Carcinogenic Risk of Air Particles in the Moravian-Silesian Region (Czech Republic)

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Abstract

The complex and systematic description of morphological, mineralogical, physicochemical and toxicological features of urban and rural particulate matter PM10 is essential because of their harmful impacts on human health condition. The exposure to ambient particulate matter PM10 is known to be able to trigger inflammatory process, allergic reaction of different type, modification of DNA and carcinogenic transformation of many various cell types of the human body. The effects mentioned above have been confirmed with lots of in vitro and in vivo studies. Although the ambient particulate matter is the subject of large spectrum of epidemiological studies and scientific explorations, there is still lack of data concerning the assessment of human health risks in association with exposure to ambient air particles including particulate matter PM10. These pieces of information are necessary especially for primary prevention of many human diseases - such as a chronic obstructive disease, bronchial asthma, Crohn disease, ulcerous colitis, several degenerative diseases of central nervous system. The data discussing the negative influences of particulate matter PM10 on human health are also essential for researching new – more efficient – drugs and choice of the best available treatment in relation to an initiating factor or factors. Moreover, the amount of environmental pollutants is still rising therefore it is unavoidable to find out all their potential negative impacts on human health condition. To take the facts described above into account, this article is devoted to the topic of PM10 participation in pathogenesis of the most dangerous and often incurable human disease – the cancer. At the present time, it is namely supposed that a contact of organism with particulate matter PM10 has a significant role in developing of several types of malignant human tumours. Among these kinds of cancers, there are two types of carcinoma with rising number in human population – that is small-cell lung carcinoma and a carcinoma of colon and rectum. Besides these ones, the exposure of organism to particulate matter PM10 is considered to be an important etiopathogenic factor of some types of skin cancer and malignant tumours of scrotum. Because of the facts mentioned above it is necessary to devote to studying of negative effects of particulate matter PM10 sufficient rate of vigilance.

Keywords: particulate matter, PM10, polyaromatic hydrocarbons, carcinogenesis, genotoxicity

Introduction

Genotoxic and associated carcinogenic capacity of PM10 (particulate matter – particles with mean diameter of 10 μm or less) is based on the two main principles. The first one is related to the ability of PM10 to initiate an inflammatory response. Subsequently, the inflammation inducts oxidative and nitrosative stress reaction causing the release of large amount of various free radicals. Finally, the oxidative and nitrosative stress results in a damage to the DNA structure responsible for initiating of carcinogenesis (Borm et al., 2007; Kolář, 2003; Nečas, 2000).

The second way of PM10 genotoxic acting is implicated with chemical composition of this particle type. The major DNA modifying role of PM10 is played by miscellaneous chemical mutagens or carcinogens. These genotoxic or carcinogenic chemical compounds are absorbed on insoluble or poorly soluble core of PM10. In relation with this aspect of genotoxicity and associated carcinogenicity, the polycyclic aromatic hydrocarbons represent one of the most significant categories of chemical substances associated with particle ability of inducing DNA mutagenesis. This view of carcinogenicity process triggered by PAHs will be further discussed in detail in this article (Komínková, 2008; Kužílek, 1994; Nečas, 2000; Pitter, 1990).

Such mixture of absorbed PAHs is classified as human carcinogen by the International Agency for Research on Cancer (IARC). Concerning the carcinogenic capacity of individual PAHs, they include in two main classes of carcinogens according to the classification of IARC – i.e. the class 1 (obvious human carcinogens) and the class 2A (probable human carcinogens). Benzo(a)pyrene is considered to be an obvious carcinogen, it is the most investigated PAH from carcinogenic point of view (its effects have been studied since the nineteen thirties) and, at the same time, the benzo(a)pyrene has been found to be the most powerful carcinogen from all PAHs yet. Dibenzo(a,i) pyrene, benzo(g,h,i)perylene, benzo(b)fluoranthene, benzo(k)fluoranthene represent the other obvious carcinogens. The PAHs with lower car-

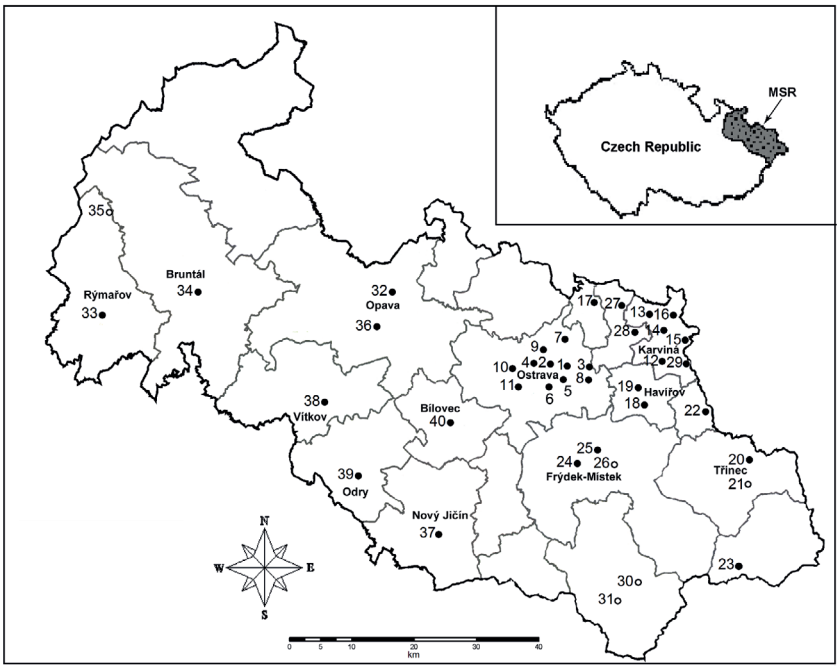

Fig. 1. Cities, towns, and municipalities in which the sampling sites were situated, solid circles – localities with cancer risk determined as significant for winter season

Rys. 1. Miasta, miasteczka i gminy, w których pobierano próbki,
koła – miejscowości z ryzykiem raka określonym jako istotne dla sezonu zimowego

cinogenicity (e.g. benzo(e)pyrene) belong to the category 2A of the IARC classification – i.e. possible human carcinogens (Klener, 2006; Kužílek, 1994; Reddy et al., 2012).

The exposure of human organism to PAH carcinogens or their mixture can be realized via three major pathways: inhalation, digestion and dermal contact. The air pollution participates in all three mentioned types of exposure. There are two principal categories of PAH sources responsible for air pollution and simultaneously for PAH exposure. The first class involves the natural contributors to PAH emissions like natural fires and volcanic eruptions. The anthropogenic sources represent the second group, which is dominating nowadays. Human-induced PAH emissions are generally derived from the incomplete combustion of wide spectrum of organic materials like fossil fuels (especially coal), wood, gasoline, domestic waste and tobacco. The PAH emissions are also produced in some industrial processes – e.g. coal gasification, aluminium production, iron and steel foundries, production of asphalt etc. The PAHs are present in road traffic fumes too; moreover, they are released from asphalt surfaces and asphalt insulation of roofs (Blažek et al., 2008; Chen, 2014; Čupr et al., 2013; Komínková, 2008; Křůmal et al., 2013; Kužílek, 1994; Reddy et al., 2012).

The PAH exposure to air sources mentioned above is in strong relation with higher frequency of certain type of human cancer. Obvious correlation between PAH exposure and bladder, lung and skin cancer was found. The increasing number of new cancer cases is in accordance with an exposure model prevailing at present – i.e. the contemporary exposure has a non-professional character, it impacts on a large part of human population, it is especially associated with industrial regions in which all three abiotic spheres of the environment - i.e. atmosphere, water and soils – are contaminated in a large scale. Earlier, the exposure was closely connected with dangerous place of work associated with direct contact with specific PAH sources - e.g. soot (Barceló, 2012; Carpenter, 2013; Kazmarová, 2003; Reddy et al., 2012).

The scale of carcinogenic capacity of diverse PAH is closely connected with the existence of a risk molecular formations in the structure of individual PAHs. The presence or absence of these hazardous formations causes big differences in PAH carcinogenicity. The well-known example of dangerous molecular substructures is a “bay region” ; its content in the structure of a certain PAH is a powerful signal giving evidence to a very probable carcinogenicity of this polycyclic aromatic hydrocarbon. Different carcinogenic potential of PAH with very similar structure (e.g. benzo(a)pyrene

versus benzo(e)pyrene) can only be explained due to the hazardous molecular substructures described above (Kužílek, 1994; Linhart, 2012).

The prerequisite of PAH carcinogenic nature is so-called metabolic activation of individual PAH induced by a complex of xenobiotic-metabolizing enzymes. By this way, the PAHs can be activated either by a family of cytochrome P450 (particularly by isoforms CYP 1A1 and CYP 1B1), microsomal epoxide hydrolase, or by aldo-keto reductase. The resulted chemical forms of metabolic activation responsible for initiating the carcinogenic process are PAH dihydrodiol-epoxides or PAH o-quinones respectively. These intermediate products with high reactive potential are able to react directly with DNA to form stable DNA adducts – i.e. they represent so-called ultimate carcinogens. Due to the soft electronphilic nature of PAH dihydrodiol-epoxides or PAH o-quinones, the nucleophilic positions in purine and pyrimidine bases are attacked. In the case of bases mentioned above, the N7 position of guanine and N3 position of adenine are the most attacked target points. If the PAH-DNA adducts are not decomposed either spontaneously or by enzymatic activity (e.g. by glycosidase), they represent a serious disorder interfering with the expression of genetic information, namely with DNA replication process, and initiating the mutagenesis in this way. These genotoxic event is the first step of the carcinogenic process – i.e. so-called initiation - that plays a key role in triggering the whole process of carcinogenesis leading to a formation of specific tumour types mentioned earlier (Barceló, 2012; Carpenter, 2013; Čupr, 2014; Kolář, 2003; Linhart, 2012).

Materials and methods

The practical part of the assessment of cancer risk can be divided into three major parts:

A) work in field – i.e. sampling procedure ;

B) laboratory work – i.e. chemical analysis and

C) assessment of laboratory data – i.e. the calculation of cancer risk.

Air particle sampling process

Samples of the ambient particulate matter PM10 were collected in the area of the Moravian–Silesian Region (Czech Republic) during four subsequent time periods:

a) winter season of 2013 (November and December);

b) summer season of 2014 (July and August);

c) transient season of 2014 (September and October) and

d) winter season of 2014 (November and December).

The samples were collected at 40 localities situated in cities, towns, and municipalities (Fig. 1). These selected localities include areas with predominance of one from subsequent human-induced influences:

a) emissions derived from industrial activities (e.g. Ostrava – Mariánské Hory, Ostrava – Poruba, Třinec);

b) road traffic emissions (e.g. Ostrava – Heřmanice, Rýmařov);

c) emissions from domestic combustion (e.g. Čeladná, Karlova Studánka);

d) combination of all influences mentioned above (e.g. Ostrava – Radvanice).

The collection of samples was realized by high volume ambient air sampler (Nanometer Aerosol Sampler Model 3089, firm TSI, USA). The apparatus allows collecting of airborne particulate matter PM10 at sampling medium – i.e. filters made from vitreous fibers and PUF (polyurethane foam) cartridges. Before initial and final weighing, all filters were stabilized in a chamber with constant temperature and humidity. Each sampling procedure lasts for 24 hours. During transport, the filters were wrapped in aluminium foil (Čupr et al.,2013).

Chemical analysis

Samples from all observed areas were analyzed with the purpose to determinate individual PAHs quantitatively. First of all, each sample had to be extracted with dichlormethane in an automatic extractor. Internal standards – i.e. fluorene-d10, p-terphenylene-d14 – were stuck on each sampling medium before extraction. In the following step the extracts were purified in silica gel column. After reducing of extract volume, the samples from all localities were submitted to analysis in gas chromatography – mass spectrometry instrument (the method GC-HRMS, EPA 429, ISO 11388). Using the analytical method mentioned above, the 16 polycyclic aromatic hydrocarbons were analyzed – i.e. naphtalene, acenaphtylene, acenaphtene, fluorene, fenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b) fluoranthene, benzo(k)fluoranthene, benzo(a) pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene (Čupr et al., 2013).

Human cancer risk assessment

The method of US EPA (Environmental Protection Agency) was applied aiming at the calculation the human cancer risk. The full-life hazard of can-

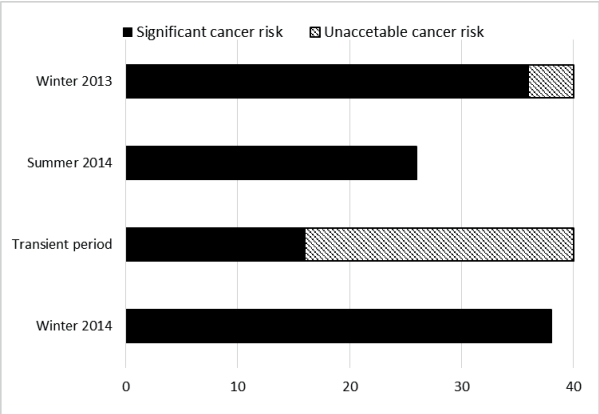

Fig. 2. Total cancer risks in all time periods for 40 sampling sites
Rys. 2. Całkowite ryzyko raka w czasie, dla 40 lokalizacji

cerous risk was evaluated using the linear inhalation exposure model in dependence on a dose of inhaled contaminant under the condition of very low atmospheric contaminant volume concentrations. In this model, human cancer risk depends on the extent of exposure and on the physico-chemical properties of certain polycyclic aromatic hydrocarbons (Čupr et al., 2013).

The first dependence is expressed in LADD (Life Average Daily Dose) that is – in the case of carcinogenic substances – equaled to CDI (Chronic Daily Intake). The second factor of cancerous probability is summed in SF (Slope Factor). Then, the specific cancer risk of the pollutant is calculated as a product of LADD and SF (i. e. CR = LADD x SF). The total cancer risk for all 40 investigated localities was calculated as a sum of the 16 specific PAH risks (Čupr et al., 2013).

Results and discussion

The final cancer risks were compared with the carcinogenic benchmark level. The boundary-mark is defined as exposure posing an upper-bound lifetime excess of cancer risk of 1E-06. The cancer risk of 1E-06 means that one cancer case occurs per one million people. The cancer risk that is higher than benchmark level is considered as significant. The cancer risks exceeding the number of 1E-04 (one case of cancer per 10, 000 people) were scored as unacceptable.

The maximum PAH specific cancer risk was found for naphthalene in locality 20 (Třinec) in transient period of 2014. The minimum individual cancer risk was calculated for acenaphtylene in areas 11, 25 and 33 (Klimkovice, Frýdek – Místek and Rýmařov) in transient period of 2014.

The highest level of cumulative cancer risk was detected in Třinec (number 20) in transient period of 2014; on the contrary the lowest value of total cancer risk was evaluated for area 39 (Odry) in summer period of 2014.

From the time point of view, the lowest values of cancer risks were noted in summer period of 2014 – the significant cancer risk was calculated for 27 localities; there was not present any case with unacceptable cancer risk. In winter period of 2014, there were found out 38 areas with significant cancer risk and no case with unacceptable cancer risk. In the case of winter 2013, the significant cancer risk was calculated for 36 localities and unacceptable cancer risk was identified in four areas. The highest levels of cancer risk were determined for transient period of 2014 (27 localities with unacceptable cancer risk and 13 areas with significant cancer risk; see more in Fig. 2.). From the facts discussed above, it is clear that the cancer risk values are smaller during summer period; there was noted a raising trend during both winters with the maximum cancer risk reached in transient period of 2014. Obviously, this trend of cancer risks seems to be associated with the winter climatic situation or model (the inverse nature of weather, high frequency of smog situations) and with the beginning of heating season (when number of domestic or local combustion sources increases) (Blažek et al., 2008; Chen et al.,2014; Kazmarová, 2003).

Concerning the individual PAH cancer risk, the highest number of values exceeding the boundary-mark was found in the case of benzo(a)pyrene (109 exceeding values), dibenzo(a,h)anthracene (74 exceeding values), benzo(a)anthracene (63 exceeding values) and benzo(b)fluoranthene (60 exceeding values).

In comparison with the analysis of cancer risk realized in cooperation with US EPA, Industrial Economics (Cambridge, Mass.) and Sullivan Environmental Consulting (Alexandria, Virgin-

ia) during 1991 and 1992, the calculated average cancer risk values for selected localities and the whole Moravian-Silesian Region are markedly lower. The reduction of cancer risks is in the range of two or three orders. This reality gives evidence about improving of the environmental quality (ambient air situation). This significantly lower levels of cancer risks are in accordance with the decreasing number of industrial sources and continuous reduction of inhabitants in Moravian-Silesian Region that is related to smaller amount of domestic combustion sources.

Conclusions

The human cancer risk assessment was derived from atmospheric volume concentrations that were measured for the case of the 16 selected PAHs in size particle fraction PM 10. The cancer risk was estimated during four time periods (winter 2013, summer 2014, transient period of 2014 and winter 2014) in 40 localities of the Moravian-Silesian Region. The individual PAH cancer risks were calculated according to linear low-dose cancer risk equation (US EPA 1998, 2012). The final cumulative cancer risks were determined as a sum of partial cancer risks of all 16 PAHs for each observed localities (Čupr et al., 2013).

The calculated cancer risks were compared to benchmark levels (1E-06, 1E-04; US EPA 1998, 2012); the exceeding values of cancer risks were considered to be significant and unacceptable. The highest PAH individual cancer risk values were found for Karviná (number 15, winter 2013), Ostrava-Radvanice (number 1, summer 2014), Třinec (number 20, transient period 2014) and Frýdek-Místek (number 24, winter 2014), which is in accordance with high industrial and road traffic burden of these localities. The highest number of exceeding values during all periods were noted for benzo(a)pyrene and dibenzo(a,h)anthracene. The worst total score was detected for transient period of 2014 (27 areas with unacceptable cancer risk and 13 with significant cancer risk); this fact is in relation with climatic situation and the increasing number of local combustion sources in the beginning of heating period (Blažek et al., 2008; Kazmarová, 2003).

Finally, the identified cancer risks were compared with cancer risks calculated by specialists from US EPA, Industrial Economics (Cambridge, Mass.) and Sullivan Environmental Consulting (Alexandria, Virginia) for time period of 1991 and 1992. The contemporary cancer risk values were markedly lower; this fact gives evidence about improving of air quality in the investigated region, which is a consequence of the decreasing number of industrial and domestic combustion sources.

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Literatura – References

1. ALVES, C., BEGOÑA, A., MIRANTE, F., PEREZ, R., PIO, C., PINDADO, O., REVUELTA, M. A. 2013. "Organic composition of size segregated atmospheric particulate matter during summer and winter sampling at representative sites in Madrid, Spain." *Atmospheric Research* 132–133: 345–361.
2. BALDUCI, C., CECINATO, A., LADJI, R., MEKLATI, B.Y., NOUREDDINE, Y. 2009. "Distribution of the solvent extractable organic compounds in fine (PM1) and coarse (PM1-10) particles in urban, industrial and forest atmospheres of Northern Algeria." *Science of the Total Environment* 409: 415–424.
3. BARCELO, D. 2012. *Emerging Organic Contaminants and Human Health.* London: Springer.
4. BLAŽEK, Z., ČERNIKOVSKÝ, L., KREJČÍ B., VOLNÁ, V. 2008. *The Atmospheric Particle Contamination in Region of Ostrava and Karviná*. Prague: Czech Hydrometeorological Institute.

5. BORM, P., DONALDSON, K. 2007. *Particle Toxicology*. New York: CRC Press.
6. CARPENTER, D. O. 2013. *Effects of Persistent and Bioactive Organic Pollutants on Human Health*. Albany: University at Albany.
7. CHEN, J., DENG, H., FU, X., KONG, S., SHAO, G., WANG, Z., WU, D.,. WU, G. 2014. "Polycyclic aromatic hydrocarbons (PAHs) in atmospheric PM2.5 and PM10 at a coal based industrial city : Implication for PAH control at industrial agglomeration regions, China." *Atmospheric Research* 149: 217–229.
8. ČUPR, P., FLEGROVÁ, Z., FRANCŮ, J., KLÁNOVÁ, J., LANDLOVÁ, L. 2013. "Mineralogical, chemical and toxicological characterization of urban air particles." *Environment International* 54: 26–34.
9. KAZMAROVÁ, H. 2003. *Health Consequences and Risks of Air Pollution*. Prague: The Health Institute of Prague.
10. KLENER, P. et al. 2006. "The Internal Medicine." *The principles of clinic oncology*: 87–111.
11. KOLÁŘ, Z. 2003. *Molecular Pathology of Tumours*. Olomouc: Epava.
12. KOMÍNKOVÁ, D. 2008. *Ecotoxicology*. Prague: The Czech Technical College.
13. KŘŮMAL, K., MIKUŠKA, P., VEČEŘA, Z. 2013. "Polycyclic aromatic hydrocarbons and hopanes in PM1 aerosols in urban areas." *Atmospheric Environment* 67: 27–37.
14. KUŽÍLEK, V. 1994. *Polycyclic Aromatic Hydrocarbons in Hydrosphere*. Prague: T. G. Masaryk Water Research Institute.
15. LINHART, L. 2012. *Toxicology*. Prague: The Chemical–Technological College. (In Czech)
16. Nečas, E. 2000. *The General Pathological Physiology*. Prague: Carolinum. (In Czech)
17. Nečas, O. 2000. *The General Biology*. Jinočany: H & H. (In Czech)
18. Pitter, P. 1990. *Hydrochemistry*. Prague: The Chemical–Technological College. (In Czech)
19. Reddy, R. G., Flora, S.J.S.; Basha, R. 2012. *Environmental Pollution: Ecology and Human Health*. Kolkota: Narosa.

Kancerogenne zanieczyszczenia powietrza w rejonie Śląsko-Morawskim (Republika Czeska)

Opis cech morfologicznych, mineralogicznych, fizykochemicznych i toksykologicznych pyłu zawieszonego PM10 w rejonach miejskich i wiejskich jest istotny z powodu jego szkodliwego wpływu na stan zdrowia ludzkiego. Wiadomym jest, że narażenie na działanie pyłu zawieszonego PM10 może powodować działanie zapalne, reakcje alergiczne różnego typu, zmiany w strukturze DNA i zmiany rakowe w wielu różnych typach komórek w ludzkim ciele. Wymienione efekty działania PM10 zostały potwierdzone wieloma badaniami in vitro oraz in vivo. Chociaż pył zawieszony obecny w powietrzu jest tematem szeroko zakrojonych badań epidemiologicznych i dociekań naukowych, wciąż ilość informacji dotyczących oceny ryzyka dla ludzkiego zdrowia związanego z wystawieniem na działanie cząstek zawieszonych w powietrzu, w tym pyłu zawieszonego PM10 jest niewystarczająca. Informacje te są kluczowe, przede wszystkim aby zapobiec wielu chorobom ludzi – takim jak przewlekłe obturacyjne zapalenie płuc, astma oskrzelowa, choroba Crohna, wrzodziejące zapalenie jelita grubego oraz degeneracyjna choroba ośrodkowego układu nerwowego. Dane dotyczące negatywnego wpływu pyłu zawieszonego PM10 na ludzkie zdrowie są również ważne ze względu na możliwość odkrywania nowych – bardziej efektywnych – leków i doboru najlepszej dostępnej terapii związanej z czynnikiem lub czynnikami inicjującymi. Ponadto, ilość zanieczyszczeń środowiskowych stale rośnie, zatem nieuniknionym jest poszukiwanie sposobów redukcji ich potencjalnych negatywnych oddziaływań na stan ludzkiego zdrowia. Biorąc wymienione fakty pod uwagę, artykuł poświęcony jest roli jaką odgrywa PM10 w patogenezie najgroźniejszej i często nieuleczalnej chorobie ludzkiej – raka. Na chwilę obecną istnieje mocne hipoteza, że kontakt ludzkiego organizmu z pyłem zawieszonym PM10 odgrywa znaczącą role w rozwoju kilku typów guza złośliwego u ludzi. Wśród nich są dwa typy raka, które co raz częściej występują u ludzi – drobnokomórkowy rak płuc oraz rak okrężnicy i odbytnicy. Ponadto, narażenie organizmu na działanie pyłu zawieszonego PM10 jest uważane za istotny czynnik etiopatogenetyczny różnego typu raka skóry i guzów złośliwych moszny. Z wszystkich wymienionych powodów, ważne jest prowadzenie badań nad negatywnym wpływem pyłu zawieszonego PM10 z zachowaniem odpowiedniej czujności.

Słowa kluczowe: cząstki stałe, pył zawieszony PM10, węglowodory poliaromatyczne, karcynogeneza, genotoksyczność