

EUROPEAN
STANDARDS FOR
DRINKING-WATER

SECOND EDITION



WORLD HEALTH ORGANIZATION

GENEVA

1970

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PRINTED IN SWITZERLAND

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PREFACE TO THE SECOND EDITION

Nine years have now elapsed since the first edition of European Standards for Drinking-Water was published. As stated in the preface to that edition, their object is to stimulate improvement in drinking-water quality and to encourage countries of advanced economic and technological capability in Europe to attain higher standards than the minimal ones specified in International Standards for Drinking-Water.⁸⁶ The latter standards are considered to be necessary and attainable by every country. At the same time, the industrial development and intensive agriculture of some European countries create hazards to water supplies not always encountered in other regions. Hence, stricter standards are demanded and justified.

The need for this revised edition has arisen because new methods and improved techniques have been developed in recent years for the examination of drinking-water, while concepts of permissible levels in regard to drinking-water quality have changed. New sections have been added, dealing with viruses, some of which may be pathogenic to man, polycyclic aromatic hydrocarbons, some of which are carcinogenic to animals and possibly to man, and pesticides, which, used agriculturally, may be toxic to man and may find their way into natural waters serving as a source of drinking-water supplies. Radiological examination is no longer dealt with under Table 1 but in a separate section, and new sections on the examination of biological material and extractable organic matter have been introduced.

Since different techniques and methods of examining drinking-water are maintained in different European countries, emphasis in the present document is placed on the determination of what are acceptable standards for drinking-water quality rather than how to determine them. However, for reference purposes, at least one well-established method is given for each examination. The order of the methods given is such that the first can be recommended for routine laboratory use. In some instances the descriptions given in different references vary in detail. Many of the methods listed are also given in publications issued by various competent institutions such as : Association française de Normalisation, Council for Mutual Economic Aid, Dansk Standardiseringsraad, Gesellschaft Deutscher Chemiker, Hoofdcommissie voor Normalisatie in Nederland, and Institut belge de Normalisation. It should be emphasized that it is not intended here to present a complete bibliography on drinking-water examination. The references given are merely to methods of estimation mentioned in the text.

Attention is drawn to the general recommendations made by the Working Group on European Standards for Drinking-Water which met in Copenhagen from 18 to 21 November 1968 to prepare this second revised edition. The participants in the Group pointed to the lack of adequate information on a number of factors relevant to water standards. It was suggested that information be collected on the cytotoxicity of water, levels of pesticide residues found in drinking-water, and levels of metal concentration in samples of drinking-water taken from consumers' taps. Investigations could also usefully be made into nitrate in drinking-water and its association with infantile methaemoglobinaemia. The health aspects of the use of desalinated water with particular reference to the minimum mineral content required study, as did the health effects of non-ionic detergents and of a number of metals in drinking-water, such as mercury, tin, vanadium, and beryllium.

A list of the participants in the meeting which led to the preparation of the second edition of the European Standards for Drinking-Water will be found in Annex 2.

PREFACE TO THE FIRST EDITION

That water intended for human consumption must be free from chemical substances and organisms which might be a hazard to health is universally accepted. Supplies of drinking-water should, moreover, not only be safe—that is to say, free from danger to health—but should be as attractive to drink as circumstances permit. Coolness, absence of turbidity, absence of colour and of any disagreeable taste or smell are of the utmost importance in public supplies of drinking-water.

The situation, the construction, the operation and the supervision of a water supply, its reservoirs and its distribution system must exclude any possible pollution of the water.

A few countries in the WHO European Region have succeeded in establishing standards of quality applicable to their respective territories, and in achieving a certain degree of uniformity in the expression of results and methods of analysis. Many countries, however, still lack official standards of quality or have no recognized methods for assessing quality. In the course of international meetings sponsored by the Regional Office for Europe of the World Health Organization, this matter was discussed by experienced hygienists and engineers dealing with problems of water supply. It was considered that great improvement could be achieved throughout the Region if various treatment processes could be made easily comparable by the adoption of uniform expressions of results; and further, that water-borne outbreaks of disease could be avoided through stricter control by the responsible health authorities of the quality of water distributed for drinking purposes. The Regional Office for Europe of the World Health Organization has therefore been conducting a study of the situation, in collaboration with member governments and with the assistance of a number of experts, in an effort to offer technical guidance to the health administrations of European countries wishing to revise their regulations on water-quality control and to bring them up to date. The preliminary results of this study were contained in a report entitled "Standards of Drinking-Water Quality and Methods of Examination Applicable to European Countries" which was issued (as a mimeographed working document) in March 1956 and which gave in a condensed form the essential principles on which, in the existing state of knowledge, sound control of public drinking-water-supply systems should be based.

Similar studies were carried out in several regions of the World Health Organization, and in June 1956 a meeting of experts from various regions

was held in Geneva. This meeting had before it the reports of the various regional meetings and it prepared International Standards for Drinking-Water which was published by the World Health Organization in 1958. This publication set out the minimal standards of chemical and bacteriological quality which the meeting considered should reasonably be expected of public supplies of water for domestic use, and gave detailed descriptions of approved methods of examination.

In 1959 a further meeting of experts in the European Region was held in Copenhagen to revise the document "Standards of Drinking-Water Quality and Methods of Examination Applicable to European Countries" in the light of experience gained and comments received since 1956. The present report takes account of the decisions reached at that meeting.

It may be asked why the World Health Organization has issued both "international standards" and "European standards". International Standards for Drinking-Water proposes minimal standards which are considered to be within the reach of all countries throughout the world at the present time. In view of the different economic and technological capabilities of various countries there will be some areas in which higher standards than those proposed for the world as a whole will be attainable—and these areas should be encouraged to attain such higher standards. It is believed that Europe is such an area and that there is, therefore, nothing illogical in setting higher standards in Europe than internationally. One of the objects of having standards at all is to stimulate improvement in water quality, and it is hoped (as was expressed in International Standards for Drinking-Water) that improvement in economic and technological resources throughout the world will allow higher standards to be suggested in the future than those at present proposed for the whole world.

The names of participants in the meetings leading to the preparation of the document "Standards of Drinking-Water Quality and Methods of Examination Applicable to European Countries" and to the preparation of the present report are given in Annex 2.

1. INTRODUCTION

1.1 Scope

It should be stressed that the proposals set out in this report are intended for guidance only ; they are recommendations and in no sense mandatory.

The report is concerned with the minimal chemical and bacterial quality that might reasonably be expected of piped supplies of water for domestic use. By a piped supply is meant a drinking-water which is supplied through a distribution system and which is under the control of, or subject to regulations made by, communal or local authorities. Though it is logically desirable that the quality of water for individual and small-community supplies should not be inferior to that supplied to the public in large communities, it is not considered that all small rural supplies could reasonably be expected to conform to the standards suggested for piped supplies as defined above.

It is, however, important that local health authorities should exercise some control over at least the bacterial quality of private and individual supplies of drinking-water.

Conditions differ widely, even within Europe. Some countries are fortunate in having an abundant supply of water from deep wells and underground springs, while others have to make extensive use of rivers, lakes, and other sources of surface water. In yet other areas it is the provision of an adequate volume of water that is the most pressing problem. It is felt, however, that the recommendations as to chemical and bacterial quality made in the main body of the report should apply to all piped supplies of drinking-water, whatever the original source of the water may have been.

No bacteriological or chemical examination, however careful, can take the place of a complete knowledge of the conditions at the sources of supply and throughout the distribution system. Every supply should be regularly inspected from source to outlet by experts, and sampling—particularly for bacteriological examination—should be repeated under varying climatic conditions, especially after heavy rainfall, and after major repair or construction work. It should be emphasized that when sanitary inspection shows a water, as distributed, to be obviously subject to pollution, the water should be condemned irrespective of the results of chemical or bacteriological examination. Contamination is often intermittent and may not be revealed by the chemical or bacteriological examination of a single sample. The examination of a single sample can indicate no more than the conditions prevailing at the moment of sampling ; a satisfactory result cannot guarantee that the observed conditions will persist in the future. The treatment that a water may require before it is distributed as a piped supply is not within the scope of this report, but it should be noted that not every

raw water can be made satisfactory by chlorination alone. Other forms of treatment—such as coagulation and filtration—are required, before chlorination, to make certain water supplies fit for distribution as piped supplies. It should, moreover, be emphasized that the quality of drinking-water is dependent on the quality of the raw water, particularly with regard to mineral constituents which are not normally removed in water treatment, and nothing in these standards should be regarded as implying approval of the degradation of an existing water source which is of a quality superior to that provided for in the present recommendations.

It is not envisaged that the standards of chemical and bacterial quality or the various methods recommended here will be the final word on the subject. New methods are constantly being introduced and developed, and it is anticipated that the methods suggested, and even the standards, will be revised from time to time.

Although this report may be of help to water undertakings and others concerned in the treatment and distribution of water, it is intended primarily to apply to water as it is supplied to the public, and in this respect it is hoped that it will be of value to health authorities, who are concerned in seeing that the supplies of water which reach the public are safe and pleasant to use.

Whatever examinations and controls are carried out by water undertakings themselves, there should nevertheless be a system of regular examination by laboratories acting on behalf of the State or other health authorities responsible for ensuring that there is a supply of water suitable for domestic use. The duties of the heads of such laboratories should include that of advising health authorities on the steps that should be taken to prevent danger to the health of the consumers of a water supply, especially when the results of their examinations indicate that a potential danger exists. It is recommended that the services of laboratories capable of carrying out bacteriological and chemical analyses of water should be available to perform tests and to give advice when the construction of public water supplies is being planned. In every instance in which such laboratories exist or are planned, it is necessary for them to have sufficient equipment, and a staff trained and competent to carry out the analyses entrusted to them.

1.2 Arrangement of Material

This report is concerned primarily with the protection of piped supplies of drinking-water from dangers to the health of the consumers. It has been divided into sections on bacteriological, virological, biological, radiological, and physical and chemical examinations. In Section 2, on bacteriological examination, consideration has been given to the choice of organisms that should be used as indicators of pollution; to methods that it is suggested

should be used for the detection of these organisms ; to standards of bacterial quality that might reasonably be set for piped supplies of drinking-water ; to the frequency with which it is suggested that samples should be taken for bacteriological examination ; and to the precautions that should be observed in the collection, storage, and transport of samples for bacteriological examination. This is followed by Sections 3 and 4 on virological examination and biological examination respectively. Although neither of these examinations can be regarded as part of the routine examination of drinking-water, they may be necessary from time to time, and more is known about them now than when the first edition of this report was prepared. Section 5 is on radiological examination of drinking-water, and Section 6 on physical and chemical examination.

In Section 6, consideration has been given primarily to the limits of concentration that should be set for certain toxic substances which may constitute an actual danger to health, and methods have been recommended for detecting and estimating these substances. Consideration has also been given to the approximate concentrations above (or below) which certain other chemical substances may give rise to trouble. These substances are not necessarily a danger to the physical well-being of the consumer ; they may make the water aesthetically undesirable for domestic use or cause trouble in the supply system itself. Recommended methods for detecting and estimating these substances are also listed. In this part of the report there are also short paragraphs on extractable organic matter, polycyclic aromatic hydrocarbons, and pesticides.

In the part of Section 6 dealing with chemical examination, consideration is also given to methods that it is suggested should be used in the general examination of supplies for their aesthetic, physical, and chemical characteristics, in order to make the results obtained in different laboratories more easily comparable. Mention is also made in this section of the frequency with which samples should be taken for chemical examination and of the precautions which should be observed in the collection, transport, and storage of such samples.

1.3 Expression of Results

In view of the importance of uniformity in the methods used to express the results of physical, chemical, and bacteriological examination of water, it has been thought advisable to set out, as a preliminary, the terms in which it is recommended that these results be expressed.

Although the expression of the results of chemical analysis in terms of milliequivalents per litre (mEq/l) is necessary in striking a balance between anions and cations, it is considered that the results of chemical analysis in general should be expressed in milligrammes per litre (mg/l), since this method of expression is well known and widely used. Milliequivalents per

litre should be used for the expression of total hardness and total alkalinity, for which milligrammes per litre are not appropriate.

Wherever possible, chemical components should be expressed in ions; volumes should be expressed in millilitres (ml), and temperature should be measured in degrees Celsius ($^{\circ}\text{C}$). In bacteriological examinations the total number of micro-organisms developing on solid media should be expressed as colonies counted per 1 ml of water, the medium and time and temperature of incubation being stated. Estimates of the numbers of coliform organisms, *Escherichia coli* (*E. coli*), and other organisms indicative of pollution should be given in terms of most probable numbers (MPN) per 100 ml when counted by a multiple tube method, or as colonies per 100 ml when counted on a membrane filter. In radiological examinations radioactivity should be expressed in picocuries per litre (pCi/l). In physical examinations electrical conductivity should be expressed in microsiemens per centimetre ($\mu\text{S}/\text{cm}$). For the expression of results of examinations for turbidity, colour, odour, and taste, see Table 5, p. 41.

2. BACTERIOLOGICAL EXAMINATION

This report is concerned mainly with the routine surveillance of water supplies. When a new source of water is being considered it is important that a full bacteriological examination should be carried out. Such an examination should include colony counts of micro-organisms on non-selective media, and an examination for faecal streptococci and possibly also for *Cl. perfringens* (*Cl. welchii*), as well as for coliform organisms and *E. coli*. Examinations of this nature should also be carried out at other times when the chief of the laboratory or the responsible authority considers them to be necessary. Special circumstances may require further examinations to be carried out—for example, for pathogenic organisms.

An example of a form for reporting the results of a bacteriological examination is given in Annex 1.

2.1 Organisms as Indicators of Pollution

2.1.1 *Organisms indicative of faecal pollution*

The greatest danger associated with drinking-water is the possibility of its recent contamination by sewage or by human excrement; and the danger of animal pollution must not be overlooked. If faecal contamination has occurred sufficiently recently, and if among the contributors there are cases or carriers of such infectious diseases as enteric fever or dysentery, the water may contain the living organisms of these diseases, and the drinking of such water may result in fresh cases of disease. Although modern

bacteriological methods have made it possible to detect these pathogenic bacteria in sewage and sewage effluents, it is not practicable to attempt to isolate them as a routine procedure from samples of drinking-water. When pathogenic organisms are present in faeces or sewage they are almost always greatly outnumbered by the normal excremental organisms, and these normal intestinal organisms are easier to detect in water. If these organisms are not found in the water it can, in general, be inferred that disease-producing organisms are also absent, and the use of normal excremental organisms as an indicator of faecal pollution in itself introduces a margin of safety.

The organisms most commonly used as indicators of pollution are *E. coli* and the coliform group as a whole. *E. coli* is of undoubted faecal origin, but the precise significance of the presence in water of other members of the coliform group has been much debated.^{8, 9, 67, 81} All the members of the coliform group may be of faecal origin, and the worst possible interpretation should, therefore, be attached to their presence in water; thus, from a practical point of view, it should be assumed that they are all of faecal origin unless their non-faecal origin in any particular circumstances can be proved. Quite apart from the question of their being indicative of faecal pollution, *organisms of the coliform group as a whole are foreign to water and must at least be regarded as indicative of pollution in its widest sense.*

The search for faecal streptococci, of which the most characteristic type is *Streptococcus faecalis*, may well be of value in confirming the faecal nature of pollution in doubtful cases.

Faecal streptococci regularly occur in faeces in varying numbers, which are usually considerably smaller than those of *E. coli*. In water they probably die and disappear at approximately the same rate as *E. coli*, and usually more rapidly than other members of the coliform group. When, therefore, organisms of the coliform group, but not *E. coli*, are found in a water sample, the finding of faecal streptococci is important confirmatory evidence of the faecal nature of the pollution.

Anaerobic spore-forming organisms, of which the most characteristic is *Cl. perfringens* (*Cl. welchii*), are also regularly present in faeces, though generally in much smaller numbers than *E. coli*. The spores are capable of surviving in water for a longer time than organisms of the coliform group and usually resist chlorination at the doses normally used in water-works practice. The presence of spores of *Cl. perfringens* in a natural water suggests that faecal contamination has occurred, and their presence, in the absence of organisms of the coliform group, suggests that contamination occurred at some remote time.

Examination for faecal streptococci and anaerobic spore-forming organisms may also be of value when water samples are examined at infrequent intervals, and when a new source of supply is being considered, when as much information as possible is required about the quality of the water.

2.1.2 *Total content of micro-organisms*

Colony counts on nutrient agar at 37°C and at 20°C are not infrequently used in the bacteriological examination of water. The colony count alone is of little value in detecting the presence of faecal pollution, since organisms of all types capable of growing at these temperatures will be counted. A series of colony counts from a source such as a deep well or a spring may be of considerable value—a sudden increase in the colony count from such a source may give the earliest indication of contamination. Colony counts frequently repeated from a series of points in a treatment plant are of considerable value in the control of waterworks treatment; they are also of value when a new source of supply is being considered and as much information as possible about the quality of the water is being collected.

An isolated colony count is rarely of value, and from raw surface waters even a series of colony counts is of little value, because of the wide variations which occur—due, for example, to changes in climatic conditions.

2.1.3 *Recommendations*

Water circulating in the distribution system, whether treated or not, should not contain any organism which may be of faecal origin. The absence of organisms of the coliform group, as defined below, should be considered as a fairly reliable indication of absence of pollution. Their presence should be assumed to be due to faecal pollution unless their non-faecal origin can be proved. Should coliform organisms be found, further investigation is required to determine their source.

The coliform group includes all Gram-negative, non-spore-forming rods capable of fermenting lactose with the production of acid and gas at 37°C in less than 48 hours.

E. coli is of proven faecal origin and its presence should be considered as a sure indication of faecal pollution calling for immediate action. For the purpose of the hygienic analysis of water *E. coli* is regarded as a Gram-negative, non-spore-forming rod which is capable of fermenting lactose with the production of acid and gas at both 37°C and 44°C^a in less than 48 hours; which produces indole in peptone water containing tryptophane; and which is incapable of utilizing sodium citrate as its sole source of carbon.

Frequent examinations are essential for hygienic control. All examinations should be carried out on at least 100 ml of water.

2.1.4 *Special examinations*

If it is desired to examine samples of water for organisms of the salmonella group or for bacteriophages, or to type strains of *E. coli* serologically for correlation with enteropathogenic strains which can cause disease in infants

^a In at least one country mannitol has been used successfully, in place of lactose, for the 44°C fermentation test. Its use avoids difficulties with strains of *E. coli* which are deficient in permease.

(and possibly in adults), these examinations—which are not part of the routine examination of water—are best carried out in special laboratories.

2.2 Recommended Methods for the Detection and Estimation of Organisms Indicative of Pollution

2.2.1 *The detection of coliform organisms and E. coli*

The two basic methods used for the detection and enumeration of coliform organisms in water are the Multiple Tube Method^{3, 25} in which measured volumes of water are added to volumes of a suitable liquid medium, and the Membrane Filtration Method^{3, 11, 12, 25, 74, 84, 85} in which measured volumes of water are filtered through a membrane filter. The two methods do not give strictly comparable results, one reason for this being that counts on membrane filters give no indication of gas production from lactose.

Multiple tube method

The examination in liquid media starts with the presumptive coliform test. The basis of this test is the inoculation of the water sample into bottles or tubes containing a suitable liquid medium, which are then incubated and, after the appropriate period of time, examined for the reaction given by coliform organisms. The test is called presumptive because the reaction observed may occasionally be due to the presence of some other organism or combination of organisms, and the presumption that the reaction is due to coliform organisms has to be confirmed. The proportion of false positive reactions obtained depends both on the bacterial flora of the water under examination and on the medium used.

By the inoculation of suitable volumes of water into a number of tubes, an estimate of the number of coliform organisms present in a given volume of water can be obtained from statistical tables. Schemes for the volumes of water and the number of tubes of each volume to be examined, as well as tables showing the most probable number of coliform organisms in the original sample for the various combinations of positive and negative tubes, are given in *International Standards for Drinking-Water*,⁸⁶ *The Bacteriological Examination of Water Supplies*,²⁵ and *Standard Methods for the Examination of Water and Wastewater*.³

In the past a variety of different media were used in different countries for the presumptive coliform test. Much work on chemically defined media has been carried out in the past ten years,^{17, 29, 36, 37, 43, 68, 70, 82, 83} and it is now possible to recommend that MacConkey broth^{13, 25, 81} with bromcresol purple as an indicator⁸¹ and a standardized concentration of bile salts¹⁰ or a glutamate medium—incubated at 37°C for up to 48 hours—be used for presumptive coliform tests. Several glutamate media are in use^{17, 68, 70, 83} but recent comparisons^{68, 70} indicate that the improved

formate lactose glutamate medium, originally described by Gray,³⁷ with minerals modified,^{25, 70} is the most generally satisfactory.

Confirmatory tests. The presumptive test should be followed by at least a rapid confirmatory test for coliform organisms and *E. coli*, the most practical being the subculture of each presumptive positive tube to 2 tubes of brilliant green bile broth^{3, 13, 57} or of lactose-ricinoleate broth,⁶⁹ one of which should be incubated at 37°C for up to 48 hours for confirmation of the presence of coliform organisms, and the other incubated at 44°C and inspected after 6 and 24 hours⁸⁰ to decide whether or not *E. coli* is present.

Further confirmation of the presence of *E. coli*, if desired, can be obtained by testing for indole production at 44°C. Where complete confirmation is necessary, presumptive positive tubes can be plated on to a solid medium, such as lactose agar, Endo medium, eosin methylene-blue agar, or MacConkey agar, and individual colonies picked off for identification by the indole and citrate utilization tests,^{3, 13, 25, 65} and by testing for fermentation of lactose at 37°C and 44°C.

Volume of water to be examined. At least 100 ml of water are required for bacteriological examination. The volumes to be used in tests in liquid media will depend on the quality of the water to be examined, and the series to be used in a particular instance will depend on the bacteriologist's experience with the supply concerned. With waters expected to be of good quality, one 50-ml volume and five 10-ml volumes would be suitable, whereas with waters of doubtful quality one 50-ml, five 10-ml, and five 1-ml quantities could be used. With heavily polluted waters, dilutions of 1 in 100 or 1 in 1000, or higher, of the original water may have to be used in order to obtain some negative reactions in the series put up and thus obtain a finite figure for the MPN. Whatever the series used, the volumes of water in individual tubes and the number of tubes containing each volume of water should be such that an estimate of the MPN of coliform organisms present in 100 ml of the original water can be obtained from statistical tables.

Membrane filtration method

The alternative method of counting coliform organisms in water is by filtering a measured volume of the sample through a membrane composed of cellulose esters or certain other substances. All the bacteria present are retained on the surface of the membrane and, by incubating the membrane face upwards on suitable media and at the appropriate temperatures and then counting the colonies which develop on the surface of the membrane, it is possible to obtain, within a total incubation time of 18 hours, direct presumptive coliform counts and direct *E. coli* counts which do not depend on the use of probability tables. Counts on membranes are, however, subject to statistical variations and replicate counts of the same water sample

will not, in general, show the same number of organisms (for confidence limits see *The Bacteriological Examination of Water Supplies*²⁵).

Neither spore-bearing anaerobes, which may be a cause of false presumptive reactions in MacConkey broth, nor mixtures of organisms, which may cause false presumptive reactions in any liquid medium, cause false results on membranes. It is, however, not possible to detect gas production on a membrane.

Filtration apparatus and outline of technique. Essentially the filtration apparatus consists of a porous carbon or sintered glass disc supported in silicone rubber gaskets fitted in a base to which can be clamped a cylindrical funnel which may be graduated at 50 and 100 ml. The membrane filter is supported on the porous disc, and for filtration the filter-holding assembly is mounted in a filter-flask with a side arm which can be connected to an electric vacuum pump, a filter pump operating on water pressure, or a simple hand-operated aspiration pump. After a measured volume of water has been filtered through the membrane under pressure, the membrane is removed and placed, face upwards, on a suitable solid medium in a Petri dish or on a pad soaked in liquid medium in a Petri dish. Descriptions and illustrations of the apparatus and its method of use are given in *Standard Methods for the Examination of Water and Wastewater*³ and in *The Bacteriological Examination of Water Supplies*.²⁵ Details of the sterilization of the apparatus and of the membranes, media that can be used, and the details of the incubation procedure are also given in these two publications. Separate membranes and different incubation procedures are required for examination for total coliforms and for *E. coli*.

After incubation the membranes should be examined with a hand lens under good lighting. The appearance of the colonies will depend on the medium used, but all colonies of the appropriate appearance should be counted irrespective of size. If necessary, individual colonies can be picked from membranes into liquid confirmatory media or on to a solid medium from which colonies can be taken for full confirmatory tests.

Volume of water to be examined. The coliform count and the *E. coli* count are made for separate volumes of water. All samples expected to contain less than 100 coliform organisms in 100 ml require the filtration of 100 ml for each test. The volumes of polluted samples should be so chosen that the number of colonies to be counted on the membranes lies between 10 and 100. When the volume to be filtered is less than 10 ml, the sample should be diluted with sterile dilution water so that a minimum of 10 ml is filtered.

Advantages and disadvantages of membrane filtration method. The outstanding advantage of the membrane filtration technique is the speed with which results can be obtained, including an *E. coli* count. This enables rapid corrective action to be taken when required, and it also enables the

waterworks plant to be put back into service more quickly when a negative result is obtained. In the laboratory, there is also a saving in technical labour and in the amount of media and glassware required. It is also possible, where it is not practicable for a sample to be taken immediately to a fully equipped laboratory, for a sample to be filtered through a membrane at the site of collection or in a local laboratory with limited facilities and sent on a transport medium to a fully equipped laboratory for examination. Reference will be made to such procedures in the section on collection and transport of samples.

Membranes are unsuitable for waters of high turbidity in association with low counts of coliform organisms since, in such instances, the membrane will become blocked before sufficient water can be filtered. Membranes are also unsuitable for water containing few coliform organisms in the presence of many non-coliform organisms capable of growing on the media used, since the non-coliform organisms are then liable to cover the whole membrane and interfere with the growth of the coliform organisms. If non-gas-producing lactose-fermenting organisms are predominant in the water, membranes will be unsuitable because of the high proportion of false positive results.

Some of the original membrane techniques require a change of medium after the first few hours of incubation. In some of the newer techniques this has been replaced by a change of temperature. This can be done either by transferring containers of membranes from one incubator to another or by using special apparatus to provide an automatic change of temperature at the appropriate time.

Since results by the membrane filtration method are not necessarily the same as those obtained by the multiple tube method, it is essential that, before membrane filtration is adopted as a routine procedure in any laboratory or for any particular water supply, an adequate series of parallel tests by the two methods be carried out in order to establish their equivalence or the superiority of one over the other.

2.2.2 *The detection of faecal streptococci and anaerobic spore-forming organisms*

On those occasions on which it is considered desirable to supplement the examination for coliform organisms and *E. coli* by examination for faecal streptococci or anaerobic spore-forming organisms the following methods can be recommended.

Faecal streptococci. Methods commonly used for the detection and estimation of the number of faecal streptococci are :

(1) The inoculation of multiple portions of water into tubes of glucose azide broth.^{25, 38} The inoculated tubes are then incubated at 37°C for 72 hours. As soon as acidity is observed, a heavy inoculum is subcultured

into further tubes of glucose-azide broth and incubated at 45°C for 48 hours; all tubes showing acidity at this temperature contain faecal streptococci.²⁵

(2) A membrane filtration technique.^{25, 76} This is essentially the same as the technique described in paragraph 2.2.1, except that a different medium and a different incubation procedure are used. After filtration, the membrane is placed on a well-dried plate of glucose-azide agar.⁷⁶ This is incubated at 37°C for four hours and then at 44°C or 45°C for 44 hours.²⁵ All red or maroon colonies are counted as faecal streptococci.⁸⁵

Anaerobic spore-forming organisms. The most satisfactory method for the detection and estimation of the number of spores of *Cl. perfringens* in water is as follows :

Inoculate multiple portions of water—previously heated at 75°C for 10 minutes to destroy non-spore-forming organisms—into differential reinforced clostridial medium (DRCM)³⁵ in screw-capped bottles. The bottles should be filled up, if necessary, so as to leave only a small air space ; they should then be incubated at 37°C for 48 hours. A positive reaction will be shown by blackening of the medium due to reduction of the sulfite and precipitation of ferrous sulfide. Any clostridium may produce this reaction. A loopful from each positive bottle should be subcultured to a tube of litmus milk²⁵ which has been freshly steamed and cooled. The tubes should then be incubated at 37°C for 48 hours. Those containing *Cl. perfringens* will produce a “ stormy clot ” in which the milk is acidified and coagulated and the clot disrupted by gas.

2.3 Standards of Bacterial Quality Applicable to Piped Supplies of Drinking-Water

Some piped supplies of drinking-water are chlorinated or otherwise disinfected before being distributed; others are not. There does not, however, appear to be any logical reason for setting different bacteriological standards for piped supplies which are chlorinated or otherwise disinfected and for those which are not so treated. Efficient chlorination yields a water which is virtually free from coliform organisms, and if piped supplies which are distributed without chlorination or other form of disinfection cannot be kept up to the bacteriological standard which can reasonably be expected of disinfected water, steps should be taken to chlorinate this water or disinfect it in some other way.

In considering bacterial standards for piped supplies of drinking-water, it is necessary to have regard to the quality both of the water entering the distribution system and of that in the distribution system itself. A water which is perfectly satisfactory when it enters the distribution system may undergo some deterioration before it reaches the consumer's tap. Coliform organisms may gain access to the water in the distribution system from

booster pumps, from packing used in the jointing of mains, or from washers on service taps. In addition, contamination from outside the distribution system may gain access to the water in the distribution system, for example, through cross-connexions, back-siphonage, defective service reservoirs and water tanks, damaged or defective mains, or defective hydrants, or through inefficient repairs to domestic plumbing systems. Although coliform organisms derived from tap washers or the jointing material in mains may be of little or no sanitary significance, contamination which gains access to the water in the distribution system from outside is at least as potentially dangerous as contamination which enters the distribution system in polluted or insufficiently treated water. It is advisable to draw attention to two points: the necessity of maintaining a sufficiently high pressure throughout the whole distribution system to prevent contamination getting into the system along the length of the mains by back-siphonage, and the necessity for every distribution system to have available a means of chlorination to deal with accidental pollution, which is always a possibility.

The precise action to be taken when coliform organisms are found in a sample taken from the distribution system will depend on local circumstances, but it should be borne in mind that just as much deterioration is liable to occur in the distribution system of a chlorinated supply as in that of a non-chlorinated supply, and that, in this respect, the two should be considered on the same footing.

It cannot be stressed too strongly that bacteriological examination has its greatest value when it is frequently repeated. The examination of a single sample can indicate no more than the conditions prevailing at the moment of sampling at that particular point in the supply system. For adequate control of the hygienic quality of the water supply it is necessary to have frequent bacteriological examinations of samples collected from carefully selected points throughout the entire supply system, including dead ends.

2.3.1 *Recommendations*

It is of the utmost importance for the control of the hygienic quality of the water supply that bacteriological examination of both the water entering the distribution system and the water in the distribution system itself be carried out frequently and regularly.

When one 100-ml sample shows the presence of coliform organisms, a further sample from the same sampling point should be examined immediately. This is the least that should be done; it may be considered wise to examine samples also from other points in the distribution system and to supplement these with samples from pumping stations, reservoirs, or treatment plants. The presence of any coliform organisms in a piped supply should always give rise to concern, but what steps—apart from the taking of further samples—it may be considered advisable to take to safeguard the purity of the water supplied to consumers will depend on local conditions.

The degree of contamination may be so great that action should be taken without waiting for the result of the examination of a repeat sample. This is a matter for decision by those who have a knowledge of the local circumstances and the duty to safeguard the health of the community.

The following bacteriological standards are recommended for piped supplies of drinking-water :

Coliform organisms must be absent from any water entering the distribution system, whether the water be disinfected or naturally pure. In a disinfected water the presence of coliform organisms must always lead to suspicion about the efficiency of the disinfection process. The appearance of coliform organisms in a water which is normally naturally pure calls for immediate investigation. Ideally, the same standard should be applied to any water in the distribution system, but in the aggregate results a limit of tolerance of the presence of one or more coliform organisms in a 100-ml sample of water can be permitted in 5% of the samples examined, providing that a positive result is not obtained in two or more consecutive samples and that at least 100 samples of 100 ml each, regularly distributed over the year, are examined. The standard suggested, i.e., that 95% of the 100-ml samples taken throughout the year should not show the presence of any coliform organisms, corresponds to an average density of about one coliform organism in 2 litres of water. This is a statistical concept indicating the generally satisfactory bacterial quality of the supply, but, clearly, whatever action is appropriate should be taken when one bad sample is obtained without waiting to see whether more than 5% of the samples examined during the year are unsatisfactory.

2.4 Sampling Procedure for Bacteriological Examination

2.4.1 *Frequency of sampling*

The frequency of bacteriological examination for hygienic control of the supply and the location of the sampling points at pumping stations, treatment plants, reservoirs, booster pumping stations, and in the distribution system should be such as to enable proper control to be kept over the bacterial quality of the water supply. Topographical inspection of the whole supply from source to consumers' premises is of the utmost importance, and the authority responsible for health matters should have the services of an expert adviser in deciding on the points from which samples should be taken and the frequency with which samples from each point should be examined. Bacteriological examinations should be carried out by authorized laboratories.

In some countries it is recommended that the frequency of sampling for certain supplies should be based on the size of the population served by the supply.^{32, 78} It would seem reasonable that the frequency of examina-

tion of routine samples of water from the distribution system, and of routine samples of naturally pure water entering the distribution system, should be based on the size of the population served ; these examinations should be spaced out over a period of time, according to the danger of pollution, geographical situation, and protection of the source of supply. When, however, water requires chlorination or some other form of disinfection before passing into the distribution system, a constant check on the bacterial quality of the water entering the distribution system would appear to be necessary, and it would seem that bacteriological examination of such water as it enters the distribution system should, in principle, be carried out at least once a day.

An example of a form for reporting the results of a routine bacteriological examination is given in Annex 1.

2.4.2 *Recommendations*

Where water requires chlorination or some other form of disinfection before entering the distribution system, constant checks both on the residual concentration of the chlorine or other chemical disinfectant and on the bacterial quality are needed. The importance of checking the residual chlorine concentration cannot be overstressed since it ensures that, should any inadequately treated, and therefore possibly contaminated, water enter the distribution system as a result, for example, of a failure in chlorination, immediate remedial action can be taken. In principle, the bacteriological examination of chlorinated or otherwise disinfected water as it enters the distribution system from each treatment point should be carried out at least once a day, and with the larger supplies this will no doubt be done. With small supplies, serving a population of 10 000 or less, daily sampling may be impracticable and reliance will have to be placed on proper control of disinfectant dosage with checks on the bacterial quality of the water at, say, weekly intervals. With the smallest supplies the interval may have to be even longer.

Some supplies which do not require disinfection are none the less chlorinated as an additional precautionary measure. Daily bacteriological examination of such water as it enters the distribution system would not appear to be necessary. The frequency of bacteriological examination proposed for non-disinfected water entering the distribution system (see below) could be applied to this type of water also.

In all supplies which are disinfected a check on the concentration of the chemical disinfectant should be carried out several times a day, not only at each treatment point but preferably also at several points throughout the distribution system. The efficiency of chlorination and some other forms of disinfection can be checked most effectively by the use of residual recorders, preferably with automatic control. These, however, require technical super-

vision and, for the small supply, regular manual testing may be all that is practicable.

The results of all these examinations should be recorded for permanent reference and should be supplemented at least twice a year by an inspection on the spot by engineering and hygiene experts acting on behalf of the responsible authority. A plan of the water supply system should be kept up to date and placed at the disposal of the experts.

For samples of *non-disinfected water entering the distribution system*, the following maximum intervals between successive routine examinations are proposed :

<i>Population served</i>	<i>Maximum interval between successive samples</i>
Less than 20 000	1 month
20 000 to 50 000	2 weeks
50 001 to 100 000	4 days
More than 100 000	1 day

On each occasion samples should be taken from all the points at which water enters the distribution system.

With regard to *samples to be collected from the distribution system, whether the water has been subjected to disinfection or not*, the following maximum intervals between successive samples and the minimum numbers of samples to be examined in each month are proposed :

<i>Population served</i>	<i>Maximum interval between successive samples</i>	<i>Minimum number of samples to be taken from whole distribution system each month</i>
Less than 20 000	1 month	1 sample per 5000 of population per month
20 000 to 50 000	2 weeks	
50 001 to 100 000	4 days	
More than 100 000	1 day	

In each distribution system both the above criteria should be satisfied.

It is considered justifiable to reduce the minimum number of samples to 1 per 10 000 population per month when the population served exceeds 100 000, since in systems serving populations of that size some samples are being examined each day.

The samples should not necessarily be taken from the same points on each occasion, but the expert advisers referred to above should determine the points on the distribution system from which samples should be collected.

It should be emphasized that in routine control it is far more important to examine numerous samples by a simple test than occasional samples by a more complicated test or series of tests.

It should be borne in mind that these are the minimum frequencies recommended for routine bacteriological examination, and in unfavourable circumstances or in the event of an epidemic or immediate danger of pollution, or when more stringent control is necessary, as for example in water supplies to dairies or food-processing plants, much more frequent bacteriological examination will be required.

Samples should be collected more frequently also from premises in which there is a danger of contamination—particularly through cross-connexions—and also after repairs to mains have been carried out.

2.4.3 *Collection, transport, and storage of samples for bacteriological examination*

Scrupulous care in the collection of samples for bacteriological examination is necessary to ensure that the sample is representative of the water it is desired to examine, and to avoid accidental contamination of the sample during collection. The way in which samples are collected has an important bearing on the results of their examination and it is important, therefore, that sample collectors should be properly trained for the work.

Where several samples are being collected on the same occasion from the same source, the sample for bacteriological examination should be collected first, to avoid the danger of contamination of the sampling point during the collection of other samples.

Sterilized glass bottles provided with a ground-glass stopper or a metal screw-cap should be used; at least the stopper and neck of the bottle should be protected by a paper or parchment cover, or by thin aluminium foil.

If the water to be sampled contains, or is likely to contain, traces of chlorine, chloramine, or ozone, it is necessary to add to the sampling bottles, before sterilization, a sufficient quantity of sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) to neutralize these substances. It has been shown that 0.1 ml of a 3% solution of crystalline sodium thiosulfate in a 170-ml bottle has no significant effect on the coliform or *E. coli* content of unchlorinated water during 6 hours' storage.²⁸ This amount of sodium thiosulfate is sufficient to neutralize up to at least 5 mg/l of residual chlorine. It is, therefore, recommended that this proportion of sodium thiosulfate solution be added to all bottles used for the collection of samples for bacteriological examination. If samples of chlorinated water are taken it is desirable to determine the content of chlorine at the sampling point.

The sampling bottle should be kept unopened until the moment at which it is required for filling. During sampling the stopper and neck of the bottle should not be allowed to touch anything. The bottle should be held near its bottom. The bottle should be filled, without rinsing, and the stopper should be replaced immediately.

If a sample of mains water is to be taken from a tap, it should be ascertained that the tap chosen is supplying water from a service pipe directly

connected with the main, and not, for instance, one served from a roof cistern. The tap should be cleaned and then it should be flamed to sterilize it. The water should then be allowed to run to waste from the tap for at least 2 minutes before the sample is collected.

In collecting samples directly from a river, stream, lake, reservoir, spring, or shallow well, the aim must be to obtain a sample that is representative of the water which will be taken for purposes of supply to consumers. It is therefore undesirable to take samples too near the bank or too far from the point of draw-off—if this is by means of a floating arm, the sample should not be taken too deeply. In a stream, areas of relative stagnation should be avoided.

Samples from a river, stream, lake, or reservoir can often be taken by holding the bottle near its bottom in the hand and plunging it, neck downwards, below the surface. The bottle should then be turned until the neck points slightly upwards, the mouth being directed towards the current. If no current exists (as in a reservoir) a current should be artificially created by pushing the bottle horizontally forward in a direction away from the hand. If it is not possible to collect samples from these situations in this way, a weighted foot may be attached to the bottle which can then be lowered into the water. In any case, damage to the bank must be guarded against, otherwise fouling of the water may occur. Special apparatus is required to collect samples from the depths of a lake or reservoir.

If the sample is to be taken from a well fitted with a hand-pump, water should be pumped to waste for about 5 minutes, the pump outlet should be sterilized, and more water should be pumped to waste before the sample is collected. If the well is fitted with a mechanical pump, the sample should be collected from a previously sterilized tap on the rising main. If there is no pumping machinery a sample can be collected directly from the well by means of a sterilized bottle fitted with a weighted foot, but in this case care should be taken to avoid contamination of the sample from the surface scum.

When the sample has been collected it should be clearly labelled and sent to the laboratory without delay, accompanied by a note of all the relevant particulars.

Changes do occur in the coliform and *E. coli* content of water samples on storage, but these changes can be reduced by packing the sample in ice during transport.^{26, 27} It is important, therefore, that samples should be examined as soon after collection as possible and in any case within 6 hours of collection. Samples should be kept cool during transport to the laboratory, preferably by being packed in ice. If bacteriological examination cannot be started within 6 hours of the collection of the sample, a note to this effect should be clearly made in the report.

Where there is likely to be delay in getting samples to the laboratory, vans fitted as laboratories could be used or the sample could be filtered through a membrane at the site of collection or in a local laboratory with

limited facilities. The membrane can be placed, after filtration, on an absorbent pad saturated with a transport medium^{25, 64} in a Petri dish. Transport medium is a very dilute medium on which the organisms survive but do not develop visible colonies in 3 days at room temperature. Polystyrene Petri dishes are preferable for despatch by post to a central laboratory. Delays of 3 days have made little difference to counts of coliform organisms and *E. coli*.

3. VIROLOGICAL EXAMINATION

It is theoretically possible for virus disease to be transmitted by water which is free from coliform organisms, but there is no conclusive evidence that this has actually occurred.

None of the accepted sewage treatment methods yields virus-free effluents, but a number of different investigators have found activated sludge treatment to be superior to trickling filters.⁶⁶

Viruses can be isolated from raw water and from springs. Enteroviruses, reoviruses, and adenoviruses have been found in water. Of these, enteroviruses are the most resistant to chlorination. It is considered that if enteroviruses are absent from chlorinated water it can be assumed that the water is safe to drink. There must be some reservation about the virus of infectious hepatitis, since it has not so far been isolated, but in view of the morphology and resistance of enteroviruses it is likely that if they have been inactivated, hepatitis virus will have been inactivated also.

In a water in which there is *free* chlorine, viruses will generally be absent if coliform organisms are absent. However, in a water with a high concentration of organic matter—in which chlorine would not remain as *free* chlorine—absence of coliform organisms would not imply freedom from viruses.

There is an exponential relationship between the rate of virus inactivation and redox potential. A redox potential of 650 mV (measured between platinum and calomel electrodes)⁵³ will cause almost instantaneous inactivation of even high concentrations of virus. Such a potential can be obtained with even a low concentration of *free* chlorine, but an extremely high concentration of combined chlorine would be required to produce it.^{54, 55} In practice, 0.5 mg/l of *free* chlorine for 1 hour would be sufficient to inactivate virus even in a water that was originally polluted; 0.4 mg/l of free ozone for 4 minutes has also been found to inactivate virus.^{15, 16}

If not even one plaque-forming unit (PFU) of virus can be found in 1 litre of water it can reasonably be assumed that the water is safe to drink. It would, however, be necessary to examine a sample of the order of 10 litres to obtain a proper estimation of the PFUs at this level. Such examinations cannot be made in ordinary control laboratories, but there should be

at least one laboratory in each country capable of carrying out virus examinations and also of pursuing further research in this field.

Clearly it would not be practicable for examination for viruses to be carried out as frequently as bacteriological examination but, in large communities which use surface water or ground water which requires treatment, examination for viruses should be carried out at intervals, which would depend on local circumstances.

4. BIOLOGICAL EXAMINATION

Biological examination of water has a place in determining the causes of objectionable tastes and odours in water and controlling remedial treatments, in helping interpret the results of various chemical analyses, and in explaining the causes of clogging in distribution pipes and filters. In some instances it may be of use in demonstrating the admixture of water from one source with that from another.

Some of the animalcules found in water mains may be free-living in the water, but others such as *Dreissena* and *Asellus* are more or less firmly attached to the inside of the mains. Although these animalcules are not themselves pathogenic, they may harbour pathogenic organisms or viruses in their intestines, thus protecting them from destruction by chlorine.

The following methods of collecting samples can be used for piped water supplies :

1. *For collecting samples from taps.* A large volume of water can be filtered through a membrane filter ; after drying, the membrane filter can be made transparent by treating it with immersion oil and a direct microscopic examination can be made ; alternatively, a special filter device can be attached to a tap and a large volume of water allowed to pass through it ; the deposit can then be examined microscopically and macroscopically.⁸¹

2. *For collecting samples from mains.* A special nylon net or cotton bag can be attached to the outlet of a hydrant and a section of the main washed through with a high water flow. Alternatively a section of the main can be " swabbed " with a specially designed cylinder of plastic,⁴⁴ or a special three-branched standpipe can be used.⁴⁸ The debris found in the bag may then be examined macroscopically and microscopically.

Results can be expressed either in terms of organisms per unit volume of water or per unit area of pipe surface, whichever is appropriate.

5. RADIOLOGICAL EXAMINATION

5.1 Levels of Radioactivity in Drinking-Water

Emphasis is at present being placed on the need for identifying the critical path by which released radioactivity may reach the group of people likely to receive the highest dose. None the less, operational standards for the population at large, in the form of concentration levels, should be used for routine surveillance procedures.

The levels for radioactivity given below are derived from the recommendations of the International Commission on Radiological Protection (ICRP) for the maximum permissible concentration in water (MPC_w) for occupational exposure to the respective nuclides ⁴⁰, ⁴¹, ⁴² by applying a factor of 1/100 for the gonadal or whole body exposure to adapt them for the use of the consumers of drinking-water belonging to the "total population".

The following levels are proposed :

Gross alpha activity	3 pCi/l
Gross beta activity	30 pCi/l

These levels are applicable to the mean of all the activity measurements obtained during a 3-month period. However, when a significant radioactive contamination of the water supply is suspected, individual water samples should be radioanalysed. Furthermore, single samples with unexpectedly high values should be investigated without delay.

The methods for analysis of gross alpha and gross beta activities should be selected in the light of local conditions in co-ordination with the appropriate authorities. Procedures for the measurement of activity levels of specific radionuclides have been published.⁸⁷

Radioactivity in drinking-water should be kept to a minimum, and it is therefore recommended that radioactive wastes should not be admitted indiscriminately to sources that are to be used for supplies of drinking-water. However, the values given include naturally occurring radioactivity as well as any radioactivity that may have reached the water as a result of radioactive fall-out or the use of atomic energy. They represent a level below which water can be considered potable without more complex radiological examination, and they should be read in conjunction with the following comments.

Alpha activity. Before starting the analysis, the activity of ²²²Rn and ²²⁰Rn should be eliminated by proper aeration of the water sample. Their short-lived daughter products can be accounted for, following a second measurement after decay.

Alpha activity of 3 pCi/l or less is acceptable, and no further examination is necessary, even if all of it is due to ^{226}Ra . However, if the activity exceeds 3 pCi/l, radioanalysis is required in accordance with the following procedure :

<i>Gross alpha activity in pCi/l*</i>	<i>Examination procedure</i>
3 to 10	<p>(1) The contribution of the short-lived daughter products of ^{222}Rn and ^{220}Rn should be excluded. If the residual activity still exceeds 3 pCi/l, then</p> <p>(2) radioanalysis for ^{226}Ra should be performed. If ^{226}Ra activity is below 3 pCi/l, no further examination is necessary, but if it exceeds 3 pCi/l, the results should be referred to the appropriate health authorities for further investigations.</p>
More than 10	Comprehensive radioanalysis is necessary. The results obtained should be referred to the appropriate health authority for further investigations.

Beta activity. Beta activity of 30 pCi/l or less is acceptable and no further examination is necessary, even if all of it is due to ^{90}Sr . However, if the activity exceeds 30 pCi/l, radioanalysis is required in accordance with the following procedure :

<i>Gross beta activity in pCi/l*</i>	<i>Examination procedure</i>
30 to 100	<p>(1) The ^{40}K contribution should be excluded. If the residual activity still exceeds 30 pCi/l, then</p> <p>(2) radioanalysis for ^{90}Sr should be performed. If ^{90}Sr activity is below 30 pCi/l, no further examination is necessary, but if it exceeds 30 pCi/l, the results should be referred to the appropriate health authority for further investigations.</p>
100 to 1000	<p>(1) The ^{40}K contribution should be excluded.</p> <p>(2) Radioanalysis for ^{90}Sr and ^{129}I should be performed. If ^{90}Sr activity is below 30 pCi/l and ^{129}I activity is below 100 pCi/l, no further examination is necessary. If these values are exceeded, the results should be referred to the appropriate health authority for further investigations.</p>
More than 1000	Detailed radiological examination (radiochemical determination of ^{90}Sr and gamma spectroscopy) is necessary. The results should be referred to the appropriate health authority for further investigations.

Where it is suspected that ^3H may have reached the water from atmospheric fall-out or effluent from nuclear power stations, a special examination for this radionuclide should be carried out. ^3H is not measured by the

* Mean of all analyses during a 3-month period.

techniques used in gross beta determinations, and special instruments such as liquid scintillation spectrometers are required. If ^3H is detected at levels of 1000 pCi/l or more, the appropriate health authorities should be consulted.

5.2 Collection of Samples

The determination of sampling frequencies and methods for collection and analysis should also take into account the fluctuation of observed activity levels of radionuclides in the water, the vicinity of nuclear installations and other major sources of radiopollution, and the risk of contamination.

Many radionuclides are readily adsorbed on surfaces and solid particles. It is important, therefore, to choose sampling points from the distribution system and from the sources of supply with care so that the sample will be representative of the water that it is desired to examine. Water samples for radiological examination should be collected in polythene bottles to reduce adsorption on the walls of the containers to a minimum. The volume of the sample should be at least one litre and it should be examined as soon as possible after collection to take account of radionuclides with a short half-life.

It is important that each country should have at least one centre where radiological examinations can be undertaken.

6. PHYSICAL AND CHEMICAL EXAMINATION

6.1 Purpose

Chemical analysis has a wide range of uses in the investigation of water supplies. This report, however, is concerned primarily with the protection of users of piped water supplies from dangers to health, and therefore attention is largely directed to the detection and estimation of toxic chemical substances and of some substances which may give rise to trouble in piped supplies. Whereas frequent bacteriological examination is required for hygienic control of drinking-water supplies, chemical examination is required much less frequently. The frequency of general systematic chemical examination should be governed by local circumstances, but frequent chemical examinations may be required for the control of waterworks treatment processes, and examination for a single chemical substance may be of great value in detecting a cross-connexion in a particular part of the distribution system. With the object of encouraging greater uniformity in the methods of carrying out the more general examination of water for physical, chemical, and aesthetic characteristics, a list of the tests that are commonly performed, and of a number of recommended methods of carrying out these tests, is given.

6.2 Toxic Chemical Substances

There are certain chemical substances which, if they are present above certain levels of concentration in supplies of drinking-water, are likely to give rise to actual danger to health. A list of such substances, of the levels of concentration which they should not be allowed to exceed in piped supplies, and of a number of recommended methods for their detection and estimation is given in Table 1.

The presence of any of these substances in excess of the concentrations quoted should constitute grounds for the rejection of the water for use as a piped supply.

TABLE 1. LIMITS OF TOLERANCE FOR TOXIC SUBSTANCES IN PIPED SUPPLIES

Substance	Upper limit of concentration	Methods of estimation
Lead (as Pb)	0.1 mg/l ^a	(a) Polarographic estimation ⁴⁶ (b) Atomic absorption spectrophotometric method ^{24, 72} (c) Colorimetric methods ^{3, 14, 34, 39, 73}
Arsenic (as As)	0.05 mg/l	(a) Polarographic estimation ⁴⁶ (b) Atomic absorption spectrophotometric method ^{24, 60, 72} (c) Using Gutzeit generator ^{3, 14, 39, 73}
Selenium (as Se)	0.01 mg/l	Colorimetric method using gum arabic solution, hydroxylamine hydrochloride, sulfur dioxide, and concentrated hydrobromic acid ^{3, 14}
Chromium (as Cr hexavalent)	0.05 mg/l	(a) Atomic absorption spectrophotometric method, which measures total chromium ^{24, 72} (b) Colorimetric methods ^{3, 14, 39, 73}
Cadmium ^b (as Cd)	0.01 mg/l	Dithizone method ³
Cyanide (as CN)	0.05 mg/l	Can be estimated by a number of methods of which the following are generally in use and are given without preference: (a) By titration with silver nitrate in dilute ammoniacal solution using diphenyl carbazide as an adsorption indicator ⁷⁹ (b) Colorimetric method: conversion of cyanide to either cyanogen chloride or cyanogen bromide, and then coupling this with a suitable aromatic amino compound such as dimedone, ⁴⁹ pyrazolone, ³ or sulfanilic acid ⁵⁶ (c) Colorimetric method: yellow ammonium sulfide converts cyanide to thiocyanate in slightly alkaline solution; the thiocyanate reacts quantitatively with ferric iron to form coloured ferric thiocyanate ^{31, 90}

^a 0.1 mg/l of lead (as Pb) should be the upper limit in the supply, but certain undertakings still use lead piping, and in these instances the concentration of lead in the water after prolonged contact with the pipes may be higher. In no instance should the concentration of lead (as Pb) exceed 0.3 mg/l after 16 hours' contact with the pipes. If the limit of 0.3 mg/l is regularly exceeded it will be necessary to take steps either to change the piping or to treat the water. Lead is used as a stabilizer in some plastic pipes, and the possibility of its being leached out must be borne in mind.

^b Cadmium has been included in this list because of the possibility of its being dissolved out of plastic pipes. Mercury and tin may also be dissolved out of plastic pipes and the possibility of such pipes giving rise to unpleasant colours and tastes in water should also be noted.

Permissible levels will be subject to review from time to time as more information about the toxicity of such substances in drinking-water becomes available.

In addition to the substances listed, there are other substances, such as mercury, tin, vanadium, beryllium, molybdenum, silver, uranium, and thiocyanate, the presence of which in drinking-water should be controlled, but insufficient information is at present available to enable levels to be given. It is considered that barium should not be present at a concentration of more than 1.0 mg/l.⁸⁶

When chemicals—particularly new chemicals, for example polyelectrolytes—are used in water treatment, care should be taken to see that their use involves no danger of toxicity.

6.3 Extractable Organic Matter

In *International Standards for Drinking-Water*⁸⁶ and in *Public Health Service Drinking-Water Standards*,⁷⁸ limiting concentrations for carbon chloroform extract (CCE) are given so as to protect consumers from the presence in drinking-water of large amounts of ill-defined organic chemicals, some of which may be toxic.

In Europe, extraction with chloroform, without the use of activated carbon—the “liquid-liquid” method—is preferred. This method does not estimate the same substances as the CCE method and the matter is one on which much more study is required. It is not at present practicable to propose limits for the substances extracted by the liquid-liquid method, but it is suggested that, for the present, the level should be kept as near as possible to the 0.2-0.5 mg/l given in the second edition of *International Standards for Drinking-Water* as the maximum acceptable and maximum allowable concentrations of CCE.

6.4 Polycyclic Aromatic Hydrocarbons

A modification of the liquid-liquid method mentioned in Section 6.3 above, using benzene in place of chloroform as a solvent, can be used in the examination for polycyclic aromatic hydrocarbons (PAH),⁷ some of which are known to be carcinogenic. As it is impossible to determine all of them, it is proposed to limit the analysis to 6 compounds (fluoranthene, 3,4-benzofluoranthene, 1,12-benzofluoranthene, 3,4-benzopyrene, 1,12-benzoperylene, indeno[1,2,3-cd]pyrene) which can be estimated fairly easily and can be taken as representative of the whole group.

Routine examination of ground water for PAH is not necessary. With the conventional methods of water treatment available today, the low concentrations found cannot be removed and these amounts are probably

not dangerous to human health. Treated surface water, however, should be examined for PAH. For the safety of consumers, the concentration should not exceed 0.2 µg/l. If higher quantities are present, this indicates remaining pollution and insufficient treatment.

There should be at least one centre in each country capable of carrying out investigations on PAH in drinking-water. It is considered that more research into their presence and importance in drinking-water is required.

6.5 Pesticides

Pesticides are under constant review through joint meetings of the WHO Expert Committee on Pesticide Residues and the FAO Panel of Experts on the Use of Pesticides in Agriculture. The concept of acceptable daily intake (ADI) serves as a guideline for the toxicological evaluation of pesticide residues,^{88, 89} and on this basis a number of pesticide residues were evaluated in 1965, 1966, and 1967 and the findings published in FAO/WHO monographs.

Although the ADI concept applies mainly to the evaluation of residues in food, the intake from other possibly contaminated sources should also be taken into account. It is suggested that the residues that may occur in drinking-water, when using pesticides under good agricultural practice, make only a minor contribution to the daily intake.

Contamination of ground or surface water with pesticides may be caused by direct intentional application (e.g., control of aquatic weeds or insects), by discharge of industrial wastewater or spray liquid remainders, by the incidental contamination of a surface source, or by percolation or leaching out by rain from treated agricultural land.

The contamination of water by pesticides should be prevented as far as possible, not only because of the possibility of their direct toxicity to man, but also because of their influence on the water biocenosis and their possible accumulation in the food-chain. For this reason, extensive preventive measures for catchment areas, water-supply streams, and underground water sources are to be recommended. In spite of all the protective measures that are taken, contamination of drinking-water sources in the ways mentioned above is not an infrequent occurrence.

Very low concentrations of some pesticides cause organoleptic changes in the water, so that it is not acceptable to the consumer, irrespective of any known toxic qualities. Conventional methods of water treatment do not remove all pesticide residues, but some can be removed by special treatment processes.

There should be at least one centre in each country capable of carrying out investigations into pesticide residues in drinking-water.

6.6 Examination for Chemical Substances which may give Rise to Trouble in Piped Supplies of Drinking-Water

Certain chemical substances that may be found in piped supplies of drinking-water, although they do not constitute a hazard to the health of people drinking the water, may nevertheless give rise to trouble of one sort or another if they are present in excessive amounts. A list of such substances is given in Table 2, together with an indication of their effects, the approximate level above which trouble is likely to arise, and a number of recommended methods for their detection and estimation. All the methods given in the twelfth edition of *Standard Methods for the Examination of Water and Wastewater*³ can be regarded as satisfactory.

TABLE 2. CONSTITUENTS IN WATER WHICH, IF PRESENT IN EXCESSIVE AMOUNTS, MAY GIVE RISE TO TROUBLE

Substance	Nature of trouble which may arise	Approximate level above which trouble may arise	Methods of estimation
Phenolic compounds (as phenol)	Taste, particularly in chlorinated water	Less than 0.001 mg/l ^a	Colorimetric methods, preferably after distillation (a) Using diazotized sulfanilic acid ³⁹ (b) Indophenol method ³⁹ (c) 4-aminoantipyrine method ³ (d) Using <i>p</i> -nitroaniline ³⁴
Fluoride (as F)	Fluorosis	See Table 3	(a) Colorimetric method with zirconium-alizarin reagent. Interfering substances (colour, turbidity, chlorine, phosphates) must be removed or sample must be distilled before examination ^{3, 39} (b) Electrochemical method—Orion electrode ¹⁹ (c) SPADNS colorimetric method ³
Nitrate (as NO ₃)	Danger of infantile methaemoglobinemia if the water is consumed by infants	Recommended: less than 50 mg/l Acceptable: 50 to 100 mg/l Not recommended: more than 100 mg/l ^{b, c}	(a) Phenoldisulfonic acid method ^{3, 14, 20} (b) Brucine method ^{3, 20, 81, 90} (c) Reduction with zinc-copper couple followed by Nesslerization either directly or after distillation ³⁹ (d) Salicylic acid method ³⁴
Copper (as Cu)	Astringent taste; discoloration and corrosion of pipes, fittings, and utensils	0.05 mg/l at pumping station; 3.0 mg/l after 16 hours' contact with new pipes	(a) Atomic absorption spectrophotometric method ^{24, 72} (b) Colorimetric method using diethyldithiocarbamate ^{14, 34, 39} (c) Cuprethol method (d) Bathocuproine method ³
Iron (total, as Fe)	Taste; discoloration; deposits and growth of iron bacteria;	0.1 mg/l as the water enters the distribution system ^{c, d}	Colorimetric methods: (a) Phenanthroline method ^{3, 14, 73} (b) Thiocyanate method ^{39, 73} (c) Bipyridyl method ^{59, 73}

TABLE 2 (concluded)

Substance	Nature of trouble which may arise	Approximate level above which trouble may arise	Methods of estimation
Manganese (as Mn)	turbidity Taste ; discoloration ; deposits in pipes ; turbidity	0.05 mg/l	(d) Reduction of ferric salts and formation of an iron-dimethylglyoxime complex ^{51, 90} (e) Thioglycollic acid method ⁸¹ Colorimetric methods : (a) Persulfate method ^{3, 34, 39} (b) Periodate method ^{3, 14} (c) Atomic absorption spectrophotometric method ^{24, 72}
Zinc (as Zn)	Astringent taste ; opalescence and sand-like deposits	5.0 mg/l	(a) Colorimetric method using dithizone reagent ^{9, 13, 34} (b) Microtitration with potassium ferrocyanide ⁴⁵ (c) Atomic absorption spectrophotometric method ^{24, 72}
Magnesium (as Mg)	Hardness ; taste	Not more than 30 mg/l if there are 250 mg/l of sulfate ; if there is less sulfate, magnesium up to 125 mg/l may be allowed	(a) Versenate (EDTA) method. Precipitate calcium as oxalate, and estimate magnesium in supernatant liquid, using Eriochrome Black T as an indicator ^{5, 14, 50, 58} (For another versenate method, see references ^{5, 14, 34}) (b) Spectrophotometrically using titan yellow ^{14, 73} (c) Atomic absorption spectrophotometric method ^{24, 72}
Sulfate (as SO ₄)	Gastro-intestinal irritation when combined with magnesium or sodium	250 mg/l	(a) Versenate (EDTA) method ^{56, 81} (b) Gravimetric method weighing as barium sulfate ^{3, 14, 34, 39}
Hydrogen sulfide (as H ₂ S) ^e	Taste and odour	0.05 mg/l	Colorimetric method using para-aminodimethylaniline and ferric chloride ³
Chloride (as Cl)	Taste ; corrosion in hot-water systems	200 mg/l. This limit may be exceeded in certain existing conditions but in no circumstances should the level exceed 600 mg/l.	(a) Titration using standard silver nitrate solution and potassium chromate indicator ^{3, 14, 34, 39} (b) Colorimetric method ⁷¹ (c) Titration with mercuric nitrate at approximately pH 3.1. Diphenylcarbazone and bromphenol blue used as indicators ¹⁴

^a This limit is justified at present in that it is low enough not to give rise to unpleasant tastes in chlorinated water. Attention should be given to the control of phenolic compounds in water; some phenolic compounds are capable of being toxic when ingested over a long period of time.

^b If the nitrate content is within the acceptable range and the water is otherwise chemically and bacteriologically satisfactory, it may not give rise to trouble, but physicians in the area should be warned of the possibility of infantile methaemoglobinemia occurring. More information is required on the exact circumstances under which infantile methaemoglobinemia occurs and the mechanism by which it is produced.

^c It is advisable that a special sample be collected for examination for nitrate and iron. The sample should be "fixed" at the time of collection by adding 1 ml of concentrated sulfuric acid for each litre of water. See also footnote a of Table 5.

^d In small installations in which removal of iron would be uneconomic, or where the iron is present in a stable form, a level of up to 0.3 mg/l can be permitted.

^e This examination should be carried out as soon after the collection of the sample as is practicable.

If any of the substances listed are present in a piped supply at higher concentrations than those given in the table, whatever steps are practicable should be taken to adjust the concentration.

6.6.1 Fluoride

The effect of fluoride on human health depends on the amount of water consumed.^a Therefore, its level in drinking-water should be based on the average maximum temperature in the area.

Table 3, the figures of which are adapted from the 1962 edition of the *Public Health Service Drinking Water Standards*,⁷⁸ gives the recommended control limits of fluoride (as F) concentration in drinking-water for a range of annual average of maximum daily air temperatures, which should be based on temperature data obtained over a minimum of five years.

TABLE 3. RECOMMENDED CONTROL LIMITS OF FLUORIDE IN DRINKING-WATER

Annual average of maximum daily air temperature in °C	Recommended control limits of fluoride (as F) in mg/l	
	Lower	Upper
10.0 – 12.0 ^a	0.9	1.7
12.1 – 14.6 ^b	0.8	1.5
14.7 – 17.6 ^b	0.8	1.3
17.7 – 21.4 ^c	0.7	1.2
21.5 – 26.2 ^c	0.7	1.0

^a Generally suitable for Northern Europe.

^b Generally suitable for Central Europe.

^c Generally suitable for Southern Europe.

6.6.2 Other substances of which the level should preferably be controlled

In Table 4, details similar to those given in Table 2 for substances which may give rise to trouble if present in excessive amounts are given for other substances of which the level in piped supplies of drinking-water should preferably be controlled. Anionic detergents have been included in this table; non-ionic detergents have not been included, but it is considered that more research into their presence and importance in drinking-water is required.

^a In resolution WHA22.30, the Twenty-Second World Health Assembly, held in Boston, Mass., USA, in 1969, recommended "Member States to examine the possibility of introducing and, where practicable, to introduce fluoridation of those community water supplies where the fluoride intake from water and other sources for the given population is below optimal levels, as a proven public health measure; and where fluoridation of community water supplies is not practicable, to study other methods of using fluorides for the protection of dental health".

TABLE 4. SUBSTANCES OF WHICH THE LEVEL SHOULD PREFERABLY BE CONTROLLED

Substance	Nature of trouble which may arise	Approximate level above which trouble may arise	Methods of estimation
Anionic detergents ^a	Taste and foaming	0.2 mg/l	Methylene-blue extraction method ^{3, 52}
Ammonia (as NH ₄)	Growth of organisms, danger of corrosion in pipes Difficulties in chlorination	0.05 mg/l ^b	(a) Nesslerization after distillation ^{3, 39} (b) Direct Nesslerization ^{34, 81} (c) Nesslerization after treatment with zinc sulfate and sodium hydroxide ³
Free carbon dioxide (as CO ₂)	Damage to pipes Danger of bringing toxic metals into solution	For aggressive carbon dioxide—zero ^c	(a) Titration with sodium carbonate using phenolphthalein as an indicator ³⁹ (b) For aggressive carbon dioxide in hard waters, the marble test using powdered calcium carbonate ^{20, 30}
Dissolved oxygen ^d	Taste and odour Corrosion Growth of organisms—if the concentration of dissolved oxygen is less than 5 mg/l the formation of a protective layer will be hampered, thus causing all the free carbonic acid of a non-aggressive water to be corrosive to iron piping	Preferably at least 5 mg/l ^e	(a) Electrometric method ²² (b) Winkler method or one of its modifications ^{3, 14, 34, 39}
Total hardness	Excessive scale formation Danger of dissolving heavy metals if the level of hardness is below the recommended limit	Limits of hardness 2 to 10 mEq/l (100 to 500 mg/l CaCO ₃) ^f	(a) Versenate (EDTA) method using Eriochrome Black T as an indicator ^{3, 34, 39, 50} (see also reference ⁷⁵) (b) By calculation from calcium and magnesium and other hardness-producing cations if present in significant amounts ³

^a Different reference substances are used in different countries.

^b In deep groundwater sources where iron is present, this limit may be exceeded in exceptional situations.

^c The examination for free carbon dioxide should preferably be carried out at the time of collection of the sample. If it is not possible to do this a special sample should be taken. The sampling bottle should be completely filled and the sample kept cool with ice until it is examined.

^d The levels for all substances in this table, with the exception of dissolved oxygen, are those which it is preferable not to exceed. For dissolved oxygen the concentration should preferably be kept above the level given.

^e A special sample is required for the dissolved oxygen test. Collect the sample in a narrow-necked bottle of 200-300-ml capacity having an accurately fitting glass stopper. If the sample is

(footnotes continued on page 40)

6.7 General Examination for Physical, Chemical, and Aesthetic Characteristics of Water

Although this report is concerned primarily with the hygienic control of piped water supplies, it has been thought wise to include a list of the tests commonly carried out for physical, chemical, and aesthetic characteristics of water, and to indicate a number or recommended methods for conducting them.

Many of the tests which are about to be considered are not directly concerned with the safety of the water for supply to the public, but with its pleasantness for use, its suitability as a piped supply, and the water-works control of any treatment applied to it. Considerable variations in the amount of organic matter, albuminoid nitrogen, nitrite, and phosphate—as well as in the amount of ammonia and nitrate—should, however, draw attention to the possibility of pollution. In some circumstances the examination of a sample from the distribution system for a single chemical component—such as chloride or sulfate—may be of great value in demonstrating the admixture of water in the distribution system with water from outside—for example, through a cross-connexion. Such an examination may give conclusive information within a few minutes.

Not all the tests given need be made on every occasion that a water supply is examined chemically, but it is suggested that the following examinations—some of which are given in Table 2, some in Table 4, and some in Table 5—should be carried out in the short routine chemical examination of piped water supplies: appearance, colour, odour, taste, temperature, methyl orange alkalinity, oxidizability, ammonia, nitrite, nitrate, chloride (and, if the water has been chlorinated, a test to determine the residual chlorine content both free and total), and possibly also tests for albuminoid nitrogen and iron. The other tests listed in the tables will probably need to be carried out much less frequently, but this will depend to some extent upon local conditions. In any event, all the tests will be required when a new source of supply is being considered. It is felt that the estimation of total solids is useful in the original analysis of a water when its suitability as a source for a supply of drinking-water is under consideration, but it is not regarded as being of value in the routine chemical examination of water.

It is hoped that the methods recommended in Table 5 and the suggested methods of expressing the results will be of some value in ensuring comparability of results.

from a tap the water should be passed down a glass tube to the bottom of the bottle and allowed to overflow for 2-3 minutes before inserting the stopper. When sampling from a stream or reservoir, a suitable apparatus to ensure severalfold displacement of the water in the sampling bottle should be used. The dissolved oxygen in the sample should be "fixed" on the spot as soon as the sample is collected.^{3, 20, 34} The water temperature at the time of sampling should be recorded in degrees Celsius.

/ It is recommended that hardness be expressed in units, one unit of hardness being 1 mEq/l of hardness-producing ion. (1 mEq/l of hardness-producing ion = 50 mg CaCO₃/l = 5.0 French degrees of hardness = 2.8 (approx.) German degrees of hardness = 3.5 (approx.) English degrees of hardness.)

TABLE 5. METHODS OF EXAMINATION FOR PHYSICAL, CHEMICAL, AND AESTHETIC CHARACTERISTICS OF WATER

Considerable variations in the amount of organic matter, albuminoid nitrogen, nitrite, and phosphate (which have been placed separately at the top of this table together with the estimation of residual chlorine), as well as in the amount of ammonia (which is given in Table 4) and nitrate and chloride (which are given in Table 2), should draw attention to the possibility of pollution.

Substance or test	Methods of estimation	Expression of results
Organic matter ^a (oxidizability)	An acid method using potassium permanganate at 100°C on a waterbath for 30 minutes is recommended. ^b In some countries an acid method, at 100°C for 10 minutes or for 20 minutes, or an alkaline method is used. Elsewhere an acid method at 27°C for 4 hours is used. ³⁹	mg/l oxygen consumed. Time and temperature at which test is performed should be stated. ^c
Albuminoid nitrogen	By addition of alkaline permanganate solution to water left in the distilling flask after the distillation of free ammonia (see Table 4). Collect portions of distillate. Nesslerize and compare with standards. ^{3, 39}	mg/l N
Nitrite ^a	(a) Colorimetric method using sulfanilic acid and naphthylamine hydrochloride ³ or α -naphthylamine. ³⁴ (b) Method using 1-naphthylamine-7-sulfonic acid. ¹⁸	mg/l NO ₂
Phosphate ^d Orthophosphate	(a) Colorimetrically, using ammonium molybdate and stannous chloride ^{3, 34, 39} or tin foil. (b) Colorimetrically, using ammonium molybdate and amino-naphthol-sulfonic acid. ³ (c) Vanadium phosphomolybdate method. ² (d) Method of Murphy & Riley. ⁶¹ (e) Method of Edwards, Molof & Schneeman. ²³	mg/l PO ₄
Orthophosphate and polyphosphate	Vanadium phosphomolybdate method. ¹	mg/l PO ₄
Total phosphate, orthophosphate, and polyphosphate	Boil with concentrated acid, neutralize and proceed as in (a) or (b) above. ³	mg/l PO ₄
Residual chlorine ^{e, f}	Both free and total residual chlorine should be estimated. ⁶² Methods (a) Ortho-tolidine-arsenite <i>g</i> method. By this method free residual chlorine, combined residual chlorine, and colour due to interfering substances can be estimated. ³ (b) Acid-ortho-tolidine <i>g</i> method. Free residual chlorine and total residual chlorine can be estimated by this method. ³ (c) The diethyl-para-phenylene-diamine (DPD) method. ⁶³ (d) The methyl orange decolorization method for free residual chlorine. ^{58, 77} (e) The amperometric titration method for free residual and combined residual chlorine. ³ (f) Iodometric titration for total residual chlorine. ^{3, 39}	mg/l Cl ₂
Turbidity	(a) Turbidimetric methods, visual or photo-electric. ^{3, 34, 39} (b) By comparison with standards in bottles. ³	Turbidity units, ³ silica scale, or formazin standard. ²²

Footnotes a, b, c, d, e, f, g, h, i, see page 43.

TABLE 5 (continued)

Substance or test	Methods of estimation	Expression of results
Colour	(a) Comparison with platinum-cobalt standards. ^{3, 34, 39} (b) Comparison with standardized glass discs. ^{3, 39} (c) Burgess' method using potassium dichromate and cobalt sulfate. ³¹	Platinum-cobalt scale Depth in mm of standard colour solution used. This figure, divided by 2.2, approximates to the platinum-cobalt scale.
Odour	Test cold and when heated. Test at several dilutions. ³	Use descriptive term or code letter as given in Standard Methods for the Examination of Water and Wastewater . ³
Taste	Test at not less than 16°C. Test at several dilutions. ³¹	Use descriptive term and state threshold dilution.
Temperature <i>e</i>	Should be measured at the time of collecting the sample. ³	Record to nearest 0.1°C.
pH <i>e</i>	(a) By means of an electric pH meter with glass electrodes. ^{3, 34, 39} (b) By using indicator solutions in a comparator—useful for preliminary estimation in the field. ^{34, 39}	Record to nearest 0.1 pH.
Electrical conductivity (or resistivity)	By use of conductivity bridge at 20°C. ^{34, 39}	Record in $\mu\text{S}/\text{cm}$ (or megohm/cm). ²
Total alkalinity <i>f</i>	Titration with standardized sulfuric or hydrochloric acid and phenolphthalein and methyl orange as indicators. ^{3, 34}	mEq/l (i.e., ml N acid/l) or mg/l CaCO_3
Bicarbonate	(a) From alkalinity by calculation. ^{3, 34} (b) From pH and total carbon dioxide by calculation. ⁴ (c) From temperature, pH, and total solids by means of nomographs. ³	mg/l HCO_3
Carbonate	(a) From alkalinity by calculation. ^{3, 34} (b) By titration with standardized hydrochloric acid with and without the addition of barium chloride solution. ⁴⁷ (c) From pH and total carbon dioxide by calculation. ⁴ (d) From temperature, pH, and total solids by means of nomographs. ³	mg/l CO_3
Hydroxyl ion	(a) From alkalinity by calculation. ^{3, 34} (b) By titration with standardized sulfuric or hydrochloric acid using strontium chloride, and phenolphthalein as an indicator ⁵ (see also reference ²⁰). (c) From temperature, pH, and total solids by means of a nomograph. ³	mg/l OH
Calcium	(a) Versenate (EDTA) method using murexide as an indicator. ^{3, 14, 34, 39, 50} (b) Volumetric method. Precipitate calcium as calcium oxalate, dissolve in sulfuric acid, and titrate with standard potassium permanganate solution. ^{3, 14, 34, 39}	mg/l Ca

TABLE 5 (concluded)

Substance or test	Methods of estimation	Expression of results
Aluminium	(c) Gravimetric method. Precipitate calcium with ammonium oxalate. Ignite and weigh as calcium oxide. ^{3, 14, 34} (d) Atomic absorption spectrophotometric method. ^{24, 72}	mg/l Al
	(a) Colorimetrically, using "aluminon" (the ammonium salt of aurin tricarboxylic acid). ^{3, 14, 73} (b) Colorimetrically, using haematoxylin solution. ³⁹	
Sodium	Flame spectrophotometry using standards. ³	mg/l Na
Potassium	(a) Flame spectrophotometry using standards. ³ (b) Colorimetrically, using sodium cobalt nitrite, sulfuric acid, and potassium dichromate. ³	mg/l K
Total silica	(a) Colorimetric or spectrophotometric determination of yellow colour obtained on forming ammonium silicomolybdate. ^{3, 14, 34, 39} (b) Gravimetric method, using hydrochloric acid or hydrochloric acid and perchloric acid. ^{3, 14, 34}	mg/l SiO ₂

a It is advisable that a special sample be collected for examination for oxidizability and nitrite. The sample should be "fixed" at the time of collection by adding 1 ml of concentrated sulfuric acid for each litre of water. See also footnote c of Table 2.

b The dichromate method of estimating organic matter,³ like the estimation of total organic carbon,³³ biochemical oxygen demand,^{3, 39} and total nitrogen are all useful in the examination of wastewaters and certain raw waters, but are not applicable to drinking-water.

c Strength of solutions are also of importance. Identical techniques should be used if results are to be comparable.

d In the estimation of phosphates the addition of polyphosphates to the water for softening purposes must be borne in mind. The harmlessness of these substances is not universally agreed upon, and they may be capable of removing the protective coat from lead pipes. The discharge of large quantities of phosphates to lakes and rivers may result in an over-abundant growth of algae.

e It is recommended that, where practicable, these examinations be carried out at the time of collection of the sample.

f In many waterworks there is now apparatus for recording residual chlorine automatically.

g In some countries, the manufacture and use of ortho-tolidine have been prohibited.

h The unit of electrical conductivity of water, $\mu\text{S}/\text{cm}$, is the reciprocal of the unit of electrical resistivity in water, megohm/cm.

i It is valuable to record the phenolphthalein alkalinity and the methyl orange alkalinity separately in terms of ml of standard acid.

Examples of forms for reporting the results of a routine short chemical examination and of a complete chemical examination are given in Annex 1.

6.8 Sampling for Chemical Examination

6.8.1 Frequency of sampling

Whereas frequent bacteriological examination is required for hygienic control of piped water supplies, chemical examination is required much less frequently.

It is recommended that examination for toxic substances—as in Table 1—should be carried out at least once a year ; this examination should be made more frequently when sub-tolerance levels of toxic substances are known to be in the source of supply, or in certain special circumstances as, for example, the establishment in the area of new industries which may be discharging toxic wastes.

Complete chemical examination of all piped supplies should be carried out once a year. Short routine chemical examination—as indicated in Section 6.7—should be carried out once a month in supplies serving more than 50 000 inhabitants, or twice a year in supplies serving smaller populations. More frequent chemical examinations may, of course, be required for the control of waterworks treatment processes.

Frequent chemical examinations of new sources of supply, both for toxic chemical substances and general chemical examination, will be required, depending on local circumstances.

6.8.2 *Collection, transport, and storage of samples*

For certain examinations special samples are required : these are indicated against the examinations for which they are necessary in Tables 2, 4, and 5.

For general chemical examination a sample of at least 2 litres is required ; it should be collected in a chemically clean bottle made of good quality (neutral) glass which is practically colourless and which should be fitted with a ground-glass stopper or a polythene-lined plastic stopper. The bottle should be rinsed out at least three times with the water that is to be sampled before the bottle is filled. Polythene bottles may be substituted for glass bottles in certain circumstances—for example, when sending samples by air.

In collecting samples for chemical analyses the general recommendations given above for the collection of samples for bacteriological examination should be followed, except that it is not necessary to sterilize taps or pump-outlets unless they are being used for collecting samples for bacteriological examination at the same time. Whenever possible, samples of water for chemical examination should be collected by an experienced sample-collector. The way in which samples are collected has an important bearing on the results of their examination.

Samples should be transported to the laboratory with as little delay as possible and should be kept cool during transport. Chemical analysis should be started as soon as practicable after the collection of the sample and should not be delayed for more than 72 hours.

Annex 1**EXAMPLES OF FORMS FOR REPORTING
THE RESULTS OF BACTERIOLOGICAL AND CHEMICAL
EXAMINATION OF WATER**

The forms that follow are intended for reporting the results of the chemical or bacteriological examination of a single sample of water. Other forms may be required for summarizing the results of repeated examinations of samples from a single source, or for comparing the results before and after treatment.

It is assumed that the methods of examination used will be those recommended in the body of the report. With the exception of temperature, no indication of those chemical or physical examinations which should be carried out at the time of collection of the sample, or of those examinations for which the sample should be "fixed" at the time of collection, is given in the forms. This information is given in the tables in the body of this report.

In chemical examinations the use of such phrases as "absent", "trace", "present", should be limited to qualitative tests only.

When a quantitative chemical analysis has been attempted and the result is less than the limit of sensitivity of the method, the result should be expressed as "less than (limit of sensitivity)".

SPECIMEN FORM FOR REPORTING THE RESULTS OF A BACTERIOLOGICAL EXAMINATION OF WATER

(Name and address of laboratory) Report on bacteriological examination of water	
Name and address of sender :	Sender's reference number : Laboratory reference number :
Nature of sample :	Date and time of collection : Date and time of arrival at laboratory : Date and time of commencing examination :
Report ^a	
Colony counts (Specify time and temperature of incubation and nature of medium in each Instance) /ml MPN ^b of coliform organisms /100 ml MPN ^b of <i>E. coli</i> /100 ml MPN ^b of faecal streptococci /100 ml MPN of <i>C. perfringens</i> /100 ml	
Date of report : Date results telephoned :	Remarks : Signed :

^a Although bacteriological examination would ordinarily be carried out only for coliform organisms and *E. coli*, spaces for recording the results of other examinations have been included in the sample form for use when necessary.
^b Where membrane filtration methods are used for these examinations, "MPN of" should be replaced by "Number of colonies of" in the report form.

SPECIMEN FORM FOR REPORTING THE RESULTS OF A SHORT CHEMICAL EXAMINATION OF WATER

Name and address of laboratory Report on chemical examination of water	
Name and address of sender :	Sender's reference number : Laboratory reference number :
Nature of sample :	Date and time of collection : Date and time of arrival at laboratory : Date and time of commencing examination :
Report	Appearance : Colour : units (platinum-cobalt scale) Odour : Taste : Temperature (at time of collection) : °C
	Cations
Ammonia (NH ₄ ⁺) : Iron (Fe ²⁺) :	Chloride (Cl ⁻) : mg/l Nitrate(NO ₂ ⁻) : mg/l Nitrate (NO ₃ ⁻) : mg/l
Methyl orange alkalinity : or ml N acid/l (mEq/l) Residual chlorine (as Cl ₂) Free chlorine : mg/l Total chlorine: mg/l	Organic matter : mg/l (oxidizability : oxygen consumed in minutes/hours at °C) Albuminoid nitrogen (as N) : mg/l
Date of report : Date results telephoned :	Remarks : Signed :

SPECIMEN FORM FOR REPORTING THE RESULTS OF COMPLETE CHEMICAL EXAMINATION OF WATER

(Name and address of laboratory) Report on chemical examination of water		mg/l
<p>Name and address of sender:</p> <p>Sender's reference number:</p> <p>Laboratory reference number:</p> <p>Nature of sample: Date and time of collection :</p> <p> Date and time of arrival at laboratory :</p> <p> Date and time of commencing examination :</p>	<p>Total hardness</p> <p>Alkalinity</p> <p>Phenolphthalein alkalinity</p> <p>Methyl orange alkalinity</p>	<p>Free carbon dioxide</p> <p>Aggressive carbon dioxide</p> <p>Dissolved oxygen</p> <p>Residual chlorine (as Cl₂)</p> <p>Free chlorine</p> <p>Total chlorine</p>
		mEq/l
<p>Appearance :</p> <p>Turbidity : units (state units used)</p> <p>Colour : units (platinum-cobalt scale)</p> <p>Odour :</p> <p>Taste :</p> <p>pH : <i>a</i></p> <p>Temperature (at time of collection) : °C</p> <p>Electrical conductivity (or resistivity) at 20°C : µS/cm (or megohm/cm)</p>	<p>Organic matter (oxidizability : oxygen consumed in minutes/hours at°C)</p> <p>Albuminoid nitrogen (as N)</p> <p>Total silica (as SiO₂)</p> <p>Phenolic compounds (as phenol)</p> <p>Anionic detergents (as reference substance)</p> <p>Hydrogen sulfide (as H₂S)</p> <p>Extractable organic matter</p> <p>Polycyclic aromatic hydrocarbons (PAH)</p>	<p>mg/l</p>

Cations	mg/l	mEq/l ^b	Anions	mg/l	mEq/l ^b	Toxic substances	mg/l	mEq/l ^b	Radioactivity	pCi/l
H ⁺			OH ⁻			Lead			Gross alpha activity	
NH ₄ ⁺			Cl ⁻			Arsenic			Rn activity *	
Na ⁺			NO ₂ ⁻			Selenium			²²⁶ Ra activity	
K ⁺			NO ₃ ⁻			Chromium (hexavalent)			Gross beta activity	
Ca ²⁺			F ⁻			Cadmium			⁴⁰ K activity	
Mg ²⁺			HCO ₃ ⁻			Cyanide			⁹⁰ Sr activity	
Fe ²⁺			CO ₃ ⁻						¹²⁹ I activity	
Mn ²⁺			SO ₄ ²⁻						³ H activity	
Zn ²⁺			PO ₄ ³⁻							
Cu ²⁺			Metaphosphate and polyphosphates							
Al ³⁺			as PO ₄							
Total :			Total :			Total :				
Date of report : _____ Date results telephoned : _____ Remarks : _____ Signed : _____										

^a State whether measured at time of collection or on arrival at laboratory.
^b Milliequivalents have been retained in this form so that a balance can be struck between anions and cations.

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