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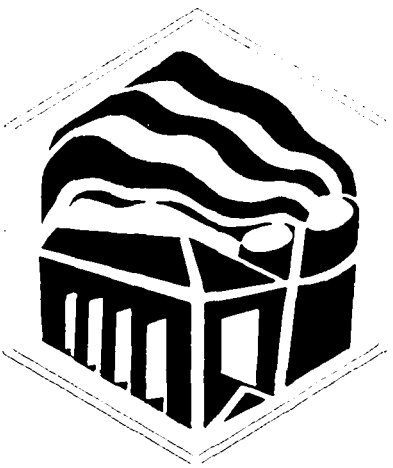

Drinking-Water Quality and Health-Related Risks

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DRINKING-WATER QUALITY AND HEALTH-RELATED RISKS

– A Framework for Developing Data Reliability –

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FOREWORD

Modern civilization has become increasingly dependent upon a variety of chemicals in ever-increasing volume. To mention but a few of the advantages that chemicals offer are the reduced effort and increased production in agriculture resulting from the use of pesticides, fertilizers and herbicides, the medical benefits resulting from the innovation and application of synthetic organic chemistry to drug manufacture, and the use by modern society of the range of products developed by the polymer chemist.

However, just as these chemicals bring advantages to the community, so also can they bring dangers unless caution is exercised during manufacture, use and in particular the disposal of such products. Often these dangers are concealed, but the insidious human health effects that can result from them are increasing concern.

A number of industries handle a variety of metal salts, many of which possess acute or subtle toxic properties. Similarly, the pharmaceutical, chemical and agrochemical industries are concerned with a host of organic chemicals, many of which could be extremely dangerous to humans. Each of these industrial activities must dispose of unwanted waste materials, in one form or another, into the environment, frequently as liquid effluent discharged ultimately to rivers or streams, or as solid waste to landfill. The latter method of disposal has often proved to be particularly hazardous to groundwater, either because of leaching of the disposed chemical or biochemical degradation and transformation of the deposited material. In either case, the aquatic environment is at risk, particularly resource water used for drinking-water supplies. In general, rising population figures are increasing the need for re-use of water from polluted rivers, thus increasing the emphasis on the water cycle as a whole, and on the quality as well as the quantity, of water for public supply.

Certain chemical substances entering a public water supply may affect the acceptability of water for drinking purposes by causing objectionable odours and tastes. However, many other chemical substances not detectable by the senses have properties toxic to humans and their presence and levels in a drinking-water supply must be rigorously monitored to ensure consumer safety. Whatever drinking-water supply is available to a community is consumed throughout the consumer's lifespan, and chemical contaminants which are present, even at very low levels, may result in bioaccumulation, increasing the toxic hazard.

In its 1984 Guidelines for drinking-water quality, the World Health Organization identified a range of commonly occurring organic and inorganic chemicals which as water contaminants pose a threat to human health. WHO has quantified values for such contaminants which it considers, on the available toxicological evidence, to be acceptable for lifetime consumption.

However, WHO realizes that such information in itself is valueless unless it is used in conjunction with water resource surveillance, which includes sampling and chemical examination, to ensure vigilant protection of public health against unwholesome drinking water. Data reliability is therefore of paramount importance. In addition, awareness is growing that data quality is not confined solely to the expertise within the analytical laboratory but is primarily dependent upon the quality of the submitted sample being representative of the water supply under examination.

This fundamental requisite is recognized by WHO and was the raison d'être for holding the UNDP-supported meeting in Bucharest in November 1986. This report presents the topics and views of the meeting within an expanded scope. We hope that it will be useful to those concerned with drinking-water quality and health and the collection of reliable data regarding quality.

The efforts of Mr William Lewis in preparing this report are gratefully acknowledged.

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Introduction

In November 1986, the WHO Regional Office for Europe convened a meeting on drinking-water monitoring and health-related risks in Bucharest, Romania. This meeting was held within the framework of the UNDP-supported project "European Cooperation on the Environmental Health Aspects of the Control of Chemicals", and attended by representatives of five European countries (Annex). The objective of the meeting was to review activities in participating countries, establish the chemicals to be monitored and make recommendations on selected work methodologies and analytical techniques. Although the meeting concurred with the list of inorganic elements identified by WHO [1] as substances posing potential health problems, it considered that very little information was available relating to levels of mercury and selenium in drinking-water supplies. In addition, the meeting identified four groups of organic chemicals in water which should be monitored: trihalomethanes, herbicides, volatile chlorinated solvents and polynuclear aromatic hydrocarbons.

After receiving the report of the meeting, the WHO Regional Office for Europe considered both the subject and the meeting recommendations of sufficient importance to extend the topic in the form of the present volume.

The European Experience

Prior to 1980, countries in Europe, accepting the principle that drinking water contaminated with mineral and industrial pollutants posed a threat to public health, used one of several approaches. They either (a) adopted the 1970 WHO European standards for drinking water [2] or a combination of these standards and the WHO international standards for drinking water published in 1971 [3], or (b) formulated their own national drinking water quality standards which presumably relied heavily upon the above two documents.

In 1980, Directive No. 80/778/EEC on the quality of water intended for human consumption was issued, which Member States of the European Community were obliged to adopt as national standards. This directive, in addition to identifying the organoleptic properties required, quantitatively enumerated 38 physicochemical values covering inorganic and organic substances. Under the separate description "toxic substances", an additional 13 compounds, such as pesticides, herbicides and polycyclic aromatic hydrocarbons, and 11 inorganic contaminants were quantified. The basis upon which such quantified values were established is not mentioned; neither is it relevant to this document. What is relevant, however, is the widespread concern about the potential danger to human health posed

by contaminated drinking water and the resulting action being taken to combat the threat within the European Community.

From 1958 onwards, WHO has issued standards for drinking water, but only in its recent (1984) Guidelines for drinking-water quality did it attempt to evaluate the threat to health by a variety of pollutants in drinking water. WHO also recognized for the first time that as a world authority advising upon health hazards, it could not recommend a single universal drinking-water quality standard. It accepted that many factors controlled the acceptability of a potable water, not the least of which was the availability of water to drink, but also geographical, socio-economic, dietary and other factors which differ significantly from country to country and region to region. Accepting that water is essential to sustain life and must, therefore, be available even if the quality is not entirely satisfactory, WHO recognized that the adoption of too-stringent drinking-water standards could limit the availability of water to meet those chosen values. The values described in the Guidelines for drinking-water quality are such that the water is suitable for human consumption over a lifetime and are intended as a means by which national drinking-water standards may be individually formulated. The values recommended for each parameter or constituent are based upon known health-related data, taking into account the total body intake from sources such as air and food and assuming a per capita daily consumption of 2 litres.

The Problem of Chemicals

Perhaps one of the most dramatic changes the world has experienced during the last four decades has occurred in what may broadly be described as the technological field and in particular the design, production and application of synthetic organic chemicals. Many of these compounds have properties which permit their commercial exploitation and thus enter, in one form or another, into our daily lives. For example, insecticides, as well as the range of herbicides, benefit agriculture and thus our well-being. In excess of four million chemical compounds have been classified, of which perhaps 70 000 are in everyday usage [4]. Currently, between 20 000 and 30 000 chemicals, many of which possess hazardous or toxic properties, are manufactured and commercially used in amounts exceeding one tonne per annum. The storage, use and disposal of such substances have sometimes resulted in serious public health problems of water pollution. As a result, the public is becoming increasingly concerned about the complex nature of such pollution which is such that often no disposal technology can guarantee absolute safety.

Because of disposal procedures adopted, either at present or in the past, well in excess of 3000 organic chemicals have been

identified as pollutants in the aqueous environment [5]. Well over 700 chemical compounds have been identified in drinking water, of which more than 600 are organic in nature, and many of which are pharmacologically active [6]. Advancements in analytical technology, with the introduction of gas-liquid chromatograpny and mass spectrometry into everyday laboratory procedures, now means that many contaminants can be identified, characterized and quantified at the microgram and even the nanogram level in water [7]. Many of these contaminants are hazardous to health. Of the 700 identified in drinking water, 20 are recognized carcinogens, 23 are suspected carcinogens, 18 are classed as carcinogen promoters and 56 are mutagenic contaminants. Thus, one can appreciate readily the grave concern such contamination engenders in the mind of the public. Furthermore, in spite of the advances in sophisticated analytical procedures, the identified organic contaminants represent but 10% of the total. The other unidentified 90% of the organic fraction is due to nonvolatile organic substances which have yet to be characterized and whose ultimate identification may well increase the public health concern. The problem of organic contamination has acquired a different perspective since the discovery that the disinfection of public water supplies, to ensure against harmful microbial organisms, has resulted in the proliferation of byproducts resulting from the interaction between natural organic material in the water and the disinfectant.

Standards versus Guidelines

The significance of health risks posed by drinking water contaminated by microbiological agents and toxic chemicals varies greatly. Microbiological contamination of the public drinking-water supply usually results in immediate ill-health of the consumers at large, whereas a chemical substance is unlikely to result in an acute health problem except under exceptional circumstances, such as a massive contamination of the supply. Chemically contaminated water of such exceptional quality would normally be undrinkable for obvious organoleptic reasons (e.g. appearance, taste, odour), whereas microbiologically contaminated water could well pass such criteria undetected. Chemical contamination is more insidious, principally due to the ability of chemicals to cause adverse health effects over prolonged periods of exposure. This is particularly so in the case of chemicals which bioaccumulate in the system (e.g. carcinogens).

In the pragmatic world of drinking-water production, using groundwater supplies - which are becoming increasingly contaminated - or abstracting raw water from lowland rivers does not ensure, by the routine water purification treatment procedures employed, the complete removal of many contaminants, especially those of an organic

nature. To be able to set standards for drinking-water quality which will protect public health against such chemicals, one must have proof that:

- the specific compound is toxic to humans at a realistic level;
- no human hazard, either acute or chronic, will arise at the proposed standard value;
- exceeding the standard value is damaging to human health;
- under different water quality conditions, a synergistic enhancement of toxicity of the chemical will not arise;
- change or relaxation of the standard will not be permissible unless specifically quantified in law; in other words, the standard value is inviolate.

The slightest suspicion that a standard lacks scientific credibility demands an alternative approach. If the objective of defining drinking-water quality is the protection of public health from unnecessary harm, any values relating to water quality must axiomatically be based upon health-related data.

WHO, in preparing its recent drinking-water values, recognized that it could not meet the criteria of proof set out above; neither was it in a position to propose inviolate drinking-water standards for universal adoption, having a purely advisory role to its Member States. WHO thus accepted its advisory role and produced water quality values for human consumption as a guide to countries. Additionally, because the main body of scientific opinion appears to be that compounds which are carcinogenic have no safe minimum dose, and because complete removal of such compounds from drinking water is frequently impossible, an entirely new approach to evaluation had to be adopted in preparing the WHO Guidelines for drinking-water quality.

Principles Adopted in Preparing Guidelines

In developing guideline values, the objective was to define water quality which could safely be consumed by all throughout their lifetime. First, this required an assessment of exposure based on a knowledge of individual water consumption. This quantity is variable not only within a population but also between countries, and WHO chose an assumed intake of 2 litres per day for an individual of 70 kg assumed weight. Second, assessing exposure required, particularly with regard to organic contaminants in drinking water, obtaining information relating to the frequency of

occurrence and concentrations commonly found in drinking-water supplies. Third, the potential of suitable treatment techniques to remove or reduce the concentration of the substances in the final potable water supply was sought. Ideally, when dealing with hazards to human health, clear-cut epidemiological data in humans are desirable. However, unequivocal epidemiological data are rare and other human data appeared equally sparse. Therefore, health data acquired in laboratory experiments using animal models were used.

The question which arises must be: How valid is the comparison between animal data and human toxicology? For example, rat strains are relatively homogeneous in terms of genetic characteristics. In addition, they lack gall bladders and are independent of a dietary source of vitamin C. Similarly, mice metabolize chemicals more rapidly than humans. Nevertheless, nearly all the chemicals which have been positively identified with human cancer also have been proven to be carcinogens in other animals [8]. This also is true for an impressive list of other chemical compounds. For most of the substances of interest as water contaminants, the pathogenesis of poisoning is therefore similar in humans and other mammals; differences in response between species are mainly quantitative rather than qualitative due to differences in rates of absorption, excretion and detoxification. For some chemicals, humans are less sensitive than laboratory animals, and for others the reverse is true. The limitations, accuracy and reliability of applying animal results to humans are covered in a WHO publication [9]. The task facing the evaluation of water quality relied heavily upon data obtained via controlled animal experimentation.

Animal experimentation is usually designed with the objective of ascertaining "the no-observable-adverse-effect-level" (NOAEL) of a particular chemical by administering, normally over a life span, a range of concentrations of chemical via the animal diet. The numbers of animals receiving a particular dose of chemical is of vital importance: increasing the population size may be expected to detect smaller and smaller effects, thereby increasing the validity of the findings.

A problem of some concern in preparing safe values for low levels of known organic chemicals in drinking water using results of laboratory animal experimentation is the extrapolation from the relatively high animal dose often necessary to induce a reaction to the hazard presented to humans by the minute chemical levels found in drinking-water supplies. WHO, in compiling its Guidelines for drinking-water quality, followed the accepted procedure of applying a safety factor or "uncertainty factor" when converting data from animals to humans, the magnitude of which was dependent upon the potential bioaccumulation propensity of the individual chemical. This conversion practice produced a value which was akin to the acceptable daily intake (ADI) of the particular chemical. Fortunately, the joint work of the Food and Agriculture Organization

of the United Nations and WHO had identified ADIs for an impressive range of chemicals over the years. The task then was simply allocating a percentage of the published ADI value to drinking water and thus providing a concentration per litre of drinking water.

This simplified explanation of the procedure adopted applied to those chemicals in water whose toxic effects were known to be dose-related and in which a threshold value can be demonstrated, (i.e. chemicals in which the biological response reaches zero before the dose becomes equal to zero). For those chemicals whose long-term effects result in neoplastic disease, a single molecule of a substance may be sufficient to initiate the process. Such substances, which may have a latency period of many years before symptoms appear, present considerable difficulty in relation to quantifying water quality.

Due to the minuteness of the dose required to initiate disease and the pragmatism associated with supplying drinking water, the total removal of all such substances from drinking water is illogical to even consider, even if the technology were available to achieve such a utopian dream. Therefore, WHO accepted the only realistic alternative and attributed, as far as possible, a risk factor associated with imbibing water containing such compounds. Low-dose carcinogenic risks were estimated from animal data by the multistage extrapolation model adopted by the US Environmental Protection Agency for chemical constituents considered to be carcinogenic [10]. This type of data interpretation depends very much upon the so-called linear dose hypothesis, and the recommended levels obtained, on the basis of this technique, are believed to be more realistic for carcinogenic chemicals than those derived from the application of safety factors.

Recommended values for low-level carcinogenic chemicals must, however, be viewed with caution because of the uncertainties involved. The risk factor adopted by WHO in deriving its values for the Guidelines for drinking-water quality is based upon an acceptable risk of 1 additional case of cancer per 100 000 population. The animal experimentation upon which the carcinogenic response was evaluated obviously involves chronic toxicity studies covering the life span of the animal, normally the rat, and this duration is usually 2 years. A weakness in this evaluation, the only one at our disposal, relates to the "body weight rule". The average life span of 70 species of mammals shows a linear correlation with body weight, but the average life span of humans is an exception [11]. Thus, applying the mammalian regression equation to a mammal having the same body weight as a human (70 kg), the average life span is 15 years. However, the average life span of a rat approaches 2-1/2 years and is thus equivalent to only 15-17 years of a human's life; yet, the rat is a vital animal used in evaluating carcinogenic properties.

The other fundamental weakness is the use of an inbred homogeneous animal strain and converting such results to the heterogeneous human population. Until a more satisfactory assessment procedure is developed, evaluation of chemical toxicity in humans must rely on animal experimentation. If the carcinogen "no-threshold" hypothesis is proven to be incorrect, the values for such compounds, as set forth in the Guidelines for drinking-water quality, will err conservatively on the side of safety.

Guideline Values Recommended

The experts who considered the problems of drinking-water quality examined criteria documents covering a total of 37 inorganic constituents which had been identified in drinking water; they recommended safe values for nine of them based only upon health considerations. Included in this number were the two metalloids (mercury and selenium) which the Bucharest meeting identified as substances for which information of levels in water supplies (i.e. resource water and drinking water) was rather scarce. Based upon health considerations, the Guidelines for drinking-water quality recommended a value of mercury of 0.001 mg/l, which is 1 µg/l, and for selenium, 0.01 mg/l or 10 µg/l. In drinking water, mercury is normally present in inorganic form, which is considered to be poorly absorbed by the animal system. The organomercury compounds, especially methylmercury, on the other hand, are considered to be rather toxic, causing neurological damage as well as embryotoxic and teratogenic effects. (It is not intended to suggest that methylmercury and such compounds are contaminants of drinking-water supplies, but microorganisms found in aquatic sediments are capable of methylating the inorganic forms which may be present at undesirable values in resource water). However, the value in the Guidelines for drinking-water quality is for total mercury (i.e. both the inorganic and organic species if present).

Unlike mercury, which has no beneficial function in humans, selenium has been identified as an essential element in several other animal species. Indeed, certain endemic diseases in farm animals are even corrected by dietary additions of selenium.

Ironically, an interaction occurs in vivo between mercury compounds and selenite, which leads to mutual modification of the respective toxic properties. Administration of selenite-selenium to laboratory animals has provided limited protection against methylmercury poisoning.

Unlike mercury, selenium, especially sodium selenite, is readily absorbed, and selenite is more rapidly excreted from the body than when an organoselenium, such as selenomethionine, is present. Presumably, selenium uses this metabolic pathway to combine with body proteins as opposed to methylation and the excretion pathway

influences the toxicity of selenium. Although an essential element, selenium is toxic at intake levels comparable with the nutritional requirements of some other trace elements.

The microorganic pollutants are a much more complicated problem. During the preparation of the Guidelines for drinking-water quality, this difficulty was eased by considering the organic contaminants in specific groups such as pesticides, nitrosamines and chlorinated alkanes and alkenes. Of the 46 organic compounds examined, the health-related evidence was sufficient to attribute water-quality values to 15. A further three compounds (chloroform, carbon tetrachloride and tichloroethene), for which the factual health data were incomplete but whose presence in drinking water was of concern, were ascribed "tentative guideline values". The latter values will be deleted, confirmed or modified, depending upon advancement in health-related knowledge.

An example of the dilemma presented by compounds in the latter class may well illustrate the need for the adopted course of action. Chloroform, identified frequently at microgram levels in drinking water, produces neoplastic changes in rats and mice at doses corresponding to 1800 mg/l. Therefore, the risk to health posed by the presence of this substance in drinking water, is very small. However, because of the very large population known to be exposed to drinking water containing chloroform, the experts considered even this small risk of sufficient concern to warrant cautionary action.

The four classes of organic compounds identified by the Bucharest meeting as substances whose presence should be monitored more diligently in drinking-water supplies are very diverse in character. The trihalomethanes, for example, (which include chloroform), occur in drinking-water supplies normally as the result of the disinfecting agent chlorine used to combat the danger of pathogenic microorganisms. As an oxidizing agent, chlorine reacts with the soluble organic carbon in water, the reaction being dependent on concentration and time, to produce the series of chloro/bromo compounds.

Surface and groundwater can be contaminated with herbicides deposited on plants and soil which reach these water sources via run-off and percolation. Volatile chlorinated solvents affect groundwater supplies rather than surface water supplies because the volatility of this class of compounds is suppressed in underground water. The chloroethenes are used extensively by industry for a range of purposes, such as solvents, paint thinners, intermediates in the chemical industry and dry-cleaning fluids. Their presence in groundwater is frequently due to, for example, leaking storage tanks, industrial discharges and unsatisfactory disposal of residues. Several of the compounds pose a danger to human health and are known to produce neoplasms in experimental animals. The Guidelines for drinking-water quality recommend values for such

substances, in some cases values less than 1 mg/l, to protect health. Coal-tar-based materials are extensively used for lining storage tanks and pipework, and polynuclear aromatic hydrocarbons (PAH) released from these materials perhaps form a major source of contamination of water. These complex benzene-ringed substances, of which there are many, are fairly ubiquitous in the environment. In some instances they are synthesized by bacteria or result from the incomplete combustion of organic matter, and so they gain access to resource water. They are relatively insoluble in water, and their concentration in drinking water would normally be very low. Nevertheless, they are considered to be hazardous to human health as several members of the group, such as benzo-α-pyrene and indeno[1,2,3-cd]pyrene, for example, have been shown to be carcinogenic in animal experimentation and also may be to humans. The Guidelines for drinking-water quality have a recommended value for benzo-α-pyrene of 0.01 mg/l, which is a measure of concern regarding its toxicity.

The Guidelines for drinking-water quality recommend levels or values of a constituent in water to ensure that the water is aesthetically pleasing and does not result in any significant risk to the health of the consumer. WHO advises that when a guideline value is exceeded, it should be a signal to investigate the cause with a view to taking remedial action. Short-term deviations from a guideline value do not necessarily mean that the water is unfit for human consumption; this depends upon the amount by which a value is exceeded, the duration of the period of excess and the specific substance involved.

Country Standards

Throughout the compilation of the Guidelines for drinking-water quality, WHO recognized that the possibilities of providing "safe" drinking water will differ greatly throughout the countries of the world. There are differences between areas of plentiful and sparse supply, differences in ability to provide treatment technology and differences between metropolitan and small communities. Each aspect necessitates individual consideration if the resulting enactment of standards is to be meaningful and, more importantly, achievable. The Guidelines for drinking-water quality, as explained above, recognized not only the desirability but the inevitability of adopting a risk/benefit approach to the setting of national drinking-water quality standards. Designed standards for individual countries must, therefore, be based upon a careful study of the health risk and other factors relating to scarcity of source water, climatic conditions, and technological and economic feasibilities. The desired result from the establishment of drinking-water quality standards will be difficult, if not impossible, to achieve without

due consideration of the measures needed with respect to finding new sources of supply, instituting types of treatment, and providing adequate back-up surveillance and enforcement facilities. As emphasized in the Guidelines for drinking-water quality, "Standards and regulations achieve nothing unless they can be implemented and enforced", and this requires relatively expensive facilities and expertise.

Management of Drinking-Water Quality

Management of drinking-water quality starts with the choice and protection of the water source, which are of fundamental importance. When such a water source requires treatment to produce drinking water of acceptable quality, then both adequacy and reliability of the treatment process chosen must be assured. For example, inorganic mercury compounds in a resource water may be removed effectively by efficiently operated conventional coagulation treatment using either alum or iron salts. If mercury is present as an organic complex, the same removal efficiency may not be achieved. Only upon such a basis can a policy of drinking-water quality management designed to ensure the protection of the health of the consumer be pursued.

As stated in the WHO publication "Surveillance of drinking-water quality" [12], "Public health protection of drinking-water supplies should assume that each component of the system - source, treatment, storage and distribution, functions without risk of failure". Flawless treatment serves no purpose if the distribution system permits contamination. For example, distribution pipework or reservoirs which have received a protective coal-tar lining may recontaminate the drinking water with PAH compounds. An excellent distribution system will not protect the public health if the distributed water receives inadequate or insufficient treatment, while a source subjected to heavy, although intermittent, pollution may overwhelm the treatment capacity. Each aspect is an integral part of the whole whose aim is the provision of a safe drinking water for the protection of public health which, in turn, necessitates the creation of water quality criteria via water quality standards.

Drinking-water quality standards expressed numerically, without qualification, in terms of concentrations, are difficult to interpret, especially when deciding practical aspects such as frequency with which the quality should be measured. This is particularly highlighted when a source water displays marked short-term changes in a particular constituent concentration. To avoid such problems, defined standards should be so formulated that they may be clearly interpreted.

Monitoring Water Quality

Two fundamental approaches can be identified for the monitoring of drinking-water quality:

- solely to check that the concentrations of undesirable constituents do not exceed the quality standards set (i.e. no interest in this instance attaches to the actual values providing they are less than the standard values set);

- to provide reasonably accurate estimates of the concentration of the various constituents.

This second approach obviously also satisfies the objective of the first approach, but leads to the problem of defining what is meant by "reasonably accurate". Thus, the practice of "monitoring" drinking-water quality can differ significantly and such differences may even present, or at least seriously impair, attempts to make wider use of the analytical data produced [13]. Increasingly, worldwide interest is directed towards assessing the health effects of deleterious substances in drinking water and measurements of the concentrations are being made throughout the world. The basic approaches, as well as the detailed sampling, analytical and evaluation techniques, differ, making comparison of results extremely difficult. Results from different sources are likely to be subject to errors of different magnitude and, thus, values cannot always be qualitatively compared with confidence, and misleading or false conclusions may be drawn from such comparisons. No internationally agreed procedure has been adopted for measuring deleterious substances in drinking water. WHO recognized this situation and to provide guidance adopted the principle of defining the accuracy required analytically for those substances covered by the Guidelines for drinking-water quality.

Sampling programme

If sampling techniques are not chosen with great care, the results of the subsequent measurements may be partially or even completely invalid to meet the objectives. In covering a subject of this nature, only the principles upon which a sampling programme can be established can be indicated, as specific advice suitable for all situations is impossible to provide. The basic aim must be to collect samples, a mere fraction of the water body supplied, such that the quality of the sample represents the quality of the water body. The samples must be collected from such places and at such times that the analytical results represent the water quality and its spatial and temporal variability during the time period of interest. Therefore, the sampling programme should be designed to

cover variations in water quality which are both random and systematic (preliminary testing will provide prior information on these aspects) and the samples must represent water quality throughout the system.

Considering only public supplies within a distribution system, samples must be collected at each point where a supply of water enters the system. Quality changes may occur within the distribution network; therefore, additional sampling locations need to be selected at points which are convenient and at which contaminants may enter the system. Consumer tap sampling is a necessity, and other locations will be chosen taking account of changes in construction materials, distance from supply and locations of high usage. The number of samples should usually be kept to a minimum to save both sampling and analytical effort. This presents the problems of selecting the number of samples and the time of sampling so that the required accuracy is obtained with the minimum effort. Whatever choice is made, obtained data must be reviewed at regular intervals to decide whether or not changes in either location or sampling frequency are necessary.

To expand somewhat on the above, water constituents of concern may be divided into two broad classes:

1. Substances whose concentrations are unlikely to vary during distribution and whose concentrations in the water are largely governed by the concentrations in the supply water entering the distribution system (e.g. chloride, arsenic, fluoride, pesticides, selenium, sodium and sulfate);

2. Substances in water whose concentrations may vary during distribution: (a) substances which may participate in reactions with other constituents from another supply or which may react with the fabric of the distribution system; and (b) substances for which the distribution system fabric is the main source.

Examples in the case of 2a are aluminium, iron, manganese, phenol, chlorinated alkanes/alkenes/benzenes/phenols, chloroform and benzene; and in case 2b, cadmium, copper, lead, zinc and benzo-α-pyrene. Experience will probably confirm that generally, if only one source of supply water is used, only the water entering the distribution system need be analysed for type 1 substances. Consumer tap sampling will generally be needed to ascertain values of type 2 constituents.

Frequency of appraisal

The control of health-related inorganic and organic compounds in drinking water requires sampling and analysis at a lesser frequency

than that of microbial contamination. Usually, a thorough appraisal is undertaken when a new water source is brought into use and always after major changes in any treatment process. Experience will dictate the frequency of sampling, depending upon, for example, changes in the catchment area of supply or whether the source of supply is river-derived or a more constant quality source such as a deep bore hole. The nature of the particular water and the fabric of the distribution system may require careful consideration to decide whether the sampling frequency needs to be increased, for example, in the case of a water supply deficient in calcium "hardness" and where lead service pipes may be in existence.

Times of sampling

The principal factors determining timing and frequency of sampling are concentration of the constituent of interest, its degree of variation and the extent, if any, by which it is affected by a treatment process or reaction. If temporal variations in water quality are completely random, the time of sampling is unimportant. When rapid changes in water quality occur, the actual time span over which a sample is collected will significantly affect the analytical results. A composite sample, collected at intervals over a time period, will produce a time-weighted average. Two extreme strategies are available: to sample many taps, each on only one or a few occasions, or to sample fewer taps, but each more frequently.

The relative magnitude of the spatial and temporal variations will clearly be an important factor in choice of strategy. Some attempt should be made to evaluate the magnitude of any daily or weekly cycle of water quality. To ascertain daily cycles, not fewer than six samples should be taken at approximately equal time intervals over a period of several days and samples analysed individually. Persistent cyclic variations will then be highlighted. For weekly cycles, at least seven samples should be collected at the same time each day during the week and individually analysed. This type of exercise should be repeated throughout the year and will enable a realistic assessment of the water quality available to the community. Information of this nature also could be beneficial in optimizing the routine sampling programme to ensure that excessive sampling and analysis are avoided.

In discussing samples, one has in mind the collection of discrete samples to represent the quality of water during the period of interest. Obviously, the number of samples may be such as to overwhelm the laboratory's facilities for analysis. This problem can be, and often is, satisfactorily overcome by taking advantage of composite samples (i.e. mixing appropriate portions of individual samples). Analysis of the composite will then indicate the average quality during a particular sampling period. This procedure can be used only when the average value is of interest; it will not reveal

variations in water quality during the sampling period. This procedure cannot be used when (a) concentrations of determinants in the individual samples change appreciably between collection and compositing, (b) constituent interactions are likely by mixing of individual samples, or (c) uncertainty of the estimate of the average quality from a composite sample will generally be worse than the estimate of analysing individual samples.

Collection of samples

To ensure that samples for analysis are properly representative of the water body, two conditions are essential: (a) the collected sample must be truly representative and (b) the concentration of constituents of interest does not change between sample collection and analysis. The sampling of a water supply to ensure an accurate assessment of the level of volatile chlorinated solvent present in the supply is a typical example of the important role that the sampling procedure plays. Flow rate from the sampling tap (including the water run to waste prior to sample collection) and volume of sample collected are the two main influencing factors controlling concentration of some constituents of interest. This may be particularly true if water of a certain quality has been in contact, unduly long, with the distribution fabric (e.g. "soft" water and lead service piping). At least three main causes may influence a change in constituent concentration between sampling and analysis: (a) external contamination occurring during sample collection; (b) contaminated sample container; and (c) physical, chemical or biological processes occurring subsequent to collection.

Methods to avoid such problems and minimize changes in composition, including advice on transportation, are to be found in several publications including that of the American Public Health Association [14].

Objectives of sampling

The objectives of any sampling programme are the prime factors in governing the resources and the effort required both in the sampling itself and in the subsequent analytical effort. Therefore, the objectives must be defined with great care. Initially, objectives should be only those which are essential, rather than desirable, and they should be clearly defined in writing. The prominence given to objectives of a programme implies the early involvement of statistical techniques in the programme design. This is necessary not only in the formulation of confidence limits on mean results obtained, but also in the appraisal of results to assist in, for example, the objective choice between alternative sampling strategies. This may be beneficial, as the detailed design of a sampling programme must often be reconsidered in order to

decide how best to reduce the amount of effort involved without compromising the effectiveness of the surveillance of water quality [15].

Water Analysis

As emphasized in the WHO publication [1], multinational interlaboratory studies have shown that serious errors of analysis, sometimes as large as several hundred per cent, occur in certain laboratories. Commonly, this analytical error is greatest for substances that are present at low concentrations, that is, those which also are frequently the most harmful to the health of the consumer. The accuracy of the analytical result depends entirely upon the errors that arise during the analysis. These errors may be simply classified as random errors or systematic errors. Random errors are characterized when repeated analyses of a homogeneous sample yield results which differ among themselves and are more or less scattered about some value. This simply means that both the sign and magnitude of the error vary at random and cannot be predicted, and each result, because of the uncertainty attached to it, may be regarded only as an estimate of the true value. This scatter of results is referred to as the precision of the method used [16]. On the other hand, systematic errors, or bias, operate when the obtained values have a tendency to be consistently greater or smaller than the true value. The bias or systematic error can, of course, also be influenced by random errors. The important difference between random and systematic errors is that the latter, in principle, may be predicted so that a correction can be made to eliminate the effect. A systematic error is likely to occur with a particular analytical method when interfering substances are present in the sample. A simple illustration may be the negative effect of fluoride when practising the absorptiometric determination of aluminium. The best analytical method is the one which can give values with a negligible systematic error. Random errors normally follow a normal or Gaussian distribution pattern.

Accuracy required

The accuracy required of an analytical procedure is usually governed by the objectives of the sampling programme, previously emphasized. However, several basic principles need consideration when making a decision on this aspect, as highlighted in the Guidelines for drinking-water quality; otherwise, speed and cost may be the influencing factors:

- The required accuracy should be explicitly defined in a quantitative manner to provide the analyst with the criteria enabling him to choose the appropriate analytical method.

- Increasing the degree of accuracy required will significantly increase the time, effort and often type of equipment needed and, thus, the cost. One should avoid unnecessary stringent targets for accuracy as sometimes even an error of ± 50% for some water constituents will have very little health significance.

- As previously mentioned, many of the contaminants harmful to health are present at very low concentration in drinking water and thus, frequently, the limit of the analytical detection is often the most critical criterion in selecting the analytical method. The aim must always be to identify the smallest value of interest vis-à-vis health and, if possible, a detection limit of one tenth this value is desirable.

- The total error (i.e. random plus systematic) should be quoted, (e.g. 95% confidence) as being equal to the required limit of detection or to p% of the concentration, whichever is the greater. When p is set at 20, an acceptable compromise usually exists between the cost of analysis and accuracy.

Analytical method

To consider that adopting a "standard" method of analysis will enable achievement of an acceptable level of accuracy is a fallacy. Many factors influence the accuracy of a chosen method, such as reagent purity, skill and care of the analyst, type and accuracy of equipment used, and laboratory ambiance. For this and other reasons, WHO does not recommend adherence to a specific method of analysis, leaving this to the judgement of the skilled professional to decide once the degree of accuracy demanded is known. For example, both mercury and selenium may be quantitatively assayed by either atomic absorption spectrophotometry or colorimetry (in the case of selenium, fluorimetry) and the analyst has the choice of evaluating speed of analysis, accuracy and precision of results, and cost of analysis. Many authoritative publications are available specifying analytical procedures suitable for a variety of water constituents. However, once an appropriate analytical method has been chosen, a systematic quality control procedure must be introduced to evaluate the continuing performance within the organization. Such a procedure should operate over the range of analytical techniques, whether it be "wet" analysis, colorimetry, potentiometry, atomic absorption spectrophotometry, gas-liquid chromatography or other methods of analysis. The operation of a quality control procedure will enable the aecuracy and the precision of results, obtained in a routine manner, to be continually assessed. The accuracy will measure how close the results approximate the true value and the precision, and how well results from repeated tests agree with each other, both of which tend to deteriorate as the time period extends.

Testing the method

The importance of water quality upon the long-term health of the population is such that it is vitally important that those water contaminants which have been identified as health-related and to which a health-related value has been ascribed should be evaluated with confidence at the levels proposed for safe drinking water. The consequences of inaccurate data may be far reaching, and the responsibility upon the analytical chemist is often not appreciated, either by the analyst personally or the authorities receiving the data. The analyst responsible must, therefore, be capable of applying statistical techniques to measure analytical errors and the reliability of his results. Repeated analyses of the analytical method will enable a mean value from which estimates of the standard deviation may be ascertained. As the number of results from the same homogeneous sample increases, the uncertainty of the estimate will decrease and the value will be more reliable.

Detection of small concentrations

When analysing a water sample for levels of several of the health-related contaminants, it is often of the greatest importance to know the smallest concentration of the substance that can be detected. When determining constituents at this low level, the analytical response between a "blank" and the sample must be compared. The experienced analyst is not surprised if the two responses differ, even when the sample contains none of the constituent: this is due to random errors. Thus, as the differences between the two responses increase, relative to the random errors, the more likely is the sample to contain the constituent. Thus, the size of the random error is of vital importance in the ability of the analyst to detect small concentrations of a constituent (i.e. the standard deviation decreases, enabling smaller concentrations to be detected). The result (R) may be expressed as sample (S) minus blank (B). If σ_ω is the within-batch (same sample) standard deviation of a single blank, the difference between the results of two blanks will follow a normal distribution and may be expressed as $\sqrt{2\sigma_\omega}$. In examining a low concentration, the probability of the above expression exceeding a given positive value also will be governed by the normal distribution. A difference of $+1.65\sqrt{2\sigma_\omega}$ ($= 2.33\sigma_\omega$) will be exceeded, on average, only once every 20 occasions. The significance of this is that if a sample and blank are analysed and R (result) $>2.33\sigma_\omega$, the chance that the sample contains the same concentration of the constituent as the blank is less than 5%. In other words, one could claim with 95% confidence to have detected the constituent, thus indicating the importance in chemical analysis of the statistical confidence level

required (see section Accuracy Required). The standard deviation of the analytical result R at zero concentration of constituent, therefore, governs the criterion of detection.

Limit of detection

Although the above criterion will decide whether or not one can claim to have detected a constituent, actual detection will not always follow when the constituent concentration is equal to the criterion of detection; detection is likely to be achieved on only 50% of the occasions. If a sample contains a constituent present at the limit of detection L, the difference S-B will follow a normal distribution with a standard deviation as above (i.e. $\sqrt{2}\sigma_{\omega}$). Calculation will show that from the normal distribution and a 95% confidence value, the limit of detection will be $4.65\sigma_{\omega}$. In other words, the limit of detection for low-level concentrations of constituents in drinking water is 4.65 times the standard deviation of the blank.

Routine quality control

When the decision has been made that a particular analytical method has sufficiently small errors to permit its routine use, efforts must be made to ensure that the accuracy of the method does not deteriorate with the passage of time and familiarity of use. A simple method of continual assessment is ensured by the use of control charts. If a standard solution were analysed with each batch of samples, a simple procedure would be to examine the results from the standard solution and decide whether or not they were of the required accuracy. This procedure is a subjective judgement relying upon memory. However, with a control chart, which may be likened to a sequential graph, guidelines may be incorporated and so enable an objective view of the data to be applied. Control charts can be used for all analytical results and techniques, although charts may vary from one technique to another. To decide which type of chart is most suitable for the particular case, authoritative publications should be studied [17,18]. However, the following simplified description should provide the essential basis for compiling a chart.

Control charts

Assuming that the analytical results for a standard solution, using a particular method of analysis chosen, follow the normal distribution pattern, only 0.3% of all results will fall outside limits of $\pm 3\sigma$ from the population mean. The normal or Gaussian

distribution of results will include the true value on 99% of the occasions within the range $R \pm 2.58\sigma$ (standard deviation). Thus, individual analytical results on a specific sample would, on repetition, be expected to fall outside of the limit $\pm 3\sigma$ so seldom that such an event would justify the assumption that a real change in the accuracy of the method had occurred, so much so as to call for immediate remedial action by the analyst.

This type of variation may, for convenience, be displayed upon a control chart so constructed to provide insertion lines corresponding to (a) the mean value μ obtained by repeated analysis on the standard solution and (b) the limit lines ($\mu \pm 3\sigma$) which permits the chart interpretation. The latter lines of identification are referred to as "action limits", calling for an immediate remedial action by the analyst when values fall outside these limits. Normally, such charts contain two additional lines inserted at values $\mu \pm 2\sigma$. Standard solution routine results which fall outside these values, which are known as "warning limits", need no action providing that the next sequential result falls within the warning limits. These latter values are useful in that results falling outside of them too frequently may suggest a systematic tendency for results to be too high or too low, depending upon whether it is the $+2\sigma$ or the -2σ limit line which is being breached, or that the random error has increased if both limits are haphazardly crossed, and the reason needs clarification.

The x-axis of the chart corresponds with the analysis date. Ideally, all control standards should be presented to the analyst as normal samples within the batch of samples submitted for analysis and this eliminates the possibility of falsely optimistic results being returned. An alternate procedure is to vary the concentration of the standard solution by 80 and 120%. In the latter case, the difference between the observed and true concentration may be plotted on the control chart from which the scatter and the mean value will provide the desired information on accuracy. Results from batch samples should be accepted only as worthy of reporting if the result of the standard is satisfactory as illustrated by the control chart. The limits of the control chart may be refined over a period as further analytical results on the standard solution permit a reassessment of the standard deviation.

As the standard deviation usually varies with the concentration of constituent, the use of at least two control charts covering the lower and higher quartile of concentration for examination of samples where the constituent of interest varies over a wide range is recommended.

Interlaboratory collaboration

In assessing the importance to health of a particular contaminant in drinking water, results quoted by laboratories should

be comparable in validity. The single weakness of isolated laboratory endeavours may well be that even though quality control charts have been introduced to monitor analysis, and thus improve precision, an analytical procedure may still suffer from bias (systematic error) inherent in a particular laboratory. To check and, if possible, eliminate this inaccuracy, a system of interlaboratory testing, within a group of laboratories and within laboratories in a country, should be introduced. The aim of interlaboratory testing is to estimate the bias of each laboratory. Basically, the method of operation is for each laboratory to analyse portions of the same sample and then compare the results with the true concentration. Appropriate statistical techniques must be used, however, both in the design and the interpretation of the results of such a collaborative exercise. Whenever possible, the distribution of at least two water samples and one standard solution, all of which must be stable, is recommended. The concentrations of the samples should preferably correspond to the lower and upper values of the concentration range of constituent evaluated by a particular method, and the standard solution should correspond to the middle of the concentration range of the constituent of interest. When real samples are unstable, "spiking" techniques or even the use of preserving agents should be considered. In commencing such a programme, a reliable coordinating laboratory of national standard, preferably one having experience of the problems of interlaboratory analytical testing, should be responsible. Its first duty would normally be the distribution of stable standard solutions to the participating laboratories for analysis and not before all laboratory results attain the desired level of accuracy should the real collaboration exercise begin. As already noted, a statistician must be available at both the planning and interpretation stage to ensure unambiguity in the exercise. In summary, the value of interlaboratory testing is threefold:

- to ascertain the type of constituent presenting the greatest analytical uncertainty by evaluation of the analytical error of each laboratory;

- to characterize either, or both, the performance achievable by a particular laboratory method or the laboratory itself by estimating the source and magnitude of random and systematic errors of each laboratory;

- to achieve a desirably low level of analytical errors in all participating laboratories.

Analytical sensitivity

As additional information becomes available from the toxicologist identifying adverse health effects of certain drinking-water contaminants, the analyst is increasingly being challenged to determine accurately such constituents at lower and lower concentrations in public drinking-water supplies. In recent years, decision-makers have come to require information on certain contaminants in the lower microgram-per-litre range. Indeed, the Guidelines for drinking-water quality recommend that mercury should not exceed 1 µg/l and that levels for cadmium should preferably be less than 5 µg/l. However, the organic chemical group offers the greatest challenge to the analyst, with recommended guidelines for aldrin and dieldrin at 0.03 µg/l, benzo-α-pyrene at 0.01 µg/l, and hexachlorobenzene at the same value. In fact, of the 18 organomicropollutants listed as health-related, no fewer than six have recommended values as fractions of a microgram per litre, one of which is 1:1 dichloroethylene (which has been proven in animal experimentation to be carcinogenic) to which the Guidelines for drinking-water quality recommended a value of 0.3 µg/l.

Frequently, such concentrations are below the limit of detection by convenient and commonly used (although sophisticated) techniques, such as flame atomic spectrometry and gas-liquid chromatography in the case of the organic contaminants. The practising analyst has often been forced to resort to concentrating techniques to assess the levels of contaminants. Various concentration techniques are available in the laboratory, but frequently, because of pressure of routine work, most laboratories are unable to evaluate the most efficient method for a particular contaminant. The usual techniques employed range from straightforward evaporation concentration to solvent extraction, carbon adsorption, electrodeposition, ion-exchange, to freeze concentration. Unfortunately, no one optimal technique will cover all problems. One of the main problems faced by the analyst is that not all techniques of concentration simultaneously concentrate all the trace material of a group with the same degree of efficiency. Many techniques additionally may introduce other problems, such as matrix interference which can seriously influence the final analytical accuracy. Over the last few years, several publications have appeared in the scientific literature dealing with the problems of concentration, especially as it affects the water industry and water analysis [19-23]. Detailing the advantages and disadvantages of each technique or the actual processes which are vitally important in obtaining satisfactory results is far beyond the scope of this document. A few brief comments may, however, enable interested persons to pursue the topic to their satisfaction.

Evaporation, via heat, will concentrate all elements except those which are volatile. On the other hand, evaporation by

freeze-drying is capable of concentrating all the metals in a sample. Between these two extremes of technique, other methods concentrate a varying proportion of constituents of interest. For example, electrochemical techniques, such as pyrolytic graphite electrodes, are useful in the concentration of copper, mercury, cobalt, chromium and nickel, whereas solvent extraction (APDC-DDTC/MIBK) is capable of concentrating silver, iron, zinc and lead, in addition to the above. Ion-exchange, as described by Riley & Taylor [23], is being increasingly used and deals with some rarer water contaminants such as thorium and scandium, as well as the conventional elements. The advantage of the three methods of concentration - solvent extraction, electrodeposition and ion-exchange - is that they provide a means for freeing the elements of interest from the matrix whose concentration by other techniques often leads to serious difficulty in subsequent quantification of the element. Apart from the use of cation exchange resins, such as Chelex 100 and others, greater use is now being made of the power of macroreticular resins for concentrating the organic material in drinking water. Junk et al. [24] have detailed the use of the macroreticular resin XAD-2 as a good general extraction technique because of its ability to concentrate (or adsorb) many different types of organic compound found in drinking water and, thus, permit analysis to detect minute concentrations in water. Bayermann [25] deals with the variety of techniques which are suitable for the extraction of microorganic material from water supplies.

Removal of Deleterious Substances from Potable Water

No system of laboratory examination, however meticulously performed, is a substitute for a complete knowledge of the conditions at a water source or the conditions existing within a distribution system, the adequacy of a treatment process or the diligence of the various operators. These items make important contributions to a safe and satisfactory drinking-water supply. Samples, as previously stressed, are but representative of a single instant in time, and the laboratory results, however expedited, are but historical records of water quality. Surveillance as an ongoing assiduous process is the most effective way in which public health may be adequately protected once the quality of the source supply has been assured. The common practice over many years was to provide drinking-water supplies, especially to large urban communities, from groundwater supplies supplemented by an upland water source free from contamination. With the population growth and the limitation in additional upland water sources, more contaminated lowland sources have had to be commissioned to provide the volume of water required to meet public needs.

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The increasing public concern about the possible health effects of certain chemical pollutants in lowland supplies has led to the introduction of more exacting methods of water treatment in an endeavour to produce potable water as free as possible from health-related contaminants. Groundwater, with its customary high degree of purity, has been the preferred source of drinking water because it required little treatment apart, perhaps, for occasional disinfection to combat microbial pollution which occasionally was troublesome. However, groundwater sometimes contains aggressive levels of carbon dioxide, iron and sometimes manganese, both the latter needing aeration and sand filtration for their removal. To increase agricultural production, the farming community has stepped up its use of fertilizers, and the leaching of nitrate applied to land has sometimes been troublesome in groundwater. The health-related aspect of nitrate intake via water supply, especially concerning babies, is of such importance that WHO particularly advised a controlled intake by recommending 10 mg of NO_3-N per litre of drinking water. Effective removal at the present time may be achieved only by ion-exchange, which is both complex and costly and leads to disposal problems of the eluate. Many groundwater supplies today, especially perhaps within the European countries, are becoming increasingly subject to contamination by industrial chemicals and agrochemicals, and the presence of many volatile organochlorine compounds is particularly worrying.

This type of pollution then relegates contaminated groundwater to the category of lowland surface waters which require more extensive treatment to render them suitable for consumption by the population. Polluted groundwater and lowland river supplies, as a preliminary treatment, often require the removal of ammonia, a common contaminant, and occasionally nitrate removal by the method mentioned above. A series of additional treatment stages is then required, depending upon the degree and variety of contaminants present in the supply. The usual sequence of treatment is the addition of trivalent chemicals, with or without polymeric additions, which, by hydrolysing in the water, coagulate and adsorb a host of undesirable contaminants, such as clays, silts and metals, and by flocculation and sedimentation of the coagulant, frees the aqueous phase from a host of objectionable substances. Filtration of the aqueous phase refines this process but does not, unfortunately, remove many of the microorganic contaminants.

Depending upon the level of contamination in the water source, the coagulation process may be a single or two-stage process. In some special circumstances the coagulation process may well be more effectively followed by a flotation process for removal of the "floc", than the sedimentation following flocculation. Processes of this nature have been repeatedly demonstrated to be ineffective in removing the health-related organic compounds in a water source.

In those water undertakings where the water source on occasion had problems of taste and odour, intermittent dosing with powdered activated carbon has been the accepted additional treatment for some time. Many investigations into the intermittent taste and odour problems indicated that the majority of such cases was due to the presence of organic substances either produced biologically or caused by the discharge to the source of a volatile organic solvent [27]. The use of powdered carbon, on an intermittent basis, is expensive and, in those treatment works not designed to accommodate such a treatment stage, often troublesome. Many river sources are now prone to continuous taste and odour problems, in addition to contamination by pesticides, herbicides and other organic chemicals, which originate from the almost constant discharge to the river of both industrial and sewage effluents. This situation has led to the permanent installation of a carbon adsorption treatment process, usually in the form of granular activated carbon towers and filters for the removal of the organic contaminants which are troublesome. Unfortunately, adsorption decreases with increasing polarity, or water solubility, of the organic compound so that not all the troublesome material is effectively removed. However, those organic compounds with the greatest adverse health effect are removed effectively by this process. To practise granular activated carbon organic removal in the most effective manner, the prior complete removal of any suspended coagulant floc must be ensured. Many different grades of granulated activated carbon are available for use, but usually the one found most effective in water treatment for the removal of trace organic compounds is the grade produced by high-temperature steam activation [see 27]. These troublesome compounds can be removed with other methods, for example, synthetic polymeric resins, reverse osmosis and ultrafiltration, the details of which also will be found in reference 27.

Future Trends

The future is never simple to anticipate, but often, by considering past events, some appreciation of future events may be gleaned. For example, laxity in the past in the disposal of hazardous and toxic waste material will result in increasing pollution of many hitherto "safe" groundwater supplies. This will be particularly so from the presence of volatile chlorinated organic solvents whose evaporation will be suppressed underground. The increasing use of substances of this character, both by dry-cleaning establishments and industry as a degreasing agent, will exacerbate the problem. The innovative organic chemist is constantly searching for compounds with properties to meet specific industrial or commercial needs, and the pesticides and herbicides are excellent examples of the progress in this field. Many such compounds will

find their way into community life far ahead of the resources of the toxicological fraternity to evaluate with assurance their human health impact. Vigilantly safeguarding water resources and preventing the access of chemicals to such resources is perhaps the most effective way in which to protect the integrity of drinking water and thus the health of the population. The correct determination of concentration levels of those water constituents which pose a threat to human health, such as polynuclear aromatic hydrocarbons, chlorinated ethylenes and the cationic species, is essential to the protection strategy.

At present practices are permitted which are known to endanger the community's most valuable possession - its health, and agricultural practices are not the least offenders. The liberal application of synthetic organic chemicals by way of insecticides, pesticides and herbicides, in an endeavour to increase agricultural production, cannot fail to have an adverse impact upon water resources. Many of these compounds are extremely potent, especially those with phosphorus in the molecule, and frequently the human health effects will not be fully appreciated within the span of one generation. Recently, the merits of the use of chlorine as a water disinfectant in combating harmful microorganisms in public water supplies has been much debated. The position of WHO has always been that the microbial safety of a public water supply must not be jeopardized in an attempt to mitigate the potential harmful effects of substances which may be formed by interaction of the disinfectant and natural organic material in resource water. Obviously, efforts should be made to ensure that no substance adverse to health is present in a drinking-water supply. However, the urge to find chlorine alternatives in an endeavour to avoid overproduction of such compounds should perhaps be tempered until clear-cut toxicological data, at present rather weak, are available upon which sound, unbiased judgement can be made quantifying the hazard.

The one outstanding weakness the administrators face at the moment concerning the formulation of drinking-water quality is the absence of firm toxicological guidance relating to the myriad of microorganic contaminants which the analytical chemist has identified in drinking water. It must also be firmly kept in mind that the compounds which the latter has identified constitute but 15 to 20% of the total organic contamination, and the unidentified organic component may indeed present just as formidable a health challenge as that by the known compounds.

The Bucharest meeting plainly showed that countries within the European Region are equally afflicted by the difficult problem of water pollution by chemicals and the problems of monitoring such water to ensure drinking-water supplies of acceptable quality. Therefore, as the meeting emphasized, more information is vitally needed to clarify the levels and, thus, the potential health problems of water contaminants about which data appear to be lacking.

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Annex

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