# Improved Technologies for Analyzing and Visualizing Effects of $PM_{2.5}$

● Teruhisa Kitani ● Shinobu Hosoda ● Masashi Yasuda

**Although the effects of particulate matter smaller than 2.5 μm in diameter ($PM_{2.5}$) on human health are still not fully understood, there is a growing demand for countermeasures. Fujitsu provides several services for "visualizing" various types of quality, including environmental quality, and is working to improve the accuracy of technologies for measuring and analyzing related data, particularly data related to $PM_{2.5}$. In this paper, we clarify the challenges presented by $PM_{2.5}$ and describe Fujitsu's approach to improving the technologies used for analyzing and visualizing its effects.**

## 1. Introduction

Japan's rapid economic development in the postwar period was unfortunately accompanied by the discharge of pollutants into the air, water, and soil. These pollutants created health hazards throughout the country as reflected in Japan's four major pollution episodes (Minamata disease, Niigata Minamata disease, chronic cadmium poisoning, and Yokkaichi asthma), which led to grave social problems.

In response, the Japanese government enacted the Basic Law for Environmental Pollution Control in 1967, established the Environmental Agency in 1971, and set environmental standards for suspended particulate matter (SPM) 10 μm or less in diameter in 1973. Japan's industrial sector, in turn, steadily implemented environmental measures over the following 50 years, leading to significant improvements in the environmental-pollution situation and the easing of environmental problems throughout the country. However, there is growing anxiety about fine particulate matter ($PM_{2.5}$) in the atmosphere (**Figure 1**) because of its potential effects on public health.[1)]

This paper describes Japan's current response to the $PM_{2.5}$ problem, introduces Fujitsu's approach to the problem, and touches upon future work.

## 2. Current response to $PM_{2.5}$

Among the various types of particulate matter suspended in the atmosphere, $PM_{2.5}$ refers to tiny particles 2.5 μm or less in diameter.[2)] Although Japan had set standards for SPM 10 μm or less in diameter, recent studies in fields like epidemiology and toxicology have linked fine particulate matter with respiratory and cardiovascular diseases, lung cancer, and other medical conditions. The International Agency for Research on Cancer, the specialized cancer agency of the World Health Organization (WHO), recently placed fine particulate matter in its highest category of carcinogenicity.[3)]

In September 2009, the Japanese government established environmental quality standards based on those in the United States and took that opportunity to draw up a plan to install 1300 monitoring stations throughout the country to measure the amount of $PM_{2.5}$ in the atmosphere. To date, more than 800 such stations have been installed.

Then, in March 2010, the government revised the "Processing Standards for Continuous Monitoring of Environmental Air Quality based on Article 22 of Air Pollution Control Law."[3)] This revision states that a "component analysis" be performed to clarify the health effects of fine particulate matter, that the discharge conditions of causative agents be determined, that a discharge inventory be created, and that studies be performed to identify effective countermeasures. These studies are aimed at clarifying the behavior of fine particulate matter in the atmosphere and the secondary

**Figure 1**
**Image of pollution caused by $PM_{2.5}$.**

generation mechanisms.

Subsequently, in April 2013, on receiving information that concentrations of $PM_{2.5}$ measured at various locations in western Japan had jumped significantly, the central government established provisional guidelines for prefectural governments to use in issuing warnings to the public on the health hazards of fine particulate matter. $PM_{2.5}$ has thus become a target pollutant in photochemical smog advisories and health warnings.

Despite these concerns about $PM_{2.5}$, its effects are poorly understood, and, since it is still a relatively new target compared to other pollutants, the amount of measurement data on $PM_{2.5}$ is inadequate. Developing means of collecting large volumes of highly accurate data has consequently become a major issue in clarifying the generation mechanisms and sources of $PM_{2.5}$ and its effects on public health.[4)]

## 3. Understanding current conditions

### 3.1 Importance of visualization

Measuring and analyzing the concentration and composition of particles suspended in the atmosphere and obtaining an accurate understanding and "visualization" of current conditions are essential to clarifying the generation mechanisms, isolating the sources, and gauging the health effects of these particles. This approach is especially important since experiments that reproduce actual air pollution conditions cannot be performed. In addition, visualization techniques that include forecast simulations that take the components of suspended particles and time into account are indispensable to formulating effective and efficient countermeasures to $PM_{2.5}$.

These activities, which have taken place for some time in Japan, have helped raise awareness of environmental problems elsewhere in the world, and the adoption of similar activities in other countries is accelerating.

Fujitsu has also been involved in overseas projects involving the visualization of environmental pollution including the construction of a volatile-organic-compound (VOC) monitoring system for the Map Ta Phut industrial estate in Thailand[5)] and the construction of an environment management system in three major industrial cities in the Kingdom of Saudi Arabia.[6)] The authors' role in these two projects was to select the monitoring devices and monitoring locations and to implement maintenance and operation systems.

### 3.2 Two elements supporting visualization

Two elements essential to visualization are high-accuracy real-time monitoring technology and know-how for clarifying pollutant generation mechanisms.

The data obtained from real-time monitoring are used for representing current conditions at designated locations. They also serve as base data for checking the overall extent of $PM_{2.5}$ pollution and for conducting forecast simulations.

Fujitsu has been extensively involved in the visualization of air pollution and water contamination, from the design of environmental monitoring stations, monitoring systems, and communication networks to their installation and deployment and subsequent operation and management. As a result, ensuring data compatibility in these processes facilitates the provision of high-quality services at low cost. Moreover, Fujitsu has been working to develop simple monitoring systems using compact sensors with the aim of providing environmental information to even more people.

Additionally, to clarify generation mechanisms, the way in which the quantity and composition of suspended matter changes over time must be visualized while considering associated reactions and dispersion processes, which are affected by wind direction and speed, ultraviolet ray intensity, and other weather conditions. This requires know-how for analyzing

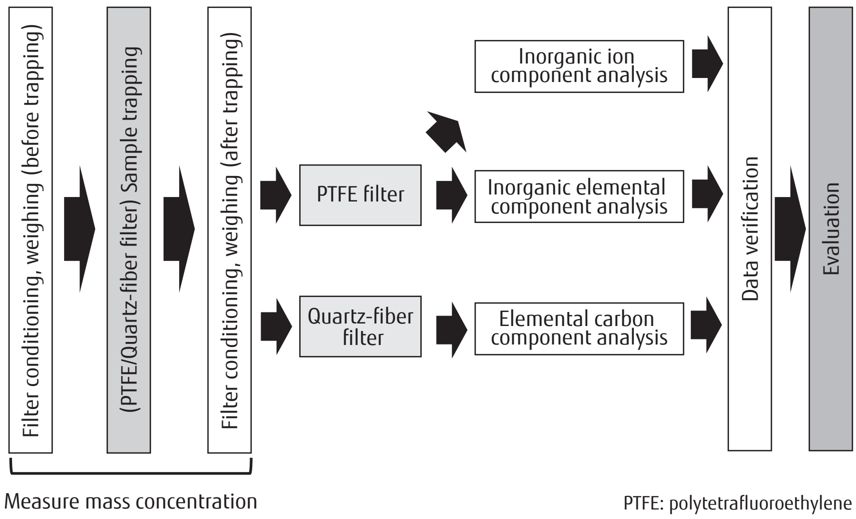



**Figure 2**
**Component analysis process.**

the components and mass of suspended matter and clarifying its composition, for isolating its origin, and for inferring the processes that take place after initial generation.

In short, component analysis that visualizes the composition of suspended matter is particularly important for clarifying its generation mechanism. Fujitsu has thus been developing technology and accumulating knowledge that can be used to achieve levels of accuracy even higher than those specified by Japan's Ministry of the Environment.

The following section introduces Fujitsu's latest developments and efforts in component analysis as part of its ongoing investigation of the $PM_{2.5}$ generation mechanisms.

**Figure 3**
**View of measurement devices.**

## 4. Component analysis techniques
### 4.1 Overview of component analysis

$PM_{2.5}$ consists of primary particles discharged directly into the atmosphere from original sources (soil, vehicles, incinerators, boilers, etc.) and secondary particles generated by the condensation, aggregation, chemical reaction, and/or photochemical reaction of gases and organic particles emitted from original sources. A better understanding of the composition of these types of particles is obtained by treating suspended substances not as simple substances but rather as a mixture of components consisting of inorganic ions, inorganic elements, elemental carbon, organic carbon, etc. and performing component analysis for each of those categories.[7]

Component analysis (**Figure 2**) consists of two main steps: filter-based trapping of $PM_{2.5}$ in the atmosphere using a sampler capable of highly accurate selective trapping and component analysis of the inorganic ions, the inorganic elements, and the elemental carbon. First, sample trapping is performed at a height of 3–10 m to avoid erroneous detections due to ground surface disturbances. An external view of the measurement devices is shown in **Figure 3**. Detailed instructions on standard sample trapping, sample preservation, and other procedures are specified in

"Guidelines on Analyzing Fine Particulate Matter ($PM_{2.5}$) Components."[8] These Guidelines, however, do not clearly prescribe how to deal with irregular situations, which means that making decisions at such a time will be difficult unless one is a component-analysis specialist in the environmental field. In other words, experience and know-how are important.

As shown in Figure 2, component analysis is carried out for three categories. Some of the analysis techniques shown are included in the Guidelines while others may be used provided that they have equivalent accuracy. It is also necessary to conduct an evaluation to guarantee the accuracy of component analysis. Such an evaluation examines the analysis procedure, checks for outlying values, checks conditions at the time of sample trapping, etc. so as to ensure the accuracy of results.

The overall accuracy of component analysis is greatly affected by differences in the assessment situation and analysis techniques used. Fujitsu is actively pursuing technical innovations in this field to further improve analysis accuracy. The following subsections introduce two examples of Fujitsu's pioneering work in the development of an advanced inorganic elemental component analysis technique.

## 4.2 Acid-digestion/ICP-MS method

The Guidelines specify 13 essential elements and 17 recommended elements for inorganic elemental component analysis. They also include a process for breaking down the trapped fine particulate matter: inductively coupled plasma mass spectrometry (ICP-MS) based on acid digestion in a pressurized container. This process can be applied to a wide variety of elements.

The acid-digestion process starts with the placement of a filter with trapped fine particles in a fluorine resin container. Concentrated hydrofluoric acid and concentrated nitric acid are added, and the solution is heated and dissolved by microwave irradiation. The dissolved solution is transferred to another fluorine resin container in which it is heated and condensed until just before it solidifies. Then it is dissolved again by using a diluted nitric acid to prepare a component analysis sample. This acid digestion process is obviously somewhat complicated and dangerous. Furthermore, the accuracy of the analysis may be degraded if the quantity of fine particles trapped by the filter is small or the constituent amount of the element targeted for measurement is relatively small. In addition, silicon—a recommended element—is not sufficiently dissolved by acid digestion using hydrofluoric acid and nitric acid, so the use of x-ray fluorescence analysis (XRF) along with this method is also included in the Guidelines.

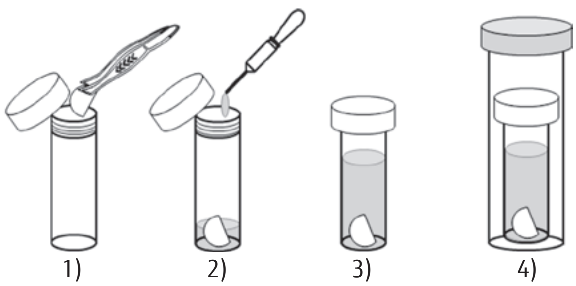
Silicon, the main component of stones and rocks, is a major inorganic element, and though it is an important index for analyzing the source of suspended particles, separately measuring only the silicon in a minute sample amount is problematic in terms of accuracy. To overcome this problem, Fujitsu has developed a pretreatment for ICP-MS, as described in the next subsection.

## 4.3 Ultrasound/heat-block/ICP-MS method

In contrast to the pressurized-container/acid-digestion process, which dissolves fine particulate matter in hydrofluoric acid and nitric acid, the ultrasound/heat-block/ICP-MS method we developed separates atmospheric particles from the trapping filter and diffuses them in a solution without dissolving them. These undissolved atmospheric particles are then broken down and ionized within the plasma of the ICP-MS method.

The ultrasound/heat-block/ICP-MS method works as shown in **Figure 4**. A polytetrafluoroethylene (PTFE) filter with trapped $PM_{2.5}$ is placed in a polypropylene container, nitric acid is added, and ultrasonic vibrations are applied while heating to extract the $PM_{2.5}$ from the filter into the nitric acid so that it can be directly injected into the ICP-MS.

To evaluate this method quantitatively, we




1) Place PTFE filter inside polypropylene container
2) Add 1% nitric-acid solution
3) Expose to ultrasonic vibrations
4) Heat using a heat block

**Figure 4**
**Ultrasound/heat-block/ICP-MS pretreatment.**

analyzed standard substances (NIST Air Particulates on Filter Media: SRM 2783) by using the ultrasound/heat-block/ICP-MS method for five times each. Results showed that the quantitative values obtained for 13 essential elements and 5 recommended elements (of 17 recommended elements) important to analyzing $PM_{2.5}$ sources satisfied the guaranteed values. These results demonstrate that quantitative results obtained by simultaneous multi-element analysis using the ultrasound/heat-block/ICP-MS method have sufficient analysis accuracy.

The development of this method has enabled the acquisition of highly accurate data by using a reliable technique with high reproducibility.[9]

## 5. Future work

Efficient and effective formulation of countermeasures against $PM_{2.5}$ requires expanding the provision of information along the time axis in addition to the efforts made to date in visualization. In particular, ways to obtain real-time information on the components of fine particulate matter must be developed.

At the same time, there is a need to enhance visualization techniques even further by leveraging the information and communications technologies (ICT) and high-performance simulation technologies of the Fujitsu Group. Furthermore, in addition to isolating the sources and causes of pollution through visualization and making improvements by eliminating those factors, we feel that it is also Fujitsu's responsibility to develop and provide to the general public enhanced-quality-of-life solutions including preventive policies through an information technology platform.

## 6. Conclusion

This paper described a pressing issue regarding atmospheric pollution in Japan today—growing anxiety about $PM_{2.5}$ pollution. It described the country's current response to the $PM_{2.5}$ problem, Fujitsu's approach to the problem, and future work. Going forward, we will treat the visualization of atmospheric-pollution information as a top priority through the further development of analysis techniques and the accumulation of more experience and know-how in this field. We will also promote the development of "problem-resolution solutions" for improving the quality of everyone's living environment centered on the ICT of the Fujitsu Group. Additionally, we will continue our efforts to provide value synonymous with Fujitsu as a leading-edge company in addressing new issues associated with the globalization of environmental problems while keeping a close watch on environmental pollution in Japan.

Finally, we would like to take this opportunity to express our deep appreciation to those concerned at the Japan Society for Atmospheric Environment (JSAE) for their extensive technical support and assistance in the activities described in this paper.

## References

1) Ministry of the Environment, Environment Management Bureau: Report on the Committee on Assessment of the Health Effects of Fine Particulate Matter on Public Health. April 4, 2008.
*http://www.env.go.jp/en/headline/file_view.php?serial=234&hou_id=789*
2) Ministry of the Environment: Information on Fine Particulate Matter ($PM_{2.5}$) (in Japanese).
*http://www.env.go.jp/air/osen/pm/info.html*
3) Ministry of the Environment, Environment Management Bureau: Processing Standards for Continuous Monitoring of Environmental Air Quality based on Article 22 of Air Pollution Control Law (in Japanese).
*http://www.env.go.jp/air/osen/law22_kijun/100331001a.pdf*
4) International Agency for Research on Cancer, World Health Organization: PRESS RELEASE No. 221—Outdoor air pollution a leading environmental cause of cancer deaths. 17 October 2013.
*http://www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf*
5) T. Suzuki et al.: Environmental Monitoring System for Map Ta Phut Industrial Estate in Thailand. *Fujitsu Sci. Tech. J.*, Vol. 50, No. 3, pp. 16–23 (2014).
6) N. Shiraishi and N. Yabe: MEMS Project in Saudi Arabia: Global Solution Business Initiative. *Fujitsu Sci. Tech. J.*, Vol. 50, No. 3, pp. 9–15 (2014).
7) Ministry of the Environment, Environment Management Bureau: Manual on Measuring Fine Particulate Matter ($PM_{2.5}$) Components in the Atmosphere. April 2012 (in Japanese).
8) Ministry of the Environment, Environment Management Bureau: Guidelines on Analyzing Fine Particulate Matter ($PM_{2.5}$) Components. July 2011 (in Japanese).
9) K. Saito et al: Quantitative Evaluation of Ultrasound/Heat-Block/ICP-MS Method by NIST Air Particulate Matter on Filter Media, Japan Society for Atmospheric Environment (JSAE). 19th Conference of Hokkaido/Tohoku Section, 2012 (in Japanese).

**Teruhisa Kitani**
*Fujitsu Quality Laboratory Ltd.*
Mr. Kitani is engaged in businesses related to $PM_{2.5}$.

**Masashi Yasuda**
*Fujitsu Quality Laboratory Ltd.*
Mr. Yasuda promotes $PM_{2.5}$-related businesses.

**Shinobu Hosoda**
*Fujitsu Quality Laboratory Environment Center Ltd.*
Mr. Hosoda is engaged in $PM_{2.5}$ sales-related businesses.