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"HERMES-IR"
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A SCIENTIFIC VIEW OF MINAMATA DISEASE

KIKUO MIYOKAWA

Introduction

Opinion poll carried out by NHK in 1992, only one-third of the respondents negatively answered to the question "Over all, modern science does more harm than good" and about a half of the respondents positively answered to "Any change humans cause in nature - no matter how scientific - is likely to make things worse." Optimists who simply believe that science will eventually solve our problems seem to be classified into the endangered species now. There is no wonder that such negative attitude against modern science closely relates to the recent extensive dispute about the degradation of the global environment such as ozone depletion and global warming. Although science is still useful to interpret scientific mechanisms of environmental problems, it appears no longer be able to provide efficient technological solutions. Furthermore, serious industrial pollutions represented by Minamata disease occurred in Kumamoto Prefecture in late 1950s, being one of the favorite topics in Japan's environmental education have definitely fermented the distrust against science (hereafter, "science" is used as a general term to express science, technology and medicine). Recent rapid development of gene engineering composed of genetic recombination and cloning techniques leaving behind serious and extensive discussion about ethical problems could be another factor to incur public's distrust against science.

This report aims to draw lessons from the pathetic experience of the Minamata disease in order to realize sound relation between science and society. The identification process of causal substance until the announcement of the government view on the cause of the disease in 1968 is reviewed in the first half and characteristics of modern science, responsibility of scientists, and communication of scientific knowledge are discussed in the second half.

Minamata Disease

Minamata disease is a severe neurological disorder caused by organic mercury com-

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1 The disease is sometimes referred as Minamata Bay disease.
3 Patients of the disease were also discovered in the Aganogawa basin in Niigata Prefecture in 1965.
4 Typical symptoms of the disease is called as Russell-Hunter syndrome and its acute symptoms are: numbness, unsteadiness in the legs and hands, tiredness, ringing in the ears, narrowing of the fields of vision, loss of hearing, slurred speech, insane, unconsciousness and death. Chronic symptoms are: headaches, frequent tiredness, and loss of senses of smell and taste, and forgetfulness. Congenital patients are also known.
### Table 1. Scientific Events Related to the Identification of the Causal Substance of Minamata Disease

<table>
<thead>
<tr>
<th>Date</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921</td>
<td>Detection of organic mercury compounds (OMC) in hydration process of ethyne (Neuwland et. al.)</td>
</tr>
<tr>
<td>1930</td>
<td>Publication of book dealing with toxicity of OMC (Zangger)</td>
</tr>
<tr>
<td>1954</td>
<td>Publication of paper concerning Hunter-Russell syndrome for poisoning of methylmercury compounds (Hunter and Russell)</td>
</tr>
<tr>
<td>1956/5</td>
<td>First report of the patient to Minamata Health Center (Chisso Minamata Hospital)</td>
</tr>
<tr>
<td>1957/1</td>
<td>Suggestion of poisoning of heavy metal (Mn, Tl, Se) from Chisso's plant (Kumamoto University Medical School, KU)</td>
</tr>
<tr>
<td>1959/7</td>
<td>Identification of OMCs as the causal substance (KU)</td>
</tr>
<tr>
<td>1959/9</td>
<td>Suggestion of unidentified explosives as the causal substance (T. Ohshima)</td>
</tr>
<tr>
<td>1959/10</td>
<td>[Cat No.400] experiment (H. Hosokawa), unpublished results</td>
</tr>
<tr>
<td>1959/10</td>
<td>Objection to KU's report (Minamata Firm, Chisso)</td>
</tr>
<tr>
<td>1960/4</td>
<td>Suggestion of amine compounds as the causal substance (K. Kiyoura)</td>
</tr>
<tr>
<td>1961/4</td>
<td>Suggestion of rotten amine compounds as the causal substance (K. Toda)</td>
</tr>
<tr>
<td>1962/3</td>
<td>Isolation of methylmercury chloride from the drain of Chisso's ethanal plant (S. Ishihara, unpublished results)</td>
</tr>
<tr>
<td>1962/8</td>
<td>Isolation of Methylmercury chloride in the drain from Chisso plant (KU)</td>
</tr>
<tr>
<td>1965/6</td>
<td>Discovery of the patients of Minamata disease in the Aganogawa basin in Niigata Prefecture</td>
</tr>
<tr>
<td>1968/9</td>
<td>Announcement of Government view on the cause of the disease (Confirmation of methylmercury chloride as the causal substance)</td>
</tr>
</tbody>
</table>

**Sources:** All Materials for the Suit of Minamata Disease, Vols. 1 and 2, Nihon-Hyouron-Sha (1998), in Japanese; Collection of Documents on Minamata Disease Incident, Vols. 1 and 2, Ashi-Shobou (1996), in Japanese. 1) Director of Japan Chemical Industry Association. 2) Medical doctor of Minamata hospital attached to Chisso. 3) Professor of Tokyo Institute of Technology. 4) Professor of Toho University. 5) Chisso’s employee.

Porteous explains Minamata disease in his “Dictionary of Environmental Science and Technology” as follows. Minamata is a town on the west coast of Kyushu Island (Japan) where an extreme case of heavy metal poisoning from methyl mercury ingested in the staple fish diet of the inhabitants caused severe disablement and death: 43 deaths and 68 major disablements were recorded between 1953 and 1956. (Environmentalists have claimed that almost 800 people have been killed in all by the discharges) The symptoms include numbness in fingers and lips and difficulty in speech and hearing. There is a marked inability to control limbs, followed by seizures. Children and old people are particularly vulnerable, as is the case with all heavy-metals ingestion. The source of mercury in the bay was eventually traced to a PVC plant that used mercuric sulfate (an inorganic chemical) as a CATALYST and which discharged effluent containing both inorganic and organic mercury. The inorganic form was subsequently converted by marine life to the methyl form. Japan’s supreme court ruled in

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5 General term for the compounds containing mercury-carbon chemical bond. Toxicity and behavior in the environment vary depending on their composition and chemical structure.


7 Polyvinyl chloride plant; author mistook ethanal (acetaldehyde) plant for PVC plant.

8 Methylmercury compounds in Minamata Bay may be composed of those discharged directly to the bay by Chisso and yielded from inorganic mercury compounds by the bacterial action. The ratio of methylmercury compounds with different origins is still unknown.
March 1989 that two former executives of a chemical firm were responsible for the mercury pollution in the 1950s. Each received two year’s imprisonment. The Minamata Disease Center says there are 18,128 victims still waiting to be formally acknowledged as Minamata patients. Minamata is now a classic case of industrial pollution and subsequent evasion of responsibility.

Now no one suspects the disease was caused by intake of methyl mercury compounds but it was a long and winding way to the settlement of scientific dispute. Table 1 shows major scientific events in the process to identify the cause of the disease until 1968. By the middle of 1930s, it had been known that organic mercury compounds are produced in the hydration of ethyne (acetylene) catalyzed by inorganic mercury compound9 and their intake causes neurological disorder.10 Two years before the first report of the outbreak of Minamata disease in 1956, Hunter and Russell published the paper dealing with symptoms for the poisoning of methylmercury compounds.11 In 1957, a group of medical doctors of Kumamoto University (hereafter, this group is abbreviated as KU) suggested that symptoms of the patients resemble those of poisoning with heavy metals (manganese, thallium or selenium), but later they corrected the causal substance of the disease from the heavy metals to organic mercury compounds in seafood in 1959.12 However, the scientists of Chisso,13 the chemical firm being suspected to discharge the effluent contaminated by organic mercury compounds to Minamata Bay, and its supporters strongly opposed to the conclusion of KU. Particularly non-mercury hypothesis of Dr. Kiyoura of Tokyo Institute of Technology14 was treated as the strongest objection in the media. He was an active member of the research committees of Minamata disease sponsored by government and Japan Chemical Industry Association. These committees are composed of prominent professors of medicine, science and engineering. Non-mercury hypothesis was further reinforced with medical data by Prof. Toda, and then “rotted amine compounds” were proposed as the causal substances. Although methylmercury chloride was isolated from the drain of acetic acid plant of Minamata firm in 1962,15 it took twelve years to confirm the cause of the disease. From the inspection of the process described above, (i) Limit of scientific knowledge, (ii) Responsibility of scientist and (iii) Transmission of scientific information emerge as the focal points of discussion.

Limits of Scientific Knowledge

The key word “scientific” frequently appeared in the documents of Chisso and its

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13 Until 1965, company’s name was Shin-Nippon-Chisso-Hiryo K.K.
14 His major research field was catalyst chemistry. Surprisingly, even after settlement of scientific dispute on Minamata disease he was treated in the media as an expert of industrial pollution.
supporters. Why did they believe that “to be scientific” was a strong weapon against the opponent?

The conclusion of KU was mainly based on the following observations:16

1. Resemblance of symptoms of the patients of the disease to those of organic mercury poisoning,
2. Higher mercury contents of the internal organs (brain, liver, kidney) and urine of the patients than reference, and
3. Growth rate of the patients in parallel with the change in the output of acetic acid products.

However, they could not point out the specific organic mercury compounds as the causal substance and suggested unknown process for the conversion of inorganic (catalysis) to organic mercury.17 In order to prove scientifically that organic mercury compounds caused the disease, indispensable were the specification of the causal substance and its formation process. Consequently, Chisso’s scientist and its supporters immediately objected to KU's conclusion seizing upon the weak points of the research. T. Ohshima, the then Director of Japan Chemical Industry Association, proposed explosives for presumptive causal substance,18 while questioning KU's conclusion from the “scientific” point of view.19 Points of his objection were:

1. Failure of reproduction of the disease to cats by feeding food mixed with fish raised in a tank containing sludge of Minamata Bay, and
2. No proper explanation for the time and site specificity of outbreak of the disease.

As Minamana firm started the operation of acetic acid plant20 using inorganic mercury in 1930s and there were several other places where other chemical firms operated similar plant, it seems legitimate to ask why at only Minamata and then. However, it was practically impossible to answer to such questions since it requires, at least, complete understanding of biogeochemical cycle of mercury compounds in Minamata Bay and such research would be time- and budget-consuming project. Furthermore, even the failure to track the suspected mercury compounds from the Chisso’s plant to the patient (Fig. 1) does not necessarily lead to the denial of the effluent as the causes the disease, since possibility of (i) improper assumption, (ii) presence of unknown elemental process, or (iii) presence of undetected mercury compounds21 cannot be excluded. Under these circumstances, persistence to be “scientific” merely meant obstacles for taking prompt measures for the pollution control of Minamana Bay.

As the objection to KU's conclusion, non-mercury hypothesis of Prof. Kiyoura appeared more persuasive than that of Ohshima as it was decorated with “scientific” data. His inference

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16 op.cit. footnote 12.
17 A change of inorganic to organic mercury in the hydration of ethyne seems not to be known commonly in spite that the article (Neuwland et. al.) appeared in the prestigious journal. Polarographic study of catalytic behavior of mercury in the hydration process by Chisso’s employee (T. Igarashi, Catalysis, 4, 234-247, 1962, in Japanese) suggested the formation of organic mercury compounds as the intermediate but not the final products.
18 It was rumored that Japanese Imperial Army discarded explosives in Minamata Bay
20 Acetic acid is synthesized in this plant by the oxidation of ethanol obtained by the hydration of ethyne using inorganic mercury compounds as a catalyst.
21 Methods to identify mercury compounds of different chemical forms were not established then.
FIG. 1  PRESUMPTIVE FLOW OF THE CAUSAL SUBSTANCE FROM CHISSO PLANT TO PATIENTS

IMCs: Inorganic mercury compounds
OMCs: Organic mercury compounds

Minamata Bay
Plankton
Biological concentration

(B) Discharge

Seawater (D)

Soil (C)

Fish, Shells (E)

Elemental Processes: (A) Mechanism of formation of OMCs and their yield, (B) Concentration of OMCs in the effluent (C) Distribution of OMCs between soil and see water, (D) Biological concentration of OMCs (food web), and (E) Concentration of OMCs in fish/shells and patients.

was based on the following observations:\textsuperscript{22}

(1) The mercury concentrations of see water of Minamata and other bays of southern Kyushu were of the same order and those of the effluents from the factory is rather lower compared with those of other factories manufacturing similar products.

(2) Digesting hydrogen chloride solution (pH = 2 \sim 3) that induced pathological change similar to that of Minamata disease did not practically contain mercury but ninhydrine-positive diamine compounds.\textsuperscript{23}

His research was far from the refutation against KU’s conclusion. He did not pointed out the specific diamine compounds as the causal substance and the description of the pathological changes was quite obscure. He discussed only about water pollution of Minamata Bay by the ordinary substance including mercury. Furthermore, without any justifiable reasons, he excluded completely the possibility of the existence of extremely toxic mercury compounds like methylmercury chloride.\textsuperscript{24} After describing extreme toxicity of the unidentified causal substance, he innocently stated, “Present toxicology does not supply any examples of such poisonous oregano-mercuric compounds.” If he took KU’s research seriously and examined intensively the pollution by organic mercury compounds, his conclusion must have been quite different one. This is a typical example of that how scientist’s preconception distorts research and leads to conclusion far from the truth.

Modern science is composed of laboratory and field sciences and their characteristics are shown in Table 2. The most outstanding feature of modern science is its systematic use of

\textsuperscript{22} R. Kiyoura, Int. J. Wat. Poll., 7, 459-470 (1963). This paper is singular as a scientific paper since it did not describe the analytical method of mercury and include any references.

\textsuperscript{23} Doubtlessly he made mistakes in his research since it was confirmed later that the methylmercury chloride was digested into aqueous solution of pH = 1.5 \sim 2.0.

\textsuperscript{24} Methylmercury chloride (MMC) is quite toxic. Its lethal dose for human is estimated to be 4mg/kg. Threshold value for onset of the symptoms is 0.2-0.4 ppm of MMC in blood (IPCS Environmental Health Criteria, No. 101 Methylmercury).
TABLE 2. COMPARISON OF LABORATORY AND FIELD SCIENCES

<table>
<thead>
<tr>
<th>Item</th>
<th>Laboratory Science</th>
<th>Field Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research subject</td>
<td>Elemental Process</td>
<td>Complex system</td>
</tr>
<tr>
<td>Environment</td>
<td>Controllable</td>
<td>Non-controllable</td>
</tr>
<tr>
<td>Major research method</td>
<td>Experiment</td>
<td>Observation Simulation</td>
</tr>
<tr>
<td>Description</td>
<td>Quantitative</td>
<td>Qualitative</td>
</tr>
<tr>
<td>Output</td>
<td>Theory, Law</td>
<td>Hypothesis</td>
</tr>
</tbody>
</table>

experiment. In laboratory science, the causal connections of the selected constituent parts of a particular system are studied by means of experiments (reductionism) and the results are usually expressed in the form of mathematical relations of experimental parameters. Scientific theories are derived so as to explain completely such relations. Experiment is also used to test and confirm the postulated theories. Laboratory science has succeeded in rational interpretation of natural phenomena and enriched our knowledge about nature when compared with other knowledge-seeking traditions so far. Furthermore, scientific knowledge that has been experimentally tested can immediately be applied to technology. It is composed of the same series of physical and/or chemical actions as experiment, but with different intentions.25

Laboratory science, however, has an intrinsic weak point when it comes to deal with time dependent phenomena. In laboratory, scientist can manipulate experimental conditions like temperature, pressure, and concentration, except for time. It is impossible to artificially expand or contract “time” in the ordinary experiments.26 Hence, subjects of laboratory science are limited to changes occurring within a certain range of time. Prediction of future change is usually accompanied by uncertainty to some extent as it is obtained by merely extrapolating of observed change. Such phrases as “Stable for thirty years” and “No color change for a hundred years” are not based on the experimentally verified facts.

Field science deals with natural phenomena occurring in complex systems. Behavior of complex systems is often unexpected based on knowledge of their components when system’s interaction with its environment cannot be neglected or the internal organization of the system is exceedingly complex. Evidently, systems that interact strongly with their environment cannot be explained with recourse to their component parts alone and reductionism may reach practically, or even principle, limits in these systems.27 As mathematical model of complex system shows, subtle change of the initial conditions often results in a drastic change in the equilibrium (final) structure of the system. Complex behavior of the system makes it impossible to express changes in quantitative manner and makes it difficult to interpret natural phenomena using scientific theories. Experiment only provides information about interrelation of the limited elements of complex system. Scientists have not invented proper tools to study complex system to which belong most of natural phenomena associated with current environmental issues.

Experiment is essentially impossible in geology and astronomy because changes occur at extremely slow rate and in extremely large scale. In these sciences, observation and computer

26 Particle physics is an exception.
27 *op.cit.* footnote 25.
TABLE 3. FEATURE OF IRRESPONSIBLE SCIENTISTS

<table>
<thead>
<tr>
<th>Type</th>
<th>Symptom</th>
<th>Cure</th>
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<tbody>
<tr>
<td>Power Elite</td>
<td>a) Refusal of criticism</td>
<td>a) Public review of</td>
</tr>
<tr>
<td></td>
<td>b) Refusal to admit their mistakes</td>
<td>i) Selection of members</td>
</tr>
<tr>
<td></td>
<td>c) Secretive</td>
<td>ii) Discussion in the committee</td>
</tr>
<tr>
<td>Company</td>
<td>a) Overconfidence to technology</td>
<td>a) Independence of scientist from company</td>
</tr>
<tr>
<td></td>
<td>b) Arrogance as a specialist</td>
<td>b) Social support for accusers</td>
</tr>
<tr>
<td></td>
<td>c) Precedence of company's interest</td>
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</table>

Simulation using mathematical model of system are ordinary methods for research.

Let's consider the following imaginary case: a new chemical plant started its operation ten years ago and now the residents of the peripheral zone start to complain of their physical disorder. Several chemicals have been emitted from the plant but their concentrations are far below threshold value to any kind of known disease. Even the most advanced science can provide little information about the chronic and synergetic biological effect caused by intake of chemical substance. Neither "Polluter Pay Principle" nor "Precaution Principle" is applicable to this type of pollution, if the cause is not clarified scientifically. What should we do then? Solution is imposed on the society, but not on science.

Tremendous success of modern science in the last century is apt to cultivate blind belief to science but it should be remember that our scientific knowledge is still limited and there remains vast unrevealed world to be explored. In other word, science is not almighty. Persistent to be scientific when we face unprecedented situation may result in irrevocable mistake, as scientific research needs long and patient work to reach conclusion.

Responsibility of Scientists

"Scientists are, because of their special knowledge, well equipped for early awareness of the danger and the promise arising from scientific discoveries. Hence, they have a special competence and a special responsibility in relation to the most pressing problems of our times." (Extract from Statement of the Third Pugwash Conference, Kitzbühel, 1958.) M. Harada, a prominent environmentalist devoted much of his career for the relief of Minamata patients discussed about the responsibility of professionals. He described the irresponsibility of two types of professionals: power elite committing to policy-making and company employee. His diagnosis of symptoms and prescription for irresponsible scientists are summarized in Table 3.

Important experiments that would, if made public, settled the dispute much earlier, Cat No. 400 experiments and isolation of organic mercury compounds in the plant drain were carried out by Chisso's scientists and were kept secret for a long time. There seems no excuse for being criticized for their lack of the consciousness as scientist, but it is the defect of the managing system of the company rather than the character of individual scientists. Inherent

29 Cat No. 400 fed with the drain of Chisso plant showed typical symptoms of Minamata disease from Testimony of H. Hosokawa in the trial of Kumamoto Minamata disease (1970).
30 The decision of the case of Kumamoto Minamata disease (Kumamoto District Court, 1973)
rights of scientist (freedom for the selection of research subject and for the publication of results) are restricted for the scientists belonging to private companies. And even worse in Japan it is not easy for occupational scientist to stand his (her) ground (professional obligations) when they are confronted with difficulty because it requires to be ready for paying a fairly high personal cost. On the other hand, Prof. Kiyoura’s case should be discussed from different point of view. As the university professor of chemical engineering, he had been at the position to be able to look squarely at the reality. What he had done seems to have merely intended to help Chisso to escape from its difficult situation. If it is true, he must have given priority to the interests of chemical industry over his professional obligations. It reflects the undesirable side of “university-industry cooperation”, which is now the key word in the argument on the university’s role in our society. To realize desirable “university-industry cooperation” and prevent recurring of serious scientific accidents, education of future scientists is important; however, Japan’s graduate schools of science and engineering seem to pay little attention to the education of professional obligations. Serious scientific incidents, AIDS infection of hemophiliacs,31 JCO,32 and Monju33 caused by the scientists of no sense of responsibility are still vivid in our memory.

Unenthusiastic or indifference of Japan’s scientists could be an indirect reason for the delay of settlement of the dispute. In spite that the suspects were organic mercury compounds, their discussion about causal substance was based mainly on the analytical data of the total mercury contents34 in the environment, fish, and the patients.35 When appropriate analytical methods for respective mercury compounds of different chemical forms did not exist then,36 scientists (specially analytical chemists) should have endeavored to develop proper analytical method. Now volatile organic mercury compounds can be determined precisely and separately by means of gas chromatography equipped with electron capture detector. First report for the determination of organic mercury compounds using gas chromatography by the foreign scientists appeared in 1961.37

**Communication of Scientific Information**

“We have arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while,

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31 Many hemophiliacs were infected with AIDS virus as they took medicine prescribed by medical doctors. A doctor and a high-ranking official were prosecuted for their professional negligence.
32 Outbreak of chain reaction of induced nuclear fission of uranium 235 by illegal operation in JCO (1999). Executives were prosecuted for their professional negligence.
33 Accidental leakage of liquid sodium in the primary cooling system of Fast Breeder Reactor “Monju”. Company sent a false report of the accident to the authority (1997).
34 It represents sum of inorganic and organic mercury contents.
36 Calorimetric (dithizone as color-producing reagent) and atomic absorption spectroscopic determinations of mercury had already been established by the late 50’s, but those methods were applicable only to the determination of total mercury content.
but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.” Carl Sagan, late American astrophysicist described concisely the existing undeniable gap between science and society. A closer look at this gap reveals that it can be described as a communication problem between science and society on the one hand and science and the media on the other. Furthermore, the opinion poll about “Consciousness and Behavior of Consumers Concerning Global Environmental Issues,” carried out in 1998, about ninety percents of the respondents chose mass media (TV, radio, newspaper and magazine) as the impressive media for environmental issues.” Now mass media play key role to develop public opinion about environmental issues.

Results of scientific research are usually published in the scientific journals after strict peer review and they circulate within the scientist society. Occasionally some results that bear social significance are transmitted to the public through mass media or are used to justify government’s industrial policies. In this process, scientific information is sometimes distorted, either deliberately or unconsciously to the advantage of mediator and Minamata’s case is a typical example of the miss-communication of scientific information by the media. From the scientific points of view then and now, the difference in the quality of the researches carried out by KU and its opponents are obvious, though both were incomplete. The subject of the former research was the patient and that of the latter was seawater and fish.

It is hard to deny that media caused the delay of prompt implementation of anti-pollution measures to expand the damage by treating non-mercury hypothesis as if it were important. What caused this “media’s failure” is not clear now, but it might arise from easy dependence on “authority” by the journalists who do not understand the context of science. No matter how neutrality of press is important, media should cover the scientific aspects of environmental issue with scrupulous care as it deals with problem of “truth or false,” sometimes directly related to the life of victims.

For the relevant communication of scientific knowledge, we need good interpreters with excellent scientific background to explain correctly scientific information in plain terms; in other words, tailoring a scientific message to suit the media, without compromising the quality of message. Moreover, the receptor of information is required to have adequate science literacy i.e. capability of understanding what signifies the given scientific information and of looking at science and technology from critical stand. Current Japan’s science education at secondary education level is not appropriate to cultivate science literacy of the students since it places disproportionate emphasis on knowledge-transmission and preparation for awaiting entrance examinations. This system seems to make vast majority of students lose interest in science and they are likely to freeze when they face to the flood of scientific information.

Importance of science education has been emphasized repeatedly in international conferences

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41 Other type of miss-communication occurs when important presumptions of researches were neglected. Typical examples are the safety of radioactivity and environmental burden of nuclear power plants.
whose agenda were the relation of science and society and it become more important as we face with the new era of "environment" and "gene engineering". Comprehension of science by public, it is the only way to guarantee the long-term health and vitality of science enterprise and the conduct of science for the public good.44

With respect to the role of scientists, Cataparo concluded his paper with the following paragraph. "The scientific community’s awareness of the importance of communicating with the public and of its role in bridging the gap is a very important change that has occurred in the last five years. However, reaching a widespread awareness among scientists is only half of the work. A quantum jump in the quality of the communication made by scientists is needed. Communicating science to a non-knowledgeable public means translating ideas and concepts that are often extremely complex and distant from common sense into a comprehensible language and creating interest in the public without betraying the scientific truth."45

GRADUATE SCHOOL OF SOCIAL SCIENCES, HITOTSUBASHI UNIVERSITY

SUMMARY

In this paper, the author reviewed the process to identify the causal substance of Minamata disease and discussed on the limit of scientific knowledge, responsibility of scientist, and communication of scientific information. The points of discussion are summarized as:

(1) Recognition of limit of our scientific knowledge about time-dependent phenomena and changes occurring in complex systems. As for the current environmental issues, chronic and synergetic effects of chemical substance to human health are urgent topics to be studied extensively.

(2) Independence of scientists from interest of organization and awareness of social responsibility of scientists. It requires strict attitude of society to the misconducts of scientist and education of responsibility to the future scientist.

(3) Correct understanding of scientific information by public. It requires training for good interpreters and cultivation of scientific literacy of public. Public review for science and technology warrants their progress for public good and is necessary to avoid "technology assessment" for the professionals by the professionals.

ACKNOWLEDGEMENT

Author wishes to express sincere thanks to Ms. S. Ozaki of Yokohama National University for her assistance in collecting reprints of papers published in 1960s and valuable discussion about Minamata disease.

45 op.cit. footnote 39.