GUIDELINES FOR DRINKING-WATER QUALITY

Vol. 1. Recommendations

WORLD HEALTH ORGANIZATION

The World Health Organization is a specialized agency of the United Nations with primary responsibility for international health matters and public health. Through this organization, which was created in 1948, the health professions of some 160 countries exchange their knowledge and experience with the aim of making possible the attainment by all citizens of the world by the year 2000 of a level of health that will permit them to lead a socially and economically productive life.

By means of direct technical cooperation with its Member States, and by stimulating such cooperation among them, WHO promotes the development of comprehensive health services, the prevention and control of diseases, the improvement of environmental conditions, the development of health manpower, the coordination and development of biomedical and health services research, and the planning and implementation of health programmes.

These broad fields of endeavour encompass a wide variety of activities, such as developing systems of primary health care that reach the whole population of Member countries, promoting the health of mothers and children; combating malnutrition; controlling malaria and other communicable diseases including tuberculosis and leprosy; having achieved the eradication of smallpox, promoting mass immunization against a number of other preventable diseases; improving mental health; providing safe water supplies; and training health personnel of all categories

Progress towards better health throughout the world also demands international cooperation in such matters as establishing international standards for biological substances, pesticides and pharmaceuticals; formulating environmental health criteria; recommending international nonproprietary names for drugs; administering the International Health Regulations, revising the International Classification of Diseases, Injuries, and Causes of Death; and collecting and disseminating health statistical information.

Further information on many aspects of WHO's work is presented in the Organization's publications.

GUIDELINES FOR DRINKING-WATER QUALITY

Volume 1

Recommendations

World Health Organization

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PREFACE

The *Guidelines for drinking-water quality* are intended for use by countries as a basis for the development of standards, which, if properly implemented, will ensure the safety of drinking-water supplies. It must be emphasized that the levels recommended in the guidelines for water constituents and contaminants are not standards in themselves. In order to define standards, it is necessary to consider these recommendations in the context of prevailing environmental, social, economic, and cultural conditions.

Guideline values for various constituents of drinking-water are given in this volume. Volume 2 of the *Guidelines for drinking-water quality* contains the criteria monographs that were prepared for each substance or contaminant; the guideline values are based on these. Volume 3 is intended to serve a very different purpose: it contains recommendations and information concerning what needs to be done in small communities and in rural areas to safeguard the water supplies.

These guidelines are intended to supersede both the *European standards for drinking-water* (*1*) and the *International standards for drinking-water* (*2*) which have been in existence for over a decade. While it is appreciated that it may not be possible in some countries to provide potable water that attains all the levels recommended in this volume, it is hoped that each country will try to develop water quality standards as close as possible to these guideline values in an endeavour to protect public health.

The compilation of these *Guidelines for drinking-water quality* covered a period of three years and, during that period, additional scientific information became available; none of this, however, alters significantly the guideline values proposed. It is possible, however, that as further new information becomes available, some guideline values may require revision in due course.

Work done under the auspices of the International Programme on Chemical Safety (IPCS) will considerably influence future updating of these guidelines. IPCS is a cooperative venture of the United Nations Environment Programme (UNEP), the International Labour Organisation (ILO), and the World Health Organization (WHO) and has as two of its main objectives the evaluation of the effects of chemicals on human health and the quality of the environment and the development of guidelines on exposure limits (such as acceptable daily intakes and maximum permissible or desirable levels in air, water, food, and the working environment) for various classes of chemicals, including food

additives, industrial chemicals, toxic substances of natural origin, plastics, packaging materials, and pesticides.

These guidelines have been developed by WHO to describe the quality of water that is suitable for drinking purposes under all circumstances. It is intended that these guidelines should be applied in developing national standards, not only for community piped-water supplies but also for all water used for drinking purposes, including that obtained from community standpipes and wells and drinking-water distributed by tankers or in bottles. The guidelines can also serve as a basis for developing standards for water supplies serving transient populations (e.g., in transportation terminals, on trains, boats or aircraft, in pilgrimage and refugee centres and recreational camps, and at rallies or fairs), as these have been implicated in a number of epidemics of waterborne diseases. The guidelines do not apply to bottled mineral waters, which should be regarded as beverages rather than drinking-water in the usual sense of the word.

The main reason for departing from the previous practice of prescribing international standards for drinking-water quality is the desirability of adopting a risk–benefit approach (qualitative or quantitative) to national standards and regulations. Standards and regulations achieve nothing unless they can be implemented and enforced, and this requires relatively expensive facilities and expertise. Furthermore, water is essential to sustain life and must be available even if the quality is not entirely satisfactory. Adoption of too-stringent drinking-water standards could limit the availability of water supplies that meet those standards— a significant consideration in regions of water shortage. Therefore, it is to be expected that the adoption of standards will be influenced by national priorities and economic factors. However, considerations of policy and convenience must never be allowed to endanger public health.

The probability and potential consequences of bacterial contamination are such that its control must always be of paramount importance. For example, drinking-water of high bacteriological quality, but subject to high salinity, may be rejected by the consumer as unpalatable, in favour of a water that is aesthetically more pleasing but may be bacteriologically unsound. There is also wide variation in different regions and countries in such factors as the amount of water consumed daily, and this will have a bearing on the potential intake of chemicals from drinking-water.

Land use in the watershed and the nature of the water source (e.g., surface-water, ground-water) will often dictate the need for standards to control the chemical and aesthetic variables included in these guidelines. Thus, in some localities, the risk posed by small amounts of carcinogenic industrial chemicals in the water may be of major importance; in others, agricultural practices or vector control programmes may lead to a potential danger from pesticide residues occurring in the water.

Although the main purpose of these guidelines is to provide a basis for the development of drinking-water standards, the information given may

also be of assistance in developing alternative control procedures when the implementation of standards is not feasible. For example, adequate codes of practice for the installation and operation of water-treatment plants and water supply and storage systems, and for household plumbing, may promote safer drinking-water supplies by increasing the reliability of the service, avoiding the use of undesirable materials (e.g., lead pipes exposed to plumbo-corrosive water), and by simplifying repair and maintenance.

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The development of these guidelines was organized and carried out jointly by WHO headquarters and the WHO Regional Office for Europe. The coordinators were, respectively, Dr H. Galal-Gorchev and Mr W. M. Lewis. The preparation of the guidelines was made possible by the financial support afforded to WHO by the Danish International Development Agency (DANIDA) which is gratefully acknowledged. Appreciation is also extended to the United States Environmental Protection Agency who supported this effort by the secondment of Dr Galal-Gorchev for a period of two years.

The preparation of the new guidelines involved the active participation of nearly 30 WHO Member States, scores of scientists, and meetings of 10 task groups. The work of these institutions and scientists, whose names appear in Annex 1, was central to the successful completion of the guidelines and is much appreciated. The collaboration of the national focal points for the WHO Environmental Criteria Programme, various international organizations, and individual experts was most helpful and their continuing participation contributed effectively to the work.

1. INTRODUCTION

1.1 Consumer perception of drinking-water quality

In assessing the quality of drinking-water, the consumer relies completely upon his senses. Water constituents may affect the appearance, smell, or the taste of the water and the consumer will evaluate the quality and the acceptability essentially on these criteria. Water that is highly turbid, highly coloured, or has an objectionable taste will be regarded as dangerous and will be rejected for drinking purposes. However, we can no longer rely entirely upon our senses in the matter of quality judgement. The absence of any adverse sensory effects does not guarantee the safety of water for drinking.

The primary aim of the *Guidelines for drinking-water quality* is the protection of public health and thus the elimination, or reduction to a minimum, of constituents of water that are known to be hazardous to the health and wellbeing of the community.

1.2 Priorities as regards water quality

The relative priorities assigned to the many substances for which guideline values are given later in this book will depend on local circumstances. Some guideline values, e.g., for colour and pH, are not related directly to health, but have been applied widely and successfully over many years to ensure the wholesomeness of water.

The microbiological quality of drinking-water is of the greatest importance, however, and must never be compromised in order to provide aesthetically pleasing and acceptable water.

1.3 Nature of guideline values

(*a*) A guideline value represents the level (a concentration or a number) of a constituent that ensures an aesthetically pleasing water and does not result in any significant risk to the health of the consumer.

(*b*) The quality of water defined by the *Guidelines for drinking-water quality* is such that it is suitable for human consumption and for all usual domestic purposes, including personal hygiene. However, water of

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a higher quality may be required for some special purposes, such as renal dialysis.

(c) When a guideline value is exceeded this should be a signal: (i) to investigate the cause, with a view to taking remedial action; (ii) to consult with authorities responsible for public health for advice.

(d) Although the guideline values describe a quality of water that is acceptable for lifelong consumption, the establishment of these guidelines should not be regarded as implying that the quality of drinking-water may be degraded to the recommended level. Indeed, a continuous effort should be made to maintain drinking-water quality at the highest possible level.

(e) The guideline values specified have been derived to safeguard health on the basis of lifelong consumption. Short-term exposures to higher levels of chemical constituents, such as might occur following accidental contamination, may be tolerated but need to be assessed case by case, taking into account, for example, the acute toxicity of the substance involved.

(f) Short-term deviations above the guideline values do not necessarily mean that the water is unsuitable for consumption. The amount by which, and the period for which, any guideline value can be exceeded without affecting public health depends on the specific substance involved.

It is recommended that, when a guideline value is exceeded, the surveillance agency (usually the authority responsible for public health) should be consulted for advice on suitable action, taking into account the intake of the substance from sources other than drinking-water (for chemical constituents), the likelihood of adverse effects, the practicability of remedial measures, and similar factors.

(g) In developing national drinking-water standards based on these guidelines, it will be necessary to take account of a variety of local geographical, socioeconomic, dietary, and industrial conditions. This may lead to national standards that differ appreciably from the guideline values.

(h) In the case of radioactive substances, the term guideline value is used in the sense of "reference level" as defined by the International Commission on Radiological Protection (ICRP).[a]

1.4 Derivation of guideline values for toxic chemicals

In arriving at the guideline values for various substances in water, the total intake from air, food, and water for each substance is taken into

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[a] "Reference levels may be established for any of the quantities determined in the course of radiation protection programs, whether or not there are limits for these quantities. A reference level is not a limit and is used to determine a course of action when the value of a quantity exceeds or is predicted to exceed the reference level." *Annals of the ICRP*, 1(3):1–53 (1977) (ICRP Publication 26).

consideration, as far as possible from the information available; it is assumed that the daily *per capita* consumption of water is 2 litres.

For the majority of the substances for which guideline values are proposed, the toxic effect in man is predicted from studies with laboratory animals. The accuracy and reliability of a quantitative prediction of toxicity in man from animal experimentation depend upon a number of factors, e.g., choice of animal species, design of the experiment and, not least, extrapolation methods (*3*). However, for most of the organic compounds considered, the difference in chemical pathogenesis between animals and man is mainly quantitative, although qualitative differences also exist.

Data on the toxicity of chemicals are obtained from experiments in which the adverse effect occurs at considerably higher dosages than would be experienced in man. When extrapolating from such animal data to man, therefore, a safety factor must be introduced to provide for the unknown factors involved. The current doubts concerning both the biological and the mathematical reliability of methods of extrapolating from high doses to low doses necessitate the use of somewhat arbitrary safety factors, such as reduction by a factor of 100 or 1000.

These uncertainties arise from the nature of the toxic effects and the quality of the toxicological information. Other considerations are the size and type of the population to be protected, and thus under certain conditions safety factors (or uncertainty factors) as high as 1000 may be necessary.

However, assessment of the health risk to the population involves more than routine application of safety factors, and it must be emphasized that strictly speaking the extrapolation from animal experimentation applies only to the conditions of the particular experiment.

The existing methods of extrapolation from animal data to man deal with exposures to single substances, whereas in the human environment a large number of hazardous chemicals and other factors may interact. In the special case of substances possessing carcinogenic properties, this book illustrates the rationale of using a risk factor in arriving at the proposed guideline value. Owing to the considerable uncertainties in the available evidence, the proposed guideline values are in many cases deliberately cautious in character and therefore must not be interpreted as standards.

A judgement about safety—or what is an acceptable risk level in particular circumstances—is a matter in which society as a whole has a role to play. The final judgement as to whether the benefit from adopting any of these proposed guidelines does or does not justify the risk is for each country to decide. What must be re-emphasized is that the guideline values proposed are not strict standards that must be adhered to, but are subject to a wide range of flexibility and are provided essentially in an endeavour to protect public health and enable

a judgement to be made regarding the provision of drinking-water of acceptable quality.

1.5 Operational procedure

In order to undertake the task of reviewing the relevant information and to develop recommendations for the values contained in these guidelines, a number of task groups were convened.[a] In arriving at their recommendations, the groups had the advantage of guidance from various WHO publications, such as the various volumes of *Environmental Health Criteria*, together with the reports of various WHO working groups on items of relevance. In addition, the groups re-examined the existing WHO drinking-water quality standards, and the various comments and observations that WHO had received over the years, before making their final decision.

In addition to a guideline value, a criteria monograph was prepared for each constituent and is the basis upon which recommendations have been prepared. The criteria monographs for each of the constituents and characteristics examined constitute Volume 2 of *Guidelines for drinking-water quality*, and contain the critical parts of the evidence used in deriving guideline values. They cover aspects such as general description; routes of exposure; metabolism; health effects; and basic literature references. Such information is of great importance in the interpretation of the guideline values.

In the subsequent chapters of the present volume, the recommended guideline values are summarized, together with a brief description of the rationale employed in establishing the values and essential information regarding monitoring and remedial measures.

1.6 Summary tables of guideline values

In presenting this summary of guideline values (Tables 1–5), it is not intended that individual values should be used directly from the tables. Guideline values must be used and interpreted in conjunction with the information contained in the appropriate section of Chapters 2–5 of this book.

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[a] Task groups and other meetings:

Initial consultation	12–15 December 1978, Copenhagen, Denmark
Microbiology	17–21 December 1979, Medmenham, England
Organic contaminants (selection)	18–20 March 1980, Leidschendam, Netherlands
Biological contaminants	15–17 July 1980, Geneva, Switzerland
Inorganic contaminants	22–26 September 1980, Copenhagen, Denmark
Organic contaminants (quantification)	18–25 November 1980, Ottawa, Canada
Aesthetic and organoleptic aspects	2–5 February 1981, Copenhagen, Denmark
Application of the guidelines	1–5 June 1981, Alexandria, Egypt
Radioactive contamination	3–5 March 1982, Copenhagen, Denmark
Final meeting	22–26 March 1982, Geneva, Switzerland.

The lists of participants for each of the above meetings are given in Annex 1.

Table 1. Microbiological and biological quality

Organism	Unit	Guideline value	Remarks
I. Microbiological quality			
A. Piped water supplies			
A.1 Treated water entering the distribution system			
faecal coliforms	number/100 ml	0	turbidity < 1 NTU; for disinfec-
coliform organisms	number/100 ml	0	tion with chlorine, pH preferably < 8 0, free chlorine residual 0.2–0.5 mg/litre following 30 minutes (minimum) contact
A 2 Untreated water entering the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 98% of samples examined throughout the year—in the case of large supplies when sufficient samples are examined
coliform organisms	number 100 ml	3	in an occasional sample, but not in consecutive samples
A.3 Water in the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 95% of samples examined throughout the year—in the case of large supplies when sufficient samples are examined
coliform organisms	number/100 ml	3	in an occasional sample, but not in consecutive samples
B. Unpiped water supplies			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	10	should not occur repeatedly, if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible
C. Bottled drinking-water			
faecal coliforms	number/100 ml	0	source should be free from faecal contamination
coliform organisms	number/100 ml	0	
D Emergency water supplies			
faecal coliforms	number/100 ml	0	advise public to boil water in case
coliform organisms	number/100 ml	0	of failure to meet guideline values
Enteroviruses	—	no guideline value set	
II. Biological quality			
protozoa (pathogenic)	—	no guideline value set	
helminths (pathogenic)	—	no guideline value set	
free-living organisms (algae, others)	—	no guideline value set	

Table 2. Inorganic constituents of health significance

Constituent	Unit	Guideline value	Remarks
arsenic	mg/l	0 05	
asbestos	—	no guideline value set	
barium	—	no guideline value set	
beryllium	—	no guideline value set	
cadmium	mg/l	0 005	
chromium	mg/l	0.05	
cyanide	mg/l	0 1	
fluoride	mg/l	1 5	natural or deliberately added, local or climatic conditions may necessitate adaptation
hardness	—	no health-related guideline value set	
lead	mg/l	0 05	
mercury	mg/l	0 001	
nickel	—	no guideline value set	
nitrate	mg/l (N)	10	
nitrite	—	no guideline value set	
selenium	mg/l	0.01	
silver	—	no guideline value set	
sodium	—	no guideline value set	

Table 3. Organic constituents of health significance

Constituent	Unit	Guideline value	Remarks
aldrin and dieldrin	μg/l	0.03	
benzene	μg/l	10[a]	
benzo[a]pyrene	μg/l	0 01[a]	
carbon tetrachloride	μg/l	3[a]	tentative guideline value [b]
chlordane	μg/l	0 3	
chlorobenzenes	μg/l	no health-related guideline value set	odour threshold concentration between 0 1 and 3 μg/l
chloroform	μg/l	30[a]	disinfection efficiency must not be compromised when controlling chloroform content
chlorophenols	μg/l	no health-related guideline value set	odour threshold concentration 0 1 μg/l
2,4-D	μg/l	100[c]	
DDT	μg/l	1	
1,2-dichloroethane	μg/l	10[a]	
1,1-dichloroethene[d]	μg/l	0 3[a]	
heptachlor and heptachlor epoxide	μg/l	0 1	
hexachlorobenzene	μg/l	0 01[a]	
gamma-HCH (lindane)	μg/l	3	
methoxychlor	μg/l	30	
pentachlorophenol	μg/l	10	
tetrachloroethene[d]	μg/l	10[a]	tentative guideline value[b]

Table 3 (*continued*)

Constituent	Unit	Guideline value	Remarks
trichloroethene[d]	μg/l	30[a]	tentative guideline value[b]
2,4,6-trichlorophenol	μg/l	10[a, c]	odour threshold concentration, 0 1 μg/l
trihalomethanes		no guideline value set	see chloroform

[a] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently Uncertainties involved may amount to two orders of magnitude (i e , from 0 1 to 10 times the number)

[b] When the available carcinogenicity data did not support a guideline value, but the compounds were judged to be of importance in drinking-water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data

[c] May be detectable by taste and odour at lower concentrations

[d] These compounds were previously known as 1,1-dichloroethylene, tetrachloroethylene, and trichloroethylene, respectively

Table 4. Aesthetic quality

Constituent or characteristic	Unit	Guideline value	Remarks
aluminium	mg/l	0.2	
chloride	mg/l	250	
chlorobenzenes and chlorophenols	—	no guideline value set	these compounds may affect taste and odour
colour	true colour units (TCU)	15	
copper	mg/l	1 0	
detergents	—	no guideline value set	there should not be any foaming or taste and odour problems
hardness	mg/l (as $CaCO_3$)	500	
hydrogen sulfide	—	not detectable by consumers	
iron	mg/l	0 3	
manganese	mg/l	0 1	
oxygen—dissolved	—	no guideline value set	
pH	—	6.5–8.5	
sodium	mg/l	200	
solids—total dissolved	mg/l	1000	
sulfate	mg/l	400	
taste and odour	—	inoffensive to most consumers	
temperature	—	no guideline value set	
turbidity	nephelometric turbidity units (NTU)	5	preferably <1 for disinfection efficiency
zinc	mg/l	5.0	

Table 5. Radioactive constituents

Constituent	Unit	Guideline value	Remarks
gross alpha activity	Bq/l	0.1	(a) If the levels are exceeded more detailed radionuclide analysis may be necessary. (b) Higher levels do not necessarily imply that the water is unsuitable for human consumption
gross beta activity	Bq/l	1	

1.7 Application of the guidelines

1.7.1 Laws, regulations, and standards

Effective programmes to control drinking-water quality depend ideally upon the existence of adequate legislation, supported by regulatory standards and codes that specify the quality of the water to be supplied to the consumer, practices to be followed in selecting water sources, in treatment, and in distribution. The precise nature of the legislation will, of course, be dictated by national, constitutional, and other considerations, but some features commonly incorporated in such legislation include:

(a) specification of the scope of authority;
(b) delegation of powers to administer the law to a specified agency or agencies;
(c) provision for the establishment and amendment of regulations for the development, production, maintenance, and distribution of safe drinking-water; and
(d) provision for enforcement.

Many countries lack such basic legislation and in others the existing legislation is seriously out of date. However, much can be done under general welfare or health legislation, or on the basis of voluntary cooperation. Implementation of programmes to provide safe drinking-water should not be delayed because of the lack of appropriate legislation.

1.7.2 Compliance and surveillance

The organizational arrangements to ensure compliance with drinking-water quality standards are fully discussed in *Surveillance of drinking-water quality (4)*. In general, it is the responsibility of the local water authority to ensure that the water it produces meets the quality defined in drinking-water standards. However, the surveillance function (i.e., a policing function on behalf of the public, to oversee operations and

ensure the reliability and safety of drinking-water) is best conducted in a separate agency (whether national, state, provincial, or local). Although these two functions are complementary, experience suggests that they are better carried out in separate agencies because of the conflicting priorities that exist when both functions are combined. The basic characteristics of the surveillance function are such that the agency responsible for public health protection is frequently assigned this task.

Drinking-water standards provide a basis for decision-making in the following activities that ideally should be included in the surveillance function:

(*a*) approval of new sources (including privately-owned supplies);
(*b*) watershed protection;
(*c*) approval of the construction and operating procedures of waterworks, including:

> (i) disinfection of the plant and of the distribution system after repair or interruption of supply,
> (ii) periodic flushing programmes and cleaning of water storage facilities,
> (iii) certification of operators,
> (iv) regulation of chemical substances used in water treatment,
> (v) cross-connection control, back-flow prevention, and leak detection control programmes;

(*d*) sanitary surveys;
(*e*) monitoring programmes, including provision for central and regional analytical laboratory services;
(*f*) development of codes of practice for well construction, pump installation, and plumbing (*5*);
(*g*) inspection and quality control in bottled-water and ice manufacturing operations.

1.7.2.1 *Source of water*

Selection of source. In selecting a source of drinking-water, a number of factors may influence the health of consumers. In particular, attention must be given to possible future developments that may influence the continued suitability of the source. Important considerations include:

(*a*) Quantity (source capacity): Is the quantity of water available at the source sufficient to meet continuing water demands, taking into account daily and seasonal variations and projected growth in the size of the community being served? Operation of treatment plants beyond design capacity may lead to deterioration in the quality of the water supplied. Periodic shortages may force users to alternative, less safe sources.

(*b*) Quality: Is the raw water quality such that, with appropriate treatment, water can be supplied that meets or exceeds the quality specified in the drinking-water standards (*6*)?

(*c*) Protection: Can the watershed be protected from pollution with human excreta, industrial discharges, and agricultural run-off? Is the institutional framework available for, and are the related organizations technically and administratively capable of, controlling pollution? Are the regulatory powers and resources available for controlling potential pollution of the water source?

(*d*) Feasibility: Is the source available at reasonable cost (both in absolute terms and in comparison with possible alternative sources of supply)?

(*e*) Treatability: Can the raw water be treated adequately under locally prevailing conditions?

Potential new sources should be examined in the field by suitably qualified and experienced sanitary surveyors and physical, bacteriological, and chemical analyses should be carried out for a suitable period (e.g., covering seasonal variations) prior to final selection of the source. Such information is essential in order to define appropriate water treatment requirements and necessary pollution control measures to protect raw water resources (*7*).

When alternative water sources are under consideration, each should be surveyed. Other things being equal, it is preferable to choose the source that requires the least treatment; in the case of small undertakings, provision of water from protected wells or springs of good quality is often preferable to treatment of surface water (*8*).

Safeguarding purity of supplies. The guideline values given in this book for potentially hazardous substances in drinking-water have been set as low as possible, with the object of discouraging the deterioration, directly or indirectly, of drinking-water quality.

Although water that contains substances at concentrations lower than the guideline values specified here is acceptable for lifelong consumption, the establishment of a guideline value should not be regarded as implying that the quality of drinking-water may be degraded to the recommended level.

Prevention of contamination. Because water from community wells and springs is often not chlorinated, there is a particular need to protect the sanitary quality of the water from such sources in order to ensure that the water will continue to meet the guideline values for microbiological quality. In particular, sources should be protected from contaminants emanating from septic tanks, sewers, cesspools, sullage water, and flooding and from contamination by users (*9, 10*).

Maintaining adequate residual chlorine levels in the distribution system is the most reliable indicator of protection against contamination resulting from cross-connections, back siphonage, leaks, etc. Interruptions of supplies, for example as a result of the frequent practice of

rotating service to different sections of the service network in areas of water shortage, often result in contamination of drinking-water supplied to the consumer.

Slum areas within towns and in rapidly growing fringe areas present special problems in maintaining drinking-water quality. Although these areas may be located within a distribution network, the density of the population, lack of house connections, intermittent service, low pressures, leaks, and lack of sewerage systems may result in high-risk water distribution systems. These areas should receive priority for extension of safe supplies; in the meantime, they should receive additional surveillance attention.

When piped water is not available, the population may resort to using contaminated ground-water, unprotected surface waters, or tanker supplies, or to illegal abstraction from the nearby system by means of unauthorized take-offs (with high potential for contamination of the main distribution network).

The obvious possibilities for widespread transmission of disease through the use of bottled water and ice indicate a special need to ensure that the water used meets the same standards as for drinking-water. Regulations for the manufacture of bottled water typically include approval and periodic inspection of the records, sanitation and maintenance practices, and the bottles, caps, and labels used, and a monitoring programme for bacteriological quality that relates sample frequency to the number of customers served or the volume bottled per month.

1.7.2.2 Sanitary surveys

While drinking-water standards provide authoritative criteria concerning the acceptability of water for human consumption, the prescription of standards in no way obviates the need for sanitary surveys.

The sanitary survey is an on-site inspection and evaluation by a qualified person of all the conditions, devices, and practices in the water supply system that pose, or may pose, a danger to the health and wellbeing of the water consumer. In 1976, a WHO monograph provided a detailed description of the requirements for sanitary surveys, including guidelines for their conduct (4).

No bacteriological or chemical analysis of samples, however carefully it is carried out, is a substitute for a complete knowledge of conditions at the source and within the distribution system, of the adequacy of treatment, and of the qualifications and performance of the operators. Samples represent a single point in time, and the results of analysis are reported after the event. Contamination is often random and intermittent and may not be revealed by occasional sampling.

Sanitary surveys should be undertaken on a regular basis by the personnel of the water authority, as well as by personnel of the

surveillance (control) agency. In addition, sanitary surveys should be conducted.

(a) when new sources of water are being developed;
(b) when laboratory analyses indicate a potential hazard to health;
(c) when an outbreak of disease, which could be waterborne, occurs in or near the area served by the water supply system;
(d) when any significant change or event occurs that could affect water quality (e.g., beginning of rainy season, change in agricultural pattern, new industrial construction on the watershed).

Sanitary surveys should be conducted with sufficient frequency to be useful in interpreting trends or sudden significant changes in the quality of drinking-water as determined by physical, microbiological, and chemical monitoring.

Although smaller systems often present proportionally greater hazards, the larger systems should be inspected more frequently because of the larger population at risk and greater cost-effectiveness of surveillance. The smaller systems should also be surveyed, but with realistic frequency depending on the quality of the source water. Rural areas give rise to special problems with regard to sanitary surveys, in particular the physical and economic difficulty of surveying innumerable small water supplies. Efforts by surveillance agencies must focus primarily on (a) encouragement and stimulation of individuals and community groups to make their own improvements, (b) provision of information on proven techniques, and (c) provision of technical assistance in site selection, design, and construction. Demonstration of proper practice is better than condemnation.

1.7.2.3 *Priorities for monitoring*

Establishing water-quality testing laboratories should be considered an item of high priority within the functions of the authorities responsible for the provision of safe drinking-water.

Because drinking-water can act as a vehicle for the transmission of a number of serious infectious diseases, the bacteriological quality of water is of paramount importance and monitoring of indicator bacteria such as coliform and faecal coliform organisms should be given the highest priority. However, since the results of conventional bacteriological testing are not available for at least 24 hours (during which time the community may be at risk), measurement of the chlorine residual, which is quick and easy to perform, should also be undertaken frequently where it is appropriate (i.e., where a chlorine residual is maintained throughout the distribution system) to permit immediate corrective action in case of a malfunction in the treatment process or if easily oxidizable material enters the distribution system.

Sanitary surveys can give valuable indications of the relative priorities that should be accorded to the monitoring of chemical constituents. A

knowledge of industrial and agricultural activities conducted in the watershed will often suggest which chemical substances are likely to occur in the drinking-water. The analytical procedures necessary to monitor for these substances, especially the organic compounds, may require the use of relatively sophisticated and expensive equipment which is rarely available. In such cases, calculation of the actual quantities of waste effluents, for example in conjunction with flow rates in water courses, may give an approximate indication of likely concentrations in drinking-water. If such calculations suggest that the probable concentrations approximate or exceed the guideline values, arrangements ought to be made for samples to be analysed at a laboratory possessing the required equipment; however, if the calculations suggest that the probable concentrations in drinking-water will be only a small fraction of the guideline values, the relative priority for monitoring can be assigned accordingly.

Taste, odour, colour, and turbidity of water can be assessed relatively easily and ought to be accorded fairly high priority since they can give useful indications, especially of sudden changes brought about by rupture of pipes, etc. Pleasing aesthetic qualities serve to discourage use of alternative sources (which may be less safe), but while individual home water treatment devices may produce aesthetically pleasing water, their performance may not be satisfactory as regards certain health-related characteristics.

1.7.2.4 *Personnel*

The adoption of drinking-water standards implies the need to provide suitably qualified and experienced staff to undertake surveillance activities, including monitoring the microbiological quality of drinking-water. Guidance on the duties, qualifications, and training of the personnel employed both by the agency responsible for surveillance activities and by the water authorities has been given elsewhere (*4*).

It must be emphasized that care should be exercised in the selection of employees for jobs in which a risk to the purity of the water is likely to arise. Employees suffering from diseases that may be transmitted in water, or who might be carriers of such diseases, should not come into contact with the water during treatment or distribution, or with surfaces that might convey contamination to the water. Any employee suffering from diarrhoea or open sores who is employed on work where there is a risk of the water becoming contaminated should be removed from such work until he or she has fully recovered. These precautions are especially important with untreated water supplies.

In the event of an epidemic or threatened outbreak, special precautions may be needed to ensure that drinking-water supplies remain safe. Close liaison between the waterworks' management and the medical authorities is essential and close medical surveillance of waterworks' employees is particularly important at such times.

1.7.3 Special considerations for small rural water supplies

There are particular problems associated with ensuring that small rural systems comply with drinking-water standards. These can arise, for example, because of the distance and lack of good transportation to the nearest laboratory; bacteriological monitoring is an especial problem. In such cases, especially in the developing countries, emphasis should be placed on:

(*a*) selection of adequate, safe sources, preferably those which do not require treatment;

(*b*) regular and frequent sanitary surveys; local operators should be adequately trained to undertake sanitary surveys;

(*c*) testing to ensure bacteriological quality; if the supply can only be tested once, the most effective samples are those that assist in selecting the source;

(*d*) testing chlorine residuals (in chlorinated systems); this is a quick and easy test to perform and is a good indicator of the bacteriological integrity of waterworks operations;

(*e*) reliability of operation and convenient access to consumers.

1.7.4 Remedial action

The main object of surveillance activities is the detection of deficiencies (and potential deficiencies) in the drinking-water supply as soon as possible, preferably before there is any effect on the health of consumers. It is axiomatic that deficiencies should be corrected with the least possible delay.

This implies rigorous, vigilant examination and analysis of information gathered in surveillance activities. When potential risks are discovered, action must follow. However, it is self-evident that not all potential risks are equally serious. For example, the failure of a chlorination plant during a typhoid outbreak would require immediate correction; provision of a standby chlorinator for a small system drawing water from a deep well might be accorded much lower priority.

1.7.4.1 *Risk assessment*

Since water is essential to life, the first priority is that it must be made available to consumers even if the quality is not entirely satisfactory. Once a potentially hazardous situation has been recognized, however, the probability that the hazard will develop, the potential consequences, and the availability of alternative sources, etc., must be considered in order to make a decision about the acceptability of the risk.

The second priority is to protect the water supply from contamination by faeces, which can contain a variety of bacterial, viral, and protozoan pathogens and helminth parasites. Failure to provide adequate protection or treatment will expose the community at risk to outbreaks

of intestinal diseases. In the community, those at greatest risk of waterborne disease are infants and young children, people who are debilitated, patients recovering from severe burns, surgery, or exposed to radiation, and the elderly. For these people, infective doses are often significantly lower than for the general adult population.

The assessment of the risks associated with variations in microbial quality is difficult and controversial because of insufficient epidemiological evidence, the number of factors involved, and their changing interrelationships. In general terms, the greatest microbial risks are associated with ingestion of water that is grossly contaminated with sewage. Microbial risk cannot be eliminated because the diseases that may be waterborne are also transmitted by person-to-person contact, by aerosols, and by food intake; thus, a reservoir of cases and carriers is maintained.

The fact that chemical contaminants are not normally associated with acute effects places them in a lower priority category than microbial contaminants, the effects of which can be immediate and massive. Indeed, it can be argued that chemical standards for drinking-water are almost irrelevant when gross bacterial contamination occurs. Another consequence of the long-term nature of any hazard associated with chemical constituents is that the guideline values recommended relate to an average level of exposure. Occasional small excesses are acceptable subject to detailed local consideration of their implications. This is made clear in the definition of the guideline values for chemical substances.

1.7.4.2 Correction of deficiencies

Depending upon the nature of the deficiency, a number of alternative measures may be available to the surveillance agency. Some of these may be temporary measures intended to provide some degree of protection in an emergency situation, such as orders to boil water, but such measures must not be allowed to become a substitute for initiating more satisfactory, long-term solutions to the problem.

Evidence of faecal contamination of drinking-water supplies must always be acted upon immediately. However, a decision to close the supply carries an obligation to provide an alternative safe supply. Instructing consumers to boil water, initiating super-chlorination, and undertaking immediate corrective measures may be preferable. Drinking-water standards are intended to ensure that the consumer enjoys safe potable water, not to shut down deficient water supplies.

The immediate objective must be to ensure that remedial action is instituted with as little delay as possible. To do nothing, once a deficiency has been discovered as the result of a surveillance programme, is perhaps worse than having no programme, because the very existence of the programme may encourage a false sense of security in the community. Invoking legal measures to ensure that necessary remedial action occurs is a powerful mechanism (indeed, failure to enforce

regulations, and especially written orders, may weaken the surveillance agency's credibility and reduce its future effectiveness) but there is an obvious danger if such procedures result in delays. Persuasion, education, and motivation are also powerful tools to ensure timely correction of deficiencies.

1.7.4.3 *Follow-up*

Whenever remedial action has been required because of failure to meet drinking-water standards, the surveillance agency must follow up these actions to ensure that the corrective measures have been effective. Failure to ensure rigorous follow-up procedures leads to apathy. Even if the deficiency is minor and immediate action is not required, continuing follow-up (e.g., at 30-day intervals) is recommended to ensure that the situation is not allowed to persist indefinitely by default.

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2. MICROBIOLOGICAL ASPECTS

2.1 The bacteriological quality of drinking-water

2.1.1 Introduction

Water quality guidelines form a basis for judgement of the acceptability of public drinking-water supplies. Any judgement associated with the use of bacteriological guidelines must, however, take into account the precision, validity, and appropriateness of the sampling procedures. Consideration should also be given to the species of waterborne pathogen present, the likely correlation between the levels of pathogens and those of various indicator species, and the capabilities and limitations of water-treatment methods.

Natural and treated waters vary in microbiological quality. Ideally drinking-water should not contain any microorganisms known to be pathogenic. It should also be free from bacteria indicative of pollution with excreta. To ensure that a supply of drinking-water satisfies these guidelines of bacterial quality, it is important that samples should be examined regularly for indicators of faecal pollution. The primary bacterial indicator recommended for this purpose is the coliform group of organisms as a whole. Although as a group they are not exclusively of faecal origin, they are universally present in large numbers in the faeces of man and other warm-blooded animals, thus permitting their detection after considerable dilution. The detection of faecal (thermotolerant) coliform organisms, in particular *Escherichia coli*, provides definite evidence of faecal pollution.

The methods used to detect and confirm the presence of coliform organisms are designed to demonstrate one or more of the properties in the following working definition, which is practical rather than taxonomic:

The term "coliform organisms" (total coliforms) refers to any rod-shaped, non-spore-forming, Gram-negative bacteria capable of growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties, which are cytochrome-oxidase negative and able to ferment lactose at either 35 or 37 °C with the production of acid, gas, and aldehyde within 24–48 hours.

Those which have the same properties at a temperature of 44 or 44.5 °C are described as faecal (thermotolerant) coliform organisms. Faecal coliform organisms which ferment both lactose and other suitable substrates such as mannitol at 44 or 44.5 °C with the production of acid and gas, and which also

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form indole from tryptophan, are regarded as presumptive *E. coli.* Confirmation as *E. coli* may be made by demonstration of a positive result in the methyl red test, by failure to produce acetyl methyl carbinol, and by failure to utilize citrate as the sole source of carbon.

These steps in the detection and confirmation of coliform organisms should be regarded as parts of a progressive sequence, those needed for any particular sample depending partly on the type of water, partly on the objective of the examination, and partly on the capability of the laboratory.

Supplementary indicator organisms, such as faecal streptococci and sulfite-reducing clostridia, may sometimes be useful in determining the origin of faecal pollution as well as in assessing the efficiency of water treatment processes. In drawing up guidelines for the bacterial quality of drinking-water, consideration should be given not only to the source of drinking-water, but also to the treatment, if any, given to it, and to the method by which it is delivered to the consumer, as well as to the frequency with which it should be examined.

2.1.2 Guideline values

The guideline values for bacteriological quality given in Table 6 (page 19) are only a guide to those required to ensure bacteriologically safe supplies of drinking-water whether piped, unpiped, or bottled.

2.1.2.1 *Piped supplies*

(a) *Treated water entering the distribution system*

Efficient treatment culminating in disinfection should yield water free from coliform organisms, however polluted the original raw water may have been. In practice, this means that it should not be possible to demonstrate the presence of any coliform organism in any sample of 100 ml. The finding of a sample of the water entering distribution that shows any deviation from this negative value calls for an immediate investigation into both the efficacy of the treatment process and the method of sampling. When water is disinfected, it is important that the residual disinfectant concentration should be measured regularly and, if possible, recorded continuously. For effective disinfection, it is important that the turbidity should be as low as possible and preferably less than 1 nephelometric turbidity unit (NTU). In addition, when chlorination is practised, the pH should preferably be less than 8.0 and the contact time greater than 30 minutes, resulting in a free chlorine residual of 0.2–0.5 mg/litre. The higher residual is desirable for water from unprotected sources.

(b) *Untreated water entering the distribution system*

The desirability of disinfecting all supplies of piped drinking-water before distribution should be considered. Supplies derived from

Table 6. Guideline values for bacteriological quality

Organism	Unit	Guideline value	Remarks
A Piped water supplies			
A 1 Treated water entering the distribution system			
faecal coliforms	number/100 ml	0	turbidity < 1 NTU, for disinfec-
coliform organisms	number/100 ml	0	tion with chlorine, pH prefer-
			ably < 8 0, free chlorine re-
			sidual 02–0 5 mg/litre follow-
			ing 30 minutes (minimum)
			contact
A 2 Untreated water entering the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 98% of samples examined
			throughout the year—in the
			case of large supplies when
			sufficient samples are
			examined
coliform organisms	number/100 ml	3	in an occasional sample, but
			not in consecutive samples
A.3 Water in the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 95% of samples examined
			throughout the year—in the
			case of large supplies when
			sufficient samples are exam-
			ined
coliform organisms	number/100 ml	3	in an occasional sample but not
			in consecutive samples
B Unpiped water supplies			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	10	should not occur repeatedly, if
			occurrence is frequent and if
			sanitary protection cannot be
			improved an alternative source
			must be found if possible
C. Bottled drinking-water			
faecal coliforms	number/100 ml	0	source should be free from
coliform organisms	number/100 ml	0	faecal contamination
D Emergency water supplies			
faecal coliforms	number/100 ml	0	advise public to boil water in
coliform organisms	number/100 ml	0	case of failure to meet guideline
			values

protected sources which are distributed without disinfection should be similar in quality to that of disinfected drinking-water. No water entering a distribution system should be considered satisfactory if coliform organisms are detected in any sample of 100 ml. The presence of not more than 3 coliform organisms per 100 ml may be tolerated in

occasional samples provided that (1) faecal coliform organisms are absent, (2) the source has been regularly and frequently tested, and (3) sanitary inspection has shown the catchment area and storage conditions to be satisfactory. As a further guide, for large supplies it is recommended that throughout any period of one year no coliform organisms should be detected in 98 % of all routine samples—provided that sufficient samples have been examined. This requirement is not applicable to small supplies, but in the event of an unsatisfactory coliform result, the desirability of increasing the frequency of sampling should also be considered. In addition, coliform organisms should not be detected in any two consecutive routine samples. Consideration should be given to the use of time intervals of less than one year when assessing results from these examinations.

In the event of persistent failures, the area should be surveyed to locate the source of pollution. Whenever the findings of bacteriological examination or of sanitary inspection indicate that the source may be subject to pollution, no matter how remote the chance may be, disinfection should be started as a precautionary measure.

(c) Water in the distribution system

Water that is of potable quality when it enters the distribution system may undergo deterioration before it reaches the consumer. Just as much deterioration may occur in the distribution system of a chlorinated supply in which the residual has been dissipated as in that of a non-disinfected supply; in this respect, therefore, the two are similar. Water in the distribution system may become contaminated through cross-connections, back-siphonage, leaking service connections, defective storage tanks and service reservoirs, and damaged hydrants, during main-laying and repair, or through inexpert repairs to domestic plumbing systems. Such contamination may be at least as dangerous as the distribution of insufficiently treated water. Ideally, all samples taken from the distribution system, including those from consumers' premises, should be free from coliform organisms. In practice, this is not always attainable and for this reason the following guidelines are recommended for water in the distribution system:

—Faecal (thermotolerant) coliforms should not be detectable in any sample of 100 ml.

—No sample of 100 ml should contain more than 3 coliform organisms. If any coliform organisms are found, the minimum action required is resampling immediately, and always within 3 days.

—As a further guide for large supplies, coliform organisms should not be detectable in 95 % of routine samples examined throughout any period of one year. For small supplies, this requirement is not applicable, but, in the event of an unsatisfactory coliform result, the desirability of increasing the frequency of sampling should be considered.

—Coliform organisms should not be detectable in any 2 consecutive routine samples of 100 ml collected from the same sampling location.

The repeated demonstration of coliform organisms, or their appearance in large numbers, suggests that contamination of the water is occurring and remedial action, especially in relation to the chlorine residual, should be taken at once. The actual measures will vary with circumstances but, as a minimum, the water must be resampled. The problem can be considered to be resolved only if a cause is found and eliminated or if a series of samples shows that the pollution was temporary.

No amount of routine bacteriological testing can be expected to detect the chance ingress of pollution caused by back-siphonage or cross-connections. Therefore, all storage tanks should be covered, adequate pressure maintained continuously throughout the supply, and a satisfactory chlorine residual should be maintained. Plumbing systems and equipment connected to the supply should be of an approved type. Special attention should be given to ensure that service connections do not leak; although these may not be under the control of the water supply authority, instructions should be given to explain the effects of such leaks on the quality and quantity of water supplied. These precautions are important as such defects may account for a large proportion of the waterborne diseases associated with a supply.

During the repair and laying of mains, the distribution systems must be protected as far as possible against the ingress of pollution, and on completion of the work the pipes should be flushed and, if possible, disinfected. Before the mains are put into service, or recommissioned, the water in them should be tested to ensure that it is free from faecal organisms. Mains that fail bacteriological tests should be reflushed and disinfected, as appropriate. The detection of coliform bacteria in storage tanks may indicate the need for repairs to, or cleaning of the structure, and may necessitate chlorination at the tank outlet as an emergency measure. Storage tanks should be fitted with suitable taps to avoid the possibility of contamination during sampling.

The unexpected disappearance of a disinfectant residual indicates that material, which could be faecal in origin, has gained access to the water supply. The disappearance of a chlorine residual represents a loss of protection, and such a finding should result in immediate sanitary inspection and bacteriological examination. Whenever there is doubt about the nature of the pollution, especially when coliform organisms only are found, further examination for the presence of supplementary indicator organisms might be of advantage.

2.1.2.2 Unpiped water supplies

Where it is impracticable to supply water to consumers through a piped distribution network and where untreated sources, such as wells,

boreholes and springs—which may not be naturally pure—must be used, the guidelines recommended for piped supplies may not be attainable. In such circumstances, disinfection—although desirable—is not always practicable, and considerable reliance must be placed on sanitary inspection and not exclusively on the results of bacteriological examination. Everything possible should be done to prevent pollution of the water. Obvious sources of contamination should be removed from the immediate catchment area, special attention being given to the safe disposal of excrement (1). Wells and storage tanks should be protected by lining and covering, surface drainage should be diverted, erosion prevented, and the surrounding area paved (2). Access of man and animals should be restricted by fencing, and the source should be so designed that fouling does not occur when water is drawn. Although not supplied through pipes, water from such sources is likely to undergo further deterioration in quality during transport or storage before drinking. Containers used for water should be kept clean, covered, and clear of the floor. The most important factor in achieving these objectives is to ensure the cooperation of the local community, and the importance of education in simple sanitary hygiene must be strongly stressed. In hospitals or medical clinics with such supplies, the value of some form of treatment is evident.

Bacteriologically, the objective should be to reduce the coliform count to less than 10 per 100 ml, but more importantly, to ensure the absence of faecal coliform organisms. If these organisms are repeatedly found, or if sanitary inspection reveals obvious sources of pollution which cannot be avoided, then an alternative source of drinking-water should be sought whenever possible. Greater use should be made of protected ground-water sources and rainwater catchment, as these are more likely to meet the guidelines for potable water quality (3).

Although private sources of drinking-water may be outside the jurisdiction of public health and water supply authorities, such supplies should still be of potable quality. The results of bacteriological tests and those of sanitary surveys should therefore be used to encourage improvement. Partial treatment may be necessary to remove turbidity even when coliform counts are low; and other quality criteria may dictate the need for treatment processes.

2.1.2.3 *Bottled drinking-water*

Bottled water must be at least as good in bacterial quality as unbottled potable water and thus contain no coliform organisms. In addition, because of the susceptibility of the very young or old to opportunistic infection by *Pseudomonas aeruginosa*, it may be necessary to treat the water to prevent the growth of this organism. The source used for bottled water should be free from faecal pollution; the bottling process and subsequent transit and storage should not contaminate the water. The source of water must therefore be protected; treatment, if

needed, must be applied consistently and bottling must be done hygienically. Failure to achieve a satisfactory product should result in a sanitary inspection of both the source and the bottling plant. It should be noted that mineral waters are not included in these guidelines, although the bottling procedures and the standards of hygiene recommended for such plants are also applicable to bottled drinking-water and are described in detail elsewhere (4).

2.1.2.4 *Emergency supplies of drinking-water*

During an emergency it may be necessary either to modify the treatment of existing sources or to use alternative sources of water temporarily (2). It may be necessary to increase disinfection at source or to rechlorinate during distribution. If possible, the distribution system should be kept under continuous pressure as failure in this respect will increase considerably the risks of entry of contamination to the pipework and thus the possibility of waterborne disease. If the quality cannot be maintained, consumers should be advised to boil the water during the emergency. Boiling non-turbid water for at least 1 minute, at sea level, inactivates the vegetative cells of bacteria and viruses as well as the cysts of *Giardia*. If bulk supplies in tankers are used, sufficient chlorine should be added to ensure that a free residual of 0.2 mg/litre is present at the delivery point (2). Before use, tankers should be either disinfected or steam-cleaned. The temporary use of slow-release disinfectant tablets in water drawn from the tap, or of filter attachments to domestic taps, if proved to give safe and reliable disinfection, should also be considered.

2.1.3 Frequency of sampling

Examination of drinking-water should be both frequent and regular, sampling must be performed carefully, and bacteriological examinations should comply with the suggestions given in these guidelines. The frequency of sampling will depend on the quality of the source, the treatment the water receives, the risks of contamination, the previous history of the supply, and the size of the population served. As the population increases so will the size and complexity of the system and thus the chances of contamination by cross-connection and back-siphonage. Another approach is to base the frequency of sampling on the volume of water supplied, but this is less appropriate in the context of international guidelines as individual use varies greatly from country to country, and such an approach cannot be recommended for small supplies in which the volume supplied may be low.

A new source of water supply should be monitored more frequently than would be necessary during subsequent service conditions so that variations in quality can be observed under a variety of weather and climatic conditions.

2.1.3.1 *Treated water entering the distribution system*

Any source of water that requires treatment—including disinfection—should be examined daily for coliform organisms, turbidity, and pH at the point at which the water enters the distribution system, as the threat of pollution from the source is continuous and the treatment barrier must not be penetrated. In addition, the residual disinfectant concentration should be measured frequently and preferably recorded continuously. Any deterioration in quality or protection thus revealed should result in an immediate investigation without awaiting the outcome of accompanying bacteriological tests.

2.1.3.2 *Water in the distribution system*

In piped water supplies, contamination of the distribution system increases in importance with the length of pipe work and the number of plumbing systems attached to it. Although it is desirable to take samples at least weekly, this may not be possible with small systems. If possible, decisions on sampling frequency should be taken by national authorities. The following *minimum* sampling frequencies are recommended, the samples being spaced out evenly throughout the month:

Population served	*Minimum number of samples*
less than 5000	—1 sample per month
5000–100 000	—1 sample per 5000 population per month
more than 100 000	—1 sample per 10 000 population per month

A proportion of the samples should be taken at certain fixed points—such as pumping stations and storage tanks — as well as from sites where previous sampling has revealed problems; other samples should be taken randomly throughout the distribution system including multiple-occupancy buildings such as hospitals, schools, public buildings, apartment blocks, hotels, factories, and other locations where there is greater possibility of contamination through cross-connections and back-siphonage. The frequencies given above should be regarded as the minimum necessary, the overall aim being to increase the sampling programme, especially at times of epidemics, flooding, emergency operations, or following interruption of supplies or repair work.

2.1.3.3 *Untreated water and unpiped supplies*

The quality of water will vary with both season and proximity to sources of pollution. The frequency of sampling for bacteriological examination of a particular water should therefore be established by the appropriate control agency and it should reflect local circumstances, including the results of sanitary surveys.

2.1.4 Collection, storage, and transport of water samples for bacteriological examination

Care must be taken to ensure that samples are representative of the water being examined, and that no accidental contamination occurs during sampling. Sample collectors should therefore be made aware of the responsible nature of their work and be adequately trained.

Most samples will be taken from taps in treatment works, storage tanks, or houses, or from public standpipes. When the distribution system is sampled, both domestic and communal taps, including public fountains, must be selected with care. Public health and water supply authorities should select sampling points according to an agreed programme. The taps chosen must be clean and should be supplied with water direct from the public main. Additional samples may be needed to monitor storage tanks supplying high-rise and multiple-occupancy buildings. Samples should not be taken from taps which leak between the spindle and gland as water from the outside of the tap may contaminate the sample. External fittings such as filters, rubber or plastic nozzles, and other anti-splash devices should be removed, and the water run to waste for at least 1 minute to ensure that stagnant water is flushed from the pipes before the sample is taken. Flaming of the tap before the sample is taken should be considered an optional procedure. To reduce some of the problems inherent in sampling from domestic taps, water supply authorities should consider the installation of sampling taps at strategic points in distribution systems.

For bacteriological examination, samples should be collected in clean, sterile, glass or autoclavable plastic bottles containing 0.1 ml of a 1.8% solution of sodium thiosulfate[a] per 100 ml of sample bottle capacity to neutralize any residual disinfectant. This should neutralize at least 5 mg/litre of available chlorine and will be suitable for routine sampling. In special situations where the chlorine residual may be greater, as for example in emergencies, additional thiosulfate is required. Samples should be kept cool and in the dark, preferably at 4–10°C, and transported to the laboratory as quickly as possible for examination, ideally within 6 hours of collection, but never more than 24 hours later.

2.1.5 Techniques for the detection of coliform organisms

Two basic procedures are used for the detection and enumeration of coliform organisms in water: (a) the multiple-tube method, in which measured volumes of water are added to sets of tubes containing a suitable liquid medium; and (b) the membrane-filtration technique, in which measured volumes of the sample are filtered through a membrane (5–8). Both methods have advantages and disadvantages and are

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[a] 18 g of $Na_2S_2O_3.5H_2O$ per litre of water

subject to statistical variability. The two methods do not give strictly comparable results—one reason being that counts on membrane filters do not give a direct indication of gas production from lactose—but in practice they do yield comparable information.

2.1.5.1 *Multiple-tube method*

In this method, the examination starts with the presumptive coliform test, in which measured volumes of the sample, or one or more dilutions of it, are inoculated into a series of bottles or tubes containing a suitable liquid differential medium containing lactose. After incubation at 35 or 37 °C for an appropriate time, the tubes are examined for acid and/or gas production. The test is called presumptive, because the positive reaction observed may be caused by some other organism or combination of organisms. The presumption that the positive reaction is caused by coliform organisms should therefore be confirmed by additional tests with further differential media. The occurrence of false-positive reactions depends partly on the bacteria in the sample of water and partly on the medium used.

By inoculation of appropriate volumes of water into a suitable number of tubes, a statistical estimate of the most probable number of coliform organisms in a given volume of water can be obtained—based on the assumption that, on incubation, each tube that received one or more viable coliform organisms will show growth. Provided negative results occur in some tubes, the most probable number (MPN) of coliform organisms in the original sample may be estimated from the number of tubes giving a positive reaction. Tables of statistical probability are normally used for this purpose, and those given in Annex 2 show the most probable number of coliform organisms in 100 ml of the original sample for various combinations of positive and negative reactions, together with their 95 % confidence limits.

The MPN procedure is a multiple-tube dilution method using nutrient-rich media which is applicable to waters of all types. The equipment required is relatively cheap and unspecialized. Positive reactions are usually easy to read and are interpreted readily. However, the technique can only provide an estimate of the number of bacteria present in any sample and this estimate is subject to considerable inherent error, though that does not detract from the ability of the test to detect pollution. Because liquid media are used, subcultures must be made on solid media to obtain pure culture isolates before further differentiation of coliform or other organisms is undertaken.

2.1.5.2 *Membrane-filtration technique*

With this method, the number of coliform organisms in water is determined by filtering a measured volume of the sample, or an

appropriate dilution of it, through a membrane filter, usually made of cellulose esters. Bacteria in the sample are retained on or near the surface of the membrane, which is then incubated face upwards on a suitable selective medium containing lactose. All acid- or aldehyde-producing colonies that develop on the membrane are counted either as presumptive coliform organisms or as faecal coliform organisms, depending on the temperature of incubation. Since it is not possible to detect gas production on membranes, it is assumed that all colonies that produce acid or aldehyde also produce gas. However, the tests used for subsequent confirmation of these colonies would demonstrate the formation of gas as would a negative cytochrome-oxidase test. Colonies are counted and the results expressed in terms of colony-forming units present in 100 ml of original sample.

It is usual to incubate 2 membranes for each sample, one at 35–37°C and the other at 44–44.5 °C. The confirmation procedure is simpler than in the multiple-tube method, as the elevated temperature of incubation provides a direct estimate of the number of faecal coliform organisms more quickly, thus permitting earlier remedial action. However, certain water samples may cause problems. Although the technique can be used for the examination of all waters, high turbidity will cause blocking of the membrane pores before sufficient water can be filtered. The membrane filtration method is also unsuitable for use with waters that contain only small numbers of coliform organisms in the presence of many other organisms, as growth of the latter may cover the whole membrane and thus interfere with, or suppress, growth of the coliform organisms. The technique may be modified for the recovery of organisms stressed or damaged, for example by exposure to heavy metals or disinfectants. Pre-incubation at lower temperatures or on less selective media may encourage recovery and initiation of growth before completion of the test on more selective media. Basic advantages of the membrane-filter technique are rapid test results, savings in materials, less incubator space per test, and a reduction in test-processing time compared with the multiple-tube procedure. In some instances, the cost of membranes may limit local use of this technique for the routine monitoring of water supplies.

2.1.5.3 Rapid methods for the detection of coliform organisms

Rapid methods for assessment of the hygienic quality of water should be within the capability of most water supply laboratories for use in the event of treatment plant failures, breaks in the integrity of the distribution system, or in disasters. One of these methods needs only relatively simple equipment and the results should be available within 8 hours. One such application for faecal coliform organisms has been described: this membrane-filtration procedure uses a lightly buffered lactose/mannitol medium with incubation for 7 hours at 41.5 °C (9).

2.2 The virological quality of drinking-water

It is recommended that, to be acceptable, drinking-water should be free from any viruses infectious for man. This objective may be achieved (*a*) by the use of a water supply from a source which is free from wastewater and is protected from faecal contamination; or (*b*) by adequate treatment of a water source that is subject to faecal pollution.

Adequacy of treatment cannot be assessed in an absolute sense because neither the available monitoring techniques nor the epidemiological evaluation is sufficiently sensitive to ensure the absence of viruses. However, it is considered at present that contaminated source water may be regarded as adequately treated when the following conditions are met:

—a turbidity of 1 NTU or less is achieved;
—disinfection of the water with at least 0.5 mg/litre of free residual chlorine after a contact period of at least 30 minutes at a pH below 8.0.

The turbidity condition must be fulfilled prior to disinfection if adequate treatment is to be achieved. Disinfection other than by chlorination may be applied provided the efficacy is at least equal to that of chlorination as described above. Ozone has been shown to be an effective viral disinfectant, preferably for clean water, if residuals of 0.2–0.4 mg/litre are maintained for 4 minutes. Ozone has advantages over chlorine for treating water containing ammonia but, unfortunately, it is not possible to maintain an ozone residual in the distribution system (*10*).

Where virological facilities can be provided, it is desirable to examine the raw water sources and the finished drinking-water for the presence of viruses (*11*). This will provide baseline data to evaluate the health risk faced by the population. A reference method should be used for the concentration and detection of viruses in large volumes of drinking-water (e.g., 100–1000 litres) (*6*).

2.3 The nature of the guideline values

2.3.1 Bacteriological guideline values

There are some differences between enterovirus and coliform strains with regard to natural survival and perhaps resistance to chlorination, but these are biological variations that are more clearly demonstrated in the laboratory than in the application of conventional water treatment processes. Field investigations of virus occurrence in drinking-water and related total coliform measurements still support the continued routine use of coliform limits for monitoring the bacterial and viral quality of

public water supplies. When chlorination is practised it has been demonstrated that virus-free water can be obtained from faecally polluted source waters when the concentration of free residual chlorine is at least 0.5 mg/litre for a minimum contact period of 30 minutes at a pH below 8.0 and turbidity equal to or less than 1 NTU. It is also desirable to maintain a free residual chlorine of 0.2–0.5 mg/litre in the distribution system to reduce the risk of microbial regrowth and to provide an indication of the absence of post-treatment contamination.

A coliform limit is not adequate to ensure the absence of *Giardia lamblia* and other pathogenic intestinal protozoans in treated water supplies because of the extreme chlorine resistance of these pathogens in the cyst or egg stage. Simple methods have not yet been developed for the detection of viable pathogenic protozoans in potable water and a suitable surrogate indicator is not yet available.

Although the total coliform count is a valid measure of water treatment effectiveness in providing a barrier to bacterial and viral contamination, the value of using the same total coliform limit as a sanitary quality index of unpiped, untreated water is questioned. Coliform bacteria are derived not only from the faeces of warm-blooded animals, but also from plants and soils. Since total coliforms in natural water originate from a variety of sources, the finding of a few of these organisms, i.e., 1–10 organisms per 100 ml, may be of limited sanitary significance, provided faecal coliform organisms are absent. There is also evidence that these moderate densities of total coliforms may be suppressed in laboratory analyses by excessive non-coliform bacterial populations of over 1000 organisms per ml. Under such circumstances, untreated water supplies could still pose an undetected health risk to individuals consuming these waters. Limiting the total bacterial plate count to 500 organisms per ml would be desirable as a goal to avoid interference in coliform detection and to restrict the densities of a wide spectrum of opportunistic pathogens as well as taste and odour organisms. Using the faecal coliform test would provide a more specific measure of faecal contamination; however, there is some evidence to suggest that faecal coliforms may die off more rapidly in ground-water than some enteric pathogens.

2.3.2 Uncertainties relating to the guideline values

While bacterial guideline values are valuable as a reference base when monitoring water supplies for an acceptable level of public health protection, these values do not ensure complete absence of some pathogens and their use has occasionally been challenged.

Strict adherence to proper sampling procedures, careful collection of an adequate sample volume, prompt transport of the sample to the laboratory, rapid processing, quality assurance of testing procedures, and rapid evaluation of results are essential to establishment of meaningful laboratory data. Each of these steps plays a very critical role

in determining the bacterial quality of water regardless of the source or quality in other respects of the water examined.

2.3.2.1 *Microbial dispersion*

Indicator bacteria and pathogens are rarely randomly dispersed in drinking-water. In untreated supplies, faecal pollution may fluctuate with storm water run-off or the rate of penetration of domestic sewage through the soil. In treated waters, contamination may be the result of excess turbidity, deficiencies in disinfection practice, cross-connections, or loss of water pressure. Furthermore, drastic changes in water pressure may dislodge bacteria from colonization sites established in slimes and sediments lining the pipe walls and result in an unpredictable and fluctuating concentration of organisms.

Bacterial populations in a water sample must be uniformly re-suspended prior to analysis of a test portion. Samples with excessive turbidity, characteristic of untreated surface waters, may require low-speed blending for 30 seconds to achieve a reasonable degree of homogeneity. Failure to achieve uniformity in the bacterial density will lead to variability in test results.

2.3.2.2 *Confidence limits*

The most probable number (MPN) obtained in the multiple-tube method for detecting coliform organisms represents only an estimate of the number of bacteria present in any sample. For example, the 95% confidence limits for a series of 3 replicate sample portions of 10 ml, 1 ml, and 0.1 ml result in an MPN test value ranging from 0.2 to 4 times the true density, whereas 5 replicate sample portions tested in a series of the same 3 dilutions produce values ranging from 0.3 to 3 times the absolute quantity. For any given estimate it is also possible that the true result will be beyond these limits in an average of 5% of such analyses; therefore, the upper limit may be regarded for practical purposes as being the maximum number of coliform organisms the sample might contain. These same quantitative estimations also apply to all other indicator bacterial systems used in the multiple-tube test.

The membrane-filtration technique allows the formation of discrete colonies from which direct counts may be obtained. However, these values should also be regarded as estimates, although they are not subject to as great an error as that encountered in the MPN method. Replicate subsamples of water will not produce the same numerical value. For example, if the true density of coliform organisms in a water sample is 100, replicate cultures produced by membrane-filtration analysis of equal sample portions may be expected to range from 78 to 124 organisms. For counts of less than 20 organisms, the statistical calculated range will be greater. As a guide, the 95% confidence limits for a true density of one colony on the membrane would range from 5.6

to 0.025 organisms per sample volume; for a true membrane count of 5 organisms, the range would be from 11.7 to 1.6 (5).

These discrepancies in the confidence limits of both the multiple-tube procedure and membrane-filtration method illustrate two points: (a) statistical differences are likely to occur in individual results from a multiple-tube and membrane-filter comparison and; (b) increasing the frequency of sampling will minimize the chance occurrence of a statistically distorted value due to methodological limitation.

2.4 Monitoring

Effective monitoring of the bacteriological quality of drinking-water requires careful consideration of sampling frequency based on many factors, including quality of source water, treatment (or lack of adequate treatment), whether there is continuous transmission into a distribution network (or whether the supply is available only from a designated outlet in the community), and the long-term integrity of the distribution system. Sampling points on piped supplies must be selected with great care, as the examination of a single sample can indicate no more than the conditions prevailing at the moment of sampling at that one site in the system. Furthermore, there must be recognition of the problems associated with proper collection and transportation of samples from small supplies at remote locations to an approved laboratory. For these reasons, guidelines on monitoring the microbial quality of drinking-water need to be carefully reviewed by local and national authorities and adjusted to meet local public health conditions.

2.4.1 Sampling frequency model

Water samples collected from a distribution system should be representative of the microbiological conditions in the system. Unfortunately, this objective may not always be possible because microorganisms are rarely randomly dispersed in the pipe network, and there are variations in flow due to variations in demand. If contamination from external sources occurred in a large diameter transmission or distribution main, it would be carried into one or more sections of the system and detected in more than one sample in the sampling pattern. If, however, contamination occurred in a small diameter main, then pollution would be detected only within the limited sections of the pipe network served by that main. The irregular detection of coliform organisms in the area around elevated storage tanks and standpipes can often be associated with the reversal of water flow which can occur during different periods of the day. It is essential that well thought out sampling programmes are used so that contamination is readily detected, water quality is monitored adequately, and trends in data can be recognized.

Since there is no practical way of obtaining a number of samples from all areas of a water system at a given instant, periodic sampling is done and the accumulated information is averaged monthly, indicating the confidence limit or the range of individual sample values.

Unfortunately, the monthly averaging of data is not satisfactory for small water systems from which only one or two samples per month may be taken. For such supplies, in order to arrive at a more reliable assessment it is desirable to include all bacteriological data collected over the past 3 months.

The use of a monthly (or quarterly) average value places equal importance on all values in contrast to the use of a median value or the geometric mean of all values. The finding of any coliforms in a potable water sample should cause the local authorities to increase sampling during the designated month. If the positive finding were truly an isolated example, then increased sampling would perhaps lower the mean to an acceptable limit, as defined by regulations. A positive finding should also alert authorities to a possible indication of some intermittent microbial contamination entering the water supply. Repeat sampling is essential, but so is the need for immediate review of treatment practices, including examination of potential problems in the distribution system.

2.4.2 Required accuracy of analysis

2.4.2.1 *Sample size*

The volume of test portions should be adequate to ensure detection of indicator organisms at concentrations below the guideline values recommended and the frequency of sampling should be adequate to develop a mean density over time. In potable-water tests, results should normally indicate the absence of coliforms in 100-ml test portions examined by the membrane-filter technique or in 5 test portions of 10 ml each analysed by the multiple-tube method. The difference in sample quantity is not scientifically defensible but reflects common practice; few laboratories routinely inoculate 100-ml test portions in the multiple-tube procedure because of the problem of preparing, handling, and incubating bottles large enough to culture 100-ml sample portions.

It would be statistically more meaningful to examine larger samples, possibly 200 ml, 500 ml, or 1000 ml; this would give greater test precision and reduce the risk of failure to detect a low level of coliforms. Failure to find faecal coliforms in a 100-ml sample does not ensure the absence of enteroviruses, bacterial pathogens, or pathogenic protozoans and helminths which may be present in smaller numbers that would be detectable only if much larger samples of the same water were analysed. A recommendation to use larger test portions whenever possible would increase the baseline sensitivity and could be particularly important in

measuring coliform reduction resulting from the application of disinfection at concentrations approaching those essential for control of waterborne viruses.

2.4.2.2 *Quality assurance*

While standardized methods should be used to monitor water quality, there are, nevertheless, numerous factors that may influence the precision of the method. Examples include the quality of the bacteriological media, reagent purity, equipment performance, and the availability of adequate laboratory space and properly trained personnel. Quality controls should include a daily check of the pH of the media, the temperature of incubators, and the sterility of media, bottles, and glassware used in processing samples. Semi-annual tests should include a check on the purity of the laboratory distilled water used to prepare media, reagents, and sample dilutions. On an annual basis, reference samples prepared from natural water should be analysed as an unknown sample by each technician to verify their continued proficiency.

When the laboratory changes to a different procedure or bacteriological medium, sufficient parallel data must be collected over a period of several months using a variety of water samples of varying quality. These data must be made available for review by the proper authority, which may approve the alternative procedure provided the sensitivity and selectivity are at least as good as those of the standard method.

2.4.3 Piped supplies

Since the greatest risk of contamination in treated piped supplies is contamination during distribution and not at the treatment works, sampling frequency will largely be determined by the size of the distribution network.

The same frequency of sampling should be used whether the supply is disinfected or not, as the risk of the entry of pollution is the same in both types of system. Sample collections should be spaced out evenly through each month, preferably at least weekly; however, this may not be possible with small systems in remote regions.

The recommended frequency of sampling should be considered as the minimum and the overall aim should be to increase sampling, especially at times of epidemics, flooding, or emergency operation, or after normal supplies have been temporarily discontinued or after repair work. It should be noted that, with networks serving populations larger than 100 000, the interval between successive samples should be very short and sampling should be very intensive throughout all areas of the supply. Even in small communities of 5000 people or less, one examination per month may not be sufficient.

2.4.4 Untreated, unpiped supplies

The quality of water can only be assured by use of pollution control measures, the protection of the catchment area, sanitary surveys, and regular bacteriological examination which may give early warning of any deterioration in quality. Generally, these are small systems that may be in remote locations where sample collection is practical only once per month or once per quarter. If samples are examined less frequently than once a month, insufficient historical data will be available from which the reliability of the source can be assessed. It is particularly important to establish the microbial quality of such water during rainy periods when storm water run-off may bring faecal pollution over the drainage basin into the untreated water supply. During such periods, more frequent sampling is desirable to establish the magnitude of the problem and the need for standby emergency measures that may include announcements instructing the public to boil water, the application of simple treatment measures, or the use of an alternative emergency supply of a better quality water.

2.4.5 Bottled water

The initial quality of any bottled water is related to both the quality of the source water and the sanitary conditions associated with bottling and handling. Contamination during bottling or storage may result from poor plant sanitation or unclean containers. Although disinfection is seldom practised, bottled water supplies should meet the bacterial qualities expected of public water supplies. If the source water is subject to faecal contamination, the processing of bottled water should include an efficient filtration procedure as well as disinfection to ensure that the water is free from pathogenic protozoa and helminths.

A systematic monitoring of bottled water is an important public health concern, particularly in areas where it is frequently used. This kind of drinking-water should be analysed at a monthly sampling frequency related to the volume produced and should include testing of both the source and the bottled product. When analyses demonstrate that the water fails to meet the drinking-water standards, repeat sampling and a follow-up sanitary survey must be done to determine the source of contamination and the action to be taken to eliminate the hazards of faecal pollution.

2.4.6 Emergency water supplies

Emergency water supplies may be alternative source waters that require some treatment because they are of a lower quality, or limited quantities of high-quality stored water for use only during periods of drought or other disasters. Ensuring the continual availability of a high-quality emergency water supply over an extended period is

difficult. Water of the highest quality must be selected to minimize the microbial hazards and care must be exercised to prevent contamination when filling storage containers or mobile tankers. Disinfection is recommended before emergency use as a precaution against contamination during storage.

Monitoring of stocks of emergency water supplies should include monthly inspections of containers at random, for evidence of water leakage and evaporation, and a semi-annual bacteriological examination of 2, 3, or 4 containers per storage area when the stockpile contains 1–100, 100–1000 or 1000–5000 containers, respectively. Water drums or tankers depleted because of water loss or fouled in dirty or flooded storage areas should be flushed to remove sediment and debris, refilled with high-quality water and treated with chlorine to re-establish a free chlorine residual, preferably of 10 mg/litre.

Alternative water supplies to be used in times of emergency should be planned in advance and selected on the basis of a sanitary survey. A brief investigation should be made of critical microbial, chemical, and radiochemical contaminants during periods of wet and dry weather. When no historical data are available, a decision on the use of an alternative supply must be accompanied by instructions to apply suitable treatment processes, especially chlorination, if the water is transmitted through the existing distribution network. If unpiped water is distributed, a public announcement should be made about the need to boil all drinking-water.

2.4.7 Mass gatherings—temporary water supplies

The local authority is responsible for the approval of an adequate quantity of safe water to serve the expected number of people over the appropriate period. Because of the possibility of massive waterborne outbreaks of disease, a free chlorine residual should be maintained and the water supply reservoirs protected. During the entire period, an intensive monitoring effort is needed with daily bacteriological examination and measurement of the free chlorine residual at frequent intervals, e.g., every 2 hours. A public announcement should be made immediately concerning the need to boil drinking-water if chlorination is not carried out or if the bacteriological results prove unsatisfactory. The water quality of the additional supply should be chemically and bacteriologically examined by the health authority at weekly intervals for 30 days before the opening date of the event (11).

2.5 Remedial measures

If microbial levels are exceeded, officials concerned with safeguarding the source quality, with treatment effectiveness, and with integrity of the distribution system should be promptly alerted for a course of action.

Depending on the severity of the microbial contamination, different levels of action are recommended.

2.5.1 Piped supplies

2.5.1.1 *Untreated water entering the distribution system*

Supplies derived from protected sources that are distributed without disinfection should be similar in quality to those of disinfected drinking-water. For practical reasons, a rare coliform occurrence (no more than 2 % of all samples analysed over a 12-month period) may be tolerated in untreated water supplies entering distribution systems. However, if successive samples are positive for coliforms a sanitary survey should be done to identify the source of surface-water pollution or an inspection should be made of the ground-water well site for possible penetration by domestic sewage. If the bacteriological status is repeatedly unsatisfactory, chlorination should be undertaken or a public notice issued concerning the need to boil all drinking-water until further notice.

2.5.1.2 *Water in the distribution system*

Ideally all samples taken from the distribution system, including those from consumers' premises, should be free from coliform organisms. In practice, this goal is not always attainable. The infrequent occurrence (5 % or less of the total samples examined throughout a 12-month period) of not more than 3 coliform organisms per 100 ml is acceptable but calls for repeat sampling at the same collection site to confirm the initial findings. Furthermore, such findings indicate the need for increased monitoring of the residual disinfectant in the distribution system.

If repeated sampling and subsequent analyses demonstrate that low densities of coliform organisms persist, a special investigation should be made of the water-treatment processes and the distribution system to determine the initial cause. Treatment deficiencies, contamination of the distribution system, and the development of persistent microbial colonies in the pipework should be explored. A regular flushing programme will often minimize the establishment of microbial colonies in pipe sediments.

When total coliform counts of more than 3 organisms per 100 ml occur in successive samples from the distribution system or when one or more faecal coliform is detected per 100-ml sample, there should be an immediate increase in disinfectant application to achieve a free chlorine residual of 0.2–0.5 mg/litre in all portions of the distribution system. Treatment practices should be reviewed immediately and a search should be made for the ingress of pollution into the distribution network. Once the fault has been detected, prompt application of appropriate corrective measures is essential. If repeat bacteriological analyses continue to

demonstrate an average of more than 3 coliform organisms per 100 ml or one or more faecal coliform organism per 100 ml, there should be a public announcement requesting all consumers to boil water until further notice or to use an approved alternative source of drinking-water.

2.5.2 Unpiped water supplies

Since contamination with coliform bacteria originates from a variety of sources (faeces of warm-blooded animals, intestinal contents of cold-blooded animals, soil, and vegetation), their occurrence in moderate densities of 1–10 organisms per 100 ml of natural waters may be of limited sanitary significance. Persistent failure to achieve this water quality objective, particularly if faecal coliforms are repeatedly found, should lead to a permanent requirement to treat the water prior to use as drinking-water or to a search for a better water source for community use.

2.6 Cost–benefit aspects

Improvements in water supply and sanitation can generate significant benefits through related improvements in health. The involuntary nature of the risks associated with consumption of drinking-water, and the immediate and widespread nature of outbreaks of waterborne disease, have engendered general public acceptance and support for adequate water treatment measures.

2.6.1 Treatment cost–benefit decisions

If all other factors are equal, water-treatment processes should be selected on a minimum-cost basis. Where the cheapest process has an unacceptable degree of risk, a more expensive one may actually have a more favourable cost–benefit ratio and should in that case be selected, provided expert plant operators are available. Disinfection is the main method of controlling pathogenic bacterial and viral agents, and chlorine has been the predominant disinfectant used in many countries. Where protozoan or metazoan parasites (*Amoeba*, *Giardia*, helminths, etc.) are present, disinfection must be supplemented with well regulated flocculation and filtration to remove the cysts or the worms and their eggs.

The reasons for the predominance of chlorine as the disinfectant have been related mainly to easier availability, lower cost, and ease of handling and measurement. While there is little dispute over the desirability of disinfecting water to control the microbial population, the recently recognized problem of the formation of halogenated organic compounds by the reaction of chlorine with organic chemicals present in some waters, and of the health hazards posed by these products, has stimulated a search for an alternative disinfectant and a modified

technique of application. If any disinfectant or combination of disinfectants is to replace chlorine, cost-effectiveness will be one of several important considerations.

2.6.2 Cost-benefit analysis of laboratory monitoring

The frequency of microbiological monitoring is based on the assumption that all people in the community are using the water supply continuously. Since the sampling frequency is generally related to population size, water supplies serving large populations are monitored more intensively than those serving small communities. Analysis of data suggests that, for small to medium plants with laboratory facilities, increased sampling frequency (above minimal requirements) not only provides more precise monitoring data, but also makes the laboratory more cost-effective.

In microbiological monitoring, the lowest cost–benefit ratio is associated with the application of the basic bacteriological techniques, i.e., pour-plate methods, membrane filtration, and the multiple-tube procedure to detect faecal contamination and undesirable changes in the general microbial quality of the drinking-water. Cost-analysis indicates that the unit cost of the pour-plate procedure is lower than that of either membrane filtration or the multiple-tube procedure; however, the latter procedures are more precise (and cost-effective) for quantifying faecal contamination. Identification of bacterial strains in indicator populations may have value in tracing a source of pollution but is too expensive for routine application.

Emphasis is placed on selecting indicators of water pollution and on test rapidity, rather than on direct searches for specific pathogens. While some specific tests may be performed in the average laboratory at reasonable cost, other analyses, such as testing for viruses, can only be performed in specialized laboratories and are relatively expensive.

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3. BIOLOGICAL ASPECTS

3.1 Protozoa

Species of protozoa known to have been transmitted by the ingestion of contaminated drinking-water include *Entamoeba histolytica* (cause of amoebiasis), *Giardia* spp. and, rarely, *Balantidium coli*. These organisms can be introduced into a water supply through human or, in some instances, animal faecal contamination.

3.1.1 Recommendations

Drinking-water should not contain any pathogenic intestinal protozoa.

3.1.1.1 *Piped and unpiped supplies*

Data available on *E. histolytica* and *Giardia* indicate that these organisms are considerably more resistant to inactivation by chlorination than are bacteria or viruses (*1*). Chlorination, with the residuals and contact times recommended for bacteria and viruses, may not therefore provide adequate protection against transmission of these agents by drinking-water. Coliform organisms do not appear to be a good indicator for *Giardia* or *E. histolytica* in treated water because of the increased resistance of these protozoans to inactivation by disinfection. In non-disinfected water, the presence of indicator bacteria could suggest the presence of pathogenic protozoa. Since there is no good indicator for the presence or absence of pathogenic protozoa, drinking-water sources not subject to faecal contamination should be used where possible.

3.1.1.2 *Bottled drinking-water*

Recommendations for these supplies are identical with those given for bacteria, in the preceding section on pp. 22–23. In addition, if the source water is subject to faecal contamination, the processing of bottled water should include an efficient filtration procedure to ensure that the water is free from pathogenic protozoa.

3.1.1.3 *Emergency supplies of drinking-water*

Recommendations for these supplies are identical with those given for bacteria in the preceding section, on p. 23. As with bottled water,

efficient filtration is required should the source water be subject to faecal contamination.

3.1.2 Monitoring

Standard methods are not currently available for the detection of pathogenic protozoa in water supplies in the context of a routine monitoring programme. Research methods employing cyst concentration by microfiltration and microscopic and/or cultural identification techniques are available (2) but are recommended for use only in association with concurrent epidemiological studies of either epidemic or endemic situations. However, the methods available at present are inefficient; the concentration techniques are not reproducible; the identification of organisms in concentrated samples is difficult, and, at least in the case of *Giardia* spp., the viability and origin of detected cysts cannot be determined. In addition, no recommendations can be made regarding frequency of sampling.

3.1.3 Remedial measures

Ground-water supplies can be protected by adhering to established sanitary engineering practices for the construction and maintenance of those supplies. Where faecal contamination is likely or unavoidable, diatomaceous earth filtration, sand filtration with coagulation and sedimentation, or slow sand filtration have been shown to be effective in removing a high proportion of pathogenic protozoa. Water supplies treated by pressure filtration and chlorine disinfection have at times been implicated in waterborne outbreaks of giardiasis. Therefore particular care should be taken with process control where there is a possibility of contamination of raw water by enteric protozoa, especially where disinfectant residuals are low.

In situations where disease outbreaks are associated with drinking-water contaminated by pathogenic intestinal protozoa, boiling of water may provide effective control for inactivation of *Giardia, Entamoeba histolytica*, and *Escherichia coli*. Attempts should be made to identify and remove sources of contamination. A sanitary survey should be conducted to identify and correct deficiencies in the treatment and distribution systems.

3.2 Helminths

The infective stages of many parasitic roundworms and flatworms can be transmitted to man through drinking-water. A single mature larva or fertilized egg can cause infection and it is clear that such infective stages should be absent from drinking-water. However, the water route is relatively unimportant except in the case of *Dracunculus medinensis* (the guinea-worm) and the human schistosomes, which are primarily hazards

of unpiped water supplies. While there are methods for detecting these parasites, they are quite unsuited for routine monitoring (*3*).

3.2.1 Recommendations

Dracunculus may be a cause of severe morbidity in rural populations and is transmitted by freshwater copepods such as *Cyclops*, which represent an obligatory intermediate stage. One infected copepod containing a single larva is sufficient to infect a human subject with *Dracunculus* and therefore such larvae should be absent from drinking-water.

Larvae reach the copepods from blisters on the limb of an infected person, larvae from the legs, for example, being washed into open wells and ponds. The parasites infect man when the copepod is ingested. As the water route is the only mode of transmission, effective source protection will eradicate the infection.

The schistosome parasites of man, *Schistosoma mansoni* (Africa and Latin America), *S. haematobium* (Africa and West Asia), *S. japonicum* (East Asia) and *S. intercalatum* (Africa), all have aquatic snails as their intermediate hosts. After development in the snails, the larvae, called cercariae, emerge and can penetrate the skin or buccal mucous membrane of anyone in contact with or ingesting the infected water. Transmission, where it involves water supplies, is a problem of unpiped sources or untreated surface water. Actual drinking is of little importance and most transmission concerns other types of water contact during bathing.

Many other helminths, especially *Ascaris lumbricoides*, *Trichuris trichiura*, *Strongyloides stercoralis*, and *Ancylostoma duodenale*, are recorded as having been transmitted through ingestion of water. But in areas where these parasites are endemic, the water route may be of less significance.

3.2.2 Monitoring

Dracontiasis (guinea-worm infection) is a problem of small unpiped water supplies (e.g., step wells or reservoirs) where regular monitoring is often impracticable. Investigation of such a situation involves study of the prevalence in man and collection of copepods, using a plankton net or other container, followed by their microscopic examination to detect the parasitic larvae. This is not proposed as a routine measure.

Detection of schistosome cercariae in water is a research procedure unsuited to routine monitoring. The cercariae may be concentrated from water by filtration or detected by immersing suitable small rodents, allowing time for development, and dissecting them. On filters of paper,

glass-fibre, or acetate, the cercariae tend to lose their shape and species identification is not reliable, though various differential staining methods have been devised. It is more feasible to look for appropriate vertebrate hosts and determine infection rates in them.

While in outbreak or research situations helminth eggs and larvae, such as those of *Ascaris*, may be extracted from drinking-water by filtration and identified microscopically in the case of most eggs, these procedures are unsuitable for routine use and the frequency of water contamination does not justify them.

3.2.3 Remedial measures

In view of the way *Dracunculus* is transmitted, source protection is the best approach to prevention. The use of well surrounds that rise above ground level and drain away from the well usually suffices, though capping the well and fixing a pump are preferable. In emergency situations, the infected copepods may be killed by addition of temephos (Abate) granules to wells in the doses required for insect larval control.

Since a single schistosome cercaria is sufficient to cause disease, cercariae should be absent from drinking-water. For lack of routine monitoring assays, reliance has to be placed on preventive measures if there is a significant risk of contamination of drinking-water. The cercariae have a free-living life of less than 48 hours and storage for this period renders water safe. It is likely that storage for 24 hours will greatly reduce infectivity. Slow sand filters will remove the majority of cercariae (but only if they are properly operated), and disinfection with chlorine, with a free residual of 0.5 mg/litre for 1 hour, will kill cercariae of the human schistosomes. A sounder approach is to use a source that does not contain the host snails and which is not subject to faecal contamination.

A single fertilized egg, mature larva, or encysted cercaria of other helminths such as *Ascaris* can also cause infection. Therefore these should be absent from drinking-water and this is best achieved by protecting the source from faecal contamination. Should they gain access to raw water, most will be removed by filtration procedures especially slow sand filters, but all are relatively resistant to chlorination, notoriously so in the case of *Ascaris*.

In general, therefore, reliance is placed on general source protection to minimize helminth problems in drinking-water and specific action should depend on the results of local epidemiological studies.

The choice of source and routine treatment methods recommended for protozoa are also applicable to the prevention of helminth transmission by bottled water. Schistosomiasis may be a hazard of water taken from inappropriate sources for emergency supplies, but chlorination by tablets or boiling will render it safe.

3.3 The free-living organisms

The free-living organisms that may occur in water supplies include fungi, algae, free-living protozoa, cladocera, copepods, and macro-invertebrates such as the nematodes, chironomids, and snails. These organisms may be of public health significance as carriers of disease-causing organisms or because they produce toxins. For example, some blue-green algae are known to release toxins or may be toxic if ingested. Adverse health effects from drinking water so affected are not common, but such algae have been reported to produce gastroenteritis in consumers. Where blue-green algae are known to cause any problems in storage reservoirs, appropriate preventive and control measures should be taken.

Health problems associated with these organisms are more likely to occur where untreated, poorly treated, or unprotected water supplies are used. However, the most common problems associated with these organisms are their interference in the operation of water-treatment processes, and their effects on the colour, turbidity, taste, and odour of finished water. For example, high concentrations of algae in raw water may result in severe clogging of filters, cause taste and odour problems, increase the chlorine demand, and lead to increased concentrations of halogenated organic compounds that may be of public health significance.

A wide range of free-living organisms can become established in water distribution systems and can give rise to complaints if they appear at the consumer taps. Infestations of the aquatic sow bug (*Asellus*) and of midge larvae (*Chironomus*), for example, are by no means uncommon.

3.3.1 Recommendations

It is desirable that these free-living organisms should be absent from drinking-water. Guideline values cannot be recommended at present, because of insufficient data to relate the quantity of these organisms to specific health effects. Knowledge of the identity and abundance of organisms (4) in raw water supplies is valuable in water resource management and treatment and this knowledge may be obtained by the application of available methods.

3.3.2 Monitoring

Adequate methods are available for the collection and analysis of free-living organisms in water supplies (2).

3.3.2.1 *Sampling*

Algae and other microorganisms may vary significantly in abundance and species composition from day to day. The microbial biomass and species composition should therefore be determined frequently if the

data are to be used effectively to modify water-treatment processes, control tastes and odours, and detect harmful concentrations of microorganisms in finished water supplies.

3.3.2.2 *Biomass*

The size, shape, and volume of different algae differ greatly, and counts alone do not provide an accurate estimate of the amount of organic matter (biomass) contributed by each species. The biomass is commonly estimated by measuring the image area, cell volume, or chlorophyll content of the algae.

3.3.3 Remedial measures

The concentrations of free-living organisms can be controlled under most circumstances by protection of sources, reducing or preventing high nutrient levels, use of algicides, adequate water treatment, including coagulation, sedimentation, filtration, and disinfection, and by protecting and covering finished water stored in reservoirs.

Toxic algae occur in significant quantities only in surface waters, whereas copepods may be found in both surface waters and wells. Sand filtration has been found effective in the removal of such organisms, but does not remove the released algal toxins, which may also remain following aluminium coagulation, filtration, and chlorination. Activated carbon, at levels usually employed in water treatment, also fails to remove algal toxins.

In piped water supplies, animal infestation of the distribution network can be dealt with by flushing out the pipes and in some cases by the maintenance of free chlorine residuals of 2–3 mg/litre for several days or the application of pyrethrin at a concentration of 0.005–0.01 mg/litre for approximately 2 days. The duration of application may vary depending upon the condition of the water mains and on the amount of pyrethrin adsorbed. The pyrethrin concentration should be monitored in running water at the end of the distribution system to ascertain its presence. Normally a high water velocity is necessary to remove organisms from pipe walls and this removal can often be achieved only by the use of polyurethane foam swabs or by air injection.

Mosquito vectors of disease must not be allowed access to breed in stored domestic water in the home.

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4. CHEMICAL AND PHYSICAL ASPECTS

4.1 Introduction

The sophisticated methods now used in analytical chemistry allow for a more specific determination of the many components in drinking-water, especially those in the organic fraction, than was possible a decade ago.

This is particularly important since advances in modern technology have resulted in the use and disposal of ever-increasing quantities of both organic and inorganic chemicals, with associated hazards to drinking-water.

This section includes guideline values for potentially hazardous chemical constituents of drinking-water as well as for substances and physical characteristics that affect the palatability and appearance of drinking-water.

4.1.1 The health effects of chemical contaminants

The health risk due to toxic chemicals in drinking-water differs from that caused by microbiological contaminants. It is very unlikely that any one substance could result in an acute health problem except under exceptional circumstances, such as massive contamination of the supply. Moreover, experience shows that the water usually becomes undrinkable after such incidents for obvious reasons such as its taste, odour, and appearance.

The problems associated with chemical constituents arise primarily from their ability to cause adverse effects after prolonged periods of exposure; of particular concern are cumulative poisons and carcinogens.

There is either direct or indirect evidence that all of the substances for which guideline values have been recommended can cause harmful effects and are known to occur in water. It must remain a basic tenet of public health protection that exposure to toxic substances should be as low as possible. The guideline values indicate tolerable concentrations, but they must not be interpreted as defining targets for water quality.

Several of the inorganic elements for which guidelines have been recommended are recognized to be essential elements in human nutrition. No attempt has been made here to define a minimum desirable concentration of such substances in drinking-water. The guideline values for these substances are concentrations that should not be exceeded over long periods of time because of the potential hazards of ingesting

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excessive amounts of these substances. None of the organic substances for which values are recommended has any known beneficial properties.

4.1.2 Basis of guideline values

In developing guideline values, the objective is to define a quality of water that can be safely consumed by everyone throughout their lifetime. These guidelines represent an informed judgement based upon several factors, including:

(*a*) scientific criteria, defining dose–response relationships for substances,

(*b*) analytical data on the frequency of occurrence and concentrations of substances commonly found in drinking-water, and

(*c*) the potential application of suitable control techniques to remove or reduce the concentration of substances in drinking-water.

The toxicological evidence concerning the various chemical constituents of drinking-water has been reviewed and, as appropriate, attempts have been made to:

—set guideline values for such substances,
—provide a brief justification (or rationale) for the chosen values,
—provide separate documentation giving the health information used in setting the guideline values,
—provide information on the application of the guidelines for each group of substances.

4.1.3 Uncertainties in the setting of guideline values

There are many reasons for which it is difficult to set guideline values for the chemical constituents of water. These involve:

—disagreements on the relevance, validity, and acceptability of scientific data;
—problems of extrapolating toxicological data from animals to man, especially in view of the relatively high doses often used in experiments and the very low doses found in drinking-water;
—uncertainty about the proportions of total intake obtained from air, water, food, and other sources (e.g., occupational).

The available data suggest that all the chemical constituents for which guideline values have been recommended can cause health problems under certain conditions. In general, these data have been obtained from either toxicity studies in laboratory animals or actual measurements on people at work. However, the health effects involved have usually been observed at higher dose levels than those to which people are exposed by consuming the trace quantities in drinking-water. Epidemiological studies are of only limited use in determining cause-and-effect

relationships for the chemical constituents found in drinking-water. For example, several such studies have examined the relationship between organic chemicals in drinking-water and the increased risk of cancer, but have provided no definite results that can be used to evaluate the risks associated with individual organic substances found in drinking-water.

4.1.3.1 *Extrapolation of animal data to man*

For many of the substances considered, toxicity studies in laboratory animals are used in order to make quantitative predictions in man. The limitations, accuracy, and reliability of such predictions have recently been summarized (*1, 2*). For most substances, the pathogenesis of poisoning is similar in both man and other mammals; differences in response between species are mainly quantitative rather than qualitative because of different rates of absorption, excretion, and detoxification. For a particular chemical, man may be more sensitive than laboratory animals; for others, animal species may be more sensitive.

4.1.3.2 *Low-dose extrapolation*

Laboratory data (and data gathered from people at their place of work) involve exposure at levels at which the adverse effects occur relatively frequently. In addition to the uncertainties associated with extrapolation from laboratory animals to man, when water contamination is being considered there is a need to extrapolate from the known dose–response range to a much lower dose range at which the shape of the dose–response curve has not been confirmed experimentally.

Traditionally, procedures that rely upon the application of "safety factors" have been developed to deal with this problem. To obtain an acceptable daily intake (ADI) for man, in the international programmes concerning food additives and the setting of tolerances for pesticide residues in foods, it has become the practice to divide the no-adverse-effect dose in animals (or man, where such data are available) by a factor, usually of 100 (*3*).

The use of safety factors (alternatively known as uncertainty factors) has been criticized on the grounds that the observed no-effect level depends upon the size of the group of animals involved, and because no account is taken of the slope of the dose–response curve. Clearly a safety factor that provides an acceptable margin of safety for a substance with a relatively steep dose–response curve will provide a smaller safety margin if the curve is relatively shallow.

However, the major criticism of the use of safety factors arises from the assumption that a threshold dose actually exists below which no adverse effects will occur. The question of the existence of such a threshold for toxic effects has prompted much discussion. In some cases, the existence of metabolic detoxification, repair mechanisms, and elimination processes suggests that a threshold may exist, whereas in

other cases it appears that a single molecule of a chemical can initiate a process which may lead progressively to an observed harmful effect, i.e., there is no threshold if the molecule can reach the appropriate receptor. In particular, many scientists now believe that mutagenic substances or those which can cause neoplastic disease should be treated as though the no-threshold concept applies.

According to the no-threshold concept, safety can be guaranteed only when the level of exposure is zero. A number of mathematical models have been developed in order to predict the potential risk associated with any given degree of exposure. It must be emphasized that, at low dose levels, the techniques which attempt to estimate added risk over background involve fitting a particular dose–response model to experimental results obtained in animals within the "observable effects" range and then extrapolating to the low-dose range that is of interest. The differences between the various suggested procedures arise because of differences in the basic assumptions made about the mechanism of action and because of the shape of the dose–response curve. Large differences in estimated risks may be obtained by selecting and using different mathematical models.

4.1.3.3 *Carcinogens*

There has been particular interest in carcinogens in recent years, partly because of an increasing recognition of the importance of environmental factors in causing cancer, and partly because of the difficulties in assessing the relative importance of future long-term effects and the immediate and direct risks such as inadequate water supply, dangers of disease outbreaks due to inadequate or non-existent disinfection, and so on.

A number of extrapolation models have been proposed (*1*) and as a result the doses calculated to produce very low response rates vary considerably, depending upon the model chosen. To facilitate policy considerations, low-dose carcinogenic risks were estimated from animal data, by the multi-stage method adopted by the Environmental Protection Agency in the USA (*4*), for chemical constituents considered to be carcinogenic. At best, this procedure must be regarded as a rough estimate of cancer risk. If the true dose–response relationship is not linear, the model may underestimate or overestimate the real risks involved. The recommended levels obtained, on the basis of this technique, are believed to be more realistic than those derived from the use of safety factors, but they must be viewed with caution because of the uncertainties involved. In the future, a better understanding of the mode of action of the chemicals involved should provide a firmer basis for determining the appropriate modelling technique to be used.

Guideline values have been recommended for a number of organic substances that are carcinogens or suspected carcinogens based upon a linear, multi-stage extrapolation model. The guideline values quoted in

this document are based upon the selection of an acceptable risk of less than 1 additional case of cancer per 100 000 population assuming a daily consumption of 2 litres of drinking-water by a 70-kg man. The cancer risk associated with other concentrations of these substances can be readily calculated.

4.1.3.4 *Apportionment of intake*

Drinking-water is not the only source from which man is exposed to many of the chemical constituents for which guideline values have been set. In many cases the intake from drinking-water may be small in relation to the intake from food and air. It was accepted that, in the evaluation of the health effects of inorganic constituents, all routes of exposure (air, food, and water) had to be considered when deciding upon a value for drinking-water. This, in some cases, proved to be problematical because of the lack of information concerning the biological availability of the contaminants present in foodstuffs.

However, in the case of chemicals for which carcinogenicity is the main concern and for which the guidelines have been based upon low-dose extrapolation techniques in order to equate the recommended value with an incremental cancer risk, other sources of exposure have not been considered. The incremental risk from food, air, occupation, etc., will be additional to that from drinking-water.

As regards pesticides, a special situation exists. In this case, the ADI has already been "used up" in setting tolerances for pesticide residues in foods. On the other hand, measurable quantities (although usually at very low concentrations) are frequently found in drinking-water. Therefore in setting guideline values for pesticides in drinking-water, values were generally based on committing not more than 1 % of the ADI. This was considered acceptable on the grounds that not all food will contain pesticides at the permitted tolerance levels.

4.2 Health-related inorganic constituents

A series of working papers dealing with the health effects of 37 inorganic constituents occurring in drinking-water were studied in order to decide upon guideline values for the undesirable inorganic substances in drinking-water (Table 7).

4.2.1 Guideline values recommended

On the basis of the health-related data concerning the 37 inorganic constituents examined it was decided that, at the present time, guideline values could be recommended for only 9 of them (Table 8), and the evidence is summarized in section 4.2.2.

However, since the effects on health of several other constituents in the list are the subject of current debate, brief explanations of the

Table 7. Inorganic constituents of potential health significance

Constituent	Guideline values set	Background document drafted	Referred for consideration of aesthetic and organoleptic aspects	No action required
aluminium			X	
antimony				X
arsenic	X	X		
asbestos		X		
barium		X		
beryllium		X		
boron				X
cadmium	X	X		
chromium	X	X		
cobalt				X
copper			X	
cyanide	X	X		
ferrocyanide				X
fluoride	X	X		
hardness (calcium and magnesium)		X	X	
iron			X	
lead	X	X		
lithium				X
magnesium			X	
manganese			X	
mercury	X	X		
molybdenum				X
nickel		X		
nitrate	X	X		
nitrite				X
selenium	X	X		
silver		X		
sodium		X	X	
tellurium				X
thallium				X
thiocyanate				X
tin				X
titanium				X
tungsten				X
uranium				X
vanadium				X
zinc			X	

reasons why guideline values could not be recommended are also provided in section 4.2.2 for 7 other constituents.

Eight of the constituents listed in Table 7, although not of direct health concern, could have an indirect effect upon health because of their effect on the aesthetic quality of drinking-water. These substances are dealt with later under "Aesthetic and organoleptic aspects" (page 77).

Table 8. Guideline values for health-related inorganic constituents

Constituent	Guideline value (mg/litre)
arsenic	0.05
cadmium	0 005
chromium	0.05
cyanide	0 1
fluoride	1.5[a]
lead	0 05
mercury	0.001
nitrate (as N)	10 00
selenium	0 01

[a] Guideline value may vary depending upon climatic conditions and water consumption

4.2.2 Summaries of the evidence used in setting guideline values

4.2.2.1 *Arsenic*

Based on human health data, a concentration of 50 μg of arsenic per litre is not associated with any adverse health effects. Estimates have been made of the risk of cancer from low intakes of arsenic, but these are very uncertain. At an arsenic concentration of 50 μg/litre, the contribution made by water to the total intake will normally be about one-half to two-thirds; for very low dietary intakes of arsenic, the proportion provided by water may be somewhat higher. Arsenic in drinking-water will normally be the main source of inorganic arsenic. An arsenic concentration of 0.05 mg/litre is recommended as a guideline value.

4.2.2.2 *Asbestos*

The health hazards associated with occupational exposure to airborne asbestos have been well documented. Epidemiological studies suggest that prolonged inhalation of asbestos also leads to an increased incidence of cancer of the gastrointestinal tract: however, it is not known whether such an effect is systemic or results from swallowing inhaled fibres.

The harmful effects of swallowed asbestos on human health have not been determined. Studies in progress should permit a more complete evaluation of any hazard resulting from the swallowing of asbestos, but available data are, at present, insufficient to determine whether a guideline value is needed.

4.2.2.3 *Barium*

There is no firm evidence of any health effects associated with the normally low levels of barium in water. Even at a barium concentration

of 10 mg/litre, there is little evidence and, consequently, it is not considered necessary to establish a guideline value for barium in drinking-water at present.

4.2.2.4 *Beryllium*

Given that ingested beryllium is very inefficiently absorbed, that there is no definite evidence that it is hazardous to man when ingested, and that, in general, the major source of exposure seems to be from food, a guideline value for beryllium in drinking-water is not recommended at present.

4.2.2.5 *Cadmium*

Normally, exposure to cadmium from food, water and air does not exceed the provisional, tolerable weekly intake of 0.4–0.5 mg per individual, established in 1972 by the Joint FAO/WHO Expert Committee on Food Additives (5). Excessive exposure to cadmium has resulted in severe health effects, both in industry and when rice crops have been polluted by cadmium. There is no evidence that the normal levels in drinking-water cause health problems in man. However, it is necessary to restrict the level of cadmium exposure; a working group of the WHO Regional Office for Europe[a] recommended a cadmium level of 0.005 mg/litre, and this is now endorsed as a suitable value. A guideline value of 0.005 mg of cadmium per litre is recommended; at this concentration about one-quarter of the total cadmium absorbed might be derived from water.

4.2.2.6 *Chromium*

Since chromium(VI) appears to be much more toxic than chromium(III), it is necessary to take account of the situations where this is the main form to which man is exposed. In chlorinated or aerated water, chromium(VI) is the predominant form. At a chromium concentration of 100 μg/litre, drinking-water could be the main contributor (40–66%) to the uptake of chromium(VI); at 50 μg of chromium per litre, water contributes less than half to the total uptake (25–49%). Data on human health effects that can be used to determine meaningful guideline limits are scanty. Since the publication by WHO in 1970 of the *European standards for drinking-water* (6), there has been no new information to suggest that the value of 50 μg/litre should be changed. Therefore a guideline value of 50 μg of *total* chromium per litre is proposed (*total* chromium has been specified because of difficulties in analysing for the hexavalent form only).

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[a] *The hazards to health of persistent substances in water.* Unpublished document, WHO Regional Office for Europe, Copenhagen. EURO 3109 W(1); 1973.

4.2.2.7 Cyanide

It is uncertain how much cyanide is derived from food; however, many of the foods we eat are cooked, and this process destroys most of the small amounts of inorganic cyanide present. In general, apart from special foodstuffs (e.g., almonds), the dietary input of cyanide appears to be small. It is recorded that up to 4.7 mg of cyanide per day is not harmful to man, and thus drinking 2 litres of water per day would mean that water with a cyanide concentration of 2.35 mg/litre could be consumed. Allowing for a safety factor, a guideline value of 0.1 mg of cyanide per litre is considered to be a reasonable level for the protection of public health.

4.2.2.8 Fluoride

Fluoride is naturally present in some foodstuffs as well as in water. There is no evidence of harmful effects associated with the relatively low levels to which people are commonly exposed. At levels above 1.5 mg/litre, mottling of teeth has been reported very occasionally, and at 3.0–6.0 mg/litre skeletal fluorosis may be observed; when a concentration of 10 mg/litre is exceeded, crippling fluorosis can ensue (7). Since the recommendations on fluoride content were made and published in the *International standards for drinking-water* (8), there has been no generally accepted evidence that would justify any changes in the guideline value. There is no acceptable evidence that fluoride in water is associated with a cancer risk. Since detectable effects, such as mottling of teeth, are sometimes associated with fluoride levels above 1.5 mg/litre in drinking-water, this concentration is recommended as the guideline value. However, its local application must take into account climatic conditions and higher levels of water intake.

4.2.2.9 Hardness

There is evidence that death rates from cardiovascular disease are inversely correlated with the hardness of water, but there is insufficient proof that either the calcium or the magnesium in water is directly involved. No recommendation on the restriction of municipal water softening or on the maintenance of a minimum residual calcium or magnesium level is therefore warranted at present. In addition, there is no firm evidence in man that drinking hard water causes any adverse effects on health.

4.2.2.10 Lead

At least two approaches can be combined to form a basis for defining a guideline for the level of lead in drinking-water; one recognizes the contribution made by drinking-water to the level of lead in the blood and the other takes account of the provisional tolerable weekly intake of

3 mg of lead per person established in 1972 by the Joint FAO/WHO Expert Committee on Food Additives (5). No tolerable weekly intake levels have been defined for children.

Children and infants, fetuses *in utero,* and pregnant women, are probably the groups most sensitive to environmental lead exposure (9), and therefore in formulating guidelines for drinking-water quality, safety factors should be incorporated to protect these particular groups. Unfortunately, only limited information is available for such groups on the blood lead levels associated with defined exposures to drinking-water, but it has been shown that an increase of 4–5 μg of lead per 100 ml of blood in young children and pregnant women would result from an exposure to 100 μg of lead per litre of water.

Exposure to lead concentrations of 100 μg/litre may cause a significant number of children to exceed the recommended blood lead level of 30 μg/100 ml, and it would thus be too high a concentration for children. At this exposure level, the provisional tolerable weekly intake for adults of 3 mg would be exceeded if the diet contained more than 230 μg of lead per day. However, if the mean level of lead in drinking-water is not more than 50 μg/litre, the 3-mg weekly intake is not exceeded even with a daily diet containing 300 μg of lead. Drinking-water containing 50 μg of lead per litre would contribute between one-quarter and one-half of the weekly *ingested* lead in adults and about one-third in children. The corresponding values for *absorbed* lead would be one-fifth to one-third for adults, and one-third for children.

Thus, based on these various considerations and allowing for some margin of safety, a guideline value of 0.05 mg of lead per litre of water is recommended.

4.2.2.11 *Mercury*

Mercury is a toxic element and has no beneficial physiological function in man. The presence of mercury in water has become of particular concern since it was found that organic mercury is accumulated by fish. Elevated mercury levels have been found in freshwater fish taken from areas with suspected mercury contamination and such fish are unacceptable for human consumption. Long-term daily ingestion of approximately 0.25 mg of mercury as methyl mercury has been observed to cause the onset of neurological impairment (10). However, mercury in drinking-water is predominantly in the inorganic form, which is only poorly absorbed. Furthermore, levels of mercury do not exceed 0.03 mg/litre even in heavily polluted waters and these levels are significantly reduced by conventional treatment processes. Consumption of 2 litres of water containing 0.001 mg of mercury per litre would normally contribute less than 10 % of the tolerable intake of mercury. Thus 0.001 mg/litre is recommended as the guideline value; it applies to all chemical forms of mercury.

4.2.2.12 *Nickel*

Soluble nickel compounds have been reported to cause minor toxic effects in experimental animals when given in food or water at levels greater than 1000 mg/litre. Levels of nickel in drinking-water of 5 mg/litre did not produce toxic effects in long-term studies in rodents. Isolated reports indicate that nickel compounds can result in allergic effects, primarily in eczematous patients, but such effects are probably more relevant to dermal rather than to oral exposures. The toxicological data available at present indicate that a guideline value for nickel in drinking-water is not required.

4.2.2.13 *Nitrate*

Nitrate is toxic when present in excessive amounts in drinking-water, and in some cases causes methaemoglobinaemia in bottle-fed infants; for older age groups, this problem does not arise, but there is a possibility that certain forms of cancer might be associated with very high nitrate concentrations. No cases of methaemoglobinaemia have been proved conclusively to be caused by the consumption of water containing less than 10 mg of nitrate–N per litre, and there are many examples where nitrate concentrations up to 20 mg/litre have not produced any clinical effects in infants. Although the clinical manifestations of infantile methaemoglobinaemia may not be apparent at these levels, undesirable increases in methaemoglobin in the blood do occur. For this reason, a guideline value of 10 mg of nitrate–N per litre is recommended.

The adverse effects of nitrate invariably involve its reduction to nitrite as a preliminary step. Hence the ingestion of nitrite leads to a more rapid onset of clinical effects, and for this ion the guideline value must be correspondingly lower than that for nitrate. Where drinking-water is correctly treated, the nitrite nitrogen level should be considerably lower than 1 mg/litre.

4.2.2.14 *Selenium*

The upper permissible limit of selenium concentration in both the *European standards for drinking-water* (6) and the *International standards for drinking-water* (8) was 0.01 mg/litre. Recently, several approaches have been used to confirm this maximum acceptable concentration. Effects considered to be due to selenium toxicity have been observed at levels of intake of 0.01–0.1 mg of selenium per kg of body weight per day. For a 70-kg man, this would amount to daily intakes of 0.7–7.0 mg of selenium. The estimates of selenium intake used to derive the recommended guideline value range between 130 and 200 μg per day, corresponding to daily intake values published in the United States of America and some other countries. The maximum daily selenium intake from drinking-water should not exceed 10% of the recommended maximum daily dietary intake of 200 μg, i.e. should not exceed 20 μg

per day. Thus, assuming an intake of 2 litres of water daily, the concentration of selenium in drinking-water should not exceed 0.01 mg per litre, and this is the recommended guideline value.

Advances in knowledge since 1970 have not decreased the uncertainties connected with these calculations, nor do they provide sufficient evidence for a revision of the level recommended in the previous standards published by WHO (6, 8). In areas of relatively higher or lower selenium dietary intake, the drinking-water guideline of 0.01 mg/litre may have to be modified accordingly.

4.2.2.15 Silver

Silver is not a particularly toxic element, and only a relatively small fraction of ingested silver appears to be absorbed. The unsightly condition known as argyria can be produced by a single injected dose of 1 g of silver. An estimated continuous daily dose of about 400 μg of silver may also produce argyria. For an average man the total daily intake from air, food and water is about 20–80 μg, which is considerably below the adverse effect level. Even the maximum reported combined exposure levels for water and food would not result in a total intake of 180 μg of silver per day. Consequently, it is not considered necessary to establish a guideline value for silver in drinking-water.

4.2.2.16 Sodium

There is evidence that high dietary intakes of sodium play a significant role in the development of hypertension among genetically susceptible members of the population; in addition, there is some evidence that drinking-water with moderate sodium levels (100 mg/litre) may be associated with an elevation of blood pressure in children. It is not known, however, if the reported small blood pressure increases are significant in terms of the development of early hypertension. It is questionable whether the low intake of sodium from drinking-water relative to that from food could be responsible for a significant additional effect. At present, there is insufficient evidence to justify a guideline value for sodium in water based on health-risk considerations.

Persons suffering from hypertension or congestive heart failure may require a sodium-restricted diet, and in such cases the intake of sodium from drinking-water may be of greater significance.

4.3 Health-related organic contaminants

In the previous standards published by WHO (6, 8) the observations on organic contamination referred only to pesticides and polycyclic aromatic hydrocarbons (PAH), with the addition of extractable organic constituents in the European standards (6). During the last

decade the increase in knowledge relating to water contamination by organic substances has necessitated the consideration of a much broader range of such contaminants. More than 2000 chemical contaminants of all kinds have been found in water, about 750 of which have been identified in drinking-water. Of these, more than 600 are organic substances, including many that are pharmacologically active, several that are recognized carcinogens or carcinogenic promoters, and a number that have been shown to be mutagenic. There is reason to believe that these 600 substances represent only a small fraction of the total organic matter present in drinking-water. The majority of the un-characterized organic fraction consists of non-volatile substances, the determination of which still presents a considerable analytical challenge.

The task of revising the previous WHO standards (6, 8) becomes increasingly complicated, particularly in relation to the organic contaminants, because of this uncharacterized fraction.

The groups of organic substances listed in Table 9 are those recognized as source contaminants and those introduced into drinking-water during the treatment processes or in the distribution system.

In selecting the organic substances that required detailed evaluation, the following criteria were used:

—well-founded evidence that the substance can cause acute or chronic illness,
—evidence that the substance is known to occur at significant concentrations,
—evidence that the substance has been detected relatively frequently in drinking-water,
—the availability of analytical methods for monitoring and control purposes,
—evidence that the concentrations of the substance in water can be controlled.

Application of these criteria to the groups of contaminants listed in Table 9 eliminated some of the groups from further consideration. After this preliminary review, detailed evidence concerning a number of compounds was examined. No recommendations were made for the compounds shown in Table 10. Guideline values were established for 15 compounds and tentative values were set for 3 others (Tables 11 and 12, page 63).

4.3.1 Reservations relating to the guideline values

The actual guideline values set tend to err on the side of caution because of insufficient evidence and uncertainties as regards interpret-ation. It should also be remembered that it may be neither necessary nor feasible in every community to ensure that drinking-water quality complies in every respect with the recommendations in these guidelines.

The most important influence on the quality of drinking-water of some of the organic compounds considered is in connection with

Table 9. Groups of organic compounds of potential health significance

Contaminant	Detailed examination required	No further action required[a]
1. Source contaminants		
humic substances		X
chlorinated alkanes and alkenes	X	
nitrosamines		X
polynuclear aromatic hydrocarbons (PAH)[b]	X	
nitrilotriacetic acid (NTA)		X
phenols	X	
synthetic detergents		X
pesticides[b]	X	
polychlorinated biphenyls (PCB)		X
phthalate esters		
petroleum oils, including gasoline		X
chlorobenzenes	X	
chlorinated phenols	X	
benzene and alkylaromatics	X	
carbon tetrachloride	X	
2. Introduced during treatment		
carbon tetrachloride	X	
acrylamide		X
trihalomethanes	X	
3. Introduced during distribution		
vinyl chloride monomer	X	
polynuclear aromatic hydrocarbons (PAH)[b]	X	

[a] Substances did not comply with criteria enumerated on the previous page

[b] Mentioned in *International standards for drinking-water* (9)

aesthetic and organoleptic aspects rather than their health effects. Such substances can often make water completely undrinkable when present at concentrations well below those that cause concern for health reasons.

4.3.2 Other factors to be considered when assessing the level of organic contamination

Drinking-water quality can affect the health and wellbeing of a community in a variety of ways. The importance of chemical contamination involving trace amounts of substances (especially organic substances) must be assessed in relation to the other health risks associated with drinking-water (e.g., transmission of waterborne diseases of bacterial and viral origin, and of parasites), and the relative importance attached to these risks must be decided by taking into account the local or regional situation. For instance, pesticides may be used to control disease vectors, and chlorine may be used for disinfection. In such situations, the risks associated with the low levels of organic compounds (e.g., pesticides, trihalomethanes) may be smaller

Table 10. Organic compounds for which no guideline value is recommended

Chlorinated alkanes and alkenes	*Chlorinated phenols*
dichloromethane	2-chlorophenol
1,1,1-trichloroethane	4-chlorophenol
1,2-dichloroethene	2,4-dichlorophenol
vinyl chloride	2,6-dichlorophenol
	2,4,5-trichlorophenol
Pesticides	*Others*
alpha-HCH	toluene
beta-HCH	trihalomethanes other
triazine herbicides	than chloroform
Chlorobenzenes	
chlorobenzene	
1,2-dichlorobenzene	
1,4-dichlorobenzene	
trichlorobenzenes	

than the risk they are eliminating, and so the authority responsible for public health should set values higher than those given in this document in order to benefit the health of its consumers.

4.3.3 Guideline values set on evidence of toxicity

It was assumed that the average consumption of water is 2 litres per person per day and that the average weight of a person is 70 kg, although these factors may vary. For toxic agents whose effect only becomes apparent after a dose threshold has been exceeded, an acceptable daily intake (ADI) previously established by the Joint FAO/WHO Expert Committee on Food Additives was used. When such an ADI was not available, a value was calculated from the published scientific literature by applying a "safety factor" to the no-adverse-effect dose (i.e., maximum ineffective dose). It must then be decided what proportion of the ADI should be allocated to drinking-water and what proportion to other sources of exposure (i.e., food, air, etc.). For these guidelines, the percentage of the ADI allocated to drinking-water was determined as an inverse function of the tendency for the chemical to accumulate in food chains. For chemicals such as chlorinated pesticides which accumulate readily as little as 1 % of the ADI was allocated to drinking-water, whereas for chemicals that accumulate to a lesser extent a greater proportion was allocated. Consideration has also been given to the proportion of the normal intake of these chemicals that is derived from alternative sources. However, for most chemicals, there are few data on potential sources of human exposure.

4.3.4 Guideline values set on evidence of carcinogenicity

In view of the problems associated with the extrapolation of data from animals given high doses it was decided that a guideline value

would be set only where reliable data were available from two species of animal, preferably with supporting evidence such as the results of mutagenicity tests, in addition to relevant, direct information from population studies.

For some toxic effects such as neoplastic disease or mutations, it has been assumed that there is a finite probability of a single molecule of a given chemical initiating a process that may lead progressively to a harmful effect. A threshold is believed to be either non-existent or non-measurable, thus requiring extrapolation of the dose–response curve beyond the observation range.

The guideline values for these substances were developed differently from those for the other chemicals and should not, therefore, be interpreted in the same way. They were, in fact, computed from a very conservative, hypothetical, mathematical model and a realistic application of these values could therefore include uncertainties of about 2 orders of magnitude (i.e., from 0.1 to 10 times the number). The "multi-stage" model assumes that there is a finite risk from any exposure, however small, and that the risk is proportional to the dose. A linear no-threshold model has been used in many cases because of insufficient data (4).

The model is designed to estimate the highest possible upper limit of incremental (excess over background) risk from a lifetime of exposure to a particular daily amount of a substance. However, the actual risk could also be "zero" if the "no-threshold" assumption in the model is invalid. An "acceptable" risk of 1 in 100 000 per lifetime was arbitrarily selected as the criterion.

4.3.5 Guideline values recommended

The guideline values recommended are shown in Table 11. Where no level was set, either the compound was considered to be of low toxicity or insufficient evidence was available on which to base a guideline value. These points are discussed further in section 4.3.7 of this book which contains the detailed rationale used to set the guideline values. In addition to the compounds given in Table 11, many other associated compounds within the groups were considered. This led to the adoption of a guideline value for a compound (1,2-dichloroethane) not previously selected for detailed consideration. These aspects are considered in more detail in Volume 2 of these guidelines (11).

In local situations, there will be a need to control the concentrations of organic contaminants not included in these guidelines in order to protect human health. Such decisions must be made for each individual case, using knowledge of local surface- or ground-water quality, and the potential for contamination by industrial effluents, agricultural run-off, etc., and also taking into account the influence of materials used in distribution and storage systems, and other similar factors.

Table 11. Guideline values for health-related organic
contaminants

Contaminant	Guideline value (μg/litre)
aldrin and dieldrin	0 03
benzene	10
benzo[a]pyrene[a]	0 01
chlordane (total isomers)	0 3
chloroform[a, d]	30
2,4-D	100
DDT (total isomers)	1
1,2-dichloroethane[a]	10
1,1-dichloroethene[a, e]	0 3
heptachlor and heptachlor epoxide	0 1
hexachlorobenzene[a]	0 01[c]
gamma-HCH (lindane)	3
methoxychlor	30
pentachlorophenol	10
2,4,6-trichlorophenol[a, b]	10

[a] The guideline values for these substances were computed from a conserva-tive, hypothetical, mathematical model that cannot be experimentally verified and therefore should be interpreted differently Uncertainties involved are considerable and a variation of about two orders of magnitude (i e, from 0 1 to 10 times the number) could exist

[b] The threshold taste and odour value for this compound is 0 1 g/litre

[c] Since the FAO/WHO conditional ADI of 0 0006 mg/kg body weight has been withdrawn, this value was derived from the linear multi-stage extrapolation model for a cancer risk of less than 1 in 100 000 for a lifetime of exposure

[d] The microbiological quality of drinking-water should not be compromised by efforts to control the concentration of chloroform

[e] Previously known as 1,1-dichloroethylene.

4.3.6 Tentative guideline values

A tentative guideline value was recommended in some cases (Table 12) when, although the carcinogenicity data did not justify a full guideline value, the compounds were considered to have important health implications when present in drinking-water. The tentative values were, nevertheless, based on the available health-related data; if additional evidence cannot be obtained, the tentative level may in the future be

Table 12. Organic substances for which tentative guideline
values are recommended

Contaminant	Tentative guideline value (μg/litre)
carbon tetrachloride	3
tetrachloroethene[a]	10
trichloroethene[a]	30

[a] Previously known as tetrachloroethylene and trichloroethylene, respectively

withdrawn. Tentative guideline values were derived using the multi-stage model even though the selected chemicals did not reveal significant carcinogenic properties. Consequently the derived values display a greater degree of uncertainty than those derived for the remainder of the guideline values.

4.3.7 Summaries of the evidence used in setting guideline values

4.3.7.1 *Chlorinated alkanes*

One of the main uses of chlorinated alkanes is as an intermediate in the production of other organochlorine compounds. They are therefore produced by industry in large quantities, and many are found in drinking-water before and after treatment. Of the large number of chlorinated ethane compounds considered, only 1,2-dichloroethane can be clearly labelled as a carcinogenic hazard from the data available. Another chemical within this group, carbon tetrachloride, occurs as a contaminant of drinking-water sufficiently frequently to justify the recommendation of a *tentative guideline value*, even though the available data are inadequate.

Both of these chemicals are carcinogenic in animals, and there is strong evidence that they are also human carcinogens. The other compounds in this group are either not found in water or are toxic only at concentrations several orders of magnitude higher than the levels at present occurring in water. The guideline values for carbon tetrachloride and 1,2-dichloroethane are therefore derived from the linear multi-stage extrapolation model appropriate to chemical carcinogens.

(a) 1,2-dichloroethane

1,2-dichloroethane has been detected in potable waters in the USA. Studies indicate that it acts as a narcotic and produces damage to the liver, kidneys, and the cardiovascular system. Studies on its carcinogenic effects have produced quantitative evidence of a significant formation of squamous cell carcinomas in male rats, mammary adenocarcinomas in female rats and mice, and endometrial tumours in female mice. It has proved to be mutagenic in several different types of test (*12*). The recommended guideline value was calculated by applying the multi-stage linear extrapolation model to the data for the incidence of circulatory system haemangiosarcomas in male Osborne-Mendel rats following oral doses of 1,2-dichloroethane over a period of 78 weeks.

The recommended guideline value for 1,2-dichloroethane is $10 \mu g$/litre.

(b) Carbon tetrachloride

Levels of carbon tetrachloride (CCl_4) have been reported in the μg per litre range in many raw and treated drinking-waters. Carbon tetrachloride has a wide variety of toxicological effects, including carcinogenesis (*12*), and damage to the liver and kidneys. Despite extensive toxicity studies with carbon tetrachloride, there is sufficient dose–response information for the extrapolation of cancer risks in only one species. These results were obtained in the B6C3-F1 mouse, where

an increase in hepatocellular carcinomas was observed, following prolonged exposure to carbon tetrachloride. However, there are qualitative supporting data in other species, namely the hamster and the rat. Guideline values derived from the mouse carcinogenicity experiments are the lowest of any calculated for carbon tetrachloride. However, since reliable evidence on which to calculate a guideline value based on carcinogenicity is available in only one animal species, an unconditional guideline value has not been recommended.

A *tentative guideline value* for carbon tetrachloride of 3 μg/litre has been recommended because of the good qualitative supporting data and the frequency of occurrence of the chemical in water.

4.3.7.2 *Chlorinated ethenes*[a]

Compounds of this group are widely used in industry as solvents, softeners, paint-thinners, dry-cleaning fluids, intermediates, etc., and they are often found in raw and hence also in treated drinking-waters. They are known to occur in ground-waters at relatively high concentrations. They are usually lost to the atmosphere from surface-waters because of their high volatility, and therefore the concentrations in such waters are lower, compared with those found in ground-waters, and vary with exposure time and temperature.

Of interest within this group are those compounds for which there are indications of carcinogenicity in experimental animals. This group includes the well known human carcinogen, vinyl chloride. Vinyl chloride was, however, not considered because its occurrence in water seems to be associated primarily with the use of poorly polymerized poly-(vinyl chloride) water pipes, a problem that is more appropriately controlled by product specification. A number of product standards exist that specify the quality for PVC water pipes, limiting the quantity of free vinyl chloride monomer (VCM) present. Provided pipes of this quality are used, the concentration of VCM likely to be present in water will be small compared with the value obtained by applying the same linear multi-stage extrapolation model used in the case of other carcinogenic organic substances. Of the other compounds suspected of being carcinogenic, there were sufficient data to set a guideline value only for 1,1-dichloroethene. Despite inadequate data for trichloroethene and tetrachloroethene, their occurrence in contaminated ground-waters is frequent enough to warrant a *tentative guideline value*.

For the non-carcinogenic compounds within this group, guideline values calculated from the toxicity data are considerably higher than the levels actually found in water, and consequently no guideline values have been recommended.

(a) *1,1-dichloroethene*

Dichloroethenes have been detected in drinking-water, generally at levels less than 1 μg/litre. The isomers have not always been differentiated. 1,1-dichloroethene is the isomer that causes most concern

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[a] These compounds were previously known as chlorinated ethylenes.

because of evidence that it is carcinogenic in experimental animals. It is a chemical commonly used in the synthesis of various polymers; for example, food wrappers are often made of 1,1-dichloroethene co-polymers. 1,1-dichloroethene produces mammary tumours in both mice and rats, and kidney adenocarcinomas in mice (*13*). It has also been shown to be mutagenic in the Ames assay. A linear multi-stage extrapolation model was applied to data concerning the incidence of kidney adenocarcinomas in Swiss mice in order to calculate the recommended guideline value of 0.3 μg/litre.

(b) Trichloroethene

Trichloroethene is found at high concentrations (100 μg/litre) in contaminated ground-waters. In general, much lower concentrations are found in surface-waters, although in some areas the presence of this contaminant is quite widespread.

Trichloroethene produces liver tumours in mice, but there was no evidence of this in rats. However, because of its relatively frequent presence in drinking-water, a *tentative guideline value* was calculated using the mouse data in a linear multi-stage extrapolation model. The recommended value is 30 μg/litre.

(c) Tetrachloroethene

Tetrachloroethene is widespread in the environment, occasion-ally being found in high concentrations in contaminated ground-waters; it also occurs at low levels in many drinking-waters.

Tetrachloroethene has been shown to produce liver tumours in a hybrid strain of mouse (B6C3-F1), but again there was no evidence of this in rats (*12*). However, no excess cancer mortality was observed in a group of 518 workers subjected to a time-weighted exposure of 160 mg of tetrachloroethylene/m^3 over a period of 10 years. The mouse data were used to establish a *tentative guideline value* for tetrachloroethene in the interests of safety because of its relatively frequent occurrence in drinking-water. The value proposed is 10 μg/litre.

4.3.7.3 Polynuclear aromatic hydrocarbons (PAH)

There are many polynuclear aromatic hydrocarbons (PAH) and each is composed of two or more benzene rings, with adjacent rings sharing two carbon atoms; non-aromatic rings may also be present. Some PAH, including benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, and benzo[*b*]fluoranthene, have been shown to be carcinogenic in laboratory animals and may be carcinogenic in man. PAH occur widely in the environment and have been detected in water supplies. Investigational work on PAH in water has largely been confined to six PAH (including benzo[*a*]pyrene) which are relatively easily detected and can serve as indicators for the whole group. Previous European and international standards for drinking-water (*6, 8*) proposed a limit of 200 ng/litre for the sum of six named indicator PAH in drinking-water, based on the

premise that the quality of all drinking-water should be comparable with that of ground-water found at that time. The concentrations of the indicator PAH in different types of water were typically 10–50 ng/litre in ground-waters, 50–250 ng/litre in relatively unpolluted river waters, and higher in polluted rivers and effluents. These compounds are mostly removed by conventional methods of water treatment (e.g., coagulation, filtration). However, contact with coal-tar-based pipe linings during distribution is known, in some instances, to lead to increases in PAH concentrations in the water. In such cases, an increase in the level of fluoranthene is particularly marked.

Human exposure to PAH in general and to benzo[a]pyrene in particular is known to occur via food, water, and air. In all cases, the relative contribution of drinking-water to PAH exposure has been estimated as 0.1–0.3 % of the total PAH ingested. Exposure to PAH via air has been estimated as 0.9 % of the total exposure. Consequently, food contributes almost 99 % of the total exposure to PAH and any decision to establish control measures for PAH in drinking-water must take this relative distribution into account.

Despite the relatively small proportion of total PAH intake from drinking-water, such substances are hazardous and exposure to them should be minimized. Among the group there is only sufficient substantiated toxicological evidence to set a guideline value for benzo[a]pyrene. The following recommendations are made for the group of PAH:

—Based on the application of the linear multi-stage extrapolation model to the available toxicological data for benzo[a]pyrene and taking account of the fact that this substance is associated in water with other PAH of known carcinogenicity, a guideline value of 0.01 μg/litre is proposed for benzo[a]pyrene.

—Because of the close association of PAH with suspended solids, the application of treatment, when necessary, to achieve the recommended level of turbidity will ensure that minimum PAH levels are obtained.

—PAH should not be added to water during water treatment or distribution. Therefore, the use of coal-tar-based and similar materials for pipe linings and coatings on storage tanks *should be discontinued.* It is recognized that it may be impracticable to remove coal-tar linings from existing pipes. However, research into methods of minimizing the leaching of PAH from such lining materials should be carried out.

—Monitoring of PAH levels should continue in order to determine the background levels against which any changes can be assessed so that remedial action can be taken, if necessary. To monitor PAH levels, the use of several specific compounds as indicators for the group as a whole is recommended. The choice of indicator compounds will vary for each individual situation.

—The control of PAH in drinking-water should be based on the concept that the levels found in unpolluted ground-waters should not be

exceeded. This concept was embodied in the earlier European and international standards (*6, 8*). At the time, this was a useful approach; unfortunately it was not applicable in all situations, and it was not based on toxicological considerations.

4.3.7.4 *Pesticides*

The pesticides that are of importance in connection with water quality include chlorinated hydrocarbons and their derivatives, persistent herbicides, soil insecticides, pesticides that are easily leached out from the soil, and pesticides that are systematically added to water supplies for disease vector control or other purposes. Of these compounds, only the chlorinated hydrocarbon pesticides occur frequently. Chlorinated hydrocarbon pesticides persist in the environment and have become ubiquitous. For example, traces of DDT have been recovered from dust known to have drifted over thousands of kilometres and from water melted from Antarctic snow. Traces of chlorinated hydrocarbon pesticides in water may accumulate progressively in different steps of a food chain; for example, DDT can accumulate in fish to levels more than 10 000 times the concentration present in the surrounding water. Several of the pesticides in this group, including some that were used extensively in agriculture in the past and some that are still used for purposes such as disease control, have been shown to produce tumours in animals. Guideline values are recommended for several chlorinated hydrocarbon pesticides because of the possibility of their presence in water. These guideline values are derived from the acceptable daily intake (ADI) values set over the years by FAO/WHO Joint Expert Meetings on Pesticide Residues with the assumption that not more than 1 % of the ADI would be derived from drinking-water. For substances where there is some evidence of possible carcinogenicity, the guideline value derived from the ADI was still less than the value obtained by applying the multi-stage model at a projected 1 in 100 000 incremental risk. Since the ADI is based on lifetime exposure, short-term concentrations above the guideline value, e.g., those resulting from vector or aquatic weed control operations, may be acceptable but require careful surveillance.

It is recognized that the pesticides for which guideline values have been recommended do not include all of those that have been identified in water. Local circumstances may require the extensive use of a pesticide for which a guideline has not yet been developed. Monitoring for the presence of such substances in drinking-water may therefore be desirable. The recommended guideline values (Table 13) are set at a level to protect human health; they may not be suitable for the protection of aquatic life. A guideline value for the herbicide 2,4-D is also recommended because of the widespread use of this substance, including its occasional use for aquatic weed control.

Table 13. Guideline values and ADIs for certain pesticides

Compound or group of isomers	Guideline value (µg/litre)	ADI (mg/kg body weight)
DDT (total isomers)	1	0 005
aldrin and dieldrin	0.03	0.0001
chlordane (total isomers)	0.3	0.001
hexachlorobenzene	0 01[a]	—
heptachlor and heptachlor epoxide	0.1	0.0005
gamma-HCH (lindane)	3	0.01
methoxychlor	30	0.1
2,4-D	100	0.3

[a] Since the FAO/WHO conditional ADI of 0 0006 mg/kg body weight has been withdrawn, this value was derived from the linear multi-stage extrapolation model for a cancer risk of less than 1 in 100 000 for a lifetime of exposure

(a) DDT (total isomers)

The structure of DDT allows several different isomeric forms and the commercial products consist predominantly of p,p′-DDT. The use of DDT in some countries has been restricted or even prohibited, but it is still extensively used in some tropical countries, both in agriculture and for vector control. It is a persistent insecticide, stable under most environmental conditions; both it and some of its metabolites are resistant to complete breakdown by soil microorganisms. Daily intake from food may be as high as 0.286 mg/person, most of which is derived from foods of animal origin. In small doses, DDT is almost totally absorbed following ingestion or inhalation and is stored in adipose tissue. Concentrations of total DDT in the blood of the general population of different countries range between 0.01 and 0.07 mg/litre and levels in human milk have been reported in the range 0.01–0.10 mg/litre.

A typical median lethal dose for the rat is 250 mg/kg body weight (administered in oil). The main effect of DDT is on both the central and peripheral nervous systems. The liver is the only other organ significantly affected. In long-term feeding tests in mice and rats, liver changes progressed from hypertrophy, margination, and lipospheres to the formation of nodules of affected cells. No teratogenic effects have been observed in several animal species and it has not been found to be mutagenic in bacterial test systems. Long-term occupational exposure provides no evidence of DDT-induced cancer in man (14). The conditional ADI for DDT (total isomers) for man was established in 1969 as 0.005 mg/kg body weight.[a]

(b) Aldrin and dieldrin

Aldrin and dieldrin are persistent insecticides that accumulate in the food chain. Dieldrin is formed from aldrin by metabolic oxidation in

[a] FAO/ WHO. 1969 Evaluations of some pesticide residues in food. Unpublished documents: FAO/PL: 1969/M/17/1; WHO/Food Add./70.38.

animals and by chemical oxidation in soil. Both insecticides have been used for soil treatment against various soil insects, for seed treatment, and for foliar application to agricultural crops, but their use has been gradually limited or prohibited. Currently, the predominant use is for termite control.

The primary site of action of dieldrin is the central nervous system. It has not proved to be mutagenic in any of the *in vitro* or *in vivo* mutagenicity studies, and no teratogenic effects have been observed following studies in different animal species. The results of various carcinogenicity tests in mice and other mammals show that there is a species-specific effect of aldrin and dieldrin that results in an increased frequency of liver tumours in mice only. Toxicological data available in 1977 supported the view that dieldrin and aldrin are not carcinogens and therefore the previously estimated acceptable daily intake of 0.0001 mg/kg body weight for aldrin and dieldrin residues separately or together was reaffirmed.[a]

(c) Chlordane (total isomers)

Chlordane is a broad-spectrum insecticide from the group of polycyclic chlorinated hydrocarbons called cyclodiene insecticides. Chlordane has been used extensively over the past 30 years for termite control, as an insecticide for homes and gardens, and as a control for soil insects. Both the uses and the production volume of chlordane have decreased extensively in recent years.

There is some evidence that chlordane is potentially mutagenic for human cells and bacteria. A bioassay for the possible carcinogenicity of chlordane was carried out with mice and rats. There was a highly significant dose-related occurrence of hepatocellular carcinoma in mice, but not in rats. Several epidemiological studies involving occupationally exposed persons do not provide any evidence of increased cancer mortality. As carcinogenicity has been conclusively demonstrated only in one species, the mouse, a limit for chlordane should be based on its toxicity. An acceptable daily intake for man has been estimated as 0.001 mg/kg body weight (*16*).

(d) Hexachlorobenzene

Hexachlorobenzene (HCB) is produced commercially, principally for use as a fungicide. However, generation of hexachlorobenzene as a by-product in the manufacture of chlorine and other chlorinated chemicals, particularly solvents, is the largest environmental source of this compound.

Although HCB has a low acute toxicity for most species (>1000 mg/kg body weight), it has a wide range of biological effects following prolonged, moderate exposure. In man, the syndrome includes blistering

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[a] FAO/WHO. *1970 Evaluations of some pesticide residues in food.* Unpublished documents: FAO/AGP/1970/M/12/1; WHO/Food Add./71.42.

and epidermolysis of the exposed parts of the body, particularly the face and hands.

A disorder was described in the infants of some Turkish mothers who either had HCB-induced porphyria or had eaten HCB-contaminated bread, resulting in contamination of the maternal milk with HCB. At least 95 % of these infants died within a year. Two studies in mice and hamsters indicate that HCB is a carcinogen (*12*).

Application of the linear multi-stage model for an additional cancer risk of 1 per 100 000 population per lifetime of exposure gives a recommended guideline value of 0.01 μg/litre.

(e) Heptachlor and heptachlor epoxide

Heptachlor is a broad-spectrum insecticide of the group of polycyclic chlorinated hydrocarbons. Its most important use agriculturally was to control soil insects. Heptachlor is still widely used on non-field crops and for termite control.

Heptachlor persists for long periods in the environment. It is converted to the more toxic metabolite, heptachlor epoxide, in the soil, in plants, and in mammals. Heptachlor, in solution or thin films, undergoes photodecomposition to photoheptachlor, which is more toxic to insects and aquatic invertebrates than the parent compound.

In long-term feeding studies with heptachlor to test for terato-genicity, cataracts developed in parent rats and in the offspring shortly after their eyes opened. Heptachlor has been reported to be mutagenic in mammalian assays although neither it nor the epoxide form was mutagenic for *Salmonella typhimurium* in the Ames test. Heptachlor caused dominant lethal changes in male rats as demonstrated by the number of resorbed fetuses in intact pregnant rats. Heptachlor and/or heptachlor epoxide induced hepatocellular carcinomas in mice in three chronic feeding studies and in rats in one such study. The calculated guideline value of 0.1 μg/litre based upon the acceptable daily intake of 0.5 μg/kg body weight is still less than the value that would be calculated by applying the multi-stage model at a projected incremental cancer risk of 1 per 100 000 per lifetime.

(f) Gamma-HCH (lindane)

Lindane[a] is a broad-spectrum insecticide of the group of cyclic chlorinated hydrocarbons and is used in a wide range of applications including the treatment of animals, buildings, man (for ectoparasites), clothes, water (for mosquitos), plants, seeds, and soils. It is slowly degraded by soil microorganisms and can be isomerized to the alpha- and/or delta-isomers by microorganisms and plants. Contamination of water has occurred from direct application of technical hexachlorocyclo-hexane (HCH) or lindane to water for the control of mosquitos, from the use of HCH in agriculture and forestry, and, to a lesser extent, from

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[a] Lindane is a product containing not less than 999 g of gamma-HCH per kilogram.

occasional contamination of waste water from manufacturing plants.

Irritation of the central nervous system as well as other toxic side-effects (nausea, vomiting, spasms, weak respiration with cyanosis, and blood dyscrasia) have been reported after prolonged or improper use of hexicid (1 % lindane) for the treatment of scabies in man. Production workers exposed to technical HCH exhibited symptoms including headache, vertigo, and irritation of the skin, eyes, and respiratory tract mucosa. Lindane does not produce teratogenic effects in rats. In both rats and rabbits, lindane given in the diet during pregnancy increased the post-implantation death of embryos. Evidence for the mutagenicity of lindane is equivocal. It was found to be mutagenic in microbial assays, but other reports indicate that it does not have any significant mutagenic activity. An increased incidence of liver tumours in mice has been reported (12).

As carcinogenicity has been demonstrated in only one species, the mouse, the guideline value for lindane is based on the FAO/WHO ADI, assuming that 1 % of the ADI would be provided by drinking-water.

(g) Methoxychlor

Methoxychlor is an insecticide used for the treatment of agricultural crops and livestock. It is a compound of relatively low acute toxicity. Methoxychlor does not exhibit teratogenicity in rats, and it is not mutagenic in bacteria. The available data do not provide any evidence that methoxychlor is carcinogenic in experimental animals. Its rapid metabolism in experimental animals accounts for its low storage and accumulation (15).

An acceptable daily intake for man of 0.1 mg/kg body weight, established in 1965, was reaffirmed in 1977 (16).

(h) 2,4-D

2,4-D (2,4-dichlorophenoxyacetic acid) is used as a herbicide for the control of broad-leaved plants and as a plant growth regulator. Commercial formulations are generally composed of salts or esters of the acid. 2,4-D is chemically quite stable, but its esters are readily hydrolysed to the free acid. The herbicide may be rapidly broken down in water. Residues are infrequently found in the soil, as the substance is broken down by soil microorganisms and there are no reports of accumulation.

Individuals who were exposed to 2,4-D through its use or manufacture have complained of rapid fatigue, headache, liver pains, loss of appetite, etc. (15). Workers exposed to 2,4-D at 0.43–0.57 mg/kg body weight per day over a period of 0.5–22 years showed no health differences when compared with an unexposed human population. Studies on the carcinogenic properties of this compound have proved inconclusive, because of either inadequate reporting or the small number of animals used. However, the indications are that 2,4-D is not a potential carcinogen. The acceptable daily intake of 2,4-D has been established by WHO at 0.3 mg/kg body weight (17). The guideline value for 2,4-D in

drinking-water is 0.1 mg/litre, based on its toxicity. However, some individuals may be able to detect 2,4-D by taste and odour at levels exceeding 0.05 mg/litre.

4.3.7.5 Chlorobenzenes

Chlorobenzenes are widely used in the chemical industry as solvents and as intermediates in the production of dyestuffs, insecticides, etc. Most chlorinated benzenes have not been detected in drinking-water at levels above 0.1 μg/litre, the exceptions being monochlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and 1,2,4-trichlorobenzene. Toxicological data on the chlorinated benzenes are scarce. Preliminary evaluation of the available data for monochlorobenzene, 1,2-dichlorobenzene, and 1,4-dichlorobenzene suggests that toxicologically-based limits and the odour threshold concentrations are of the same order of magnitude. Insufficient health data are available from which to derive a guideline value for 1,2,4-trichlorobenzene. (See also section 4.4.3.19.)

(a) Monochlorobenzene

Monochlorobenzene (MCB) is widely used as a solvent and is an intermediate for dyestuffs, pesticides, and other chemicals. It may also be formed during the chlorination of water contaminated with benzene. Its presence in raw and treated potable waters at levels up to 10 μg/litre has been recorded. There are no toxicological data based on long-term exposure, but there is sufficient evidence to show that MCB causes dose-related target organ toxicity. No data are available on its carcinogenicity, teratogenicity, or mutagenicity. From short-term studies in rats and dogs, no-observed-adverse-effect levels of 15 and 27 mg/kg body weight, respectively, may be derived.

Since there are no long-term toxicity data, a conservative safety factor of 1000–10 000 has been used to estimate a tentative acceptable daily intake of 0.0015–0.015 mg/kg body weight. Allocating 10% of this dose to daily water consumption results in a calculated toxicological limit for drinking-water of 5–50μg/litre. Following consideration of both these figures and the fact that the threshold odour concentration of MCB in water is 30 μg/litre, 10% of this latter figure has thus been recommended to avoid taste and odour problems in drinking-water.

(b) 1,2-dichlorobenzene and 1,4-dichlorobenzene

1,2-dichlorobenzene and 1,4-dichlorobenzene (DCB) are the most widely occurring dichlorobenzenes, both compounds being used as intermediates in the production of dyestuffs. 1,4-DCB is also used as a moth repellent and in toilet blocks, while 1,2-DCB is used as a solvent in the chemical industry. The two compounds are frequently detected in surface-water and drinking-water; concentrations up to 10 μg/litre levels have been reported.

Non-metabolized DCB may accumulate in tissues, especially in fat. Several short-term studies with laboratory animals have been reported for 1,4-DCB. In a 4-week study with rats, no effect was observed after a 100 mg/kg body weight dose was given orally. Other experiments with rats involving 130 oral doses showed that no adverse effects were observed at a dose level of 18.8 mg/kg body weight given for 5 days of the week. Using the no-effect dose of 18.8 mg/kg body weight per day, derived from the short-term study with rats, and by applying a safety factor of 1000–10 000, an acceptable daily intake (7-day week) of 0.014–0.0014 mg/kg body weight can be calculated. Allocating 10 % of this dose to water consumption, a toxicological limit for drinking-water of 5–50 μg/litre has been derived. The threshold odour concentration of 3 μg/litre is quoted for the 1,2 isomer and 1 μg/litre for the 1,4 isomer; 10 % of each of these values is recommended as a level unlikely to give rise to taste and odour problems in drinking-water supplies.

4.3.7.6 Chlorophenols[a]

Chlorophenols are used as biocides and are found following the chlorination of water containing phenol. Chlorophenols are widely recognized for their low taste and odour thresholds; the thresholds for the most odorous compounds are as low as 1 μg/litre. Therefore, generally, individual phenols and chlorophenols should not be present in drinking-water at a level above 0.1 μg/litre, for organoleptic reasons. However, in the absence of chlorination, some phenols are organoleptically acceptable at levels up to 100 μg/litre; when organoleptic considerations are secondary to the provision of a disinfected drinking-water supply, it should be noted that some phenolic compounds exert toxic effects at these higher concentrations. The spectrophotometric method of analysis for phenols is not sufficiently sensitive to detect chlorophenols at their threshold taste and odour levels or to detect phenols at levels at which the products resulting from their chlorination would cause taste and odour problems. In such cases, direct taste and odour assessment by panels, or analytical determination by chromatographic techniques, may be used.

The best way to control the pollution of drinking-water by chlorophenol is to prevent the release of phenol and chlorinated phenols into the raw water. Where high phenol levels are present in the raw water, these should be reduced as far as possible before chlorination takes place. Lower-substituted chlorophenols can be removed from water by oxidation, while the higher-substituted compounds can be effectively removed by activated carbon adsorption. (See also section 4.4.3.18.)

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[a] Including 2- and 4-chlorophenol; 2,4- and 2,6-dichlorophenol; 2,4,5- and 2,4,6-trichlorophenol; 2,3,4,6-tetrachlorophenol; and pentachlorophenol.

(a) 2,4,6-trichlorophenol

2,4,6-trichlorophenol occurs at low concentrations in many water supplies as a product of the reaction between chlorine used for disinfection and certain precursor substances (including phenol) or other naturally occurring organic chemicals. Typical concentrations in finished drinking-water range from 0.003 µg/litre to less than 1 µg/litre. As with other chlorinated phenols, 2,4,6-trichlorophenol at high doses can increase the body temperature and produce convulsions. However, the main concern is that 2,4,6-trichlorophenol has been shown to induce leukaemia or the formation of lymphomas in male rats and to increase significantly the incidence of hepatocellular carcinomas in male and female mice. In addition, 2,4,6-trichlorophenol has been shown to be mutagenic in yeast, a result that suggests carcinogenic properties. On the basis of these results, it has been concluded that 2,4,6-trichlorophenol is a chemical carcinogen that might increase the cancer rate in man, if present in sufficient quantities. Very little is known about the metabolism of 2,4,6-trichlorophenol except that it seems to be cleared rapidly from the body.

In view of the carcinogenic properties of this compound, a guideline value of 10 µg/litre has been calculated, based on a linear multi-stage extrapolation model. However, 2,4,6-trichlorophenol may be detected by its taste and odour at a concentration of 0.1 µg/litre.

(b) Pentachlorophenol

Pentachlorophenol is commonly used as a wood preservative and occasionally occurs in drinking-water at concentrations that may be objectionable from both the health and taste and odour points of view. Acute toxicity in man and animals is accompanied by an elevation in temperature, accelerated respiration, and ultimately cardiac arrest. Purified pentachlorophenol has been shown to damage both the kidneys and the liver in experimental animals. Some evidence of similar alterations has been observed in people exposed occupationally to the technical product. Pentachlorophenol is toxic to both embryos and fetuses in experimental animals. It also increases the frequency of mutation in yeast, although negative results have been obtained in other mutagenicity assays. Pentachlorophenol has not proved to be carcinogenic in any tests on experimental animals. It is well absorbed from the gastrointestinal tract and may also be absorbed through the skin. Most of the systemically absorbed pentachlorophenol in man is excreted unchanged in the urine. In rats and mice, approximately 20 % of the systemic dose is dechlorinated to form tetrachlorohydroquinone and trichloro-p-hydroquinone, but this pathway has not yet been examined in man.

On the basis of these results together with evidence of mild toxicity in occupationally exposed populations with intakes estimated at 2–4 mg of pentachlorophenol a day, an uncertainty factor of 1000 has been applied to animal data to arrive at an acceptable daily intake of 3 µg/kg body

weight for pentachlorophenol (*18*). A concentration of pentachloro-phenol of $10 \mu g$/litre of water would account for 10% of this acceptable daily intake, and this is recommended as the guideline value.

4.3.7.7 *Benzene and lower alkylbenzenes*

Benzene and lower alkylbenzenes such as toluene and ethylbenzene are widely used in the chemical industry as intermediates in the production of, for example, phenol and cyclohexane. Lower alkylbenzenes are components of gasoline and are used as solvents in paints and coatings. Benzene and lower alkylbenzenes can be present in ground-water at levels higher than those usually found in surface-water because there is no evaporation. Concentrations of the chemicals in ground-water of up to the mg/litre level have recently been reported, as a result of contamination from spills and chemical waste dumps, but levels in drinking-water generally do not exceed $1 \mu g$/litre.

Benzene is used in large quantities as a solvent and as an intermediate in many syntheses in the chemical industry. It occurs occasionally in surface-waters at concentrations of up to $10 \mu g$/litre and has been reported in ground-water at levels above $100 \mu g$/litre. Benzene has been periodically reported in drinking-water, typically at low μg/litre levels; however, concentrations of up to $300 \mu g$/litre have been found.

Benzene is a chemical with well established toxic properties in man and experimental animals. In sensitive individuals, exposure to benzene has resulted in aplastic anaemia, a fatal disease. Recently, there has been concern because of the association of occupational exposures to benzene with leukaemia. Human exposure in these situations has been used to estimate, with respect to inhalation exposure, the probability of the development of leukaemia at low levels of risk (1 additional cancer per 100 000 persons, with lifetime exposure). Because of the chemical and physical properties of benzene and the fact that its effects are systemic, rather than specifically involving the lung tissue, it is supposed that similar levels of exposure to benzene via drinking-water would result in the same level of risk. A guideline value of $10 \mu g$/litre has therefore been recommended, based on the data for leukaemia applied to a linear multi-stage extrapolation model.

4.3.7.8 *Trihalomethanes*

Chlorination of drinking-water containing natural organic substances produces a number of by-products including the trihalomethanes: chloroform, bromodichloromethane, dibromochloromethane, and tri-bromomethane (bromoform). Chloroform has been shown to produce cancer in two species of laboratory animal. The other trihalomethanes, often formed when bromide ions are present, are only now being tested for carcinogenicity in bioassays similar to those used to show that chloroform is a carcinogen under test conditions. These other

trihalomethanes are, however, known to be more active than chloroform in the Ames *Salmonella* test for mutagenicity.

Chloroform has been shown to cause cancer in two species of laboratory animal and is regarded as a potential cancer risk in man, although the mechanism of carcinogenesis has yet to be discovered. Chlorine is, however, an effective water disinfectant and the hazards of disease caused by microbiological contaminants resulting from incomplete disinfection are substantial and must be recognized. This is particularly true in developing countries, where waterborne diseases cause thousands of deaths every day. Chlorine is the most convenient and easily controlled disinfectant, and is widely used. The World Health Organization supports its use for water disinfection in developing countries.

The formation of trihalomethanes (THM) is largely dependent upon the interaction of chlorine and certain precursor substances in the water (e.g., fulvic and humic acids). A high THM concentration should not arise if the water contains small amounts of the precursors or if they are removed by treatment. However, it is clear that inadequate disinfection in order not to elevate the THM level, is not acceptable. This does not mean that the presence of THM is without risk, however, and every practical, safe alternative for minimizing their formation should be encouraged.

The recommended guideline value for chloroform is obtained using a linear multi-stage extrapolation of data obtained from male rats. Although the available toxicological data are only useful in establishing a guideline value for chloroform, the concentration of other trihalomethanes should also be minimized. Limits ranging from 25–250 μg/litre have been set in several countries for the sum of four specific trihalomethanes. Taking into account the uncertainty of the data, these limits represent a balance between the levels that can be achieved given certain circumstances and those that are desirable.

The recommended guideline value for chloroform alone is 30 μg/litre.

4.4 Aesthetic and organoleptic aspects

As previously mentioned, the guideline values presented in this book represent an informed judgement based upon several factors, including (*i*) levels and frequency of occurrence, (*ii*) toxicity, and (*iii*) availability of control technology. Substances which affect its aesthetic and organoleptic quality are commonly found in drinking-water, although these are seldom present at toxic levels, and control techniques may be costly.

Countries developing national drinking-water limits or standards should carefully evaluate the costs and benefits associated with the control of aesthetic and organoleptic quality. At least one developed country has set enforceable standards for contaminants directly related

to health, while only recommendations have been made for aesthetic and organoleptic characteristics. For countries with severely limited resources, it is even more important to establish priorities and this should be done by considering the impact on health in each case. This approach does not underestimate the importance of the aesthetic and organoleptic quality of drinking-water. An aesthetically displeasing source water may encourage the consumer to use an unsafe supply and point-of-use treatment devices may not necessarily provide a solution to this problem. In addition, taste, odour, and colour may be the first indication of a potential health hazard.

For the characteristics of water that are based on human sensory evaluation, judgement is often subjective. For health-related contaminants, what is unsafe for one is unsafe for all, while aesthetic and organoleptic characteristics are subject to social, economic, and cultural considerations. The establishment of any limit should therefore take into account the possibilities for implementation in view of the socioeconomic and environmental constraints facing the country.

Since the majority of consumer complaints regarding water quality relate to its colour, taste, or odour, the quality of drinking-water, as perceived by the senses, largely determines the acceptability of a particular water.

To guarantee that the majority of consumers are unaware of the taste or odour of a water constituent, its concentration should be significantly lower than the threshold level. The latter is the concentration at which 50 % of a group of individuals are able to detect the constituent in the water. A prerequisite of the test is that at least 10–15 persons make up the group or panel and that they operate under controlled conditions; smaller panels reduce the accuracy and reliability of the determination. Generally, however, about 5 % of the population can taste or smell a given substance in water, even when the concentration is only 1 % of the threshold value (19). The suggestion that drinking-water should be free from taste and odour could therefore place an unnecessary and unattainable burden on the personnel responsible for water quality.

In endeavouring to provide drinking-water free from taste for the majority of consumers it has been found that the concentration of organic substances, in particular, must be restricted to levels below 10 % of their particular taste and odour threshold values.

Although several individual organic substances have been associated with an adverse taste, this document deals only with chemicals that occur frequently as contaminants in drinking-water and for which analytical methods are generally available. Local circumstances may mean that perceptible odour and taste of drinking-water is unavoidable, because the removal methods are either of dubious efficacy or are not available. In such situations, local health authorities should be approached for advice, if a technical solution is not available. When taste and odour problems occur in a drinking-water supply, the cause should be investigated and immediate measures taken to eliminate the

contamination. However, it is most important that attempts to provide aesthetically pleasing and acceptable water, for example by reducing the chlorine dosage, should not compromise the microbiological safety of drinking-water.

In addition to taste and odour, the appearance of water can also cause consumer complaints. Discoloration, with or without particulate matter, may have many causes. Apart from reflecting deficiencies in water treatment it may, in untreated water, indicate unsatisfactory source water. Therefore, colour and turbidity measurements are important and may reflect abnormal concentrations of aluminium, iron, or manganese or perhaps a deficiency in the dissolved oxygen or excessive microbial growth.

4.4.1 Guideline values recommended

A total of 23 constituents and characteristics of drinking-water have been carefully examined to ascertain their influence on the aesthetic quality of water. Guideline values have been recommended for 15 of these (Table 14) and five additional monographs are included for constituents or characteristics which, under certain conditions, may cause problems.

4.4.2 Synthetic detergents

The *International standards for drinking-water* (8) included a "highest desirable level" for anionic detergents of 0.2 mg/litre. In many countries,

Table 14. Guideline values for chemical constituents and physical characteristics that may affect the aesthetic quality of drinking-water

Constituent or characteristic	Guideline value
aluminium	0.2 mg/litre
chloride	250 mg Cl^-/litre
colour	15 true colour units
copper	1.0 mg/litre
hardness	500 mg/litre (as $CaCO_3$)
hydrogen sulfide	not detectable by consumer
iron	0.3 mg/litre
manganese	0.1 mg/litre
pH	6.5–8.5
sodium	200 mg/litre
solids—total dissolved	1000 mg/litre
sulfate	400 mg SO_4^{2-}/litre
taste and odour	not offensive for most consumers
turbidity	5 nephelometric turbidity units, preferably < 1 for disinfection efficiency
zinc	5.0 mg/litre

the earlier, persistent types of anionic detergent have been replaced by others that are more easily biodegraded and hence the levels found in water sources have decreased. New types of cationic, anionic, and non-ionic detergent have also been introduced. At first, it was expected that the problem of non-degradable detergents would diminish, but in a number of countries this is not yet the case. The concentration of detergents in drinking-water should not be allowed to reach levels giving rise to either foaming or taste and odour problems.

4.4.3 Summaries of the evidence used in setting guideline values

4.4.3.1 *Aluminium*

Although orally ingested aluminium compounds do not generally appear to have deleterious health effects on normal individuals, the presence of aluminium compounds in water used in kidney dialysis has been associated with neurological disorders in patients receiving treatment. Aluminium compounds are used extensively in water treatment, and if levels above 0.1 mg/litre remain in the distributed water, discoloration may be observed. The guideline value of 0.2 mg/litre has been proposed as a compromise. The presence of aluminium may increase the discoloration of water when iron is also present.

4.4.3.2 *Chloride*

High concentrations of chloride give an undesirable taste to water and beverages. Taste thresholds for chloride (as sodium, potassium, or calcium chloride) are in the range of chloride ion concentration of 200–300 mg/litre. High chloride concentrations are corrosive to metals in the distribution system, particularly in waters of low alkalinity, and conventional water treatment does not remove chloride from the water.

The main source of human chloride intake is from salted foods, the average intake being about 6 g of chloride ion per day (20).

The guideline value for chloride in drinking-water is 250 mg/litre, based on taste considerations.

4.4.3.3 *Colour*

The colour of drinking-water may be due to the presence of coloured organic matter (primarily humic substances), metals such as iron and manganese, or highly coloured industrial wastes. Consumers may turn to alternative, perhaps unsafe, sources when their water is coloured to an aesthetically displeasing degree, so it is desirable that drinking-water should be colourless.

The guideline value is 15 true colour units (TCU), although levels of

colour above 15 TCU can be detected in a glass of water by most people.

4.4.3.4 *Copper*

Copper is an essential element in human metabolism (*21*) and is generally considered to be non-toxic for man at the levels encountered in drinking-water. The presence of copper in a water supply, although not considered as a health hazard, may interfere with the intended domestic uses of the water. Copper in public water supplies increases the corrosion of galvanized iron and steel fittings. At levels above 5 mg/litre, it also imparts a colour and an undesirable bitter taste to water. Staining of laundry and plumbing fixtures occurs at copper concentrations above 1.0 mg/litre. Copper is extensively used in domestic plumbing systems, and levels in tap-water can therefore be considerably higher than the level present in water entering the distribution system.

The guideline value is 1.0 mg/litre based on its laundry and other staining properties.

4.4.3.5 *Hardness*

Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions, and in some instances a water hardness in excess of 500 mg/litre is tolerated.

The hardness of water is caused by dissolved polyvalent metallic ions, principally calcium and to a lesser extent magnesium, and is often expressed as the equivalent quantity of calcium carbonate ($CaCO_3$).

The taste threshold for the calcium ion is in the range of 100–300 mg/litre depending on the associated anion. The taste threshold for magnesium is probably less than that for calcium.

Since a guideline value is proposed for total hardness, individual levels are not proposed for calcium and magnesium. Magnesium, in association with the sulfate ion, may have laxative properties, but the human body can adapt to this effect in time.

Depending on the interaction of other factors, such as pH and alkalinity, water with a hardness above approximately 200 mg/litre may cause scale deposition in the distribution system, and will result in excessive soap consumption and subsequent "scum" formation. On heating, hard waters have a tendency to form deposits of scale. Soft water, with a hardness of less than 100 mg/litre may, on the other hand, have a low buffer capacity and so be more corrosive for water pipes.

The guideline value for hardness at 500 mg/litre (as $CaCO_3$) is based on taste and household-use considerations.

4.4.3.6 *Hydrogen sulfide*

Hydrogen sulfide is particularly noticeable in some ground-waters and in stagnant drinking-water in the distribution system, as a result of

oxygen depletion and the subsequent reduction of sulfate by bacterial activity. The presence of hydrogen sulfide in drinking-water requires immediate corrective measures for its elimination.

At pH 7.0 and below, hydrogen sulfide predominates; it is dissociated into odourless ions in more alkaline conditions. The sulfide ion is present in appreciable concentrations only above pH 10.

Sulfide is oxidized rapidly to sulfate in well-aerated water and hydrogen sulfide levels in oxygenated water supplies are normally very low.

A guideline value is not needed since any contamination can be easily detected by the consumer.

4.4.3.7 *Iron*

Although iron is an essential element in human nutrition, drinking-water is not considered to be an important source. At levels of about 0.3 mg/litre, iron stains laundry and plumbing fixtures and causes an undesirable taste in beverages. The precipitation of excess iron gives an objectionable reddish-brown colour to the water. Increases in the concentration of iron in water during distribution may be due to either corrosion of iron pipework or disturbance of existing deposits. The presence of iron at concentrations greater than 0.1 mg/litre may lead to deposits in pipes, and in the presence of aluminium may lead to dirty-water problems. At levels higher than 0.3 mg/litre there may be increased maintenance costs and complaints about taste.

Since iron compounds are used extensively in water treatment, the guideline value for iron of 0.3 mg/litre was chosen as a compromise.

4.4.3.8 *Manganese*

At levels exceeding 0.15 mg/litre, manganese in water supplies stains plumbing fixtures and laundry. At higher concentrations, it causes an undesirable taste in beverages. In common with iron, its presence in drinking-water may lead to the accumulation of deposits in the distribution system. Even at a concentration of 0.05 mg/litre, manganese will often form a coating on pipes which may slough off as a black precipitate.

The guideline value of 0.1 mg/litre is based on its staining properties.

4.4.3.9 *Oxygen—dissolved*

Oxygen dissolved in water primarily affects oxidation-reduction reactions involving iron, manganese, copper, and compounds containing nitrogen and sulfur. Studies of oxygen concentrations in water may give valuable indications concerning the cause of various problems during distribution.

No guideline value is recommended because the acceptability of low levels of dissolved oxygen depends on the presence of other water

constituents. However, it is desirable that dissolved oxygen levels be maintained as near saturation as possible. To achieve this, the concentrations of biologically oxidizable materials, including ammonia, should be as low as possible. This does not preclude the use of ammonia for chloramination purposes.

4.4.3.10 *pH*

One of the main objectives in controlling the pH is to minimize corrosion and incrustation in the distribution system, which result from the complex relationships between pH and other constituents or characteristics, such as carbon dioxide, hardness, alkalinity, and temperature. pH levels of less than 7 may cause severe corrosion of metals in the distribution system. Elevated levels of certain chemical substances, such as lead, may result from the corrosion of specific types of pipe, and the rate of corrosion increases with decreasing pH. At pH levels above 8.0, there is a progressive decrease in the efficiency of the chlorine disinfection process.

An acceptable pH for drinking-water is between 6.5 and 8.5 and this is the range proposed as the guideline value. In the absence of a distribution system, the acceptable range of pH may be broader.

4.4.3.11 *Sodium*

Sodium concentrations in drinking-water depend on factors such as hydrogeological conditions, the season of the year, and industrial activities. Sodium levels in drinking-water are normally below 50 mg/litre, but these levels may be increased during treatment, particularly when water is softened. High levels may be associated with saline soils and concentrations in excess of 1000 mg/litre have been recorded in some drinking-waters (*20*). The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature the taste threshold for sodium, in salts commonly found in drinking-water, is about 200 mg/litre (sodium ion).

The guideline value of 200 mg/litre is based on taste considerations.

4.4.3.12 *Solids—total dissolved (TDS)*

Total dissolved solids consist mainly of inorganic substances. The principal constituents of TDS are calcium, magnesium, sodium, bicarbonates, chlorides, and sulfates. An important aspect of TDS, with respect to drinking-water quality, is the effect on taste. The palatability of water with a TDS level of less than 600 mg/litre is generally considered to be good whereas at TDS levels greater than 1200 mg/litre, drinking-water becomes increasingly unpalatable.

The guideline value for TDS in drinking-water is 1000 mg/litre, based on taste considerations.

4.4.3.13 *Sulfate*

Ingestion of water containing high concentrations of sulfate can have a laxative effect, which is enhanced when the sulfate is consumed in combination with magnesium. Water containing magnesium sulfate at levels about 1000 mg/litre acts as a purgative in adults, while lower concentrations may affect new users and children. In addition, metal corrosion may be increased by high sulfate levels.

Sulfate is not removed from water by any of the common treatment processes. The use of aluminium sulfate for the chemical flocculation step during purification appreciably increases the concentration of sulfate.

Sulfates generally have less effect on taste than chlorides and carbonates. Taste thresholds vary according to the associated cation and are in the range of 200–500 mg/litre (sulfate ion).

The guideline value for sulfate in drinking-water is 400 mg/litre, based on taste considerations.

4.4.3.14 *Taste and odour*

Water odour is mainly due to the presence of organic substances. Some odours are indicative of increased biological activity; others may originate from industrial pollution. Sanitary surveys should always include investigations of possible or existing sources of odour, and attempts should always be made to correct an odour problem.

The combined perception of substances detected by taste and smell is often simply called "taste". "Taste" problems in drinking-water supplies represent the largest single class of consumer complaints. Generally, the taste buds in the oral cavity specifically detect inorganic compounds, such as magnesium, calcium, sodium, copper, iron, and zinc. Certain salts, such as sodium bicarbonate and calcium chloride, must be present in the water at concentrations similar to those in the saliva to make the water seem tasteless. An unpleasant taste may result in reduced water consumption or may cause the consumer to change to an alternative, unsafe source.

Chlorination may produce chlorine residues that are perceptible by the consumer, but lowering the chlorine dose to overcome taste problems must not compromise the microbiological safety of the water.

Changes in the normal taste of a public water supply may point to changes in the quality of the raw water source or deficiencies in the treatment process.

As water should be free of objectionable taste and odour for the majority of its consumers, the guideline value is "not offensive to most of the consumers".

4.4.3.15 *Turbidity*

High levels of turbidity can protect microorganisms from the effects of disinfection and can stimulate the growth of bacteria. In all cases where

water is disinfected, therefore, the turbidity must be low (preferably below 1 NTU) so that disinfection can be effective.

The guideline value is 5 nephelometric turbidity units (NTU) or 5 Jackson turbidity units (JTU), but preferably less than 1 NTU when disinfection is practised. Turbidity in excess of 5 NTU (5 JTU) may be noticeable and, consequently, objectionable to consumers.

4.4.3.16 *Temperature*

Cool water is generally more palatable. Low water temperature tends to decrease the efficiency of treatment processes, including disinfection, and may thus have a deleterious effect on drinking-water quality. However, high water temperature enhances the growth of microorganisms, and taste, odour, colour, and corrosion problems may be increased.

No guideline value is recommended for the temperature of drinking-water, since its control is usually impracticable.

4.4.3.17 *Zinc*

Zinc is an essential element in human nutrition. The daily requirement is 4–10 mg depending on age and sex. Food provides the most important source of zinc (*21*). Long-term ingestion of quantities considerably in excess of these amounts does not result in adverse effects. The guideline value of zinc in drinking-water is, therefore, based on aesthetic considerations.

Water containing zinc at concentrations in excess of 5.0 mg/litre has an undesirably astringent taste and may be opalescent, developing a greasy film on boiling. Although drinking-water seldom has a zinc concentration greater than 0.1 mg/litre, levels in tap-water can be considerably higher because of the zinc used in plumbing materials.

The guideline value for zinc in drinking-water is 5.0 mg/litre, based on taste considerations.

4.4.3.18 *Chlorophenols*

To avoid taste and odour problems resulting from the formation of chlorophenols during treatment, the total phenol content of water to be chlorinated should be kept below 1 μg/litre. If water is not chlorinated and chlorophenols are not present, higher levels of phenol can be tolerated. Taste thresholds for mono-, di-, tri-, and tetrachlorophenols are in the range 0.1–1μg/litre (*19*). (See also section 4.3.7.6.)

4.4.3.19 *Monochlorobenzene and dichlorobenzenes*

The highest levels of chlorobenzenes reported are for monochlorobenzene and 1,2- and 1,4-dichlorobenzene, with maximum concentrations in the range 0.1–10 μg/litre. The odour threshold concentrations for

monochlorobenzene and 1,2- and 1,4-dichlorobenzene are approximately 30, 3, and 1 μg/litre, respectively (*19*).

To provide pleasant drinking-water for the majority of consumers, concentrations less than 10% of the odour threshold levels should be acceptable. (See also section 4.3.7.5.)

4.5 Monitoring

Practical implementation of the water quality guidelines requires the collection and analysis of samples. Both these operations present problems which, if not controlled, may invalidate the conclusions of monitoring[a] and undermine the usefulness of the guidelines. This section describes the main difficulties involved, and also outlines the approaches needed to deal with them. If sampling and analysis programmes are to provide valid information on water quality, it is vital that their objectives are defined clearly and unambiguously. In turn, therefore, it is essential that water quality guidelines should be defined as precisely as possible. The definition of the substances of interest and the numerical formulation of the guideline values are particularly important.

Many substances can exist in water in a variety of physicochemical forms or "species", the properties of which may differ markedly from each other. Analytical methods must be carefully selected so that all "species" of interest are determined, while forms of no concern are excluded. Therefore, all the substances specified in the water quality guidelines must be defined unambiguously; for this purpose, it should be assumed that the values recommended in these guidelines are for total concentrations, i.e., all forms of the substances present.

4.5.1 Surrogate variables

Evaluation of the quality of drinking-water has frequently depended on the use of surrogate variables, in addition to the indicator-type variable that is also widely used. The basic principle is one of substitution, with the object of facilitating application and providing an evaluation procedure which, although not strictly correlated with any known constituent, provides a useful working tool. The coliform count is an illustration of the indicator-type variable, and is used to evaluate simply and rapidly the overall microbiological safety of a water supply. Surrogate and indicator-type measurements result mainly in reduced monitoring costs and rapid quality evaluation; but they have the disadvantage of substitution, causing doubts about the completeness of

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[a] The International Organization for Standardization defines "monitoring", as applied to water quality, as "The programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives"—*Draft International Standard ISO/DIS 6107/2 Water Quality*—Vocabulary—Part 2 (1980)

the protection. A number of proposed surrogate variables have been considered which, it was suggested, would reduce the task of assessing the degree of contamination by organic constituents.

4.5.1.1 *Total organic carbon (TOC)*

Measurement of this quantity is of great value in the operational control of a water supply, but it is of extremely limited value when used as an indicator of potential health risks. To a large extent it reflects the level of natural organic substances (humic materials), which varies according to the season and river flow. Important changes in the concentration of potentially harmful substances are not detected except under special circumstances and a single measurement is not of any significance in relation to health considerations. The measurement of TOC may be valuable for other purposes, but if this value were used alone to ensure that no compound was present in excessive amounts, the TOC would have to be reduced much below the detection limits of present equipment.

4.5.1.2 *Total organic chlorine (including VOCl, AOCl, EOCl)[a]*

Measurement of the total organic chlorine content (including VOCl, AOCl, EOCl) is potentially useful but further development of the analytical methodology is required before any guideline can be based on it. The technique is already useful, however, for screening purposes.

4.5.1.3 *Other variables*

Measurements of total organic sulfur and total organic phosphorus are also potentially of value but the methods involved are still at far too early a stage of development for further consideration. Measurements of carbon chloroform extract, carbon alcohol extract, and liquid–liquid chloroform extract are all of extremely limited value.

The level of cholinesterase inhibition could possibly be used in situations where there is a danger of contamination with organic phosphorus or carbamate insecticides, but any positive result would have to be followed by chemical analysis to identify the substance responsible. Mutagenicity screening is considered to be a valuable research tool, but the technique is very labour-intensive, requiring a high degree of expertise in its application and in the interpretation of the results. It is not suitable for the routine monitoring of water quality at present. Mutagenicity testing combined with modern methods of chemical identification is used to focus attention on identified organic substances that are potentially harmful. Mutagenicity tests that utilize specially developed bacterial strains of *Salmonella typhimurium* are used

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[a] VOCl—volatile organic chlorine; AOCl—adsorbable organic chlorine, EOCl—extractable organic chlorine.

to detect potentially harmful chemicals. These tests may be applied to the water directly or to concentrated extracts, but both procedures are problematical. Unfortunately, one cannot simply extrapolate from a positive test to a human health hazard since the compounds responsible must be identified before a complete toxicological assessment can be made.

4.5.2 Design of a sampling programme

In order to assess the quality of potable water supplied to consumers, information on its quality is normally required over a given period (during which the quality may vary). The sampling programme should be designed to cover both random and systematic variations in water quality and should ensure that the collected samples are representative of the water quality throughout the whole distribution system. The frequency of sampling must be high enough to enable the programme to provide meaningful information while, at the same time conserving sampling and analytical effort. However, the frequency of sampling may be reduced when there is evidence that particular substances are never present or where water supplies are obtained from sources with limited exposure to industrial, domestic, and agricultural wastes.

The type and magnitude of spatial and temporal variations in the concentration of water constituents will depend upon both their sources, and their behaviour in the distribution and service systems.

Substances can be classified into two main types:

Type 1. Substances whose concentration is unlikely to vary during distribution. The concentration of these substances in the distribution system is largely governed by the concentration in the water going into the supply and the substances do not undergo any reaction in the distribution system.

Type 2. Substances whose concentration may vary during distribution.

(*a*) Substances whose concentration during distribution is dependent mainly on the concentration in the water going into the supply, but which may participate in reactions (which change the concentration) within the distribution system.

(*b*) Substances for which the distribution system provides the main source(s).

This classification applies only to piped water supplies. In all other types of supply, water constituents should be regarded ·as Type 1 substances.

The same substance may belong to different classes in different distribution systems. Chemical and physical constituents for which guideline values have been recommended may be classified as follows:

Type 1. Arsenic, chloride, cyanide, fluoride, hardness, pesticides, selenium, sodium, sulfate, and total dissolved solids.

Type 2a. Aluminium, benzene, chlorinated alkanes/alkenes/benzenes/phenols, chloroform, colour, odour, and taste, iron, manganese, pH, phenol, and turbidity.

Type 2b. Benzo[*a*]pyrene, cadmium, chromium, copper, lead, and zinc.

4.5.2.1 *Frequency of appraisal*

Frequent sampling and appraisal are necessary for microbiological constituents, but sampling and analysis for the control of health-related organic and inorganic compounds in drinking-water are required less often. A thorough appraisal should be made when any new water source comes into service, and immediately following any major change in the treatment processes. Subsequently, samples should be analysed periodically, the frequency being determined by local circumstances. In addition, local information on changes in the catchment area (especially agricultural and industrial activities) is important and can be used to predict possible contamination problems, and consequently the need for more frequent monitoring of specific compounds.

The subject of frequency of appraisal of drinking-water for evaluation of aesthetic qualities cannot be generalized. Some constituents, for example sodium or chloride, are in the drinking-water at the source and others are added during the water-treatment processes. Other characteristics and constituents, such as taste, copper, zinc, etc., may vary considerably as a result of other considerations or in relation to the type of distribution system. Obviously for some constituents and characteristics the appraisal will need to be fairly frequent, whereas for others where the levels show little variation, less frequent determination will be required.

4.5.2.2 *Sampling locations*

The exact sites for sampling need to be chosen carefully to provide samples that are representative of the whole system or of the particular problem area. Exact recommendations cannot be given on the selection of the correct site because of the complexities involved; sample locations are best chosen using local knowledge concerning the specific problems, the water source, and the distribution system.

For Type 1 substances, it is generally sufficient to sample only the water going into the supply. Where two or more waters with different concentrations of a Type 1 substance are being fed into the same distribution network, some additional sampling may be required within the distribution system.

The concentrations of Type 2 substances are liable to change between the supply point(s) and consumers' taps. Many interconnected processes may occur (e.g., corrosion of pipes, deposition of solids, reactions between substances in the water), which necessitate the collection of samples from consumers' taps. The selection of taps cannot be made on a general basis and must rely on consideration of the particular

circumstances involved. However, two extreme sampling strategies may be distinguished: (i) taps selected on a wholly random basis; (ii) taps systematically selected from knowledge of factors affecting the substance of interest.

The nature and magnitude of spatial variations of quality and the monitoring objectives will determine which of these approaches (or a combination) is most appropriate. Random sampling is usually desirable when the spatial variations in quality are completely random, but it may not be ideal if there are systematic differences in quality between different parts of the distribution system. For lead, for example, random sampling might not be appropriate in a distribution system in which only 1 % of the service/domestic plumbing pipes are made of lead. On the other hand, complete reliance on systematic sampling may be unwise, since it does not provide any evidence on the adequacy of this approach. If random sampling is decided upon, it is important that the sample points should be selected on a truly random basis, care being taken that certain locations are not sampled regularly because of convenience or ease of access.

4.5.2.3 Sampling times

Raw water quality, the efficiency of treatment processes, and the effects of the distribution system on drinking-water quality will all vary with time.

For Type 1 substances, analysis of the water going into the supply usually provides an appropriate basis for monitoring. The principal factors that determine the times and frequency of sampling are therefore the concentration of the substance of interest, its variation, and the extent, if any, to which it is affected by treatment.

The concentrations of Type 2 substances are affected by many processes, and therefore tend to show complex and erratic variations with time. Each situation (substance, distribution system, information need) will require individual examination. The objectives of monitoring will greatly affect the choice of sampling times.

If temporal variations are completely random, the time of sampling is unimportant. Statistical estimation of the number of samples to be taken from a particular tap over a given period can, in principle, be made in such situations, but problems arise if systematic variations occur.

When there are rapid changes in water quality, the actual time span over which the sample is collected can significantly affect the analytical results. A composite sample, collected over a period of time, will give a time-weighted average value, whereas a single sample will give values highly dependent on cyclic and random variations. Continuous monitoring devices may be useful, but these are not generally available for all the variables of interest.

Sampling locations and times should be chosen jointly, since there is a limit to the amount of sampling and analysis that can be carried out.

Two extreme strategies are: (a) to sample many taps, each on only one or a few occasions (b) to sample fewer taps, but each more frequently. It should be noted that too frequent sampling will produce unnecessary data, and will considerably increase the cost.

The relative magnitudes of spatial and temporal variations will clearly be an important factor in selecting the strategy. Where spatial variations predominate a greater effort will generally be directed to strategy (a) than to strategy (b) and *vice versa*.

4.5.2.4 *Compliance monitoring*

If the guideline values for Type 2 substances are regarded as concentrations that must not be exceeded at any time or place, designing a sampling programme becomes extremely difficult. In the case of Type 1 substances for which monitoring at perhaps only one (or a few) locations is necessary, the difficulties are fewer, but some problems do still arise.

If continuous monitoring is not possible, a number of individual samples should be taken for analysis, and the quality of the supply at other times inferred statistically from the results. It is difficult, however, to estimate maximum values from such data (especially since the nature of the statistical distribution of sample concentrations will often not be known) and the estimated maxima will be subject to relatively large uncertainties. In these circumstances, alternative criteria for judging compliance will be needed. For example, the criterion of compliance could be defined as follows: "That $x\%$ of all possible samples (i.e., $x\%$ of the statistical population) do not exceed the guideline value". However, because only a limited number of results will be available, uncertainties in estimating such a percentage must be recognized. The risks of drawing false conclusions must be reduced to acceptable levels by the choice of an appropriate number of samples and of appropriate analytical error requirements. Of course, other criteria—for example, based on the mean concentration of the substance (determinand)—could be employed.

In addition to the statistical approach to judging compliance, attention must also be paid to the choice of sampling times (and locations, in the case of Type 2 substances) in relation to the behaviour of the particular substance in the given distribution system. For example, in the case of lead, a variety of sample types is possible, such as first-draw samples (i.e., samples taken after overnight stagnation), random daytime samples, flushed samples, etc. First-draw samples give the highest lead concentrations, but are the least convenient to collect. Flushed samples, on the other hand, give the most consistent values but reflect the minimum exposure of the water to lead. The random daytime samples, while most truly reflecting the water that the consumer drinks, give the most variable levels and so it is necessary to collect more samples to determine the mean level of exposure. Similar considerations

to those outlined above will apply to other Type 2*b* substances, although the spatial and temporal variations are likely, of course, to follow different patterns.

Finally, when considering criteria for judging compliance with a guideline value, attention must be given to the area and time over which the assessment of compliance will be made. Generally the area should be based on individual water supply systems, although subdivision of water supply systems may be useful if the distribution materials differ markedly in different parts of the system. In some circumstances, it may be desirable to design sampling programmes so that the risks of drawing false conclusions concerning compliance vary in relation to the size of the population served in the different areas selected.

4.5.3 Sample collection

Samples should fulfil two conditions: (*a*) the water entering the sample container should be a representative sample and (*b*) the concentrations of the substance being determined should not alter between sampling and analysis.

4.5.3.1 *Consumers' taps*

When all or part of the water emerging from a tap is collected, the concentration of a substance of interest may be affected by two main factors: the flow-rate from the tap, and the volume collected. Substances of Type 1 are not usually affected by these factors; this is not true for substances of Type 2, where two fundamental problems arise:

(*i*) If the flow-rate normally used by the consumer is also used for sampling, there may well be difficulties in comparing the qualities observed at different taps sampled at different flow-rates. On the other hand, if a standardized flow-rate is adopted to reduce this problem, the observed qualities may then not reflect the quality of water as used by the consumer.

(*ii*) When the samples are taken at times of rapid or systematic change in water quality, the volume of the sample collected may affect the observed quality. This situation may arise, in particular, for Type 2 substances. In this case, a practical solution is to specify the particular sample volume to be collected.

4.5.3.2 *Sample stability*

The concentrations of the substances to be determined in a sample may change between sampling and analysis as a result of (*a*) external contamination during the collection of the sample, (*b*) contamination from the container, or (*c*) chemical, physical, and biological processes in the sample (*22*).

Serious errors can occur unless appropriate precautions are taken, but

generally, standard or recommended methods of analysis are designed to avoid contamination from the sample container and to minimize concentration changes during storage (*23*). Moreover, the method of sample preservation will often be determined by the analytical method employed. Tests should nevertheless be carried out to check that the concentration of the substance being determined does not change unacceptably during the period between sample collection and analysis.

4.5.4 Analysis

When a representative sample of water is analysed for a substance of interest, the accuracy of the result depends entirely on any errors that arise during analysis.

Multinational interlaboratory studies have shown that in certain laboratories serious errors of analysis occur, sometimes as large as several hundred percent. Commonly, this analytical error is greatest for substances that are present at low concentrations. Quality control should be a fundamental part of any programme of sampling and analysis, especially when the results of the work are to be compared with numerical standards or guidelines. Suitable analytical procedures are generally available to reach the required standards of accuracy; the practical problem is to ensure their adoption and correct application. In some countries there will also be problems related to the availability of the necessary equipment. If these problems are to be avoided, it is important that (i) the maximum total tolerable error for each substance should be decided upon on the basis of the information required from the monitoring (or identification) work; (ii) appropriate analytical methods should be employed and properly applied so that the required accuracy is achieved.

Various general aspects related to these two points are considered in the following sections.

4.5.4.1 *Defining the required accuracy*

The accuracy required of an analytical procedure is, in principle, governed by the objectives of the programme of sampling and analysis, which may differ according to the circumstances. Consequently, a generally applicable definition of the required accuracy cannot be given, and attention is restricted here to consideration of four points of particular importance:

(*i*) The accuracy required should be defined in an explicit, quantitative manner, so that unambiguous criteria are available for the selection of suitable analytical methods. In the absence of such criteria, a laboratory's approach to the selection of methods may be governed by other factors (e.g., speed, cost), to the detriment of accuracy.

(*ii*) As the target for the accuracy of any analysis is made more stringent, the time and effort required to carry it out (and therefore the

cost) will increase—often disproportionately to the improvement in accuracy. A frequent and costly practice is to set the limit of accuracy on the basis of analytical and statistical considerations only and not to consider the real meaning of a given error. For some substances at low concentrations, even an error of $\pm$ 50 % may not have a real sanitary or health significance. The setting of needlessly stringent targets is therefore to be avoided.

(*iii*) Many of the substances considered in these guidelines may be present at very low concentrations, and therefore the limit of detection is often likely to be the single most important criterion in selecting a method of analysis. It is essential that the smallest concentration of interest should be identified. This concentration will, in general, be considered as the required limit of detection. It may be useful, therefore, to set the required limit to one-tenth of the recommended guideline value.

(*iv*) Careful consideration should be given to the manner of expressing target accuracy. Statements like "the error of a result should not exceed 10 %", though commonly used, are not recommended, for three reasons:

(*a*) the required statistical confidence level is not stated,
(*b*) percentage error inevitably increases as the limit of detection is approached, and
(*c*) no indication is given of the tolerable magnitudes of the random and systematic components of the total error.

A more realistic and practical approach would be to express the accuracy required as follows: "The maximum tolerable total error (95 % confidence) is equal to the required limit of detection or to p % of the concentration, whichever is the greater. The random (95 % confidence) and systematic errors should each be not more than one-half of the total error." Setting $p = 20$ gives an acceptable compromise between accuracy and cost, but the value of p, the division of the total error between the random and systematic components, and the confidence level should all be considered (and may need to be varied) in relation to particular monitoring circumstances. Nevertheless, whichever values are chosen, the general form of expression quoted is recommended.

4.5.4.2 *Selecting suitable analytical methods*

Various collections of "standard" or "recommended" methods for water analysis are published by a number of national or international agencies (*23, 24*).[a] It is often thought that adequate analytical accuracy can be achieved without problems provided that all laboratories use the same standard method. Experience shows that this is not the case, since a variety of extraneous factors may affect the accuracy of the results.

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[a] See also: UNEP/WHO/UNESCO/WMO Project on Global Water Quality Monitoring. *GEMS/Water operational guide.* Unpublished WHO document ETS/78.5.

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Examples[1] include reagent purity, apparatus type and performance, degree of modification of the method in a particular laboratory, and the skill and care of the analyst. These factors are likely to vary, both between laboratories and over time in an individual laboratory. Moreover, the accuracy that can be achieved with a particular method frequently depends upon the nature and composition of the sample. It is not essential to use standard methods except in the case of "non-specific" variables such as taste and odour, colour, and turbidity. In these cases the result is determined by the method employed, and it is necessary for all laboratories to use identical methods if comparable results are to be obtained.

A number of considerations are important in selecting analytical methods:

(i) The overriding consideration is that the method chosen can result in the required accuracy. Other factors, such as speed and convenience, should be considered only in selecting among methods that meet this primary criterion.

(ii) There are many markedly different procedures for measuring and reporting the errors to which methods are subject. This needlessly complicates, and prejudices the effectiveness of method selection and suggestions for standardizing such procedures have been made (23). It is desirable that details of all analytical methods are published together with performance characteristics that can be interpreted unambiguously.

(iii) If the analytical results from one laboratory are to be compared with those from others and/or with a numerical standard, it is obviously preferable for them not to have any associated systematic error. In practice, this is not possible, but it emphasizes the need for each laboratory to select methods whose systematic errors have been thoroughly evaluated and shown to be acceptably small.

4.5.4.3 Analytical quality control

Whichever method is chosen, appropriate analytical quality control procedures must be implemented to ensure that the results produced are of adequate accuracy. Analytical quality control has been discussed in detail elsewhere (23, 24).[a] Because of the wide range of substances, methods, equipment, and accuracy requirements likely to be involved in the monitoring of drinking-water, many detailed, practical aspects of analytical quality control are concerned. These are beyond the scope of this document, which can only give an idea of the approach involved.

Before analysing samples by the chosen method, preliminary tests should be conducted by each laboratory to provide estimates of its precision (random error of the results). The routine analysis of samples (accompanied by regular checks of precision) can begin when the results

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[a] See also: UNEP/WHO/UNESCO/WMO Project on Global Water Quality Monitoring. GEMS/Water operational guide. Unpublished WHO document ETS/78.5.

from the preliminary tests have acceptably small errors. These preliminary tests can, and should, check certain sources of systematic error, but this is usually very difficult for a routine laboratory. This emphasizes the need for a sound method selection initially, and also for another form of analytical quality control, namely, interlaboratory testing. Such testing is usually the best single approach to check systematic error, but should only be undertaken after satisfactory completion of preliminary precision tests. There may be some difficulty in implementing an analytical quality control programme if the coordinating laboratory has to deal with a large number of other laboratories, or if the laboratories are far apart. A hierarchical structure of coordinating and participating laboratories allows any such difficulty to be overcome.

4.6 Remedial measures

4.6.1 General

Monitoring water supplies can provide the local water utility and regulatory authority with valuable information on at least two aspects: (a) it helps assess the efficiency of treatment, if any, and also indicates whether the water quality variables are within the acceptable limits, and (b) it provides useful information on the natural, seasonal quality variations. Values above the set limit must be viewed in perspective before any remedial or corrective measures are planned. It is most important first to assess and identify whether the observed increase in the level of any of the variables is due to inherent variations in water quality or to extraneous pollution factors. For example, a river or stream receiving treated domestic effluents may, during seasonal reductions in flow, show a higher level of chloride, because there is less dilution, than during the rainy season. As discussed earlier, the concentration of certain substances may show an increase or decrease owing to changes that occur within the distribution system. Hence, a thorough knowledge of the local conditions is a prerequisite for both a proper diagnosis of a particular situation and a decision on a suitable course of remedial action.

Where the guideline value for a constituent or contaminant is exceeded, the control agency should be consulted for advice on appropriate corrective action. The period for which a guideline value may be exceeded without prejudice to health depends on the nature and concentration of the substance. However, the concentrations in any particular water supply should not be permitted to exceed any of the health-based values for long periods. Appropriate remedial action should be taken and the control agency should possess the necessary legal powers to enforce this action. In addition, the motivation and education of the consumers will often prove effective in solving most of the problems. Once the problem has been identified, and its magnitude

and any consequent health implications assessed, the urgency of the corrective action to be taken must be decided. In extreme cases an alternative supply of potable water may have to be provided immediately.

The axiom "prevention is better than cure" is relevant to the maintenance of a uniformly acceptable quality of water supply. Many potential problems can be prevented by safeguarding the integrity of the raw water source and its associated watershed, by proper maintenance and inspection of the treatment plant and distribution system, by the training of managers and plant personnel, and by consumer education. Source protection should receive the greatest attention since even the best treatment plant is not completely reliable all the time.

4.6.2 Corrective measures for chemical constituents of health concern

The action required to correct a contamination problem will necessarily depend on the nature and severity of the problem, and on whether it originates at the raw water source, the treatment plant, or the distribution system.

4.6.2.1 *Raw-water source*

For surface-waters, a judicious change of the point of withdrawal of raw water may satisfactorily solve some of the problems. Some flexibility in control may often be feasible where treatment is preceded by storage. Sometimes, the immediate corrective action may involve the temporary suspension of supply (i.e., after chemical spillage) with the provision of an alternative supply of potable water or the use of stand-by treatment procedures (carbon filters, superchlorination). Medium- and long-term corrective action may involve switching to a new source of supply, identification and elimination or control of an industrial, municipal, or non-point source of pollution (e.g., changing agricultural practices), and restricting access to or modifying permitted activities in the watershed or on the water source itself.

4.6.2.2 *Treatment plant*

Although the chemicals used in potable water treatment are not usually a significant source of contamination, the specifications of these chemicals should be controlled by the appropriate national authorities. Inadequate control over the various treatment steps in a waterworks may produce water with an unacceptable level of contamination. These deficiencies can be readily corrected by ensuring that proper attention is paid to the effective operation and control of each individual process. A well equipped laboratory, with trained personnel, can greatly help to

achieve this. When the chlorine used for disinfection reacts with organic compounds, unacceptable levels of chlorinated organic contaminants may be produced. Effective coagulation, changes in chlorine dosage and points of application, and the use of alternative disinfectants can all reduce the levels of chlorinated organic compounds. Many organic contaminants can be removed from treated water by passing it through activated-carbon filter beds, but the effectiveness of the filters varies with the type of organic contaminant. Fouling and the growth of organisms on the carbon bed can also adversely affect the efficiency of this treatment. Nitrate levels can be reduced at the treatment works by a biological denitrification process or, at much greater cost, by ion exchange. The most appropriate course of action for any given problem can only be judged by the control agency familiar with the local conditions and the technology available.

4.6.2.3 *Distribution system*

Contaminants can enter a potable water distribution system through cross-connections, back-flows, breakages, and leaks or they may result from materials used in the construction of the system. Such problems can usually be overcome by the appropriate repair, replacement, or substitution of parts of the distribution system. Meanwhile, alternative ways of distributing potable water have to be ensured. Where lead concentrations at the tap are unacceptably high because of lead plumbing, central water treatment to reduce plumbo-solvency should be introduced. To achieve this for water of low alkalinity, the pH of the water at the treatment works should be raised to give a pH of 8.0–8.5 at the consumers' taps, possibly with an additional increase in alkalinity to raise the buffer capacity. For water with an already high alkalinity a simple increase in pH, for example by the removal of carbon dioxide or by adding alkali, may not reduce lead concentrations sufficiently and another treatment method, such as the addition of orthophosphate, may be needed. If the problem persists the replacement of lead service pipes with those made of a more suitable material should be considered. As a short-term measure consumers should be advised to flush the tap before taking water for drinking.

4.6.2.4 *Unpiped supplies*

Public supplies, particularly those drawn from ground-waters, may tend to have increased levels of some constituents (e.g., fluoride) over a certain period. In such cases, monitoring would determine whether or not it is necessary to find an alternative source as a long-term measure.

Roof-top collection systems are used in many developing countries. Precautions should be taken to ensure that roof construction materials are not a source of pollution.

4.6.2.5 *Bottled supplies*

If a bottled supply is found to contain an unacceptable level of a chemical contaminant, it could be the result of either contamination at the source or leaching of chemicals from the container itself. In the former case, the source may have to be rejected in favour of another acceptable one or the bottling will have to be suspended until normal conditions are restored. If contamination is from the material of the container, the use of a suitable alternative material will have to be considered.

4.6.2.6 *Water-treatment chemicals and construction materials*

Toxic chemicals in drinking-water that are derived from treatment chemicals or construction materials used in water supply systems are best controlled by appropriate specifications for the chemicals and materials used.[a] For example, a wide range of polyelectrolyte coagulant aids is now available and the presence of residues of the unreacted monomer may cause concern (25). Many polyelectrolytes are based, for example, on acrylamide polymers and on copolymers, in both of which the acrylamide monomer is present as a trace impurity. Chlorine used for disinfection has sometimes been found to contain carbon tetrachloride. This type of drinking-water contamination is best controlled by the application of regulations concerning the products themselves rather than the quality of the water. Similarly, strict national regulations on the quality of pipe material should avoid the possible contamination of drinking-water by vinyl chloride monomer and other trace constituents of plastic pipes. The control of contamination of water supplies by *in situ* polymerized and solvent-applied coatings requires the development of suitable codes of practice, in addition to controls on the quality of the materials used.

4.6.2.7 *Effectiveness of remedial measures*

Remedial action to solve one contamination problem should not lead to the creation of new problems. Any changes introduced in water treatment and distribution must be carefully monitored to ensure that the remedial action has been effective. This can be particularly difficult if the contamination is intermittent, but with a good follow-up system, efficient feedback of results, and careful record-keeping, a reliable assessment can usually be made. In fact, with a systematic review of operational and water quality data, it may even be possible to forecast some of the water quality problems that are likely to arise and so adopt appropriate preventive measures.

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[a] Treatment agents and processes for drinking-water and their effects on health. Report of a working group. WHO Regional Office for Europe. Unpublished document ICP/CEP 101(6); 1978.

4.6.3 Corrective measures related to the aesthetic quality of drinking-water

Every effort should be made to produce drinking-water whose colour, turbidity, odour, and taste are acceptable to consumers. Failure to do so will result in complaints and, in some cases, in the use of alternative unsatisfactory sources of drinking-water. High levels of turbidity can also lead to disinfection difficulties.

In many countries a high proportion of the capital investment in water treatment plants is for processes to control colour and turbidity. The techniques usually employed include chemical coagulation followed by sedimentation and filtration (26). There is no basic difficulty in achieving the values recommended in these guidelines, but a significant cost is involved.

At times, judicious relocation of the water intake may resolve taste and odour problems. Processes for the control of tastes and odours in the water supply are well established. When there are intermittent taste and odour problems, powdered activated carbon or oxidative treatment, e.g. with chlorine dioxide, may be used. Sometimes, the taste and odour of water can be improved by aeration or by break-point chlorination. Where taste and odour are a continuing problem, because of the contamination of the source water, it may be necessary to use more expensive forms of treatment, including oxidation with ozone or adsorption on to granular activated-carbon filters.

Tastes and odours often arise within the distribution system as a result of biological growths or occasionally of contamination by materials used during the construction or repair of the system. Regular monitoring of the taste and odour of the water passing into the supply helps to identify this kind of problem, whose solution requires a different approach. Checks on water samples taken from various parts of the distribution system usually enable the identification of the contamination source. Taste and odour problems can be minimized by preventive maintenance of the distribution system through regular swabbing, flushing, and in extreme cases by mechanical scraping of the pipelines, and also by the detection and repair of leaks in the system. This is particularly important, especially when water supplies are intermittent.

Iron and manganese can be removed from water by aeration or by other oxidative treatments (chlorine, chlorine dioxide, potassium permanganate) at an elevated pH followed by sedimentation and filtration, as necessary. In some cases a special filter medium that minimizes the oxidation requirement can be used.

Iron and aluminium are sometimes present in tap-water as a result of their use as coagulants in water treatment. This can lead to serious complaints and usually indicates unsatisfactory pH control, unsuitable conditions for coagulation, filter breakthrough, or some other failure in the treatment process.

Copper, zinc, and iron may occur in drinking-water as a result of corrosion of pipework. This can be corrected by anti-corrosion treatment or by replacement with pipes made from an alternative material.

The guideline values recommended for total dissolved solids, hardness, sodium, chloride, and sulfate will be of value mainly in providing a basis for source selection, since the desalting processes necessary for purification are non-selective and very expensive. However, where no other sources are available, processes such as reverse osmosis, electrodialysis, or distillation may have to be considered.

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5. RADIOACTIVE MATERIALS IN DRINKING-WATER

5.1 Introduction

The effects of radiation exposure are called "somatic" if they become manifest in the exposed individual, and "hereditary" if they affect his descendants. Malignant disease is the most important delayed somatic effect (1).

For some somatic effects such as carcinogenesis, the probability of an effect occurring, rather than its severity, is regarded as a function of dose without a threshold (stochastic effect) whereas for other somatic effects the severity of the effect varies with the dose (non-stochastic effects); a threshold may therefore exist for such effects (1).

The aim of radiation protection is to prevent harmful non-stochastic effects and to reduce the probability of stochastic effects to a level deemed acceptable. To achieve this objective dose-equivalent (H) limits are set sufficiently low that the threshold dose is unlikely to be reached during a complete life-span.

Various body tissues have different sensitivities to radiation exposure and the International Commission on Radiological Protection (ICRP), in an endeavour to provide measures of equal risk, introduced the concept of dose-equivalent weighting factors. A measure of the total risk from non-uniform radiation exposure is the effective dose-equivalent (H_E) (see Annex 3) (2, 3).

Long-lived radionuclides are retained for very long periods in the body and consequently the resulting personal exposure may extend over many years. The committed effective dose-equivalent (H_{E50}) resulting from an intake of radioactive material into the body is the effective dose-equivalent that will be accumulated during the 50 years following the intake (4).

The levels of radioactivity in drinking-water recommended by WHO in 1970 and 1971 (5, 6) were based on data available from the International Commission on Radiological Protection (ICRP) over the period 1959–66 inclusive. However, since then additional information has become available (1, 7, 8) and has been taken into consideration in the preparation of these guidelines.

5.2 Nature of the guideline values[a]

The guideline values proposed are based on an assumed daily intake of drinking-water of 2 litres and the dose resulting from a given intake of radioactive material has been calculated on the basis of the metabolism of an adult. Deviations from these assumptions, e.g., the influence of age on metabolism, or larger intakes of drinking-water, are not considered likely to necessitate modification of the screening or guideline values recommended since the latter provide a large margin of safety.

It must be noted, however, that the requirements described below are intended to apply only to routine operational conditions. The competent authorities, on a case-by-case basis and in conjunction with the water suppliers, should prepare individual plans for dealing with emergency situations appropriate to local requirements.

Radioactivity in drinking-water should not only be kept within safe limits; it should also, within those limits, be kept as low as is reasonably possible.

5.3 Guideline values recommended

The guideline values recommended take account of both naturally-occurring radioactivity and any radioactivity that may reach the water sources as a result of man's activities. From a radiological point of view, they represent a value below which water can be considered potable without any further radiological examination.

The following guideline values are proposed:

gross alpha activity: 0.1 Bq/litre
gross beta activity: 1 Bq/litre.

These values apply to the mean of all radioactivity measurements obtained during a sampling period that is appropriate for the source water. The frequency of sampling is a matter of judgement but clearly should be sufficient to establish confidence in the water quality. When a significant increase or change in the radioactive contamination of the water supply is suspected, additional water samples should be collected and analysed without delay.

The guideline values are specified assuming that only the most toxic radionuclides likely to be present in significant quantities, namely, ^{90}Sr

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[a] The term guideline value is used in the sense of "reference level" as defined by the International Commission on Radiological Protection (ICRP):

"Reference levels may be established for any of the quantities determined in the course of radiation protection programs, whether or not there are limits for these quantities A reference level is not a limit and is used to determine a course of action when the value of a quantity exceeds or is predicted to exceed the reference level. The action to be initiated may range from simply recording the information, through investigations into causes and consequences, up to intervention measures "(*1*).

and/or ^{226}Ra, contribute to the gross radioactivity of the drinking-water.

5.4 Methods of examination

The methods of analysis of gross alpha and gross beta activity should be selected in the light of local conditions in collaboration with the appropriate authorities. Procedures for the sampling and measurement of gross radioactivity levels in water have been published, together with methods for the analysis of some specific radionuclides (9).

Where the results of the gross alpha and/or gross beta analysis show activities that exceed the values given above, the appropriate competent national authorities should be notified. They should investigate which radionuclides are present in the water, and their activity levels, before taking action.

5.4.1 Alpha activity

Before starting the analysis for alpha activity, ^{222}Rn and ^{220}Rn should be eliminated. If the alpha activity is less than 0.1 Bq/litre, no further examination is necessary except for such routine surveillance as may be required by the competent authorities. If the alpha activity exceeds 0.1 Bq/litre, further examination of the water is required.

The following alpha-emitting radionuclides occur naturally and have high toxicity: ^{226}Ra, ^{224}Ra, ^{210}Po, ^{232}Th, ^{234}U, and ^{238}U. In addition, beta-emitters such as ^{228}Ra and ^{210}Pb, which have alpha-emitting daughters, are associated with these radionuclides. The need to examine the water for particular radionuclides should be based on knowledge of local hydrogeological and other information. Where necessary, the expertise and equipment to perform the necessary examinations must be sought in regional and national laboratories.

5.4.2 Beta activity

If the beta activity measured in a sample of water is less than 1 Bq/litre, no further examination is necessary except for such routine surveillance as may be required by the designated authorities.

The following have been identified as beta-emitting radionuclides having high toxicity: ^{90}Sr, ^{89}Sr, ^{134}Cs, ^{137}Cs, ^{131}I, and ^{60}Co. Examination of the water for these particular radionuclides should be based on local knowledge concerning discharges of specific radionuclides from operations in the river basin.

5.5 Radiological surveillance

The determination of sampling frequency and the choice of methods of collection and analysis should take into account the fluctuation of

observed activity levels of radionuclides in the water and the vicinity of nuclear installations and other sources of radioactive pollution (10).

Many radionuclides are readily adsorbed on to surfaces and solid particles. It is important, therefore, to choose sampling points in the distribution system and at the sources of supply with care so that the sample will be representative of the water to be examined. Water samples for radiological examination should be collected in suitable bottles which reduce adsorption on to the walls of the container to a minimum.

It is recommended that each country should have access to at least one centre where relevant radiological examinations can be undertaken.

5.6 Limitations of the guideline values

Soft beta-emitters will not be detected if the standard method of measurement (9) is used. The guideline value recommended does not take into account such soft emitters, so if a method such as liquid scintillation counting is used which does detect these emitters, the soft beta-emitters must be excluded when the results are compared. However, when the presence of potentially significant quantities of ^{3}H is suspected, a special examination for this radionuclide should be carried out.

It should be noted that the gross alpha guideline value excludes radon and whichever method of screening is used, radon must be eliminated from the sample. Where high levels of radon are known to be present, reference must be made to the competent authorities regarding both radon and its daughter products because of the hazards resulting from their ingestion and inhalation. Before a "non-action" level in drinking-water can be set, further investigations are required to determine the actual radon concentration in drinking-water and the relationship between this concentration and the doses resulting from inhalation of the released radon.

When considering the radioactive materials that contaminate drinking-water, some that may become significant in the future, e.g. ^{237}Np and ^{129}I, were not included.

5.7 High levels of radioactive materials in drinking-water sources

In general, the alpha-emitting radionuclides, such as ^{226}Ra, ^{234}U, and ^{238}U, are of natural origin and are likely to be detected in ground-waters in areas of appropriate mineralization; ^{228}Ra, a beta-emitter, has also been found in ground-waters.

Most beta-emitters (except for ^{228}Ra) are more likely be associated with man's activities.

If levels in excess of the guideline values for radioactivity are found in a drinking-water, it is important that further analyses be carried out. In this way, any hazard present can be assessed in consultation with the

competent authorities and a decision made whether any corrective action is justified bearing in mind the requirement that all exposure be "as low as reasonably achievable, economic and social factors being taken into account" (1). For subsequent routine screening the competent authority may decide to modify the screening levels in the light of the altered situation.

5.8 Remedial measures

If treatment is required to reduce excessive exposure to radium, typical water-treatment processes that should be considered include lime or lime-soda softening, cation exchange softening, or reverse osmosis. Since uranium is often present as the negatively charged uranyl ion, anion exchange may be a promising treatment.

Less information is available on water-treatment methods that might be applied to other radionuclides (assuming that the source cannot be controlled); however, lime and ion exchange softening may generally be effective.

Since radon (which also occurs naturally in some ground-waters) is an inert gas, aeration would be effective.

Water-treatment plant sludges and spent exchange resins should be disposed of in a manner consistent with national safety standards.

NOTE

It should be emphasized that the purpose of the guideline values proposed is to allow water suppliers to demonstrate, in conjunction with the screening system outlined, that the concentrations of radioactive materials present in drinking-water do not represent a significant hazard. The measurements of gross alpha and gross beta activity are intended to indicate the upper limit on the associated hazard. If the guideline values are exceeded, more detailed analyses of the water will be necessary to assess the hazard; only then will it be possible for the competent authority to decide whether or not the hazard justifies corrective action.

A value in excess of the guideline value does not in itself imply that the water is unsuitable for consumption.

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Annex 1

Consultation on the Revision of Drinking-Water Standards

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TABLES FOR DETERMINING THE MOST PROBABLE NUMBER (MPN) OF PARTICULAR ORGANISMS PRESENT IN 100 ml OF WATER

These tables indicate the estimated number of organisms of the type for which examination is being made in 100 ml of water, corresponding to various combinations of positive and negative results in the portions used for the test.

Table 1. MPN and 95% confidence limits within which it can lie, for various combinations of positive and negative results when five 10-ml portions are used

Number of tubes giving positive reaction out of 5 of 10 ml each	MPN	95% confidence limits	
		Lower limit	Upper limit
0	0	0	6.0
1	2.2	0.1	12.6
2	5.1	0 5	19.2
3	9.2	1.6	29 4
4	16.0	3.3	52 9
5	Infinite	8.0	Infinite

Table 2. MPN and 95% confidence limits within which it can lie, for various combinations of positive and negative results when five 10-ml portions, five 1-ml portions and five 0.1-ml portions are used

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
5 of 10 ml each	5 of 1 ml each	5 of 0.1 ml each		Lower limit	Upper limit
0	0	1	2	<0 5	7
0	1	0	2	<0.5	7
0	2	0	4	<0 5	11
1	0	0	2	<0.5	7
1	0	1	4	<0 5	11
1	1	0	4	<0.5	11
1	1	1	6	<0 5	15

[a] Reprinted from *International standards for drinking-water*, 3rd ed. Geneva, World Health Organization, 1971.

Table 2 (*continued*)

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
5 of 10 ml each	5 of 1 ml each	5 of 0.1 ml each		Lower limit	Upper limit
1	2	0	6	<0.5	15
2	0	0	5	<0 5	13
2	0	1	7	1	17
2	1	0	7	1	17
2	1	1	9	2	21
2	2	0	9	2	21
2	3	0	12	3	28
3	0	0	8	1	19
3	0	1	11	2	25
3	1	0	11	2	25
3	1	1	14	4	34
3	2	0	14	4	34
3	2	1	17	5	46
3	3	0	17	5	46
4	0	0	13	3	31
4	0	1	17	5	46
4	1	0	17	5	46
4	1	1	21	7	63
4	1	2	26	9	78
4	2	0	22	7	67
4	2	1	26	9	78
4	3	0	27	9	80
4	3	1	33	11	93
4	4	0	34	12	96
5	0	0	23	7	70
5	0	1	31	11	89
5	0	2	43	15	114
5	1	0	33	11	93
5	1	1	46	16	120
5	1	2	63	21	154
5	2	0	49	17	126
5	2	1	70	23	168
5	2	2	94	28	219
5	3	0	79	25	187
5	3	1	109	31	253
5	3	2	141	37	343
5	3	3	175	44	503
5	4	0	130	35	302
5	4	1	172	43	486
5	4	2	221	57	698
5	4	3	278	90	849
5	4	4	345	117	999
5	5	0	240	68	754
5	5	1	348	118	1 005
5	5	2	542	180	1 405
5	5	3	918	303	3 222
5	5	4	1 609	635	5 805

Table 3. MPN and 95% confidence limits within which it can lie, for various combinations of positive and negative results when one 50-ml portion and five 10-ml portions are used

Number of tubes giving positive reaction out of		MPN	95% confidence limits	
1 of 50 ml	5 of 10 ml each		Lower limit	Upper limit
0	1	1	<0 5	4
0	2	2	<0.05	6
0	3	4	<0 5	11
0	4	5	1	13
1	0	2	<0 5	6
1	1	3	<0.5	9
1	2	6	1	15
1	3	9	2	21
1	4	16	4	40

Table 4. MPN and 95% confidence limits within which it can lie, for various combinations of positive and negative results when one 50-ml portion, five 10-ml portions and five 1-ml portions are used

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
1 of 50 ml	5 of 10 ml each	5 of 1 ml each		Lower limit	Upper limit
0	0	1	1	<0 5	4
0	0	2	2	<0 5	6
0	1	0	1	<0 5	4
0	1	1	2	<0 5	6
0	1	2	3	<0 5	8
0	2	0	2	<0 5	6
0	2	1	3	<0 5	8
0	2	2	4	<0 5	11
0	3	0	3	<0 5	8
0	3	1	5	<0 5	13
0	4	0	5	<0.5	13
1	0	0	1	<0 5	4
1	0	1	3	<0 5	8
1	0	2	4	<0.5	11
1	0	3	6	<0.5	15
1	1	0	3	<0 5	8
1	1	1	5	<0 5	13
1	1	2	7	1	17
1	1	3	9	2	21
1	2	0	5	<0 5	13
1	2	1	7	1	17
1	2	2	10	3	23
1	2	3	12	3	28

Table **4** (*continued*)

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
1 of 50 ml each	5 of 10 ml each	5 of 1 ml each		Lower limit	Upper limit
1	3	0	8	2	19
1	3	1	11	3	26
1	3	2	14	4	34
1	3	3	18	5	53
1	3	4	21	6	66
1	4	0	13	4	31
1	4	1	17	5	47
1	4	2	22	7	69
1	4	3	28	9	85
1	4	4	35	12	101
1	4	5	43	15	117
1	5	0	24	8	75
1	5	1	35	12	101
1	5	2	54	18	138
1	5	3	92	27	217
1	5	4	161	39	>450

Table 5. MPN and 95% confidence limits within which it can lie, for various combinations of positive and negative results when five 50-ml portions, five 10-ml portions and five 1-ml portions are used

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
5 of 50 ml each	5 of 10 ml each	5 of 1 ml each		Lower limit	Upper limit
0	0	1	1	<0.5	2
0	1	0	1	<05	2
0	1	1	1	<0.5	2
0	2	0	1	<05	2
0	3	0	1	<0.5	2
1	0	0	1	<05	2
1	0	1	1	<05	2
1	1	0	1	<05	2
1	1	1	1	<0.5	2
1	2	0	1	<0.6	2
1	2	1	2	<0.5	4
1	3	0	2	<05	4
2	0	0	1	<05	2
2	0	1	1	<0.5	2
2	1	0	1	<05	2
2	1	1	2	<0.5	4
2	2	0	2	<0.5	4
2	2	1	2	<05	4
2	3	0	2	<0.5	4

Table 5 (*continued*)

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
5 of 50 ml each	5 of 10 ml each	5 of 1 ml each		Lower limit	Upper limit
2	3	1	3	1	7
2	4	0	3	1	7
3	0	0	2	<0 5	4
3	0	1	2	<0.5	4
3	1	0	2	<0 5	4
3	1	1	2	<0 5	4
3	1	2	3	1	7
3	2	0	3	1	7
3	2	1	3	1	7
3	2	2	4	1	9
3	3	0	3	1	7
3	3	1	4	1	9
3	4	0	4	1	9
3	4	1	4	1	9
4	0	0	2	<0 5	4
4	0	1	3	1	7
4	0	2	3	1	7
4	1	0	3	1	7
4	1	1	4	1	9
4	1	2	4	1	9
4	2	0	4	1	9
4	2	1	4	1	9
4	2	2	5	2	12
4	3	0	5	2	12
4	3	1	5	2	12
4	3	2	6	2	14
4	4	0	6	2	14
4	4	1	7	3	17
4	5	0	7	3	17
4	5	1	8	3	19
5	0	0	4	1	9
5	0	1	4	1	9
5	0	2	6	2	14
5	1	0	5	2	12
5	1	1	6	2	14
5	1	2	7	3	17
5	2	0	6	2	14
5	2	1	8	3	19
5	2	2	10	4	23
5	2	3	12	4	28
5	3	0	9	3	21
5	3	1	11	4	26
5	3	2	14	5	34
5	3	3	18	6	53
5	4	0	13	5	31
5	4	1	17	6	47
5	4	2	22	7	70
5	4	3	28	9	85

Table 5 (*continued*)

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
5 of 50 ml each	5 of 10 ml each	5 of 1 ml each		Lower limit	Upper limit
5	4	4	35	11	101
5	5	0	24	8	75
5	5	1	35	11	101
5	5	2	54	18	140
5	5	3	92	27	218
5	5	4	161	39	424

Table 6. MPN and 95% confidence limits for various combinations of positive results when three 10-ml portions, three 1-ml portions and three 0.1-ml portions are used

Number of tubes giving positive reaction out of			MPN	95% confidence limits	
3 of 10 ml each	3 of 1 ml each	3 of 0 1 ml each		Lower limit	Upper limit
0	0	1	3	<0 5	9
0	1	0	3	<0.5	13
1	0	0	4	<0 5	20
1	0	1	7	1	21
1	1	0	7	1	23
1	1	1	11	3	36
1	2	0	11	3	36
2	0	0	9	1	36
2	0	1	14	3	37
2	1	0	15	3	44
2	1	1	20	7	89
2	2	0	21	4	47
2	2	1	28	10	149
3	0	0	23	4	120
3	0	1	39	7	130
3	0	2	64	15	379
3	1	0	43	7	210
3	1	1	75	14	230
3	1	2	120	30	380
3	2	0	93	15	380
3	2	1	150	30	440
3	2	2	210	35	470
3	3	0	240	36	1 300
3	3	1	460	71	2 400
3	3	2	1 100	150	4 800

Annex 3

SOME UNITS AND TERMS USED IN RADIATION PROTECTION[1]

1. *becquerel (Bq)*: the SI unit of activity (of a radionuclide); 1 becquerel is equivalent to 1 spontaneous nuclear transformation per second and corresponds approximately to 27 picocuries.
2. *gray (Gy)*: the SI unit of absorbed dose (radiation), defined as the dose of ionizing radiation that imparts 1 joule of energy to 1 kilogram of absorbing material.
3. *sievert (Sv)*: the SI unit of dose equivalent. The dose equivalent of 1 sievert is equal to 100 rems.
4. *Stochastic effects* are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose without threshold.
5. *Non-stochastic effects* are those for which the severity of the effect varies with dose, and for which a threshold may therefore occur.
6. *Dose equivalent (H)*: As all types of radiation do not produce the same biological effect per unit of energy absorbed, the concept of dose equivalent has been introduced. The dose equivalent, H (sieverts) is equal to the absorbed dose, D (grays), multiplied by a quality factor Q which depends upon the density of ionization produced in the tissue by the radiation.

$$H = DQ$$

The factor Q for X-rays and γ-rays and electrons is equal to 1, whereas for α particles it is 20.
7. *Effective dose equivalent*: The effective dose equivalent (H_E) is defined as:

$$H_E = \Sigma\, W_T H_T$$

where H_T is the mean dose equivalent in tissue T and W_T is a weighting factor representing the proportion of the detriment from stochastic effects resulting from tissue T to the total detriment from stochastic effects when the body is irradiated uniformly. The values of W_T are specified by ICRP (ICRP Publication No. 26).

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[1] Based on references 1, 2, 3, 4, 8 and 11 of the list on page 107.

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8. *Committed effective dose equivalent*: Radionuclides that enter the body irradiate organs and tissues until they are excreted from the body or disappear by radioactive decay. For workers, the ICRP has recommended summation of the accumulated dose over a 50-year period, but in some instances 70 years or more would be more appropriate. The total dose received in the period of summation (recommended by ICRP) is referred to as the committed effective dose equivalent, H_{E50}.

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The *Guidelines for drinking-water quality* are intended for use by countries as a basis for the development of standards which, if properly implemented, will ensure the safety of drinking-water supplies. It must be emphasized that the levels for water constituents and contaminants that are recommended in the guidelines are not standards in themselves. In order to define standards, it is necessary to consider these recommendations in the context of prevailing environmental, social, economic, and cultural conditions.

These guidelines are intended to supersede both the European (1970) and International (1971) Standards for Drinking-Water, which have been in existence for over a decade. The main reason for departing from the previous practice of prescribing international standards for drinking-water quality is the desirability of adopting a risk–benefit approach (qualitative or quantitative) to national standards and regulations. Standards and regulations achieve nothing unless they can be implemented and enforced, and this requires relatively expensive facilities and expertise.

Although the main purpose of these guidelines is to provide a basis for the development of standards, the information given may also be of assistance in developing alternative control procedures where the implementation of drinking-water standards is not feasible. For example, the existence of adequate codes of practice for the installation and operation of water-treatment plants and water supply and storage systems, and for household plumbing may promote safer drinking-water supplies by increasing the reliability of the service, avoiding the use of undesirable materials (e.g., lead pipes exposed to plumbo-corrosive water), and by simplifying repair and maintenance.