〈総　　説〉

The Role of Risk Analysis and Risk Management in Public Water Supply in Japan

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The service ratio of public water supply in Japan has reached 95 % of the total population, but the circumstances surrounding water supply are not so peaceful. The changes in raw water quality revealed the limited capability of the traditional and conventional water purification system. Potentially hazardous chemicals are found in the ambient waters and raw waters for public water supply, because the regulation concerning their discharge into the ambient waters is not sufficient.

The government has not yet introduced a health risk management system in the field of environmental management including water supply. Since people are not informed of the magnitude of the health risk associated with such substances, they only feel anxious and the public water supply loses their reliance. Therefore, the authors consider that the introduction of the health risk assessment and management is an urgent task for the continuous development of the public water supply. But it is very difficult to achieve a rational and quantitative health risk assessment and management with limited data and resources.

The health risk assessment and management is not matured in Japan, but the Ministry of Health and Welfare has introduced its concept in the development of the guidelines on the advanced water purification system and the amendment of the drinking water quality standards. The authors consider that the first application of the health risk assessment and management in public water supply system would be a very effective tool to facilitate the communication between consumers and public water supply authorities for the continuous development of the public water supply system.

Key Words water supply, hazardous chemicals, risk assessment, risk management, water quality standards

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INTRODUCTION

The service ratio of public water supply in Japan has reached 95 % of the total population, and, as the result, most of people in Japan can access clean and palatable water [1]. However, the circumstances surrounding the public water supply are not so peaceful. There is a social climate of decreasing public reliance on the public water supply system so that people buy six million sets of home tap water purifiers in recent years and 250 million liters of bottled water a year. Such a social climate becomes stronger year by year.

The public water supply system can provide us with a requested amount of water by a single water pipe wherever and whenever necessary, and it brings a lot of benefits to the people as well as the

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community concerned. The public water supply system is managed in principle, by water charge as the price of benefits brought by the system. The benefits are quite different according to the purpose of water use. Therefore, if the public water supply system can not bring various kinds of benefits to the people and community at the same time, its significance as a social infrastructure may be diminished.

The Japanese modern public water supply system started in Yokohama city applying British water works technology about 100 years ago. Before that, there were traditional public water supply systems in many large cities. The purpose of either traditional and modern public water supply system was to provide a community with hygienic water by transmitting the water taken from isolated areas. By doing so, the community could recognized the benefits of hygienic water in controlling enteritis and other pathogenic diseases. The public water supply system also provided a community with fire-fighting water. There were a limited number of large cities, and their water demand was not so large until the industrialization started. Consequently, the public water supply systems established in the era could provide safe and clean water only by constructing the transmission facilities from a water source to the community, and water quality management technology as well as water treatment technology was far behind from water transmission technology. Actually, the continuous chlorination was not practiced in every public water supply until an order of the General Head Quarters of the Occupation Force was issued in 1945.

The new Constitution of Japan, so called the peace constitution, declared the promotion of public health for all, and the government set a national policy to develop public water supply systems not only in urban but in rural areas. Then the public water supply service ratio has sharply increased from 35 % in 1955 to 95 % in 1990.

PROBLEMS IN PUBLIC WATER SUPPLY MANAGEMENT

Along with the industrialization of Japan, the water demand increased very much. A couple of decades ago, there was a big difference of water consumption between urban and rural areas. However, in these days, there is no significant difference between them, and the maximum water consumption is about 500 liters per capita per day. Water supplied by the public water supply system is used not only for conventional domestic and commercial purposes but also for another purpose of cooling in cold-chain food market as well as in information sector, i.e. cooling computers directly or indirectly.

The total water consumption through the public water supply system increased up to sixteen billion cubic meters a year because of increases of the service ratio of public water supply and per capita water consumption as well as increase of the total population. The industrialization also caused increase of industrial water demand up to about fifteen billion cubic meters a year. Since the water resource had been originally allocated so as to put a priority on the traditional water use sector of agricultural irrigation, the public and industrial water supply sectors had to develop water resource management facilities such as dams and river-mouth salt barriers in order to effectively use surface waters, that would be otherwise discharged to the sea during the storm season, and to meet their ever increasing demand. As shown in Figure 1, the proportion of raw water originating from dams and reservoirs is going to overwhelm that originating from rivers [1]. And, even if a dam or reservoir was constructed, the transmission facilities were not provided. The main reasons were shortage of budget for construction of the long transmission facilities and also difficulties in water resource management among the sectors concerned. Even in some areas, where ground water resources could be

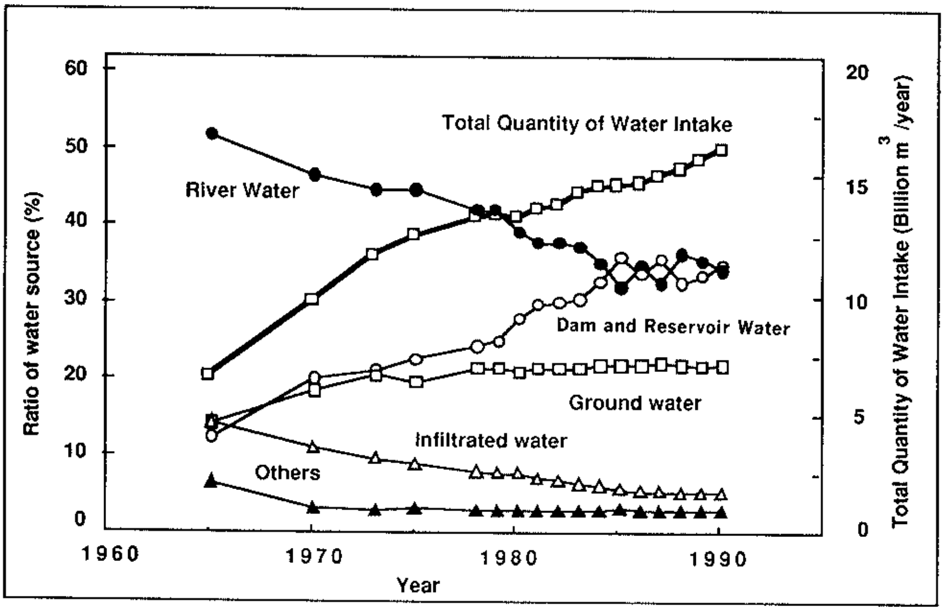

Figure 1. Trends of total quantity of water intake and the proportion of each type of raw water source to total intake

further developed, the utilization of ground waters was restricted for the reason of preventing land subsidence. Nevertheless, the Japanese public water supply sector endeavored to meet the water demand by development of dams and reservoirs throughout the country and in bringing great benefits to the communities.

The development of dams and reservoirs has changed the properties of raw water for public water supply. The changes in raw water quality revealed the limited capabilities of the traditional and conventional water purification system composed of the separation process for removing silt and inorganic colloids and the disinfection process for disinfection of pathogenic microorganisms.

Since the Japanese islands are located in a subtropical and temperate region, algal growth potential in stagnant water bodies is originally high. According to the development of industry, agriculture and tourism, water resource development was enhanced in isolated areas. Eutrophication of dams and reservoirs is observed throughout the country. In stagnant water bodies, the amount of inorganic turbid substances is reduced by sedimentation, and the properties of the turbid substances changes from inorganic to organic. For example, most populated areas such as Tokyo and Osaka metropolises, located downstream of rivers, do not have their own long transmission facilities for public water supply. Therefore, the raw water quality of those water supply systems is directly affected by eutrophication of dams and reservoirs. Actually the quality of the drinking waters for consumption of twenty million people is deteriorated by the offensive odor caused by algae. In addition, many water works are troubled with interference of coagulation and filtration processes by algae and their metabolites resulting in decrease of the production capacity to less than the designed value.

According to the increase of water consumption, the volume of domestic and industrial waste waters and the amount of pollutants in the waste waters discharged to the ambient water bodies have increased. Sanitary treatment of domestic waste waters is managed properly, but it can not be anticipated to remove algal nutrients, i.e. nitrogen and phosphorous, as well as hard-biodegradable organic substances including synthetic chemicals. In order to conserve the ambient water bodies utilized for public water supply, agricultural irrigation and other purposes, the Ambient Water Quality Standards and other related regulations for control of chemicals and pesticides have been established. But many potentially hazardous pollutants, that are not regulated by the environmental or drinking water quality standards, have been detected not only in raw water but also in tap water of public water supply systems.

The regulatory agency responsible for public water supply has to take necessary actions so as to identify the health risk of tap water, and, if necessary, to reduce the risk through improvement of the quality. Although, the health risk assessment and management are not common in various sectors in Japan, the Japanese Ministry of Health and Welfare has introduced the concept of risk assessment and management into the amendment of the existing drinking water quality standards.

REGULATORY SYSTEM FOR CONTROL OF PESTICIDES

Since Japan has such characteristics as limited arable land area, insufficient labor force and temperate climate with a plenty of rainfall favoring outburst of pests, the use of pesticides is inevitable for promotion of agricultural activity and stable foodstuffs supply. On the other hand, the application of pesticides in agricultural activity increases the potential of health risk caused by the toxicity of residual pesticides in agricultural products as well as discharge of pesticides into the ambient water bodies. Therefore, it is necessary to assure a wide range of safety towards protection of pesticides users, environmental pollution control and residual toxicity control in agricultural products. The Agricultural Chemicals Regulation Law and the Food Sanitation Law have been enacted to cope with the issues above mentioned. The system of registration, supervision and control of agricultural chemicals by these laws is shown in Figure 2.

The Agricultural Chemicals Regulation Law aims at the optimization of the quality of agricultural chemicals and their proper use under the registration system for achievement of stable agricultural production and conservation of the living environment.

The control of pesticides by the Agricultural Chemicals Regulation Law is divided into two steps, namely: the first step to check an agricultural chemical before its registration so that any suspicious pesticides, likely to cause a problem, e.g. serious environmental pollution, will not be used and the second step to supervise and control the use and trade of an agricultural chemical after its registration for ensuring its proper use.

When applying for registration of an agricultural chemical, the following data are requested: the data of toxicity such as (1) acute toxicity data on more than two species of animals, (2) chronic toxicity test data on more than two species of animals, (3) generation test data including reproduction teratogenicity tests, (4) mutagenicity test data and (5) any other necessary toxicity data to human and animals. Other data on acute toxicity to carp and water fleas, persistence in crops, persistence in soil showing a half life, the effectiveness and the phytotoxicity of chemicals, and the fate and life in the environment are also requested to be included in the application documents.

The application documents on an agricultural chemical is examined by the Ministry of Agriculture, Foresty and Fisheries, but the standards for the evaluation and examination is established by the Environment Agency. If an agricultural chemical, due to its high residual concentration level in crops, fails to comply with the food standards according to

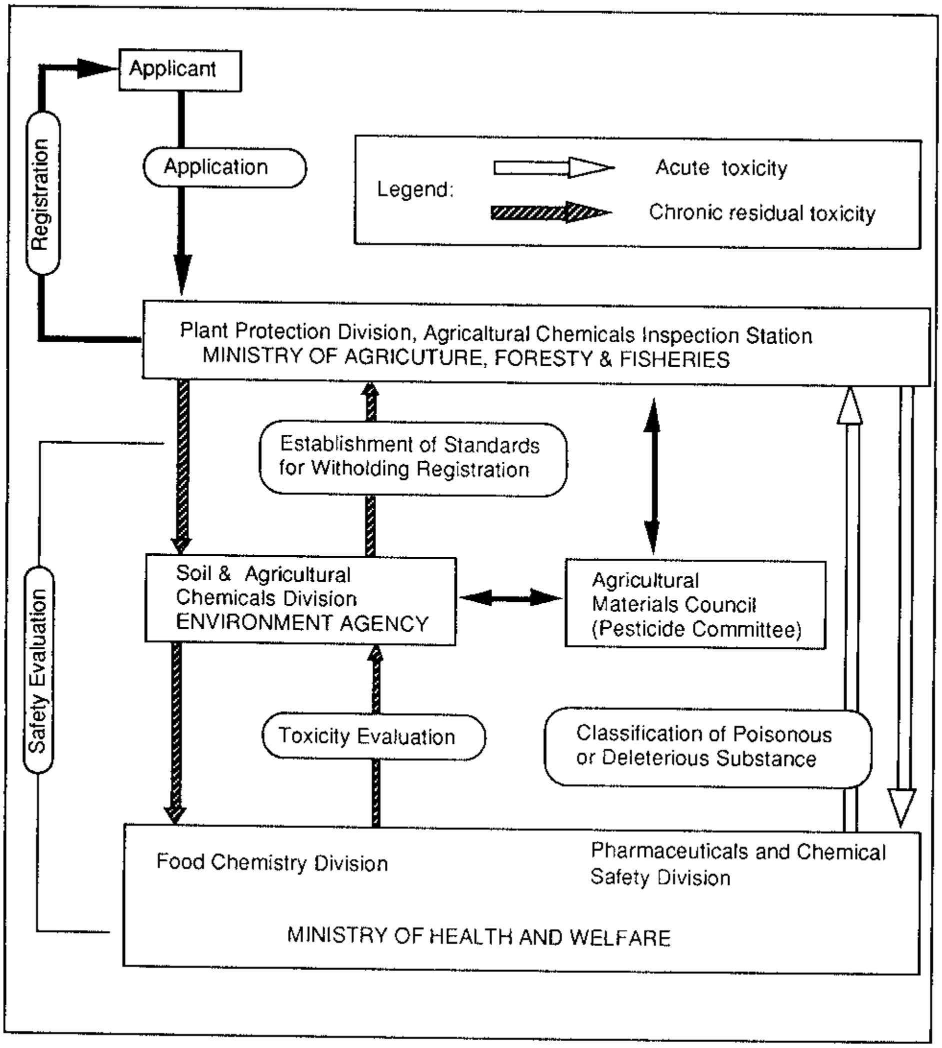

Figure 2. The system of registration, supervision and control of agricultural chemicals in japan

the Food Sanitation Law or the standards established by the Environment Agency whose examples are shown in Table 1, or it is concentrated in livestock through cattle feed, its registration will be withheld. Thus the manufacture and import of such agricultural chemicals is strictly controlled.

An agricultural chemical, once registered passing various checks as above mentioned, is specified with an indication on the manner of its proper application so as not to induce an unexpected effect to human health, livestock and the environment through its too extensive and incorrect application. The manufacturer should also report on its trade and the result of spot inspections to the Agency. By the end of March 1990, the Ministry of Health and Welfare established the food standards only for 26 pesticide, and the Environment Agency established the standards for 232 pesticides. In contrast, the number of proprietary pesticides and herbicides is about 6300.

Table 1. Examples of the residual agricultural chemical standard in agricultural products

Pesticide	Crop	Standard(ppm)
3-(3,4-dichlorophenyl)-1,1-dimethyl urea (or DCMU, Diuron)	Rice	0.05
	Wheat and cereal	0.05
	Fruit	0.05
	Vegetable	0.05
	Taro and potato	0.05
	Pulse	0.05
	Sugar cane	0.05
	Tea	1.00
2-isopropoxiphenyl N-meth carbamate (or PHC, Propoxisul)	Rice	1.00
	Wheat and cereal	0.50
	Fruit	1.00
	Vegetable	2.00
	Taro and potato	0.50

REGULATORY SYSTEM FOR OTHER HAZARDOUS CHEMICALS

Chemical substances are also controlled by the Law Concerning the Examination and Regulation on Manufacture etc. of Chemical Substances (the Chemical Substances Regulation Law) having a control system similar to the Agricultural Chemicals Regulation Law as above mentioned. Anyone who intends to manufacture or import a new chemical substance must submit, prior to commencement of the business, a notification to both the Ministry of Health and Welfare and the Ministry of International Trade and Industry to let the substance be subject to the pre-examination, and, based on the results, the government makes judgement whether the new chemical substance has hazardous properties or is safe, as shown in Figure 3.

If an applied chemical substance is identified to be difficult to decompose through a natural process by microorganisms, easily accumulated in living bodies, and hazardous, it is specified as a Category I Specified Chemical Substance that is restricted in its production and import for commercial purposes. If an applied chemical is identified to have low bioaccumulation characteristics but not to be biodegradable and it is suspected of chronic toxicity, it is designated as a Designated Chemical Substance whose manufacture and import should be reported to the related Agencies. Afterwards, if the additional test of a Designated Chemical Substance according to the instruction by the related Agencies shows the possibility of an adverse health effect through dispersion in the environment, it is specified as a Category II Specified Chemical Substance that is restricted in its production and import in its volume of handling as well as in its use. A chemical substance authorized as a safe substance can be manufactured and imported freely.

According to the Agricultural Chemicals Regulation Law and the Chemical Substances Regulation Law, hazardous chemicals such as the Specified Chemical Substances are controlled at a pre-manufacturing stage. In addition, since those chemical substances are strictly controlled by the Environmental Quality Standards as well as the Effluent Quality Standards, they are not found in raw waters for public water supply. Therefore it is considered that the health risk related with those hazardous chemicals is managed satisfactory in Japan.

Regarding potentially hazardous chemicals such as registered pesticides and herbicides, the Agricultural Chemicals Regulation Law requires them to be applied to agricultural fields in the authorized way. So long as the law is strictly observed, it is expected that the human uptake of the chemicals through

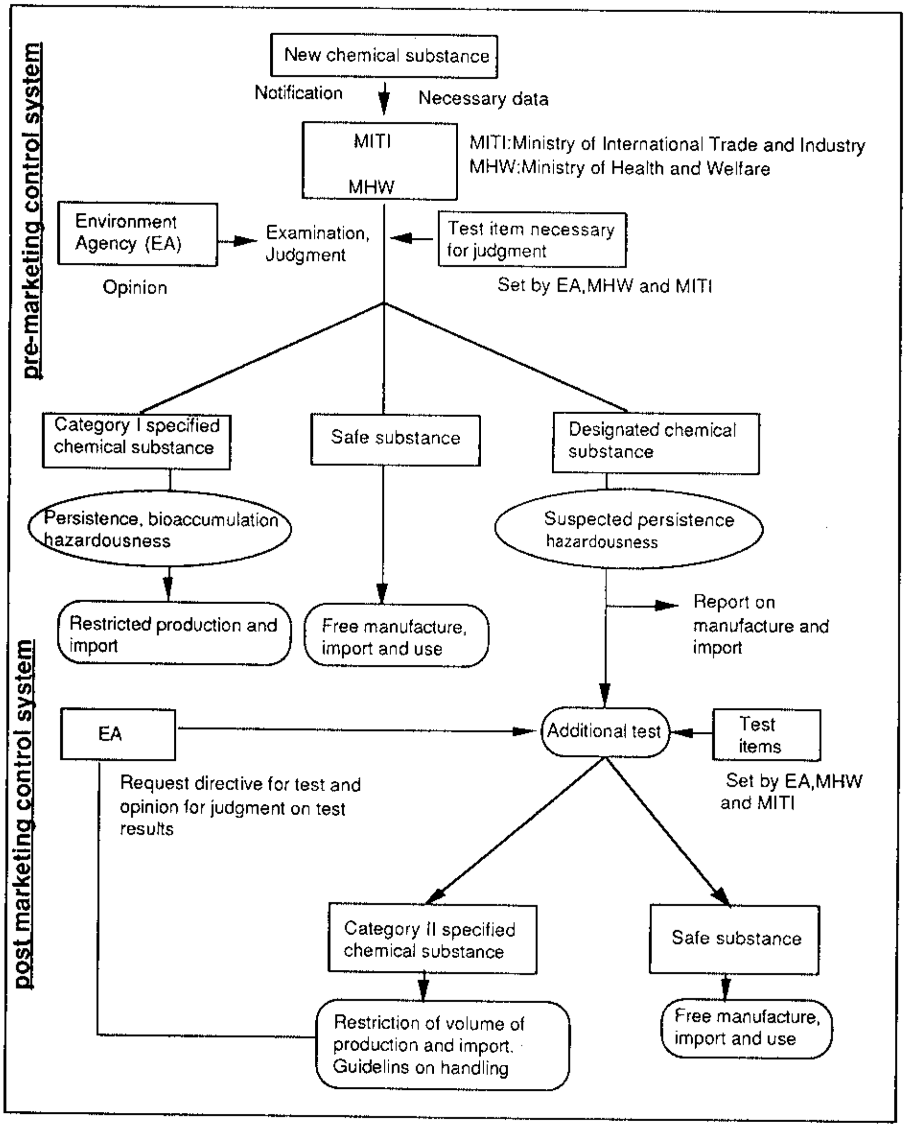

Figure 3. General procedure of chemical substance control system according to the Law Concerning the Examination and Regulation of Manufacture etc, of Chemical Substances

crop consumption may not exceed their ADI values or no adverse effect of the chemicals may not be given to the aquatic ecosystem. In Japan, the ADI values of agricultural chemicals are determined by the Ministry of Health and Walfare using the toxicity data prepared by the manufacturers. However, some of the registered agricultural chemicals can be found in the ambient waters and raw waters for public water supply, because the regulation concerning the effluent discharge into the public water bodies dose not satisfactorily cover all of them.

Thus, the occurrence of potentially hazardous chemical substances in raw waters is unavoidable in Japan. Actually on the occasion of their evaluation according to the related laws, no attention is paid to their occurrence in drinking waters. Therefore, people show concern only about the health risk of chemical substances in drinking water.

RISK ASSESSMENT AND MANAGEMENT IN PUBLIC WATER SUPPLY

Japan has experienced the serious health damages such as Minamata disease caused by organic mercury and the respiratory disease caused by air pollution about 30 years ago when the environmental pollution control was not so effective as today. A conceptual classification of environmental problems relating to health effect is illustrated in Figure 4 (2). In order to prevent such typical health damages caused by serious environmental pollution, the environmental pollution control system was established in 1970's referring to the occupational exposure control system. Since then, the government continued to focus its attention on the control of the typical environmental exposure to hazardous substances. As the result, the incidence of a new environmental pollution problem causing serious health effect has not been reported for a long time. However, it is important today to pay much more attention than before to the ordinary environmental exposure to a very wide variety of potentially hazardous substances commonly used and dispersed into the environment.

The government has not yet introduced a health risk management system in the environmental management including public water supply system. In the public water supply sector, a routine monitoring of potentially hazardous substances in drinking water as well as raw water is not adequate. Even if some public water supply implements a spontaneous monitoring of potentially hazardous substances, it will not disclose the results to the public for the

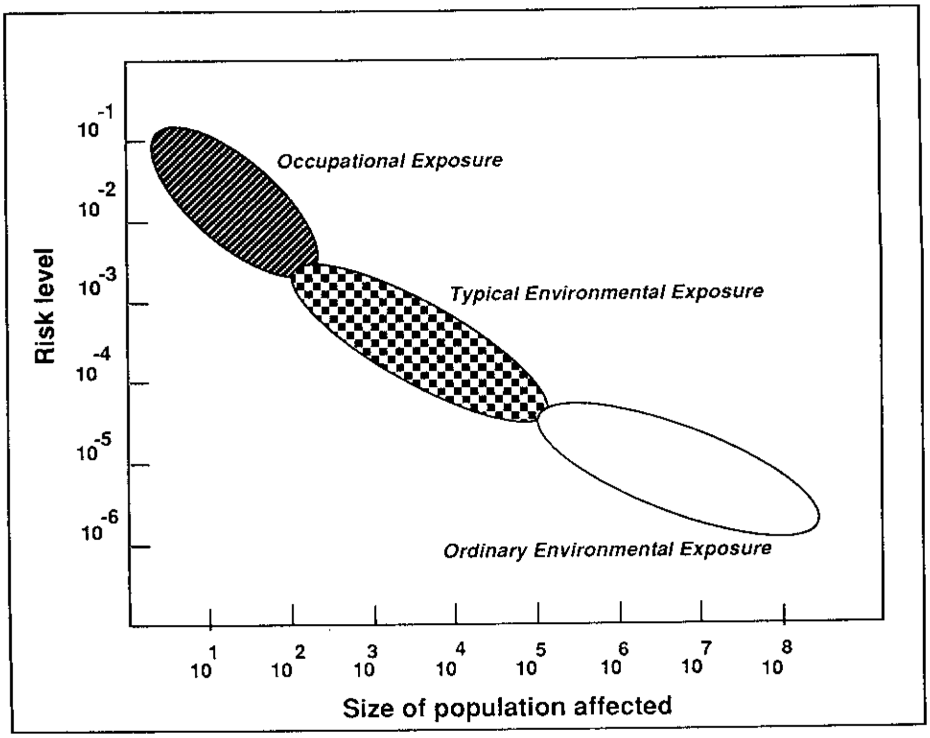

Figure 4. Classification of environmental pollution problems according to the risk level and the size of population affected

purpose of not enlarging social anxiety about drinking water quality. But, on the other hand, the mass-communication reports the occurrence of potentially hazardous substances based on publications by scientists. Since people are not informed of the magnitude of the health risk associated with the substances by either the public water supply sector or the mass-communication, they only feel anxious and the public water supply loses their reliance. Therefore, the authors consider that the introduction of the health risk assessment and management is an urgent task for the continuous development of the public water supply.

In order to implement the health risk assessment and management, it is necessary to identify the parameters as shown in Figure 5. However, it is difficult to obtain every necessary information on the parameters. In order to develop an appropriate method for assessment of the total exposure to potentially hazardous substances, the authors conducted a pilot study supported by the Ministry of Health and Welfare with other researchers [3].

This study was implemented through total diet sampling, passive air sampling and tap water sampling. Table 2 shows an example of the total exposure study on volatile chlorinated compounds. The level of total exposure to chloroform varied with location of monitoring, Nagoya and Yokohama, and occasion of sampling, Yokohama (1) and Yokohama (2). The contribution of drinking water to the total

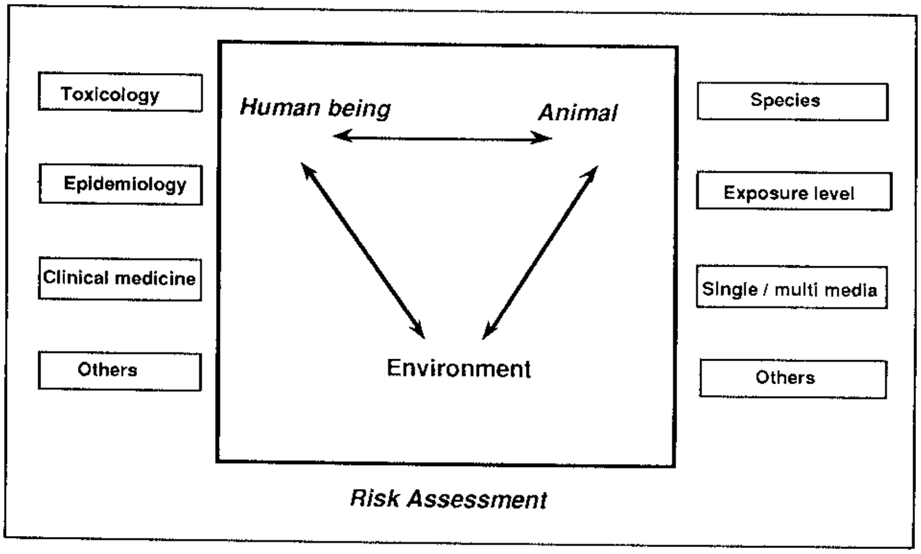

Figure 5. Risk assessment in environmental exposure to hazardous substances

Table 2. The result of a total exposure study on chloroform, trichloroethylene and tetrachloroethylene

Substances	Locations	Mean Exposure (μg/day)			
		Food	Air	Water	Total
chloroform	Nagoya city	26.3	11.0	43.8	81.1
	Yokohama city(1)	16.7	43.7	21.7	82.1
	Yokohama city(2)	19.1	10.0	8.0	37.1
trichloroethylene & terachloroethylene	Yokohama city(2)	0.2	99.1	0.1	99.4

exposure also differed in each study. However, the variance of mean exposure levels, the ratio of maximum exposure level to minimum exposure level, in monitoring population differed from the media to media, i.e. about 60 times via food, about 100 times via air and only about 3 times via tap water. Since those who took much liquid food such as soup, milk and beverage showed higher exposure to chloroform, we considered that the exposure to chloroform via diet was affected by chloroform in tap water used for processing the foods. Concerning the exposure to trichloroethylene and tetrachloroethylene concentration, the proportions via food and drinking water were much lower than that via air. Since the tap water of that monitoring area was derived from surface water, their concentrations in tap water were very low. The trichloroethylene and tetrachloroethylene concentrations in indoor air were higher than those in the ambient air. We observed a typical case that the concentrations in indoor air increased when the washed clothes were brought into the house from a dry-cleaning shop. We considered, however, if the monitoring area was supplied with ground water, the contribution of water might be similar to that via air. As shown in our study, it is very difficult to achieve a rational and quantitative health risk assessment with limited resources. Therefore, further studies on health risk assessment and management concerning drinking water are needed.

METHODS OF HEALTH RISK ASSESSMENT AND MANAGEMENT IN PUBLIC WATER SUPPLY

Since the raw water quality of a public water supply is largely affected by intensive human activities in the catchment area, the risk related to pathogenic bacteria and viruses has much increased compared with that in former days. Therefore, a priority should be put on microbiological risk among others in the health risk assessment and management of drinking water. However, microbiological risk can be reduced by continuous chlorination in water treatment system and keeping free residual chlorine concentration in tap water at more than 0.1 mg/l as well as reduction of residual turbidity as low as possible.

In the evaluation of synthetic chemicals regulated by the related laws as above mentioned, their behavior in the public water supply system is not considered satisfactorily. The hazardous chemicals related to the serious health damages experienced in the past is not detected in raw water, but the occurrence of potentially hazardous chemicals in raw water is unavoidable. Furthermore, the strength of reaction in the oxidation processes, i.e. chlorination and ozonation, is beyond consideration in the evaluation of synthetic chemicals in the related laws. Therefore, the occurrence of potentially hazardous chemicals as well as oxidation byproducts should be seriously considered in the health risk assessment and management of drinking water.

The quality of drinking water supplied by the public water supply system is interrelated with raw water quality and treatment technology in Figure 6. The quality of supplied water depends on the quality of raw water when using a given water treatment system. The supplied water quality is also affected with a water treatment system even if the raw water quality remains the same. In this figure of a conceptual illustration, the relationship between raw and supplied water qualities under a typical water treatment system is indicated by a straight line.

In Japan, the Environmental Quality Standards for the ambient waters require that the water bodies utilized for the purpose of public water supply should be kept at a level equivalent to or higher than the Class B. Therefore, it is of great concern to what extent the Class B water can be purified by a water treatment system. The water quality of the Class B in a low water flow season corresponds to

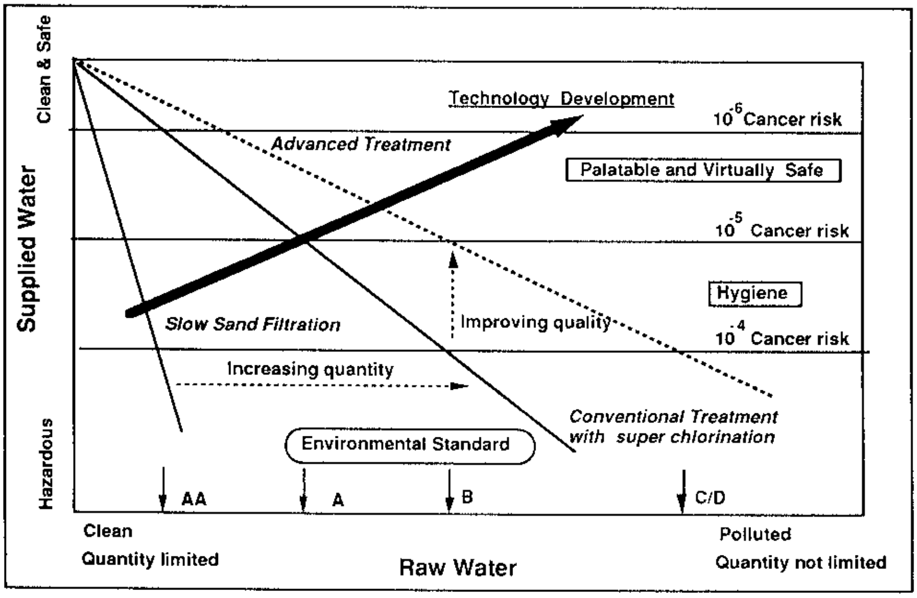

Figure 6. The significance of water treatment technology development

about 100 μg/l of a total trihalomethane formation potential [4]. Since the rapid sand filtration with superchlorination can not reduce total trihalomethane formation potential effectively, the supplied water by such a treatment of a Class B raw water is considered to have a cancer risk of about 10^{-4}. The Ministry of Health and Welfare is now going to amend the Drinking Water Quality Standards with increasing the number of contaminants including carcinogens. Considering the feasibility from technological and economical viewpoints, the risk level of carcinogens in the new drinking water quality standards will be 10^{-5}, i.e. one order smaller than that of the existing standards and the same as the virtually safe target level already adopted by the WHO.

In order to meet the new standards, a proper health risk management should be implemented by introducing advanced water treatment technologies such as activated carbon adsorption and ozonation. They can effectively reduce soluble and potentially hazardous chemicals though the conventional treatment with superchlorination can not do so. The Ministry of Health and Welfare already issued the guidelines developed on selection of an appropriate water treatment system in cooperation with the Japan Water Works Association [5], and the Ministry also provides the governmental subsidy to the public water supply authorities if necessary.

Although there are various kinds of potentially hazardous contaminants in drinking water, it is not possible or appropriate to set the drinking water quality standards for all of them. Because the Japanese drinking water quality standards compulsory requires water quality monitoring in every public water supply system including even a small rural one, it is not feasible to enforce the rule throughout the country. Therefore, the drinking water quality standards, even on the health related contaminants, should be set considering their occurrence in drinking water and the feasibility of the enforcement to public water supply authorities.

In preparing the draft of new drinking water quality standards, the Ministry of Health and Welfare implemented a preliminary health risk assessment of potentially hazardous contaminants in drinking water. Firstly, a priority list of contaminants was prepared by referring to reports and publications on the environmental pollutants, and, secondary, a literature survey on their toxicity was implemented.

And then the primary acceptable concentrations of contaminants in drinking water were calculated by the method as shown in Figure 7. The primary acceptable concentration in drinking water is basically calculated by the approach of the acceptable daily intake (ADI) below which no adverse effect will occur. Besides the ADI approach, each contaminant was evaluated on their carcinogenicity according to a similar classification adopted by the IARC. If a contaminant is classified to be known or probable human carcinogen, its primary acceptable concentration in drinking water is the value calculated using of a low-dose extrapolation model. If a contaminant is classified to be a non-genotoxic carcinogen or possible human carcinogen, its primary acceptable concentration in drinking water is the value after application of an additional uncertainty factor 10 to the value obtained using the ADI approach. In case of pesticides, due to lack of sufficient information to assess the contribution of water to the total exposure, the primary acceptable concentration in drinking water is calculated by arbitrarily allocating 10 % of the ADI.

Because of insufficient data reported by scientists, a national drinking water quality survey was implemented by the Ministry of Health and Welfare. Compiling all of the information, the primary acceptable concentrations of contaminants were compared with their actual concentration in raw and tap waters of public water supply in Japan. If the maximum concentration of a contaminant is more than 50 % of the primary acceptable concentration for noncarcinogen or 10 % of it for carcinogen, the contaminant will be routinely monitored and its concentration will be evaluated by the public water supply authority concerned. If its concentration reaches the primary acceptable concentration in drinking water, an appropriate counter measure will be taken. And if the maximum concentration is between 10 % to 50 % of the primary acceptable concentration for noncarcinogen or between 1 % to 10 % of it for carcinogen, the contaminant will be only monitored regionally under the cooperation of

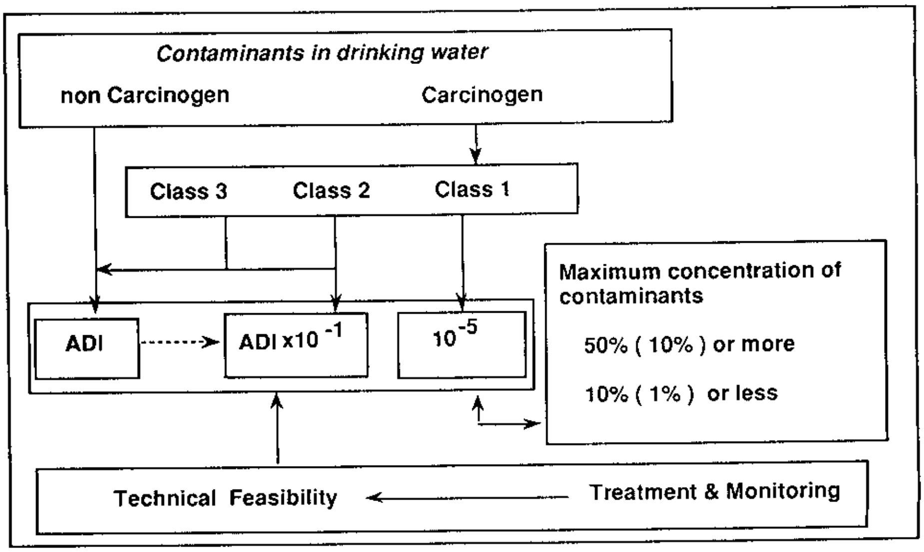

Figure 7. The rule of setting the new drinking water quality standards

public water supply authorities. The other contaminants whose concentration are lower than those as above mentioned will not be given any further consideration. The former two classes of contaminants are taken into the framework of the new drinking water quality standards after ensuring the technical feasibility of monitoring and treatment. The first class contaminants will be registered in the standard items, and the second class contaminants will be registered in the monitoring items.

The Japanese Drinking Water Quality Standards are going to be amended based on a preliminary health risk assessment as above mentioned. Recently it is becoming rather common in the world that the health risk assessment and management are implemented separately. In the process of establishing the new standards, however, they were implemented combinedly because of the nature of the Water Works Law. The number of contaminants listed in the standards may become about four times of the existing standards. About a half of them registered in the monitoring items will not be compulsorily monitored in every public water supply authorities, but the information on potentially hazardous contaminants in drinking water will be expected to increase much more than before.

According to the result of the preliminary survey of contaminants in drinking water, it was seldom to detect potentially hazardous contaminants at high concentration in drinking water. Therefore, there may be little number of public water supply authorities who will take an immediate action for improving drinking water quality in Japan. But the public will become to feel easier in using tap water supplied by the public water supply with increase of information on its safety. Although there is no effective way for the public to access the health risk information related to drinking water quality, the Water Works Law assures a consumer of its right to request the pertinent public water supply at least to examine the tap water quality.

CONCLUSION

Though the Ministry of Health and Welfare is going to amend the Drinking Water Quality Standards applying the concept of the health risk assessment and management, the concept is not so much developed in Japan. This is the first application of the risk assessment and management in the environmental administration. Nevertheless, the new Drinking Water Quality Standards are expected to be a very effective tool to facilitate the communication between consumers and public water supply authorities and to improve drinking water quality as a whole.

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