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REVIEW

AIR POLLUTION STUDIES

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The aim of this paper is to give an overview of the research in the area of air pollution, carried out exclusively at the Institute for Medical Research and Occupational Health and performed by the scientists of the Institute. For the past fifty years, air quality has been studied at work, in the ambient air of urban and industrial areas, and in various indoor environments without occupational exposure. Methods for sampling and measuring air pollutants have been introduced or developed and verified. The behaviour and the fate of air pollutants in the environment have also been investigated. Since the primary goal of the studies was to assess the extent of human exposure to air pollutants, the data were used to calculate the risk for various population groups. A dynamic model of exposure for various population groups relied on calculations of collected data, taking into account time spent in various microenvironments. This text describes the cooperation of the Institute with other institutions and agencies on the national and international level and outlines the current and prospective activities.

Key words:
air quality surveillance, ambient air, dynamic model of exposure, human exposure assessment, indoor air, passive samplers

SIGNIFICANCE OF THE AIR POLLUTION FOR HUMAN HEALTH

Air is the inevitable transfer medium of environmental pollution to people. While polluted food or water can be avoided, the air is inevitably breathed in any environment in which people stay or through which they pass. The problem is encountered not only in large urban and industrial areas, but also in different indoor environments which – in addition to penetration of outdoor pollution – contains pollutants originating from the building and furnishing materials, heating, cooking, cleaning, smoking, and other human activities.

Whether the health effects of pollutants are immediate or delayed will depend on their chemical composition, concentration, and the exposure duration. The effects may not be allways specific, especially if people are exposed to a combination of agents. Besides, the same toxic agents may be simultaneously consumed by polluted food or water resulting in possible cumulative adverse effects.

In addition, air pollutants or the products of their transformation may have harmful effect on natural and man-made goods in the local or global environment. A good example is the acid rain which indiscriminately affects vegetation and buildings. The same goes for halogenated hydrocarbons affecting the stratospheric ozone layer.

HISTORICAL ASPECTS OF RESEARCH AT THE INSTITUTE

The studies of air pollution at the Institute began with its foundation and have continued throughout. The primary goal of the studies has been to assess human exposure to air pollution.

Since the Institute was established as the Institute of Industrial Hygiene, studies of air quality at the workplace were an inherent activity from the very beginning. In the middle of this century, smog episodes in large towns and industrial areas demonstrated that not only workers were exposed to polluted air, but all citizens (small children, pregnant women, sick and elderly persons, and so on) were exposed to constant pollution originating from heating, industry, and traffic. The Institute started to measure characteristic ambient air pollutants in urban and industrial areas of Croatia. The measurements gradually expanded through collaboration with local Public Health Institutes and have continued to this day under the coordination of the Institute.

Soon it became evident that urban inhabitants spent most of their time indoors. Thus, if the true exposure of people was to be assessed, the air pollution studies had to include the indoor environment. The next step was the investigation of air quality in various indoor environments not related to occupational exposure. The data served to develop a calculation model for the total human exposure.

Concurrently with the development of exposure assessment methods, the Institute focused on such issues as physical and chemical behaviour and the fate of air pollutants, which, in their turn, entailed either adoption or development and verification of methods for sampling and measuring air pollutant levels and trends.

To this day, the collaborators of these programmes have published more than 200 papers in journals, proceedings, chapters in books, and unpublished reports. However, in this review we refer only to those published papers which are the most significant landmarks or illustrations of our research achievements, whereas the reader may look up other references in annual reports of the Institute or in cumulative lists published every five years.

The results of our investigations became the basis for our proposals of remedies and legislation, of cooperation between the Institute and other national or international organisations dedicated to research and responsible for surveillance of air quality on the national and international scale. The scientific merits of this research gave incentive for organisation of many national and international meetings.

INTRODUCING AND DEVELOPING METHODOLOGIES

A number of methods for measurement of air pollutants have been introduced, adapted, or invented in that period such as those for measuring pollutants at work, in the ambient air, and indoors or those for measuring personal exposure.

Most methods were manually operated using active sampling for collection of air pollutants. Recently, passive sampling – based on diffussion and absorption of a pollutant on impregnated surface – has become popular, as it does not need a pump or connection to power supply which makes it easy to place it on the most representative locations either outdoors and/or indoors. Light and silent, they are also very practical for measuring personal exposure. Automatic instruments, on the other hand, have been used for specific purposes such as tracing the source of emission, measuring dispersion of air pollution around the source, or studying the daily pattern of air pollutant concentrations.

The methods introduced have been verified in the laboratory and/or simultaneous field measurements. The method to be tested was compared with the reference or generally accepted procedure. In laboratory testing of methods for sampling and analysis of air pollutants, systems were developed for separation of particles by size, for preparing calibration mixtures of pollutants with air (1) and an experimental gas chamber was constructed for the same purpose (2).

The Institute produced a number of studies of human exposure to heavy metals and developed and adjusted many measuring methods for the investigation purposes. For instance, colourimetric dithizone method was introduced for measuring mercury in mines, whereas Beckman spectrophotometer was adapted (including the setup of a calibration system) in the laboratory measurements of the efficiency of a miners' mask for direct measurement of optical density of an air sample containing mercury vapours at 253.6 nm (3).

Polarographic method was introduced for measuring lead in the air at work, whereas a more sensitive method, that is, atomic absorption spectrophotometry (AAS) had to be applied for the surveillance of ambient air predominantly polluted by lead from car exhausts. A new method for microdetermination of lead as chromate using ring-oven technique was developed for measuring lead in smoke samples collected in urban areas through the basic networks (4). The method was verified by comparative AAS measurement of lead in high volume samples of airborne particles. The AAS was also used to determine other heavy metals (Cd, Cu, Fe, Mn, and Zn) in the same samples. The Institute organised an interlaboratory comparison of results of determination of lead and cadmium in field samples of suspended particles which showed very good agreement between the three participating laboratories (Swedish, Japanese, and Croatian) (5).

Concentrations of smoke, which is a result of incomplete fuel combustion, are usually determined by measuring the reflection reduction of a filter paper due to the deposited black particles. However, a new method was invented, based on fluorescence quenching of fluorescein impregnated filter paper which is subsequently exposed to smoke. Smoke concentration (determined by reflectometry) was also used as an indicator of polycyclic aromatic hydrocarbons (PAH), another product of incomplete combustion. A method was developed for semiquantitative determination of PAH in smoke samples. It involved fluorescence measurement using the ring-oven technique after the PAH was extracted by cyclohexane. Determination of individual PAH in smoke samples was also developed and verified by comparative measurements of PAH in high volume samples (6). In both cases samples were analysed by means of high performance liquid chromatography (HPLC).

The reason for adapting methods to measure air pollutants for small samples was to make them appropriate for indoor and personal measurements and not only for large urban areas.

As to the gaseous pollutants, the most widespread urban air pollutant SO_2 was at first measured using a nonspecific acidimetric method, that is, after SO_2 was converted to sulphate. The method was acceptable in 1963 when SO_2 was the dominant pollutant. As in 1970s oil, gas, and electricity greatly replaced coal in heating and production of energy and SO_2 concentrations in the air started to decrease, NH_3 interference became more and more evident. A filter impregnated with a solution of oxalic acid in ethanol was put in front of SO_2 sampler, to remove ammonia from the air stream, which proved to be very efficient (7). The same filter was used for sampling and determination of smoke and ammonia. Later on, a specific method for SO_2 determination was introduced (the sulphate method) and the two methods were evaluated through comparison. Ion chromatography has been introduced quite recently and is generally used for pollutants which can dissociate into ions.

To determine NO_2 and NO levels in the air – pollutants originating from car exhausts, heating, smoking, and cooking and present both outdoors and indoors – scientists at the Institute devised and verified a specific colourimetric method based on the Saltzman reagent. Two authomatic instruments (G.E. detector, ECOLYZER) and detection tubes were used to measure CO coming from the same sources as NO_x. They were compared and proved to be in a good agreement.

The determination of H_2S (by means of molybdenum blue method) and mercaptants (applying the Moor's method) present around oil refineries, coke works, and waste dumps, required modifications of the sampling procedure in order to ensure stable samples (8) and to enable simultaneous sampling through the use of two filters in sequence: one impregnated with mercury chloride to bind H_2S and the other with mercury acetate for mercaptans.

Fluoride, which is encountered in production of aluminium, phosphate fertilizers and building materials, was determined in the air using the ion specific electrode.

Colourimetric method based on Schryver's reaction has been used to determine formaldehyde (HCHO) a pollutant mostly associated with plywood and synthetic adhesives and present predominantly indoors. Phenols, which are commonly associated with asphalt, car exhausts, and industry, were measured both in the indoor and in the outdoor air using the spectrophotometric method based on reaction of phenol with p-nitroaniline, which has already been tested. Passive samplers have been developed for NO_2, HCHO, and HF and verified through comparison with active samplers.

SURVEILLANCE OF AIR POLLUTION AT WORKPLACE

Most of these investigations were made in collaboration of the Department of Industrial Hygiene and the Department of Occupational Health of the Institute, at the request of industries encountering serious practical problems. Most of the results were presented in unpublished reports.

The first significant project was the investigation of exposure to mercury vapours of miners in a mercury mine in Idrija, Slovenia. The investigation led to the development of a method for measurement of mercury. Since high levels of mercury vapours have been found in the air at some production points, it was necessary to develop a protective mask for miners (3).

Followed a variety of similar activities such as the assessment of workers' exposure to air pollutants in a lead smeltery, a ferro-manganese factory, a storage battery factory, cement works, a barite mill, a brick factory, and in factories using organic solvents. Workers' exposure to air pollutants was measured by means of personal samplers.

In a plant for electrolytic extraction of aluminium the Institute conducted extensive investigation of occupational exposure to SO_2, HF, and particulate fluorides. These were only occassionally found to exceed the maximum allowable concentrations. While asthma-like symptoms could be expected in susceptible workers, delayed bronchoconstrictions which occurred in some workers after the workshift suggested that exposure to airborne particles and SO_2 and HF adsorbed on them may partly cause the symptoms and impairments observed (9). This initiated studies of adsorption and desorption of gaseous pollutants on suspended particles (see below).

AMBIENT AIR QUALITY

The Institute has conducted the surveillance of the levels and trends of air pollution in Zagreb since 1961. It resulted in a number of reports, reviews, and papers, to mention just one comprehensive review (10) in which drastic reduction of SO_2 concentrations in Zagreb air after 1970s was confirmed. This was attributed to the change of fuels for heating and energy production.

Within the UNDP/SFRJ project the Institute conducted an investigation of the spatial distribution of air pollutants around a lead smeltery (11) in the Adriatic region (see below, Assessment of exposure to air pollution) which was to provide a basis for epidemiological studies of the lead-polluted area (12) as well as in Zagreb. These results were also useful for studying health effects of urban air pollution on school children. Studies expanded to seasonal and spatial distribution of suspended particles by concentration and size in the urban area (13). Summer concentrations were consistent at all sites set in many places for sample collection. Winter concentrations were significantly higher in a densely populated city centre with traditional heating. The particle size distribution was bimodal and very consistent for three of these sites, but there was a significant shift towards smaller particles in winter.

Daily patterns of air pollutant concentrations caused by the daily fluctuations of meteorological parameters and human activities were studied. The studies showed that under stable meteorological conditions daily SO_2 concentrations reached the first peak between 8 and 10 a.m. and the second peak between 3 and 6 p.m. The regularities in daily pattern were used to calculate the maximum and the mean daily concentrations of SO_2 from the obtained data on short-term concentrations (14). Seasonal differences in the daily cycle of NO_x concentrations were also monitored (15). NO levels were nearly two times higher in winter while there was no significant seasonal diference in NO_2 levels. Similar to SO_2, the daily pattern of NO concentrations in winter shows two peaks, but the second was higher for NO due to denser traffic in late afternoon. The influence of traffic on NO levels was even more obvious in summer when the second peak was much higher than the first since there was no NO from heating. As NO_2 is a product of photochemical oxidation of NO, its morning peak occured about one hour later than that of NO, while the second, sunset peak was far less expressed as photochemical reactions ceased.

The behaviour and the fate of pollutants in the transport from emission sources to the receptor were studied within two COST projects (see below: Assessment of exposure to air pollution). The first project focused on the conversion of sulphur dioxide in the air to sulphate and the second on the fate of heavy metals in the environment.

It has been shown that the percentage of sulphate S in the total S (sulphate+SO_2) decreased with the increasing total S concentration. The results of our investigation indicated that the relationship is characteristic for the type of the area, since the stagnation of SO_2 conversion is significantly influenced by the composition of aerosol on which SO_2 is adsorbed. The adsorption and the oxidation of SO_2 are pH-dependent and slow down when pH is below 6. This is not the case, however, in the presence of catalysts such as manganese salts or of alkaline substances which keep the process going by increasing the pH (16, 17). Further laboratory investigation has shown that in addition to chemical composition of particles (e.g. metals, soot, and cement dust) smaller particle size, higher relative humidity, and longer contact positively affect SO_2 conversion (18). The presence of ammonia enhanced the oxidation of SO_2. Under experimental conditions, the conversion of SO_2 to sulphates was shown to be complete when the SO_2:NH_3 ratio was 2:1.

The adsorption of formaldehyde on suspended particles was also investigated on model systems (19). Depending on experimental conditions, up to 50% of HCHO was adsorbed. No significant chemical transformation occured during the adsorption since most of the HCHO could be recovered from particles by extraction with water at the room temperature. Therefore, it may be assumed that, when adsorbed on particles, HCHO may reach deep into the small airways of the lungs, regardless of the fact that it irritates the upper respiratory tract.

Scientists at the Institute studied the fate of heavy metals in the environment following their path from suspended particles emmitted by a lead smeltery to deposited dust, soil, and household dust (20) before and after introduction of control measures (21). Selective solubility of metalic compounds in suspended particles, household dust, and soil shows that the transport of metals through the soil after deposition from the air is a slow process with a relatively small portion penetrating the deeper strata or being absorbed by plants. A major portion transforms into non-soluble or poorly soluble chemical forms and becomes part of the soil. This may explain the fact that the concentrations of metals in the soil around the lead smeltery showed no tendency to decrease regardless of radical reduction in the airborne metal content as a result of substantial improvements in air quality control.

INDOOR AIR POLLUTION

With the recognition of the relevance of indoor air pollution to human exposure, the Institute initiated monitoring of levels of indoor air pollutants released by building and furnishing materials or such activities as cooking and smoking (22).

Indoor air pollutant concentrations (formaldehyde, CO, NO_2, NH_3, and settled dust) were measured over summer and winter in ninety households, five newly built office buildings, ten primary schools, ten kindergartens, and ten bank offices. Formaldehyde concentrations showed significant correl ation with the age and the make of furniture, while nitrogen dioxide concentrations depended on gas consumption and the type of gas used (natural gas, propane-butane). Ammonia concentrations were much higher in households located in the »green areas« than in those in the city centre. When compared with the air quality guideline values, pollutant concentrations showed that the average indoor air pollution in a Zagreb household does not represent a significant health problem. However, high formaldehyde levels were encountered in some newly prefabricated buildings.

At a certain point, the Institute's scientists focused on the relation between the indoor and the outdoor concentrations of the same air pollutants such as SO_2, smoke, and SPM (23) penetrating from the outside, or NH_3 coming from both the outside and the inside sources. The attention of the scientists was drawn by the »sick building syndrome« associated with the objective and/or subjective sense of discomfort common for residents of large buildings with forced ventilation (24). A review of our investigations on indoor air was presented recently at the meeting »Protection of air '97« in Crikvenica (see below: Contribution at national and international level).

ASSESSMENT OF EXPOSURE TO AIR POLLUTION

Scientists at the Institute first attempted to assess actual exposure to an air pollutant taking into account concentration levels and the time spent in various indoor and outdoor microenvironments. This model of human exposure to lead from various emission sources and at various concentrations was presented at the International Symposium on Environmental Health Aspects of Lead in Amsterdam in 1972. Further elaborated, and including exposure to other pollutants (SO_2, Mn) in addition to lead, the model was presented in 1975 at the International Symposium on Environmental Monitoring (25) where it was generally accepted.

Investigation of human exposure to various pollutants continued relying on the results of measurements in households (see above: Indoor air pollution) and on time--budget data obtained from the diaries kept by 172 volunteers over a week (26, 27) to calculate human exposure of four population subgroups (high school students, university students, the employed, and the retired). Personal exposure of selected subjects was measured and compared with values obtained by calculating their exposure from pollution levels and time spent in various indoor environments, in public means of transport, on the streets, and in the country over weekdays and weekends, taking the week as a time unit. Studies included exposure to respirable particles and carbon monoxide

(28), nitrogen dioxide (29), heavy metals (see below: Contribution at the national and international level), and polycyclic aromatic hydrocarbons (30). The subjects' experience with personal samplers indicated that personal samplers with electric pumps, which are heavy and noisy, may cause such change in behaviour as the avoidance of going out and visiting some places where the noise may attract attention of other people (31).

Further development of the exposure model focused on health effects of multi-pollutant exposure, on lifetime exposure to a pollutant through a variety of media, which finally resulted in the development of a dynamic model of exposure, presented in a handbook published by IARC (32).

CONTRIBUTION AT THE NATIONAL AND INTERNATIONAL LEVEL

National

The Institute started the surveillance of air pollution in Zagreb in 1961. Ever since 1970 it has cooperated with local public health institutes in other urban and industrial areas. The Institute has been reporting the results of that cooperation to the Ministry of Health of the Republic of Croatia on the annual basis.

The analysis of air pollution measurements in Zagreb over 5 years demonstrated that the situation was critical (primarily due to coal used for heating and energy production) and prompted the Institute to organise a Conference on the Control of Air Pollution Problems Due to Combustion Products in the City of Zagreb in 1970, which initiated the proposal of the first local document on measures for control of air pollution through combustion products (*Službeni glasnik* 16/1971). In 1976, the Institute organised the 2nd Conference on the Control of Air Pollution Problems in the City of Zagreb to asses the impact of the decision on air quality. That assessment eventually led to an annex to the document (*Službeni glasnik* 21/1978).

Some scientists from the Institute participated in the preparation of the Law on Air Protection (*Narodne novine* 48/1995) and Ordinance on Recommended and Limit Values of Air Quality (*Narodne novine* 101/1996). These scientists have also participated in the activities of the Technical Committee »Air quality« at the State Institute for Standardization and Metrology, in postgraduate studies on environmental hygiene, and in editorial boards of relevant journals. (*Archives of Industrial Hygiene and Toxicology* and *Zaštita atmosfere* 1973–1992).

In 1971, the Institute formed a Society for Clean Air of Croatia as a section of then the Federal Association of Yugoslavia which organised two symposia: Effects of Air Pollution on People and Limit Values (1977) and Conference on Air Quality and Possibilities to Reduce Air Pollution in the Socialist Republic of Croatia (1982). The Society became an independent association in 1991 and changed the name to Croatian Air Pollution Prevention Association (CAPPA). It joined the International Union of Air Pollution Prevention and Environmental Protection Association (IUAPPA) in 1992 and the European Federation of Clean Air (EFCA) in 1998. The permanent seat of CAPPA is at the Institute. In 1997, it organised the first Croatian expert meeting entitled »Protection of Air '97« in Crikvenica and in 1998 »Emission of Air Pollutants from Stationary Sources« in Trakošćan with remarkable participation and engagement of the Institute's scienticsts and personnel.

International

Ever since the seventies, three stations in Zagreb have been included in the Urban Air Quality Monitoring Network of the Global Environmental Monitoring System operated by WHO. The Institutes excellent performance was acknowledged as it became a WHO Collaborating Laboratory and participated in international intercalibration exercises. Further collaboration with WHO included projects such as »A comparative study on the determination and reporting of particulate air pollution« (WHO file reference A 6/181/1, 1965–69) with special stress on the application of the ring oven method for determination of heavy metals, »Human exposure to carbon monoxide and suspended particulate matter in Zagreb« (EFP A 6/445/15, 1979–81), and the »Assessment of human exposure to polycyclic aromatic hydrocarbons« (WHO file reference A 6/181/12, 1982–84). Furthermore, the Institute participated in two international pilot studies within WHO/UNEP Human Exposure Assessment Locations (HEALs) programme (33): »Exposure monitoring of lead and cadmium« (1990) and »Exposure monitoring of nitrogen dioxide« (1991).

The Institute carried out several projects supported by the United States Environmental Protection Agency (US EPA). The project »Biological significance of some metals as air pollutants« – Part 1, Lead (EPA 02–302–3, 1970–74) (see above: Assessment of exposure to air pollution) prompted a personal exposure model and gave incentive for further projects such as »Biological effects of manganese« (EPA 02–513–3, 1972–75), »Indoor air quality as a relevant factor in human exposure« (EPA–JFP–573, 1986–89), »Exposure to particles and particle associated pollutants« (EPA–JFP–869, 1989–92), »Passive samplers in a human exposure study« (EPA–JFP–907, 1990–94), »Air pollutant exposure distributions and their evaluation with the respect to proposed limit values« (IMI/EPA 55, 1995–98).

The International Lead and Zinc Research Organization (ILZRO) gave support to the Institute to continue research of lead polluted areas through the project »Health study of a lead exposed population« (ILZRO project LH–171, 1974–77). The investigation intensified after drastic reduction of pollutant emission and followed the response of health effect indices to the reduction of lead in the environment (34).

The Institute carried out air quality research in the Adriatic region within the Sector I of the UNDP/SFRJ project 72–004/1 (1972–76) »Protection of the human environment in the Yugoslav Adriatic region«.

The Institute's international activity expanded through participation in two European Community COST projects: 61a »Research into the physico-chemical behaviour of SO_2 in the atmosphere« (1972–76) and 61a bis »Physico-chemical behaviour of air pollutants« (1978–82) (see above: Ambient air quality). Ever since 1977, the Institute has participated in the COST project 615 »Data base, monitoring and modelling of urban air pollution«.

In 1975, the Institute in cooperation with ILZRO organised the International Symposium on Environmental Lead Research in Dubrovnik (the Proceedings were published as the supplement of the *Archives of Industrial Hygiene and Toxicology*, 1975;26:1–272) and in Dubrovnik in 1977, it was the host of the International Symposium »Sulphur in the Atmosphere« based partly on investigations of the first COST project (Proceedings: special issue of Atmospheric Environment 1978). Still in Dubrovnik, in 1985 the Institute also hosted a meeting of the WHO Working Group on Indoor Air Quality entitled »Radon and Formaldehyde« (Report: WHO Regional Office for Europe, Copenhagen, 1986). The Institute's scientists were members of many WHO expert groups and advisory panels, temporary advisors at WHO workshop, members of management committees for COST projects, members of the »Atmospheric Environment« Committee of the International Union of Pure and Applied Chemistry, and members of the editorial board of the journal *Science of the Total Environment* (1972–1980).

CURRENT AND FUTURE RESEARCH

Presently the investigation of air pollution in urban areas focuses on the air pollution from car traffic, that is, on the change in concentrations of NO_2, PAH, VOC, and benzene with the distance from a traffic lane.

A passive sampler for ozone is being developed and will be evaluated through comparative determination of ozone collected by the active sampler and recorded by automatic instruments.

Newly devised equipment for measuring mass concentration of particle fractions with an equivalent aerodynamic diameter of less than 10 μm (thoracic particles) or 2.5 μm (respirable particles) will be tested and used for sampling airborne particles. The samples will be analysed for the content of heavy metals, PAH, sulphates, nitrates, and chlorides in both fractions.

Distribution of thalium levels in the environment (air, soil and vegetation) will be studied in the vicinity of cement works.

Measurements of fluoride and manganese levels in the air of Šibenik will continue in order to register and analyse improvements in the air quality which is a direct consequence of a shutdown of major industries in the area (ferromanganese and light metals factories) upon Serbian aggression on Croatia.

The study of exposure of children to environmental tobacco smoke (ETS) will include the analysis of children's urine samples for cotinine and a questionnaire for parents. The aim is to assess the influence of family education, socioeconomic status, and the awareness of the child's health status as determinants of the child's exposure to ETS at home.

A questionnaire has been distributed to the population of Zagreb. The answers are expected to show individual attitude and awareness with respect to the air pollution issues. The results should serve for education planning and proper information to general public through mass media.

Currently the Institute is involved in the organisation of the second expert meeting »Protection of Air '99« that is to take place in Šibenik, Croatia in September 1999.

REFERENCES

1. *Fugaš M, Pauković R, Topolnik Z.* Preparation of calibration mixtures of gases and vapours with air. Arh hig rada toksikol 1959;10:155–69 (in Croatian).
2. *Vouk VB, Topolnik Z, Valić F, Weber OA.* Design and operation of an experimental gas chamber. Arh hig rada toksikol 1955;6:29–32.

3. *Vouk VB, Topolnik Z, Fugaš M*. Respirators for protection against mercury vapour. Br J Ind Med 1953;10:69–75.
4. *Fugaš M, Pauković R*. Microdetermination of lead as chromate by the ring-oven technique. Anal Chim Acta 1970;49:356–8.
5. *Hršak J, Fugaš M*. International interlaboratory comparison of lead and cadmium determination in samples of suspended particulate matter. Arh hig rada toksikol 1993;44:327–30.
6. *Šišović A, Fugaš M*. Comparative evaluation of procedures for the determination of PAH in low volume samples. Environ Monit Assess 1991;18:235–41.
7. *Šišović A, Fugaš M, Gentilizza M*. Elimination of ammonia interference in acidimetric determination of sulphur dioxide. Environ Monit Assess 1982;2:345–51.
8. *Vađić V, Gentilizza M, Hršak J, Fugaš M*. Determination of hydrogen sulphide in the air. Staub-Reinhalt Luft 1980;40:73–6.
9. *Šega K, Šarić M, Kalinić N*. Potential cause of delayed bronchoconstrictive effect of occupational exposure to upper respiratory irritants. Acta Biol Med Exp 1986;11:175–83.
10. *Fugaš M*. Air quality in Zagreb and related problems. In: Rogli J, ed. Conference »Human environment in Zagreb«. Proceedings. Zagreb: Sveučilišna naklada Liber, 1982:147–59 (in Croatian).
11. *Hršak J, Fugaš M*. Distribution of particulate lead, zinc and cadmium around a lead smeltery. In: International Conference »Management and Control of Heavy Metals in the Environment«. Proceedings. Edinburgh: CEP Consultants Ltd., 1979:584–7.
12. *Fugaš M, Šarić M*. Health study of a lead exposed population. In: Lynam DR, Piantanida LG, Cole JF, eds. Environmental Lead. New York: Academic Press, 1981:145–68.
13. *Šega K, Fugaš M*. Seasonal and spatial differences in mass concentration levels and particle size distribution of aerosols over an urban area. Atmosph Environ 1984;18:2433–7.
14. *Wilder B, Fugaš M, Valić F*. Estimation of maximum and mean daily concentrations of sulphur dioxide based on two samples of short duration. Sci Total Environ 1972;1:165–71.
15. *Pauković R*. Characteristics and seasonal differences in the daily cycle of nitrogen oxide concentrations in the air. Zašt atm 1984;12:59–62 (in Croatian).
16. *Fugaš M, Gentilizza M*. The relationship between sulphate and sulphur dioxide in the air. Atmosph Environ 1978;12:335–7.
17. *Vađić V, Gentilizza M, Hršak J, Eškinja I*. The effect of metals and ammonia on SO_2 oxidation to sulphates in the ambient air. Environ Monit Assess 1991;18:163–71.
18. *Vađić V, Gentilizza M*. The effect of MnO_2 and some manganese salts on the behaviour of sulphur dioxide in the air investigated on model systems. Sci Total Environ 1985;44:245–51.
19. *Kalinić N, Vađić V*. The adsorption of formaldehyde on suspended particles investigated on model systems. Environ Monit Assess 1999; in print.
20. *Hršak J, Fugaš M*. The fate of lead, zinc and cadmium particles emitted from a lead smeltery stack. In: Versino B, Otts H, eds. The Second European Symposium of the Commission of European Communities »Physico-chemical behaviour of atmospheric pollutants«. Proceedings. Dordrecht: D. Riedel Publishing Company, 1982:287–91.
21. *Fugaš M, Hršak J, Souvent P*. The effect of a new emission control system on lead, zinc and cadmium concentrations in the environment of a lead smeltery. Staub-Reinhalt Luft 1984;44: 273–5.
22. *Šega K, Fugaš M, Kalinić N*. Indoor concentration levels of selected pollutants and household characteristics. J Expo Anal Environ Epidemiol 1992;2:477–85.
23. *Šega K, Kalinić N, Šišović A, Fugaš M*. Indoor/outdoor relationship for respirable particles, total suspended particulate matter and smoke concentrations in modern office buildings. Environ Int 1986;12:7
24. *Šega K, Kalinić N*. Sick buildings syndrom – a case study in Zagreb. Arh hig rada toksikol 1994;45:1–10.
25. *Fugaš M*. Assessment of total exposure to an air pollutant. In: International Symposium on Environmental Monitoring. Proceedings. New York: Institute of Electrical and Electronics Engineers Inc., 1975;2:1–3, 38–5.
26. *Šega K*. Distribution of long-term household exposure of different population groups to nitrogen dioxide. J Exposure Analysis Environ Epidemiol 1995;5:35–43.

27. *Šega K*. Distribution of long-term household exposure to ammonia. Environ Manage Health 1996;7:1
28. *Fugaš M, Šega K, Šišović A*. Study of personal exposure to respirable particles and carbon monoxide. Environ Monit Assess 1982;2:157–70.
29. *Šega K, Fugaš M*. Different approaches to the assessment of human exposure to nitrogen dioxide. J Exposure Analysis Environ Epidemiol 1991;1:227–34.
30. *Šišović A, Fugaš M, Šega K*. Assessment of human inhalation exposure to polycyclic aromatic hydrocarbons. J Exposure Analysis Environ Epidemiol 1996;6:439–47.
31. *Fugaš M*. Monitoring of personal exposure to air pollutants. Subject's experience. Arh hig rada toksikol 1995;46:237–4.
32. *Fugaš M, Šega K*. Integrated lifetime exposure. In: Seifert B, van de Viel HJ, Dodet B, O'Neill IK, eds. Environmental carcinogenesis: Methods of analysis and exposure measurement. Lyon: International Agency for Research on Cancer, 1993;12:153–60.
33. *Šarić M, Fugaš M, Drevenkar V*. Human Exposure Assessment Location (HEAL) – Historical review. Arh hig rada toksikol 49;1998:45–64.
34. *Prpić-Majić D, Fugaš M, Souvent P, Sušnik J, Šarić M,* eds. Investigations of lead, cadmium and zinc in the Meža valley. Monograph, Zagreb: Institute for Medical Research and Occupational Health, 1996 (in Croatian).

Sažetak

ISTRAŽIVANJA ONEČIŠĆENJA ZRAKA

Dan je pregled istraživanja na području onečišćenja zraka provedenih većinom u Institutu za medicinska istraživanja i medicinu rada, koja su izveli znanstveni suradnici Instituta. Proučavali su kakvoću zraka na radnim mjestima, u vanjskom zraku gradskih i industrijskih područja i u atmosferi različitih zatvorenih prostora u kojima izloženost nije posljedica proizvodnje. Uveli su i provjerili metode skupljanja i mjerenja onečišćujućih tvari iz zraka. Istraživali su ponašanje i sudbinu onečišćujućih tvari u okolišu. Kako je prvenstveni cilj istraživanja bio ocjena izloženosti ljudi onečišćenom zraku, podatke istraživanja su rabili za izračunavanje izloženosti pojedinih skupina stanovnika uzimajući u obzir vrijeme provedeno u pojedinim mikrookolinama. Razvijen je i dinamički model izloženosti ljudi.

Opisana je suradnja s drugim institucijama i organizacijama na državnoj i međunarodnoj razini. Dan je i pregled aktivnosti koje su do sada u toku, kao i onih koje se planiraju izvesti u skoroj budućnosti.

Ključne riječi:
dinamički model izloženosti, metode mjerenja, ocjena izloženosti ljudi, pasivni skupljači, praćenje kakvoće zraka, unutarnja i vanjska atmosfera

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