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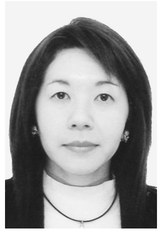
The US Strategy for Research on the Health Effects of Airborne Fine and Nano Particles — A Comparison with Japan



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1 Introduction

The quantitative relationship between air pollutant concentrations and their health effects needs to be assessed to set environmental standards, which should be the central part of the environment administration. Environmental standards for five air pollutants including particles (so-called "traditional air pollutants") were established about 30 years ago in Japan. From a scientific point of view, the scientific basis has nearly been established for the health effects of traditional air pollutants. This particular subject belongs to "old research areas," and is considered unrelated to "rapid development," at least in Japan.

As in Japan, it was understood in the U.S. that the atmosphere had been cleaned in the 1970s thanks to a series of air pollution preventive measures. The results of epidemiological studies, moreover, showed that air pollution did not have serious health effects. The number of research papers on the epidemiology of air pollutants continued to decrease until the latter half of the 1980s, as far as those registered in MEDLINE are concerned. However, it began to increase rapidly thereafter[1].

The Science and Technology Foresight Center is conducting a variety of technology forecasting surveys to develop the "3rd Phase Science and Technology Basic Plan." One of these surveys concerns the quantitative analysis of rapidly growing research areas, using a database of research papers (e.g., basic research or scientific areas whose findings have been published as research papers)[2]. Among 51 research areas specified in this survey is the "Health Effects of Airborne Particles." Because the majority of other areas concern state-of-the-art technologies (life sciences, etc.) on which Japan and other countries place a premium, it may seem strange that this particular subject was specified. This can be directly attributed to two factors that emerged in the U.S.: progress in research on the health effects of airborne particulate matters, and the establishment of environmental standards (the most important measure in the environment administration).

In July 2004, EPA announced that it would grant the largest subsidy ever (US$30 million or ¥3.2 billion) to the University of Washington for epidemiological research on the relationship between air pollution and cardiovascular diseases[3], a research area showing signs of further development.

2 Background

2-1 History of the analysis of the health effects of airborne particulate matters

Table 1 shows major air pollution incidents that took place in the first half of the 20th century, each of which raised public awareness of the health effects of airborne particulate matters.

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http://www.nies.go.jp/index-j.html

Table 1 : Major air pollution episodes

Year	Location	episode	Damage
1930	Belgium	Meuse Valley	Sixty-three people died from air pollution along Meuse River, where a number of factories including iron mills were located, with each combusting coal. Calm, foggy conditions contributed to the increasing SO_2 concentrations in the atmosphere.
1948	Pennsylvania (U.S.)	Donora	Fluoride emissions from steel plants and zinc smelters located in the valley killed 20 people and left 5,910 seriously injured (about 43% of the local residents).
1950	Mexico	Poza Rica	A local factory accidentally released hydrogen sulfide (H_2S) into the ambient air while recovering sulfur from natural gas, killing 22 people and leaving 300 hospitalized.
1952	U.K.	London Smog	The concentrations of particulates and sulfur dioxide continued to increase for a week, killing some 4,000 local residents.
The 1960s	Yokkaichi (Japan)	Yokkaichi Asthma	A number of local residents developed asthma and bronchitis.

2-2 Health risk assessment

In general, health risk assessments of air pollutants are conducted based on several methodologies, the most popular of which are in vivo experiments (using laboratory animals) and epidemiological studies. Epidemiology is basically a non-experimental science; it is designed to find correlations between the incidence of diseases in a particular group of people and a variety of environmental factors. Taking into account correlations with other factors, for example, the incidence of bronchial asthma is compared between two groups of people: those exposed to high concentrations and low concentrations of air pollutants. Toxicology, meanwhile, investigates the development of various biological reactions and their mechanisms, exposing laboratory animals to specific environmental factors under certain conditions. For example, biological reactions to auto emissions are monitored using rats.

As far as health effects studies for airborne particulate matters are concerned, epidemiological findings are generally announced prior to the results of experimental studies that are usually conducted to corroborate epidemiological hypotheses. Where reliable epidemiological findings are available, epidemiological data is preferred to animal experiment data in assessing health effects. A report submitted by the Central Environmental Council last year reads as follows:

While epidemiological studies and animal experiments provide the quantitative data on toxicity needed to set numerical targets for environmental standards, the former are particularly important because they collect data directly from humans. Thus, in principle, environmental standards have been established based on human data obtained through epidemiological studies. Where reliable human data are not available, animal experiment data are usually extrapolated forward to assess the effects on humans in setting numerical targets[4].

Placing a premium on epidemiological data is one thing; emphasizing the results of a handful of epidemiological studies is another. As epidemiological studies are basically observatorystudies, consistency among reliable data, i.e., consistency among the results of different groups of people, is paramount in the field of environment studies.

2-3 Properties of airborne particulate matters and their effects on humans

Human respiratory organs comprise the nasal cavity, oral cavity, pharynx, trachea and bronchi, which bifurcate repeatedly into dozens of smaller bronchi before reaching the alveoli. The trachea is about 2 cm in diameter, while the bronchioles measure less than 1 mm, each of which is linked to the alveolus. When inhaled, particulate matters with large particle diameters*1 collide with or precipitate in the airway wall before accumulating there; particles with a small diameter, which reach the alveoli, accumulate on the alveolar wall through dispersion.

Airborne particulate matters differ in composition according to their diameter. In general, fine particles contain more components that are considered hazardous. Particle diameters, therefore, are a decisive factor in the health effects of airborne particulate matters in terms of both particulate accumulation in the respiratory organs and the composition of the particles, which varies depending on how they are formed in the atmosphere.

Of airborne particulate matters, those with a diameter of less than 10μm (SPM: Suspended Particle Matters) are regulated by environmental standards in Japan, whereas in the U.S., two types of particulate (PM_{10} and $PM_{2.5}$) are regulated. The aerodynamic diameters of $PM_{2.5}$ are less than 2.5μm. $PM_{2.5}$, however, include a certain amount of particles with a diameter greater than 2.5μm. Specifically, $PM_{2.5}$ refers to particles whose collection efficiency reaches 50% at an aerodynamic diameter of 2.5μm. Similarly, PM_{10} refers to particles whose collection efficiency reaches 50% at an aerodynamic diameter of 10μm. SPM in Japan, meanwhile, are totally free of particles with a diameter greater than 10μm. SPM and PM_{10}, therefore, differ in the distribution of the aerodynamic diameters of particles, and the average particle diameter becomes greater in the order of $PM_{2.5}$, SPM and PM_{10}.

In addition to these definitions of particles based on their diameters, there are various terms for airborne particulate matters used in a variety of laws and regulations (dust, soot, smoke, etc.). Dust includes suspended dust, asphalt dust generated by studded tires and specified dust such as asbestos. Many of these are termed according to their formation processes, measurement methods and sources of origin. “Diesel emission particles,” for example, refers to their source of origin. “Airborne particulate matters” and “aerosols” are almost synonymous in atmospheric science.

3 The US strategy for research on airborne particles in and after the 1990s

3-1 Impact of the $PM_{2.5}$ air quality standards

In the U.S., air quality standards for particulate matters were established for the first time in 1971, and they were later revised in 1987 and 1997. The original standards set in 1971 were designed to regulate TSP (Total Suspended Particles); PM_{10} were regulated in 1987, and $PM_{2.5}$, in 1997. Although there were no regulations for the diameters of TSP, the characteristics of high volume air samplers suggest that particles with a diameter of less than 40μm were collected. US environmental standards for particulate matters, therefore, have been revised twice to regulate smaller particles, from 40 to 10 and 2.5μm[5].

Environmental standards were set for $PM_{2.5}$ because of some new findings. First, a association was found between health effects (including diseases) and airborne particulate concentrations, even though existing environmental standards were met. In relation to this, $PM_{2.5}$ were considered to pose a greater risk than PM_{10}. Environmental standards are usually set for both the annual average and the 24-hour average. The health effects of long-term exposure to airborne particulate matters concern health indexes such as adult mortality, the incidence of childhood bronchitis, and the pulmonary function of children. It was also pointed out that short-term changes like daily fluctuation in $PM_{2.5}$ concentrations are related to premature death, increased hospital admissions, increased respiratory symptoms and disease, and decreased lung function. Particularly noteworthy was the finding that the daily average of $PM_{2.5}$ concentrations on a given day is related to the number of deaths of that day or the next day. More relevant, this correlation was found in daily fluctuation in airborne particulate matters (a common phenomenon observed in big cities), not in high-concentration phenomena such as the London Smog Incident - a finding that runs counter to the established theories.

In 1980, the American Journal of Epidemiology, one of the most authoritative scientific journals in epidemiology, featured an article by prominent British epidemiologists, which reported the health effects of air pollution caused by particles[6]; there was no evidence whatsoever that usual concentrations of particulate matters or sulfur dioxide (SO_2) caused mortality. Although the fact that the US steel industry sponsored this article aroused controversy, its conclusion was in keeping with common understanding in academic society in those days. Many researchers thought that health effects caused by short-term exposure to air pollutants no longer existed and that only long-term exposure to low concentrations of air pollutants mattered.

There has been great progress in computers and statistical analysis since 1987, when the environmental standards were revised, which opened up a new way for research on airborne particulate matters. At the same time, a series of notable research papers were published, each showing positive correlation between airborne particulate concentrations and daily mortality in some cities in the U.S. and Europe. Among others, research findings appearing in the New England Journal of Medicine[7] in 1993 raised public awareness of the health effects of airborne particulate matters, i.e., epidemiological findings regarding the health effects of long-term exposure to airborne particulate matters, based on the mortality reported in the "Harvard Six City Study," one of the most distinguished epidemiological studies on the subject. This particular period coincides with the increase in the number of research papers. With this as a backdrop, EPA began to review the environmental standards in 1994, which resulted in the second revision in 1997.

Similarly, EPA revised environmental standards for ozone (O_3). Volatile organic compounds (VOC), gaseous air pollutants such as nitrogen oxides (NOx) and sulfur oxides (SOx), and ozone, which is produced by reactions of these compounds in the atmosphere, all take part in the formation of SPM and $PM_{2.5}$ (see Table 1). Regulations designed to meet environmental standards for fine particles and ozone, therefore, extend to emission sources of an array of air pollutants including gaseous air pollutants. In other words, setting such environmental standards goes beyond regulating the emission of primary particulate matters; these standards have a substantial impact on those who emit air pollutants.

Setting environmental standards and their associated regulations often cause a conflict of interests. In the case of air pollution, for example, a large proportion of the population (including highly vulnerable people such as children, the elderly and invalids) could be exposed to risk, while industries and consumers alike can be polluters since the combustion of fossil fuels is a major source of air pollution. On the other hand, pollution prevention measures and health hazards result in substantial economic cost. EPA conducted regulatory impact analysis[9] in 1997 in parallel with the revision of the environmental standards; benefits derived from achieving the environmental standards were estimated to be US$19-104 billion a year, and their costs, to be US$8.6 billion. Benefits include a decrease in mortality, disease, labor loss, and activity constraints. Cost is primarily capital investment in air pollution control facilities to comply with the regulations.

With the environmental standards revised in 1997, the US industry took the case to court, questioning the validity of the air quality standards and, by extension, the scientific basis of the revision itself. Its allegations: the mechanism of the health effects of $PM_{2.5}$ has yet to be elucidated; the correlation between exposure to air pollution and its health effects cannot be confirmed, and hence is inappropriate as a basis of environmental standards even if epidemiological studies presented by EPA confirmed a strong statistical linkage between the two parameters. In the end, EPA won the case and the revised environmental standards for $PM_{2.5}$ took effect.

3-2 Selection of priority subjects and budgetary measures

The 1997 revision, particularly the addition of environmental standards for $PM_{2.5}$, is based on several epidemiological studies. EPA revised the environmental standards, emphasizing the consistency of epidemiological research findings. It is proven, however, that these scientific findings involve a lot of uncertainties. The US congress, in an effort to minimize such uncertainties, doubled the research budget for airborne particulate matters, while instructing the National Research Council (NRC), through the EPA director, to promote and supervise research on airborne particulate matters. In response to this, NRC selected priority subjects considered necessary to set environmental standards, presented research schemes for airborne particulate matters and set up a committee to monitor the progress in research activities.

Moreover, scientific uncertainties were identified in five major factors concerning airborne particulate matters: emissions, dynamics in the atmosphere, human exposure, inhalation, and development of health effects. There is also uncertainty in the correlations between these factors[10].

Naturally, the quantitative relationship between the exposure to the air pollutants concerned and its health effects (the exposure-response relationship) needs to be clarified to set environmental standards. At the same time, all processes from the formation of air pollutants to human exposure to them should be elucidated to meet prescribed environmental standards through the fair and efficient implementation of regulations[11] (Figure 1). For this reason, the US strategy for research on airborne particulate matters goes beyond achieving the immediate objective of meeting environment administration requirements (i.e., reducing uncertainties in the scientific basis of the environmental standards); they encompass basic areas in medicine, biology, atmospheric science and measurement technology concerning the lifecycle of airborne particulate matters (emissions, dynamics in the atmosphere, human exposure, inhalation, and development of health effects).

Priority subjects in airborne particulate research were selected based on three criteria: scientific value, decisionmaking value, and feasibility and timing. As a result, 10 priority subjects (see Figure 2) were selected in time for

Figure 1 : Formation of particulates and oxidants in the atmosphere[8]

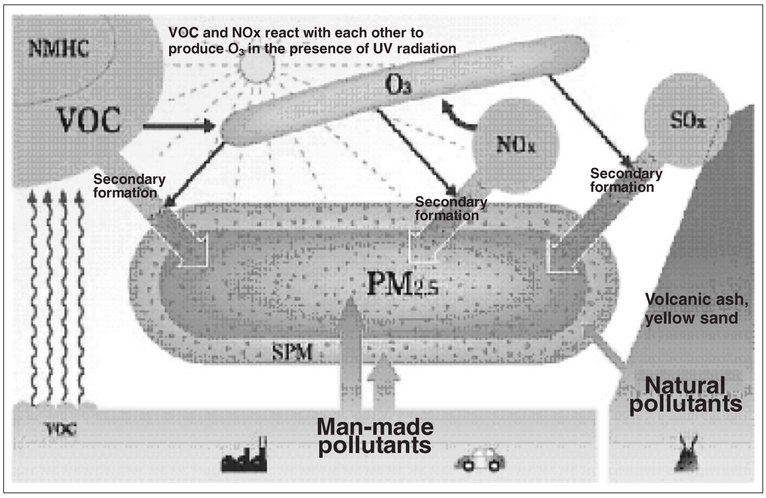
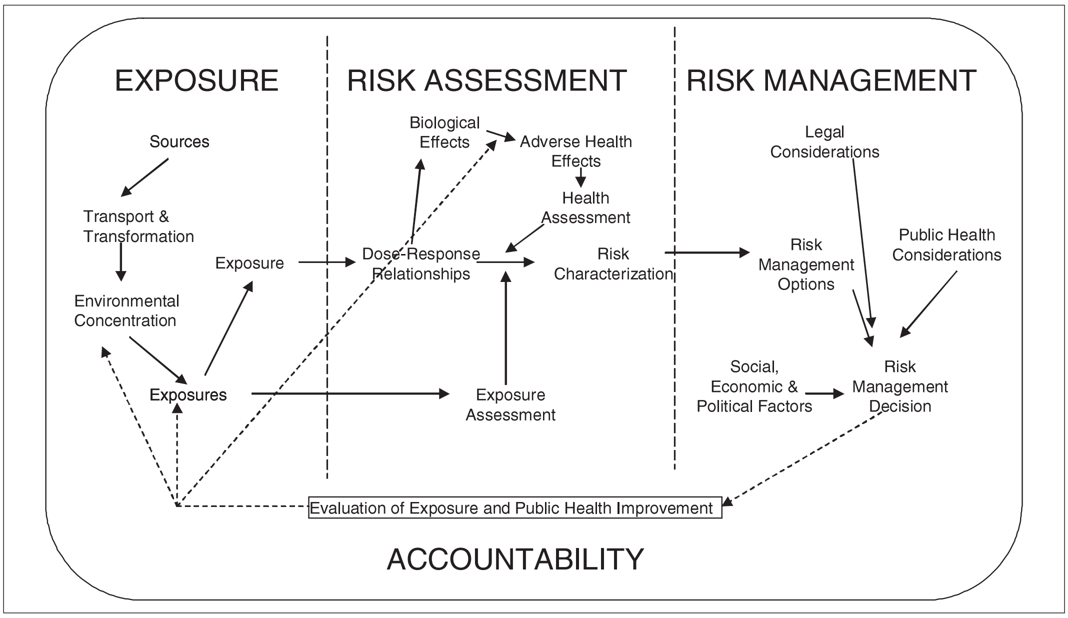


Figure 2 : Framework for US airborne particulate research that identified scientific uncertainties[10]



revision of the environmental standards in 2002.

A 13-year research portfolio was also set up for these 10 subjects, targeting the period between 1998 and 2010. EPA capitalized on the Science to Achieve Results (STAR) Program, a framework for providing competitive and non-competitive funds, to promote specific research activities, providing research funds to universities, external research institutions and EPA's research arm. In 1999, the Particulate Matter Research Center was established at the request of the US congress. Twenty research bodies applied for participation in the center's research programs, and five universities, Harvard University, New York University, University of Washington, U.C.L.A. and University of Rochester, were selected as COE, each receiving a total of US$8 million between 1999 and 2004 (The second recruitment is underway at the center).

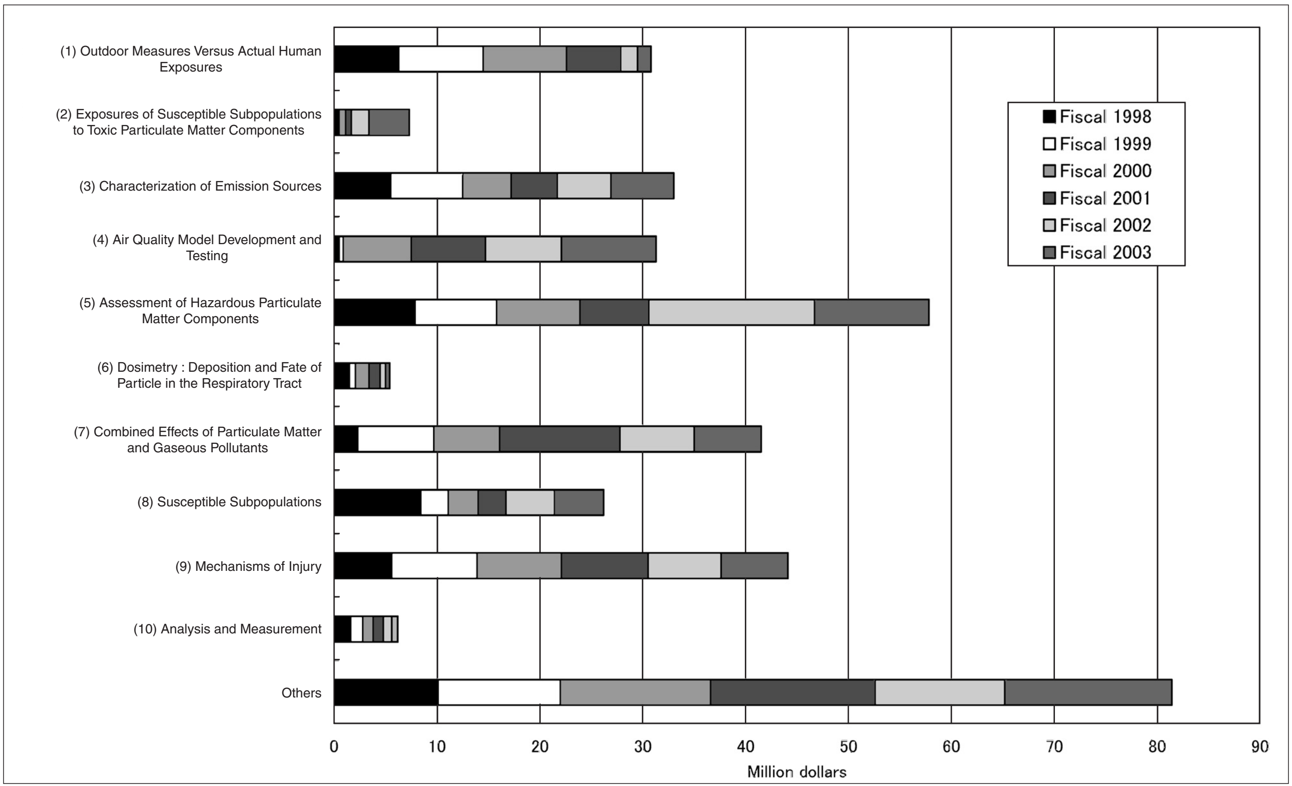
EPA funded a total of some US$370 million in airborne particulate research between 1998 and 2003, about US$60 million a year (see Table 2). Research funds for external research institutions such as universities account for about 32% of the total, with the rest provided to EPA's research arm including its affiliated research institutions. These funds were also appropriated to the basic research areas of the 10 subjects, e.g., review of a standardized measurement method for airborne particulate matters, development of methods to analyze the chemical constituents of airborne particulate matters, management of seven advanced monitoring facilities in the U.S. (Particulate Matter Super Site), and development of a database of emission sources.

In its interim reports released in 1999 and 2001[12,13], NRC made minor revisions to the research subjects and assessed progress in research activities. In 2004, it evaluated research findings published between 1998 and 2003[14], while releasing a report summarizing research findings over the past five years[15]. This report refers to some 700 items of literature funded by EPA and about 50 items of literature funded by other competent authorities.

Table 2 : Priority subjects regarding airborne particulate matters in the U.S.

Subject	Description
(1) Outdoor Measures Versus Actual Human Exposures	The purpose is to shed light on the quantitative relationship between measurement data provided by outdoor stationary monitoring stations and the actual personal exposure. This research is conducted in response to the criticism that data provided by outdoor stationary atmospheric measurement stations have been used as index of the exposure of the groups concerned.
(2) Exposures of Susceptible Subpopulations to Toxic Particulate Matter Components	Subject (1) is explored in greater depth, focusing on highly vulnerable groups and hazardous components. In principle, it is conducted based on the achievements in Subject (5).
(3) Characterization of Emission Sources	It is designed to make inventories and review their methodologies regarding the amount of primary particles originating from emission sources, distribution of particle diameters, chemical compositions and the amount of gaseous air pollutants that can be converted into secondary particles in the atmosphere.
(4) Air Quality Model Development and Testing	It is designed to model and verify the formation and dynamics of various airborne particulates (nucleation in the atmosphere, formation of organic aerosols, atmospheric chemical reactions, dry deposition, vertical mixing, effects of climate models, etc.)
(5) Assessment of Hazardous Particulate Matter Components	Physiochemical components of airborne particulates that have adverse effects on human health are identified.
(6) Dosimetry: Deposition and Fate of Particles in the Respiratory	The topics concerned are accumulation of particulates in the respiratory organs (the nasopharynx, trachea, bronchi and lung) of highly vulnerable people, and the elimination rate of the particulates and its mechanisms.
(7) Combined Effects of Particulate Matter and Gaseous Pollutants	The purpose is to distinguish between the health effects of particulates and those of other gaseous substances, and to shed light on the impact of exposure to the atmosphere in which these substances coexist.
(8) Susceptible Subpopulations	Groups highly vulnerable to exposure to particulates are identified.
(9) Mechanisms of Injury	It is designed to elucidate the mechanisms explaining the correlation between exposure to airborne particulates (demonstrated by epidemiological studies) and mortality/morbidity.
(10) Analysis and Measurement	The purpose is to review how statistical approaches designed to analyze epidemiological data affect estimates of the health risks of particulates, and how measurement errors and miscategorization interfere with improving statistical approaches or estimates of the health effects of air pollution.

Figure 3 : EPA's research budgets for airborne particulate matters



4 Japan's air environment administration and research trends

4-1 Japan's air quality standards

Japan's environmental standards for airborne particulate matters were first established in 1972. The following year, additional standards for other traditional air pollutants (sulfur dioxide, carbon monoxide, photochemical oxidants and nitrogen dioxide) were promulgated, while those for nitrogen dioxide were revised in 1978. The "Health Effects Index," which is the basis of Japan's environmental standards for airborne particulate matters, concerns parameters such as mortality, increased bronchitis, and decreased lung function; it was established based on epidemiological findings in the U.S. and Europe, complemented by scientific findings in Japan.

Japan's environmental standards for airborne particulate matters and traditional air pollutants, as well as critical decisions in the air environment administration, have been based on an array of scientific findings from the U.S. and Europe, with a few research findings obtained by the Ministry of the Environment (the former Environmental Agency) complementing them. The "Survey of the Health Effects of Smoke, etc.," conducted by the former Ministry of Health and Welfare before the establishment of the Environmental Agency, served as a basis for setting environmental standards for sulfur oxides, as well as for designating areas in accordance with the Pollution-related Health Damage Compensation Law. In relation to this, the "Survey of the Health Effects of Combined Air Pollution," conducted in 1978 in response to the revision of the environmental standards for nitrogen dioxide, and the results of two other surveys presented by the Environmental Agency to cancel the designated areas in accordance with the Pollution-related Health Damage Compensation Law played an important role in the air environment administration[16-19]. The Ministry of the Environment (the former Environmental Agency) set up investigative committees for each of these surveys, with their staff members assigned to universities and research institutions conducting the actual surveys. For instance, a survey of the health effects of $PM_{2.5}$ launched in 2000 by the Ministry of the Environment is underway, led by the Investigative Committee for the Health Effects of Exposure to Fine Particles, a framework that is not changing in any significant way.

4-2 Research funds for conventional pollution problems including air pollution

The competitive research funds provided by the Ministry of the Environment are not designed for research on such traditional air pollutants, except for pollution control in the framework of research on global environment conservation. This exceptional research, however, is participated in only by the research institutions of government agencies and of independent administrative agencies, with those of universities excluded. In fact, these competitive research funds are limited to research activities in global environment conservation, environmental technology development and waste disposal. The US strategy for airborne particulate matters, where both competitive and non-competitive research funds are mobilized, cannot be put into practice in Japan. In fact, the Ministry of the Environment has been conducting research on traditional air pollution using non-competitive funds.

5 Growing concerns over the toxicity of nanoparticles

The fundamental concept in assessing the biological impact of certain substances is that their biological effects (toxicity) increase linearly in proportion to the dosage (weight). It has been argued, however, that this concept may not be applicable to nanoparticles; some researchers point out that nanoparticles, even if their weight is negligible, may have health effects, depending on their counts or due to their large surface areas. Concerns are thus growing that nanoparticles could be different from other particles in their intake routes, dynamics in the body, recognition by the body's defenses and expression of toxicity.

The US strategy for research on airborne particulate matters, from the vantage point of setting appropriate standards for particle diameters, has already taken into account $PM_{1.0}$ (particles smaller than $PM_{2.5}$) and even $PM_{0.1}$ (fine particles with diameters of less than 0.1 μm) in assessing the health effects of airborne particulate matters. The University of Rochester, one of COE, focuses on research on ultra-fine particles[20], while review is underway primarily in Europe for the measurement of nanoparticles in auto emissions[21].

The National Institute for Environmental Studies of Japan, meanwhile, is setting up experimental facilities to assess the health risks of nanoparticles in auto emissions, with animal experiments, etc. scheduled to begin shortly. Nanoparticles are therefore becoming a subject of research in the field of the health risk assessment of airborne particulate matters.

Concerns are also growing over the toxicity of nanomaterials that are increasing along with progress in nanotechnology. The National Institutes of Health (NIH) recently added nanomaterials (single-layer nanotubes, titanium dioxide, quantum dots, fullerene, etc.[22]) to the list of the National Toxicology Program to evaluate their toxicity. In addition, EPA, NSF (the National Science Foundation) and NIOSH (the National Institute for Occupational Safety and Health) began to advertise for research proposals for the environmental and health effects of nanomaterials, putting up a total of US$7 million[23]. Research on the toxicity of nanomaterials is burgeoning in the U.S.

6 Prospects and challenges for research in Japan and policy recommendations

Airborne aerosols in the East Asian region and by extension in the world, which are beyond the subject matter discussed above, are receiving attention as a global environmental problem. Feature Article 4 (Research on the Impact of Aerosols on Global Warming - Approaches to Remaining Problems) in the Science and Technology Trends journal (November 2002) addresses this problem; competitive funds such as the Global Environment Research Funds (provided by the Ministry of the Environment) and research subsidies granted by the Ministry of Education, Culture, Sports, Science and Technology have played a part in promoting research in this particular area. On the other hand, the promotional framework for research on airborne particulate matters as a domestic problem needs to be reviewed and discussed.

To begin with, the extent to which Japan should have its own scientific findings on the health effects of airborne particulate matters needs to be determined. The scientific basis required to set environmental standards is usually derived from research findings in other countries (which is not the case with the U.S. and some countries in Europe); guideline values set by WHO are used in some cases as environmental standards. However, scientific findings on health effects on local residents exposed to airborne particulate matters are necessary to establish Japan's own environmental standards. Epidemiological findings have been emphasized as the scientific basis of environmental standards because epidemiology can keep track of exposure to pollutants in the real world along with its health effects. However, the reality is that both the financial and human resources needed to conduct research on air pollution and epidemiology related to environmental pollution are far from sufficient in Japan. Due to the absence of competitive research funds in this area, moreover, maintaining laboratories for developing human resources is not feasible, while a shortage of human resources makes it difficult to create a framework for competitive research funds; it is a vicious cycle. To gather scientific findings unique to Japan, therefore, it is imperative that short-term research funds be made available and long-term support programs be administered to develop the necessary human resources.

In the meantime, how much research fund is needed, and whether the scale of fund made in the U.S. is needed in Japan, should be thoroughly discussed. Following EPA's regulatory impact analysis, moreover, quantitative estimates should be made of the population exposed to air pollution, the significance of health risks and the cost-effectiveness of preventive measures, each of which should take into account health risks associated with other environmental pollution.

Secondly, research that is needed for the most efficient measures should be designed to meet prescribed environmental standards. As the US strategy suggests, there is a need to promote basic medicine, biology, atmospheric science and measurement technology regarding air pollutant emissions and their dynamics in the atmosphere, air pollutant exposure to humans, air pollutant inhalation and the development of biological effects, as well as research that sheds light on quantitative relationships between the amount of exposure and its health effects.

Lastly, research on the toxicity of nanoparticles should be promoted in the framework of Japan's R&D strategy for nanotechnology, encouraging participation of not only researchers specializing in nanomaterials but also those in the fields of biology, pharmacology, epidemiology and medicine. While research in this particular area is still in its infancy in the U.S., the authorities and research institutions concerned are beginning to discuss the health risks of nanomaterials in Japan[24]. There is a fair chance of Japan taking the initiative in this area through the concerted efforts of all parties concerned.

An international consensus regarding the concept "precautionary approach" or "precautionary principle" is being reached on methods of addressing environmental problems[25]. Specifically, it is generally agreed that scientific uncertainties should not be an excuse to postpone cost-effective measures when human beings and ecosystems are expected to suffer serious or irreversible damage. Decision-making based on precautionary approarch or principle is incompatible with current approaches to traditional air pollutants, where the toxicity of target pollutants is defined to closely assess the scientific uncertainties involved. A slim chance of nanoparticles having adverse effects on human beings and ecosystems may thus result in the enforcement of regulations based on precautionary principle, and those taking the initiative in developing next-generation products will likely benefit.

In the U.S., assessment methods based on "regulatory science" are being discussed and implemented to address quite a few environmental problems. Regulations related to health effects should be established on a scientific basis supported by basic research. In relation to this, problems associated with nanoparticles should be addressed properly according to regulatory science, achievements in which are expected to contribute to improving Japan's quality of life and its science and technology.

Glossary

*1 Particle diameter

A "particle diameter" does not refer to a length measured physically; it involves the inertial force of the airflow and hence is called an "aerodynamic diameter."

References

[1] Samet, JM. Air pollution and epidemiology: déjà vu all Over again? Epidemiology, 2002:13:118-119.

[2] NISTEP: The 8th Science and Technology Foresight Survey —Study on rapidly developing research areas— Interim Report, June 2004. (in Japanese)

[3] Press Release by U.S. Environmental Protection Agency, July 29, 2004: http://www.epa.gov/pmresearch/pm_grant/

[4] Central Environment Council: Future measures against hazardous air pollutants (7th report), 2003.: http://www.env.go.jp/council/toshin/t07-h1503/t07-h1503.pdf. (in Japanese)

[5] U.S. Environmental Protection Agency. Air quality criteria for particulate matter, EPA report No. EPA-600/P-95/001cF, 1996

[6] Holland, WW, et al.: Health effects of particulate pollution: reappraising the evidence. Am. J. Epidemiol., 1979;110; 527-659.

[7] Dockery, D. et al.: An association between air pollution and mortality in six U.S. cities. N. Engl. J. Med. 1993; 329; 1753-1759.

[8] National Institute for Environmental Studies: Urban air pollution by volatile organic compounds. Kankyogi (NIES Research Booklet), NO.5, 2002. (in Japanese)

[9] U.S. Environmental Protection Agency. 1997. Regulatory impact analyses for the particulate matter and ozone national ambient air quality standards and proposed regional haze rule. Research Triangle Park, NC.

[10] National Research Council (1998). Research priorities for airborne particulate matter: I. Immediate priorities and a long-range research portfolio. Washington, DC: National Academies Press. ISBN 0-309-06094-X.

[11] Air Quality Research Subcommittee, Committee on Environment and Natural Resources. Strategic research plan for particulate matter, 2002.

[12] National Research Council (1999). Research priorities for airborne particulate matter: II. Evaluating research progress and updating the portfolio. Washington, DC: National Academies Press. ISBN 0-309-06638-7.

[13] National Research Council (2001). Research priorities for airborne particulate matter: III. Early research progress. Washington, DC: National Academies Press. ISBN 0-309-07337-5.

[14] National Research Council (2004). Research priorities for airborne particulate matter: IV. Continuing research progress. Washington, DC: National Academies Press. ISBN 0-309-09199-3.

[15] U.S. Environmental Protection Agency (2004). Particulate matter research program-five years of progress, EPA 600/R-04/058 Washington, DC.

[16] Environmental Pollution Division, Environmental Health Bureau, Ministry of Health and Welfare: Summary of the survey report on the effects of smoke, etc. 1964. (in Japanese)

[17] Health Division, Environment Agency: Survey of the health effects of combined air pollution; Summary of the survey and major findings 1977. (in Japanese)

[18] Health Division, Environment Agency: 1986. Questionnaire survey of respiratory diseases, April 1986. (in Japanese)

[19] Air Quality Bureau, Environment Agency. 1986. Report on survey of the health effects of air pollution (1980-1984), March 1986 (in Japanese)

[20] University of Rochester School of Medicine & Dentistry, EPA Particulate Matter Center: http://es.epa.gov.ncer/centers/airpm/rochester/

[21] U.N. Economic Commission for Europe, Report of the GRPE particle measurement programme (PMP), government sponsored work programmes, 2003.

[22] Hood E. Nanotechnology: Looking as we leap, environmental health perspective, 2004; 112: A741-A749.
[23] Nanotechnology Research Grants Investigating Environmental and Human Health Effects of Manufactured Nanomaterials: A Joint Research Solicitation - EPA, NSF, NIOSH.
http://es.epa.gov/ncer/rfa/2004/2004_manufactured_nano.html
[24] http://www.aist.go.jp/aist_j/research/honkaku/symposium/nanotech_society/symposium.html
[25] Ministry of the Environment: Report on research on preventive measures and principles in the environment administration; 2004. (in Japanese)
http://www.env.go.jp/policy/report/h16-03/index.html

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