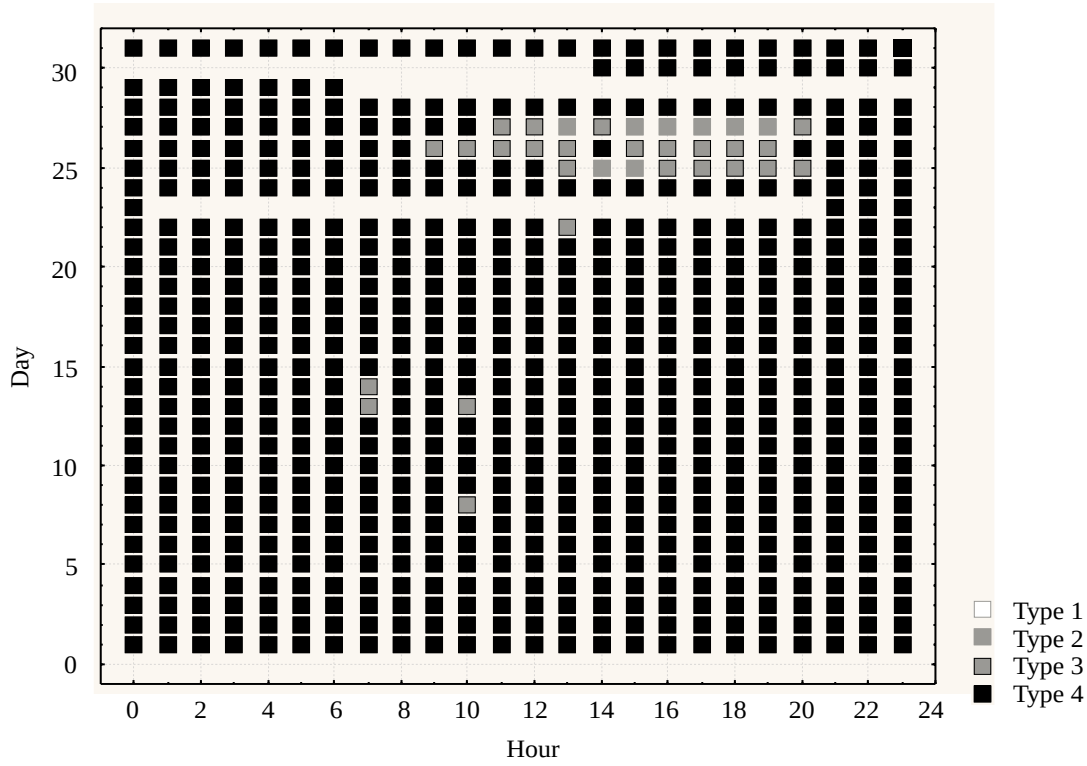

Figure 5:
Time changes of typical profiles of PM fractions share in PM10 in Ostrava, January 2006

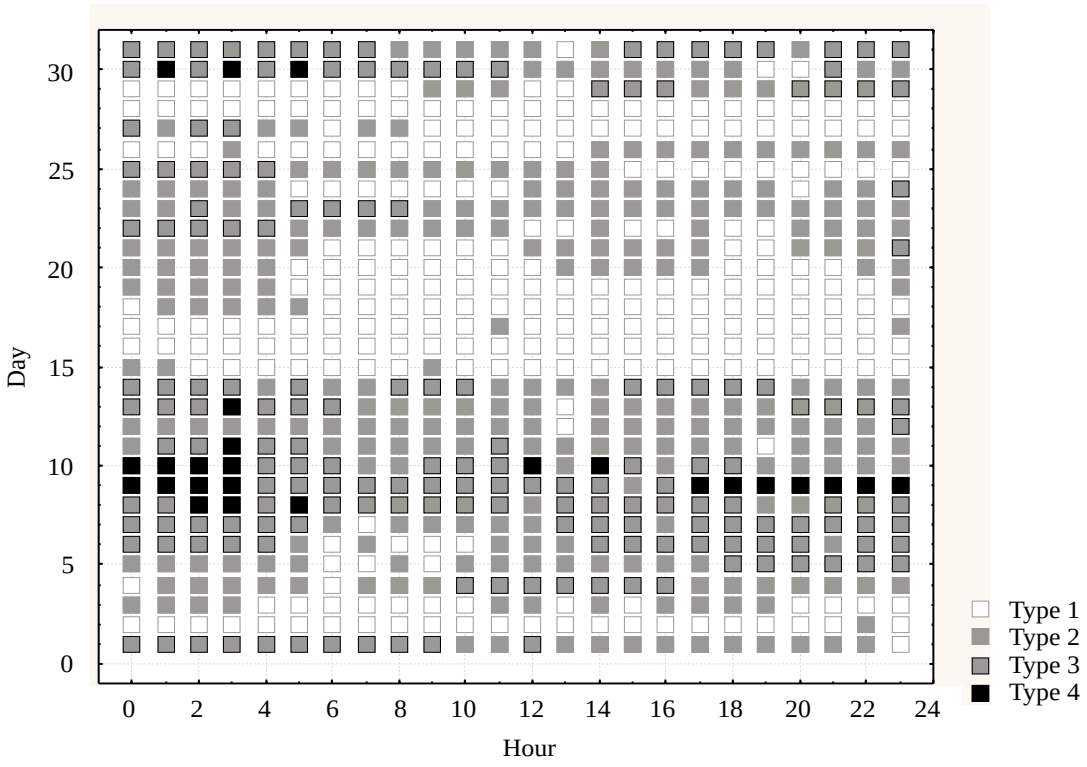

Figure 6:
Time changes of typical profiles of PM fractions share in PM10 in Ostrava, July 2006

For further analysis, proportions of particular fractions measured by GRIMM were determined, where e.g. GM1/ GM10 stays for the share of PM1 in total PM10 concentration. Changes of share of PM1 and PM2.5 in PM10 with air temperature and relative humidity were studied and it has been found that the share of fine fraction in total PM10 concentration increases when air temperature decreases. For low temperatures, practically the whole PM2.5 fraction consists of the finest PM1 particles, which are the most dangerous form the aspect of health effects. Similarly, the share of both fractions in the total PM10 increases with increasing relative humidity and the share of PM1 in PM2.5 increases as well. In range of relative humidity between 80 and 90% practically all PM2.5 consists of PM1.

For the purpose of health protection and for considerations on particle origin there is necessary to answer the question if and how the share of particular fraction in PM10 changes in time. The results of multicomponent statistical analysis showed that this share has been changing at both locations during the day and from one month to another as well. Four typical profiles of share of PM1 and PM2.5 fractions in PM10 were found by means of cluster analysis, marked from 1 to 4. Each hourly profile was then allocated into one profile class. The share of fine fraction in total PM10 increases with the increasing class number and for class 4 practically the whole PM10 consists of PM1. Thus, the rate of danger for the human health increases with the class number.

Figure 5 shows the daily changes of profile classes in Ostrava for winter (January) and summer (July) month. The most dangerous profile class dominated in Ostrava over the whole January 2006, without any indication of the daily course. The different picture showed July, when amount of less serious classes increased and daily course of them is also apparent. The described approach enables to map the changes of burden by particular PM fractions during the whole year and study their relation to meteorological parameters and emission sources types.

Clearly, not only the proportion of fractions but also their mass concentration is crucial from the viewpoint of health effects. Figure 7 gives an example of combination of parallel GRIMM and standard analyzer measurement. The PM10 mass concentration from standard analyzer has been disaggregated among particular fractions by means of coefficients derived from the share of PM1 and PM2.5 fractions measured by GRIMM. The PM1 and PM2.5 concentrations derived from PM10 ones are marked as “hypothetical”. If the GRIMM analyzer were set for measurements of broader spectrum of fractions, the parallel measurements provided by both analyzers would give the possibility to assess particulate mass concentrations in separate spectral bands and determine their time changes.

Significant changes of PM10 concentration during the time period presented at Figure 6, accompanied by simultaneous particle size spectrum changes (being demonstrated by changes of share of size fractions in PM10), caused

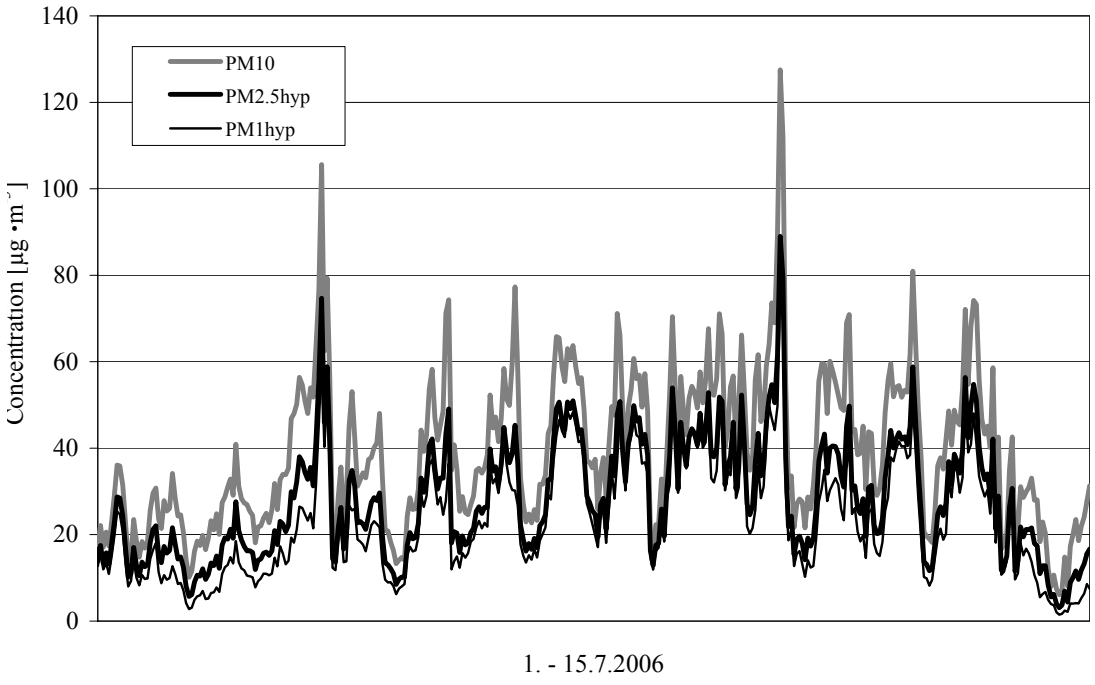

Figure 7:
Disaggregation of operationally measured PM10 mass concentrations measured by means of fraction proportions determined from GRIMM. Ostrava, July 2006

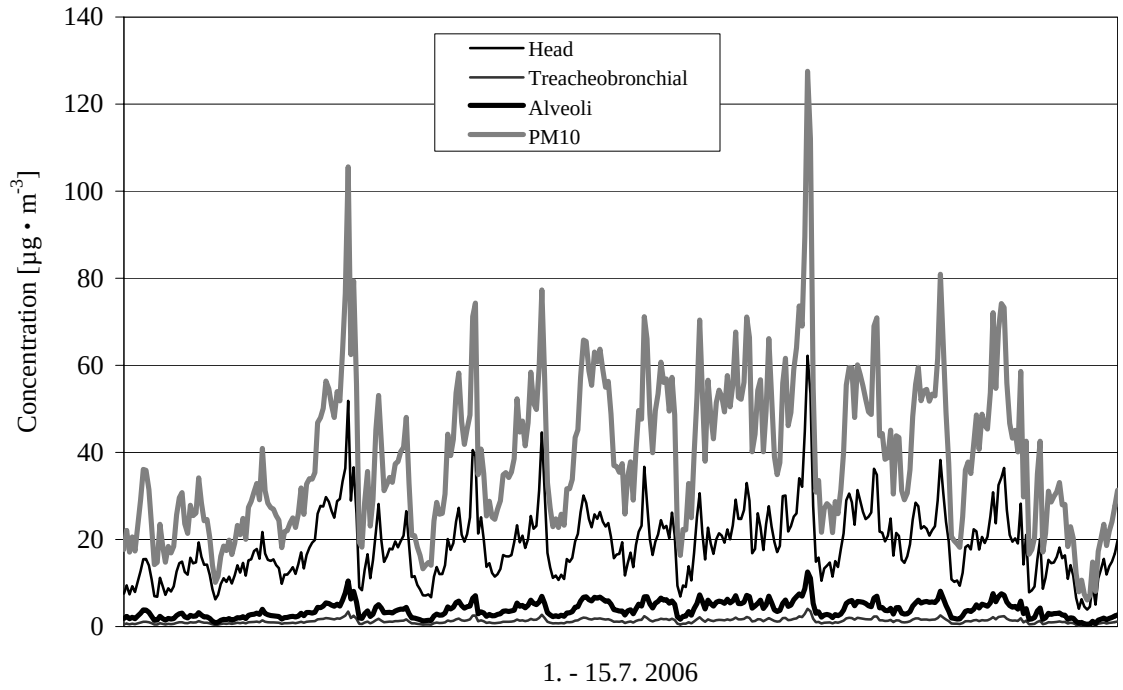

Figure 8:
Potential deposition of particle mass concentration in particular parts of human respiratory tract, derived from ICRP model

that the particle mass which might be potentially deposited in particular parts of human respiratory tract was time-dependent as well. The ICRP deposition model enables us to assess these values for each hour. Results of such assessment are shown in figure 9. Median particle diameters for each size class measured by GRIMM, i.e. 0 - 1, 1 - 2.5 and 2.5 - 10 micrometers, were taken as an input of deposition fraction calculation provided by the ICRP model. The dose potentially deposited in particular parts of respiratory tract can be treated as a measure of health hazard caused by the presence of particles in the air. This dose might differ even if the ambient PM10 concentration would be the same, depending on the actual particle size spectrum.

Conclusions

- The PM10 mass concentrations measured by GRIMM analyzer are underestimated significantly, nevertheless the data are homogenous and well correlated with the routine analyzer measurements
- It is possible to derive correction formulae for the recalculation of GRIMM data and disaggregate the PM10 data from regular monitoring into particular fractions, using the fractions proportions derived from GRIMM
- Share of particular fractions (PM1 and PM2.5) in total PM10 concentration showed significant time changes and was related to the meteorological conditions
- It was possible to define typical profiles of such proportions and to highlight the presence of structures in measured data that way
- The share of particles, depositing in the low respiratory tract (PM1 and PM2.5) at the total PM10 concentration increased with the decrease of air temperature and increase of relative humidity. This is very serious fact in relation to the human health protection
- The routine measurements expanded by GRIMM data can be used as an ICRP deposition model input and assess how the health risk caused by particles changes in time.

Acknowledgements

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