Drinking Water
Standards and Guidelines

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An FWR Guide

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Abbreviations

ADI	Acceptable Daily Intake
EU	The European Union
IAEA	International Atomic Energy Authority
ICRP	International Commission on Radiological Protection
IPCS	International Programme on Chemical Safety
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LOEL	Lowest Observed Effect Level
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
mg/l	Milligram per litre or one thousandth of a gram per litre
NOAEL	No Observed Adverse Effect Level
NTU	Nephelometric Turbidity Unit (for turbidity measurement)
PAH	Polycyclic Aromatic Hydrocarbon
PTWI	Provisional Tolerable Weekly Intake
QMRA	Quantitative Microbial Risk Assessment
TDI	Tolerable Daily Intake
THM	Trihalomethane(s)
TOC	Total Organic Carbon
UNCED	United Nations Conference on Environment and Development
USEPA	United States Environmental Protection Agency
USNAS	United States National Academy of Sciences
WHO	World Health Organization
WSP	Water Safety Plan
µg/litre	Microgram per litre or one millionth of a gram per litre

1.0 Introduction

Standards and guidelines for drinking water quality have been in place for about fifty years; the World Health Organization (WHO) published International Standards for Drinking-water in 1958. Since then standards have gradually become much more complex as our understanding of the possible contaminants that can occur in drinking water has increased. Drinking water has been recognised as a potential source of disease for thousands of years, although the cause of disease was not known. In Sanskrit writings of about 2000 BC it was suggested that drinking water should be exposed to sunlight and filtered through charcoal and foul water should be boiled before filtering. Hippocrates advised Alexander the Great not to let his men drink from stagnant pools, and on desert marches to first boil water to prevent it becoming sour. The Romans had the first proper water supply in which they clearly separated drinking water, which was brought from outside the city or raised from wells, and wastewater, which was discharged away from the drinking water source.

In the mid-nineteenth century the London physician John Snow identified drinking water as the source of the cholera outbreaks that were common in the cities of Europe and the United States. His work in Soho, with the area around Broad Street, was considered to be the true beginning of epidemiology and led to the rediscovery of the importance of separating drinking water from wastewater and also the reason why it was important.

Drinking water therefore has a vital role in public health and this is a major driver for the development of standards to ensure the safety of drinking water and to safeguard public health. The early requirement was that drinking water should be “wholesome”, which meant that it should not only be safe to drink but should also be pleasant. The concept of wholesomeness has endured to the present day, and is enshrined in European and UK law. However, it is supported by a wide range of standards and guidelines for microbial, chemical and, to a lesser extent, radiological contaminants. These provide the framework for supplying safe and pleasant drinking water all over the world.

WHO changed the name of its standards to guidelines in 1984 because the WHO guidelines do not have legal force and are intended to be the basis for developing national standards, taking into account local needs as well as technical, social and economic constraints,. These Guidelines are continually reviewed and since 1984 three new editions have been published, the latest being the 4th edition in 2011. By contrast, standards are usually enshrined within a legal framework and in the Member States of the European Union provide a common basis for judging drinking water quality across the Union. Failure to meet the standards can lead to enforcement action by local enforcement agencies or against Member States by the European Commission, to make sure that wholesome drinking water can be found all over the European Union, at least for public water supplies.

The European standards not only give numerical values for specific contaminants, but also include strict requirements for monitoring to demonstrate compliance with the standards. These requirements include the number of samples to be taken and from where in the system, and the adequacy of the methods used to measure the parameters concerned. These requirements are intended to ensure that the data generated by monitoring are meaningful and reliable. However, it is not possible to set standards for all potential contaminants and most authorities use a combination of mandatory standards and guidelines, often the WHO Guidelines, to assist in deciding whether a drinking water is wholesome.

The monitoring and enforcement of standards varies in different parts of the world. In most cases monitoring is carried out by water suppliers but in many cases the data is checked and audited by public health authorities or regulatory authorities responsible for environmental health, such as in the United States, or specific drinking water regulators, such as in the United Kingdom. The manner and extent of enforcement of the quality of public water supplies will also vary but the most intensive enforcement of drinking water standards is probably in England and Wales. The situation with private supplies is usually different and the responsibility for enforcement usually falls to local environmental health authorities. However, unless a private supply is being used for purposes that will result in significant exposure of members of the public, such as a hotel or camp site, the level of enforcement is normally much less than for public water supplies.

While the importance of microbial pathogens has been known since the nineteenth century, knowledge with regard to potential chemical contaminants came much later. However, knowledge about chemicals in source waters and drinking water has increased with the result that a significant number of guidelines and standards have been developed for specific chemicals. Guidelines and standards have the following functions:

- to protect public health,

- to ensure that drinking water is acceptable to consumers in terms of taste and smell, colour and clarity,

- to provide a benchmark for the operations of water suppliers to ensure that water is safe and acceptable at all times and to minimise the risk of things going wrong.

They may also represent a means of political pressure for action on particular contaminants or aspects of water supply.

Once standards have been set, it is also important that they are reviewed at regular intervals to take into account new knowledge on contaminants and of the science behind the values in guidelines and standards.

Just as standards have evolved over the past 50 years, they are continuing to evolve, not only in the number of specific parameters and the values associated with them, but also in the approach used for assuring drinking water safety. WHO, in their latest Guidelines for Drinking-water Quality (WHO 2011), which are the benchmark for drinking water standards in most parts of the world, including Europe, have further advanced the concept of Water Safety Plans (WSPs) first introduced in the 3rd edition in 2004. Water supply practitioners, regulators and other drinking water professionals also endorsed the concept of WSPs and this resulted in a joint initiative with WHO that gave rise to the Bonn Charter for Safe Drinking Water (IWA 2004). WSPs are based on the hazard assessment and critical control point principles originally developed by the food industry and provide a more holistic means of ensuring the safety and acceptability of drinking water by managing the risks from source to tap. Water suppliers are already using WSPs as a means of bringing together the various components of their water quality and water quantity management strategies. They provide a means of assuring consumers, regulators and health authorities with regard to emerging concerns without an ever-increasing list of specific parameters that need to be monitored using highly sophisticated and expensive measurements. They also provide a means of ensuring that the water supply is safe at all times and can be demonstrated to be so. WSPs require that the hazards in the catchment through to the tap are identified, the risks arising from these hazards assessed and appropriate barriers are put in place, by controlling hazards at source in the catchment, by installing suitable treatment and by putting in place appropriate and robust management procedures. WSPs also require internal and external verification. In the UK this role falls to the independent quality regulators. However, WSPs go beyond those areas under the control of the water supplier and require that other stakeholders also take responsibility. In the catchment this involves the Environmental Regulator and also the potential polluters and in buildings it requires that plumbing systems are installed and operated properly.

2.0 Approaches to developing guidelines and standards

There are a number of ways in which drinking water guidelines and standards can be developed. However, there are broad similarities between the approach used by all of the agencies that develop guidelines or standards. WHO, in developing guidelines that can be used anywhere in the world as the basis of local or regional standards, have set out their procedures in a manual to ensure transparency and consistency (WHO 2010). This also means that because the procedures are open to scrutiny they can include the best and most robust science available.

It is instructive to examine the approach used by WHO for the Guidelines for Drinking-water Quality. WHO has established a steering committee of international experts from different parts of the world. Most of the experts come from developed countries but a significant proportion of those experts are from developing countries bringing a broader range of experience to these international guidelines. The committee members are selected for their individual expertise and are not on the committee to represent the views of a particular country, organisation or sector.

The process for developing the Guidelines requires the preparation of background documents, often by members of the committee or, at the committee's request, by organisations or individuals with the necessary expertise. These background documents are an up-to-date assessment of the available science, including exposure, toxicology and the practical implications of a specific guideline for measurement and for achievability in a range of circumstances. The background document and the proposals in that document undergo peer review by the committee and selected experts, and when a final document is prepared this is posted on the WHO website for a period of up to 3 months for an open external peer review. This peer review process helps to ensure that the latest data have been incorporated into the assessment and that significant scientific views are taken into account. The document and a summary are then published on the website and are incorporated into the revised volumes of the Guidelines at intervals of two years. These documents are all openly available from the WHO website (www.who.int/water_sanitation_health/en/) in order to ensure that there is a very high degree of transparency to the process.

WHO member states use the Guidelines to develop their own standards but WHO encourages them to be selective and to incorporate only relevant guidelines into standards. It also encourages member states to make adjustments to take into account local circumstances both in terms of drinking water intake, which varies in different parts of the world, and exposure to a contaminant from other sources than drinking water, particularly food. This latter requirement is particularly important for chemical contaminants since the total exposure to a particular chemical from all sources is usually an important consideration. There are exceptions such as those chemicals that cause damage only by inhalation or where the form of the chemical will change the toxicity. For example arsenic in food is primarily in the form of organic arsenic compounds, which are much less toxic than the inorganic arsenic found in water and exposure from food is less significant than that from water. Member states are also encouraged to take into account their particular socio-economic status in setting standards. Apart from standards for microbiological contaminants, the standards for chemicals almost invariably have a significant degree of precaution built in and so there is usually potential for accepting a lower degree of precaution without serious implications for public health.

The European Union (EU) generally follows WHO in developing drinking water standards, which are encompassed in the European Directive on the quality of water for human consumption (98/83/EC), published in November 1998. In the UK the European Directive is transposed into legislation for public water supplies through the Water Supply (Water Quality) Regulations 2000 for England & Wales, the Water Supply (Water Quality) Regulations 2001 for Wales, and subsequent amendments, and for private supplies through the Private Water Supplies Regulations 2009. Scotland and Northern Ireland are covered by equivalent statutory instruments.

The Directive contains mandatory standards for microbiological quality and a number of mandatory standards for chemical contaminants. However, it also contains a number of indicator parameters that are mostly associated with acceptability by consumers, for which WHO has not set guideline values. Member States must monitor for indicator parameters but do not have to take remedial action in response to a breach of an indicator value unless the breach poses a risk to public health. Member States may also add additional parameters and may make particular parameters more stringent.

In England and Wales about half of the indicator parameters are included as mandatory national standards. In addition there are mandatory national standards for coliforms and *E.coli* at treatment works and service reservoirs and a mandatory national standard for tetrachloromethane (or carbon tetrachloride) at consumers taps. Separate provisions apply to the regulation of *Cryptosporidium* (an infective parasite[1]).

It is not possible, nor desirable, to set standards for every contaminant that could reach drinking water. In order to cover other possible contaminants, the Directive contains a requirement that drinking water should be free from any micro-organisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health. It is not, therefore, enough just to meet the standards set out in the Directive. Water suppliers need to be aware of other possible contaminants in a particular supply and take appropriate advice regarding safe numbers or concentrations and, if necessary, take action to reduce the numbers or concentrations to safe levels. This is an important part of the role of WSPs, discussed above, and where there is a WHO guideline for a particular contaminant this would normally be taken as the benchmark for judging the safety or wholesomeness of the supply.

In countries such as the USA and Canada, the WHO Guidelines are less important, although they do influence the standards and guidelines produced in those countries. Both countries follow a similar process to WHO in which background documents are produced with proposals for standards in the USA, and guidelines in Canada. These documents and proposed standards undergo both expert peer review and are posted for public comment before they are finalised. There are, however, some differences in the detail of the way in which values are derived due to different policy considerations in these countries. In addition the approach in the USA is to develop maximum contaminant levels (MCL) that are often based on achievability. The standards also list maximum contaminant level goals (MCLG) that are health-based. However in accordance with USEPA policy, all substances that are considered to possess carcinogenic properties have an MCLG of zero. There are also health-based non-enforceable advisory values listed for a number of substances that can be used to inform actions if there is an exceedence of the MCL.

3.0 What is covered by the standards?

WHO Guidelines are intended to apply to any drinking water but as indicated, the Guidelines are not mandatory. In the EU the Directive on the quality of water intended for human consumption applies to "all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers". It does not, however, apply to bottled waters that are recognised as natural mineral water by the appropriate authorities in a Member State. Natural mineral waters are covered by a separate Directive, 80/777/EEC and subsequent amendments, relating to the exploitation and marketing of natural mineral waters and which makes specific provisions for their recognition. Internationally, bottled waters are covered by the Codex Alimentarius, which also covers food. The Codex bases the majority of its bottled water standards on the WHO Guidelines.

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1 See the FWR publication FR/R0005 '*Cryptosporidium* in water supplies'

There may also be limitations on the requirements set out in the standards according to the size of the drinking water supply, with smaller supplies facing less onerous obligations. This is largely recognition of the more limited resources available for investment and monitoring and an attempt to ensure that private supplies and small municipal supplies are able to meet the most important requirements relating to public health.

Throughout this document the term standards is used as a generic term but the term guideline is used in referring specifically to the WHO Guidelines for Drinking-water Quality.

As indicated above the standards provide a basis for judging the safety of drinking water in relation to contaminants of concern but they also cover contaminants or characteristics that are important for the supply of acceptable drinking water and which may be important in helping to support drinking water safety, especially in relation to contamination by waterborne pathogens. However, standards usually go beyond a listing of different contaminants and include requirements for monitoring, both in terms of where samples should be taken, how frequently samples should be taken and the quality of the analytical methods to be used. These are all important in ensuring that standards are applied properly and that water quality is assured.

However, there is often guidance or additional regulation that is also an important part of the standards. For example, requirements for treatment are often covered in supporting legislation. In addition, there are usually requirements governing the quality of materials and chemicals that are to be used in contact with drinking water. These are often associated with an approval scheme such as those operated by the Drinking Water Inspectorate in the UK or the National Sanitation Foundation in North America.

4.0 Influences on standards

No matter how objective agencies try to make the process of developing standards, there are a number of influences that can make significant differences to the values produced. These influences are important and it is equally important that such influences are as transparent as possible. The most significant of these influences are discussed below.

4.1 Scientific knowledge
Scientific knowledge is not always complete and as a consequence, there may be uncertainties in the data or knowledge base that require that some assumptions be made in order to develop standards. These assumptions usually err on the side of caution but it is important that this is clear in order to aid decisions that are made with regard to the implications of exceeding the standard.

4.2 Quasi-scientific considerations
In calculating standards or guidelines, particularly for chemicals, there are a number of assumptions that are important but necessary, partly because of scientific uncertainty but also because there is a need to use values that reflect such factors as average water consumption. WHO, for example, uses a drinking water

consumption of 2 litres per day, while Health Canada uses 1.5 litres per day. These assumptions regarding average intake are appropriate for temperate climates. While this average is probably slightly conservative, WHO covers all of the world and there is a wide spread in consumption of drinking water not just as tap water but in tea, coffee and similar drinks, and in foods that absorb water such as pasta or rice. There are a number of other more detailed scientific assumptions that affect both microbiological and chemical standards and these are discussed in the relevant sections below.

4.3 Socio-political climate

The effects of public perception and media coverage can have a significant impact on standards. The best example of this is the EU standard for individual pesticides, which is 0.1 µg/litre, or one ten millionth of a gram per litre of water. This is not a health-based value but a political judgement that has set the standard as a surrogate for zero and reflects pressures regarding pesticides in the environment.

In the EU the precautionary principle has also been formally adopted and this can have a significant impact on drinking water standards, particularly for chemicals. There is considerable confusion as to what the precautionary principle means and there is a tendency for different groups to use it in support of their particular position without any proper definition. As a consequence the application of the precautionary principle can be rather uneven. While there is no universally accepted definition of the precautionary principle the version used in the Declaration made at the United Nations Conference on Environment and Development (UNCED) in 1992 and commonly referred to as the Rio Declaration defines the precautionary principle as follows;

Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation.

It is, therefore, important that the principle is used so that actions taken are in proportion to the risks. However, the principle itself, when considered in the light of such a definition, is sound and provides a sensible means of tackling some of the problems that arise even when there are uncertainties. However, the application of the precautionary principle has also resulted in the EU choosing standards tenfold lower than the WHO guideline value for some specific chemicals to provide a perception of additional safety that is not necessarily real.

4.4 Practicalities and costs

This can be an important consideration, particularly for chemicals that are naturally occurring or if their presence in the environment is difficult to control. In such a case a small increase in the standard would be insignificant in terms of public safety but would be highly significant in practical terms for meeting the standard.

5.0 Microbiological standards

5.1 Background

As indicated in the introduction, waterborne pathogens[2] have been recognised as a significant risk to public health for more than a century. Pathogens can take the form of bacteria, viruses or parasites and infections usually give rise to gastrointestinal disease of varying severity and duration and can sometimes give rise to complications with long term consequences. The greatest risks of waterborne microbial disease are known to be associated with drinking water that is contaminated with human or animal faeces. The range of pathogens that may be of concern through drinking water is covered in considerable depth in the WHO Guidelines for Drinking-water Quality but are briefly discussed below.

The major waterborne diseases, which have been recognised for centuries, are typhoid fever, caused by the bacterium *Salmonella typhi*; cholera, caused by the bacterium *Vibrio cholerae;* and bacillary dysentery caused by *Shigella* species. More recently other bacteria such as *Campylobacter* and some pathogenic strains of *Escherichia coli* (*E.coli*), in particular *E. coli* O157, have been recognised as being important bacterial pathogens that can be transmitted through drinking water. It is important to recognise that *E.coli* is a normal component of the human faecal flora and most strains of *E.coli* are not pathogenic. There are a number of other bacterial pathogens, including several *Vibrio* species other than *V.cholerae*, and a number of *Salmonella* species, which are capable of being waterborne but have rarely if ever been implicated in causing disease via tap water but present a threat when untreated surface water is used for drinking, as is often the case in developing countries.

There are many viruses that can be present in water sources and can cause disease through drinking water. The most well known is *Norovirus*, which is also known for causing outbreaks of vomiting and diarrhoea on cruise ships. However, there are a number of other families of viruses that can be a hazard to drinking water. These include adenoviruses, astroviruses, caliciviruses other than *Norovirus*, enteroviruses, rotaviruses and orthoreoviruses. In addition, hepatitis A and hepatitis E viruses can be transmitted through drinking water in some parts of the world. Viruses are responsible for a significant number of cases of gastroenteritis in the population but by no means all cases are a consequence of exposure through drinking water, since food and person-to-person contact are often more important routes. However, the viruses do appear to be more resistant than bacteria to disinfectants, such as chlorine, which are used in drinking water treatment and they play a very important part in waterborne disease.

The third group of organisms is the protozoan parasites, of which the most important are *Cryptosporidium* and *Giardia*[3]. These organisms multiply in the gut of an affected animal and are excreted in extremely large numbers in the form of cysts. In this way the organism is protected in the environment until another susceptible host ingests it when it can begin to grow and multiply. Not all animals are susceptible and not all species will infect man, however both are known to be

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[2] An infectious agent (such as a bacterium or a virus) that can cause disease.

[3] See FWR publications FR/R0005 '*Cryptosporidium'* in water supplies' and FR/R0006 '*Giardia* in water supplies'

transmitted in drinking water and a number of waterborne disease outbreaks have been associated with these organisms, although there are other major sources of infection, including swimming pools that are not properly managed. Both organisms are more resistant to oxidative disinfectants, such as chlorine, than bacteria, but *Giardia* is much less resistant than *Cryptosporidium*. However, the cysts of both organisms are larger than many bacteria and are largely removed in drinking water treatment by coagulation and filtration. There are other parasites that are found in water but their role in waterborne infections is of much lower significance, particularly through drinking water. *Acanthamoeba* has been found in drinking water and can cause eye infections if present in sufficient numbers. However, the concern is for improperly prepared water based solutions for washing contact lenses and not from other uses of drinking water. Organisms such as *Cyclospora cayetanensis, Entamoeba histolytica* and *Toxoplasma gondii* have been associated with infections through drinking water, primarily in tropical countries with water receiving little or no treatment, while data on other organisms are limited or they are only found under specialised environmental conditions.

While the risks in developed countries have decreased to the extent that any waterborne disease outbreak is a matter for serious note, waterborne disease remains a major source of endemic illness and death in many developing countries, particularly among infants and young children. Infection with pathogens occurs after even a single exposure to a sufficient number of organisms in a susceptible individual and some pathogens may be able to cause disease with an infective dose as low as between 1 and 10 organisms. While the risks in developed countries are low it is essential that we remain vigilant because important pathogens are still present in the environment. A salutary lesson happened in 2000, at the small town of Walkerton in Ontario, Canada. Vigilance by the water supply operators was allowed to drop and as a consequence the water supply became contaminated with *E. coli* O157. This led to a number of consumers being infected and in the deaths of several residents (Hrudey et al, 2003).

The greatest risk in developed countries is that occasional incidents of microbial contamination can lead to large numbers of consumers being affected at one time since the population has little natural immunity from previous exposure. This may occur if there is a breakdown in the water treatment barriers in association with high numbers of the pathogen in the source water. However, there is also a risk that occasional small numbers of pathogens can contribute to background levels of some microbial diseases, along with other major sources such as food and person-to-person contact. Preventing pathogens entering water supplies, therefore, remains the highest priority for maintaining safe drinking water and is a key part of standards for drinking water quality.

5.2 Guidelines and standards for protecting health

Because pathogens are difficult to measure, microbial standards are based on indicators and indices of faecal pollution. An indicator organism is used to show that water treatment has been adequate whereas an index organism gives a measure of the amount of faecal contamination in a source water or evidence of contamination after treatment. The same organisms often fill both roles. If an indicator organism is detected in final water at a treatment works then there is a possibility that pathogens may also have survived treatment. The more index organisms are detected in a source water the greater the likely numbers of pathogens. If an index organism is found in a properly treated water supply then the water has been contaminated in distribution and pathogens may also have gained access. Although the organisms used as index and indicator organisms have limitations they have been shown to provide a very effective system for ensuring safe drinking water supplies. For simplicity the term indicator organism is used below to refer either to index or indicator organisms. The WHO Guidelines are used as the basis for standards in most countries. In the EU the standards are: -

Escherichia coli (E. coli)	0 organisms/ in any 100 ml sample
Enterococci	0 organisms/100 ml

These standards apply at consumer's taps but the various UK Regulations require that additional samples are taken at water treatment works and in key parts of the distribution system.

E. coli and enterococci are normal constituents of the microflora of faeces from animals and man. Their presence is, therefore, indicative that there has been contamination by faeces and although it does not necessarily mean that pathogens are present, there is a very real possibility that this is the case. The use of *E. coli* and enterococci as indicators of faecal pollution is based on the premise that none should be detectable in any sample and the normal sample volume tested is generally 100ml., hence the standard of zero organisms per 100 ml sample. WHO include thermotolerant coliform bacteria as an alternative to *E. coli* where resources available within a Member State are limited. Thermotolerant coliforms will include *E. coli* but will also include some other less specific organisms. However, although the method for the culture of thermotolerant coliforms is less expensive, the reliability is not as high as for *E. coli*. The level of protection afforded by the faecal indicators against waterborne infectious disease remains a matter of some debate and has received attention by WHO and others (Fewtrell and Bartram, 2001).

However, it is clear that simply meeting the standard does not necessarily mean that the drinking water is safe. The size of the sample taken is actually very small in relation to the total volume of water produced and most of the methods only give a result after a delay of some hours. The water will, therefore, usually be in supply before the results for faecal indicators are available. These indicators are also very susceptible to chemical disinfectants while there are pathogens, such as *Cryptosporidium* and some viruses, that are much more resistant to such treatment. The use of faecal indicators on their own is not sufficient to ensure the safety of a drinking water entering supply and other operational data such as indicators of the efficient operation of coagulation and filtration also provide important supplementary information.

WHO has, therefore, introduced the concept of Water Safety Plans (WSPs) as previously mentioned. The WSP should not only identify the risks from micro-organisms in the environment but should also identify the circumstances, such as following heavy rainfall, when the numbers of organisms in raw water, and therefore the challenge to drinking water treatment, will be greatest. Drinking water treatment consists of more than one barrier, the multiple barrier approach, and management procedures are put in place to ensure that the barriers are adequate to mitigate the risks and all of the barriers are working properly at all times. Monitoring techniques, usually continuous monitoring, are put in place to measure the operation of the treatment processes and these measures are used in conjunction with the measurement of microbiological indicators. The indicators, therefore, still provide an important means of monitoring the final water as it leaves the treatment works and at different points in distribution through to the tap, as well as providing a legal standard against which to judge water quality. Whether or not WSPs are specifically included in standards remains to be seen but there is no doubt that they will be taken into account by regulators of drinking water quality in assessing the safety of water supplies and whether or not a supply is fit for purpose. The Drinking Water Inspectorate has stated that it strongly supports the World Health Organisation's initiative in promoting water safety plans as the most effective means of consistently ensuring the safety of a drinking water supply.

In England and Wales there were specific regulatory provisions relating to *Cryptosporidium* but these were revoked by The Water Supply (Water Quality) Regulations 2000(Amendment) Regulations 2007.

5.3 Other microbiological standards not specifically based on health

There are other microbial indicators that are widely used to check for untoward changes in the water supply system. These include the spores of *Clostridium perfringens*, total coliforms and bacterial colony counts at 22^{o}C and 37^{o}C.

The standards relating to these other indicators are not considered in the same light as faecal indicators and in the EU Drinking Water Directive they are included in the section on non-mandatory indicator parameters. They are however included in Schedule 2 of the various UK regulations as indicator parameters. The indicator standard for *Clostridium perfringens* including spores is 0 per 100 ml. The spores of *C. perfringens* are commonly found in the faeces of humans and animals but in much smaller numbers than *E. coli*. *Clostridium perfringens* spores are smaller than protozoan cysts and may be useful indicators of the effectiveness of filtration processes. Filtration processes designed to remove enteric viruses or protozoa should also remove *C. perfringens* and its detection in water immediately after treatment should lead to investigation of filtration plant performance. In view of the exceptional resistance of *C. perfringens* spores to disinfection processes and other unfavourable environmental conditions in comparison with *E.coli* and enterococci, *C. perfringens* can serve as an indicator of faecal pollution that took place previously and hence can indicate groundwater sources liable to intermittent contamination.

The coliform group of bacteria contains *E.coli* and a diverse range of other organisms many of which grow and are found widely in the environment, as well as those that are found in the intestinal tract of animals. They are generally not considered to be of direct significance for health, although a small number are opportunist pathogens; that is they are not normally disease causing but can cause infections in those who are immunologically compromised or have wounds, particularly those in hospitals. They are also not specific as indicators of faecal contamination. Some can even grow in distribution systems, both primary distribution and consumer's water systems. They should however be completely eradicated by water treatment. The indicator standard is 0 organisms per 100 ml of water. When they are found in treated drinking water it is necessary to investigate the source and the cause. If detected in final water at a treatment works this indicates failures in treatment. When detected in distribution it may be due to ingress into storage reservoirs or the distribution system through leaking reservoir hatches, air and stop valves and from cross-connections and back-flow from consumer systems without the correct back-flow prevention devices. They can also occur as a consequence of contamination of storage tanks and other parts of distribution systems in buildings or from growth on unsuitable plumbing materials and fittings. All such events are investigated in case they are indicative of a vulnerability of part of the system to contamination that needs to be corrected.

Colony counts are measured in samples by incubation at 22^{o}C and 37^{o}C in order to detect different organisms. Those that grow at 22^{o}C are termed heterotrophic bacteria and are not considered to be of direct significance for the sanitary condition of the supply (Bartram et al., 2003). They consist of many different organisms that are found naturally in the environment, including water, and are part of the normal bacterial flora that surrounds us. While colony counts can be of value in assessing the efficiency of treatment and the cleanliness of the distribution system, they are also helpful in indicating changes in water quality in the system, although there will usually be seasonal variation. The value of the 22^{o}C plate count is not, therefore, in the number of colonies per se, but in increases over the normal plate count, particularly sudden increases, which can indicate deterioration in general water quality for a range of reasons. Sudden changes in 37^{o}C plate counts can be an important indicator of ingress into the distribution system. Such changes in plate counts do, therefore, need to be investigated to ensure that no serious problem exists.

5.4 What are the consequences of exceeding the standard?

When the standard for a faecal indicator is exceeded this is a serious consideration and requires immediate investigation to determine the reason for the exceedence. If this were shown to be due to the distribution system within a consumer's premises a notice would normally be issued by the water undertaker to advise the consumer on the problem and possible remedial measures. However, if the exceedence reflects contamination of the whole supply or a significant proportion of it, immediate action may be required to protect public health. Decisions are taken in conjunction with public health authorities and can take the form of action to increase disinfection at a subsequent point in the distribution system or the issue of a boil water advisory requiring that all water for drinking should be boiled. This latter action is not taken lightly because there are risks associated with boiling water, particularly the potential for an increase in the number of incidents of scalding. When a boil water advisory is put in place then it is also essential that the basis for removing the advisory is also understood. For situations in which the problem can be identified by the faecal indicators, the requirement might be that the order would be lifted following two successive days of samples that showed no faecal indicator organisms, with the additional requirement that treatment was confirmed to be working optimally.

However, exceeding the standard does not automatically mean that this will cause illness as the faecal indicator only shows that there is a possibility that pathogens may be present and this is by no means a certainty. On most occasions the exceedence of the indicator values does not lead to any impact on public health, either because the level of contamination is low and no pathogens were present or because a sufficiently rapid intervention has been made. In some cases there may be a false positive result as a consequence of contamination during sampling or analysis but even when a false positive is suspected, it must be investigated thoroughly and quickly to prove that there is no risk to human health.

Table 1. Comparison of microbiological standards and Guidelines

World Health Organisation Guidelines	European Union Directive requirements	UK Standards
Applied to all water directly intended for drinking, food preparation and personal hygiene including packaged water, treated water entering the distribution system, treated water in the distribution system.	Apply to treated water at consumers' taps, bottled water other than natural mineral water at the time of bottling, and drinking water at the point at which it emerges from a tanker.	Treated water at consumers' taps. Some additional requirements for water leaving treatment works
***E. coli* or thermotolerant coliforms** 0 per 100 ml sample	***E. coli*** 0 per 100 ml sample	***E. coli*** 0 per 100 ml sample
	Enterococci 0 per 100 ml sample	**Enterococci** 0 per 100 ml sample
		Service reservoirs and water treatment works. Coliform bacteria 0 per 100 ml sample. *E. coli* 0 per 100 ml sample
	Water, other than natural mineral waters, for sale in bottles or containers *E. coli* & enterococci 0 per 250 ml sample *Pseudomonas aeruginosa* 0 per 250 ml Colony counts 20-22°C & 37°C max. 100/ml and 20/ml respectively within 12 hours of bottling	**Water, other than natural mineral waters, for sale in bottles or containers** *E. coli* & enterococci 0 per 250 ml sample *Pseudomonas aeruginosa* 0 per 250 ml Colony counts 22°C & 37°C max. 100/ml and 20/ml respectively within 12 hours of bottling

6.0 Guidelines and standards for chemicals

6.1 Background

All natural water sources contain a variety of chemicals. These consist of those that are naturally occurring and those that arise as a consequence of man's activity. The natural inorganic constituents are minerals that leach from the rocks and soil through which the water percolates. Those such as calcium and magnesium are present in concentrations of tens to hundreds of milligrams per litre, while many others are only present in trace concentrations of a few micrograms per litre or less. The mineral content contributes to the taste of drinking water and some highly mineralised waters are prized for their taste or reputed health-giving properties. The majority of the minerals present are of no significance but some, such as calcium and magnesium, are essential elements and, under certain circumstances, may make a beneficial contribution to dietary mineral intake. Some such as fluoride may be beneficial at low concentrations but can sometimes be naturally present in drinking water at high concentrations that give rise to adverse health effects. Others such as arsenic are of concern for health at low concentrations, although in most waters they are present at concentrations below those of concern.

Most natural organic contaminants are complex chemicals from the soil and breakdown of plants. These are not usually considered to be of significance to health on their own but they may impact on the acceptability of drinking water and can react with some important treatment chemicals.

Man-made chemicals, or chemicals that are used by man, (although some may also occur naturally in the environment) may reach water sources as a consequence of run-off or percolation downwards to groundwater from farmland and roads, or from industrial discharges and discharges of wastewater. Some chemicals play an important role in the water treatment process and some used in treatment can react with natural organic chemicals to produce other chemicals that are unwanted by-products. Materials used for building the distribution system and in plumbing can also contribute to the chemical content of drinking water. There is, therefore, a need for standards that provide a basis for judging safe levels of a range of chemicals in drinking water. These standards provide a benchmark for drinking water suppliers, pollution control authorities and health authorities.

WHO has developed health-based guideline values for over 100 chemicals in drinking water. These are based on the best available science and in many cases the guideline values are well above the levels normally found in drinking water sources and in drinking waters. Concern has been expressed that this may be taken as a license to pollute up to the guideline value but WHO makes clear that such a policy is not acceptable or appropriate and contamination should be kept as low as practicable.

Although there are guideline values available for a large number of chemicals, it is not appropriate to incorporate all chemicals for which there are guideline values into national standards. Many substances will not occur in a particular region and others will always be present at concentrations well below the levels of concern for health. Introducing standards for such chemicals would introduce a very large amount of unnecessary monitoring and analysis. WHO, therefore, recommends that standards are developed to include those chemicals that are of greatest importance and that are most likely to be present in a particular country or region. This is the primary basis for the chemicals included in standards in the EU and in the UK. The introduction of WSPs also provides an alternative mechanism for dealing with chemicals both in a proactive way by preventing contamination at source, and by the use of operational monitoring to demonstrate that drinking water treatment will remove the substances of concern and that it continues to do so. This approach is increasingly valuable with regard to some trace substances for which highly specialised analysis is required and for which routine monitoring is simply not practicable.

6.2 Development of health-based standards

In general, while microbial contaminants can cause disease following a single exposure to an infective dose, the great majority of chemicals can only exert their toxic effects after exposure for an extended period, often many years. However, the potential for a chemical to cause toxicity depends both on the period of exposure and the dose, or concentration if the substance is in drinking water. Just as microorganisms need to be present in sufficient numbers to cause an infection, chemicals also need to be present in a sufficiently high concentration to be able to overcome the body's natural defence mechanisms and cause toxicity. In addition the severity of toxicity increases with the dose. While the risk of toxicity from substances in drinking water from short-term exposure is not normally of any concern there are some exceptions, e.g. nitrate causing methaemoglobinaemia in bottle-fed infants.

Health-based standards for chemicals are developed in one of several ways and mostly refer to individual chemicals, although sometimes a group of chemicals is considered.

For most chemicals there is a dose below which no toxic effects will be seen. This is known as a threshold mode of action. The way in which standards are developed for such chemicals is by the determination of a tolerable or acceptable intake, usually a tolerable daily intake. Such an approach is very well established and has been used successfully for many decades by authorities all over the world, including WHO. The term 'acceptable daily intake', or ADI, is usually applied to substances that are food additives or pesticide residues. The term 'tolerable daily intake', or TDI, is applied to contaminants that have no intended function. The definition of ADI/TDI is the combined amount of a substance in food and drinking water, expressed on a body weight basis (e.g. mg/kg of body weight), that can be ingested daily over a lifetime without appreciable risk to health. This means that the value refers to an average exposure over a lifetime and exceedences for short periods are not, therefore, of concern.

TDIs are developed from data in which animals are given large doses of the chemical, usually over a lifetime but sometimes for shorter periods, and the toxic effects are detected by changes in physiological function, measured in similar ways to humans undergoing medical investigation for disease, and microscopic changes in organ or tissue structure. Sometimes the TDI is based on epidemiological or experimental data in humans. However, using epidemiological data for many substances can be very difficult because frequently the level of intake is not well characterised and the level associated with an effect is not known, or there is exposure to high levels of other chemicals at the same time. Most of the epidemiological studies are carried out on workers who have been exposed in their workplace. A wide range of different studies is considered in order to examine different possible toxic endpoints. The difficulty with experimental studies in humans is that with few exceptions, it would not be acceptable to give the subjects enough to cause an adverse effect so the margin of safety above the top dose is very uncertain and could be very large or quite small. Such data are, therefore, primarily used in support of other data.

The 'no observed adverse effect level' (NOAEL) in a suitable study is taken as the starting point for extrapolation to the wider human population. This usually reflects the most sensitive endpoint in the most sensitive species and is the next dose below the lowest dose at which effects have been observed. However, the NOAEL is heavily dependent on the experimental design and can significantly underestimate the actual no effect level, which may be much higher. More advanced methods that take into account all of the experimental data to give a more reliable starting point are, therefore, increasingly being employed. A value determined this way is called the benchmark dose and is based on the lower 95% confidence limit associated with a 1% or 5% incidence of the key toxic effect in the group of animals studied. This is still a conservative approach but uses the science in a much more robust way.

The NOAEL or benchmark dose is divided by an uncertainty factor that reflects various levels of uncertainty. While specific uncertainty factors usually require some level of expert judgement, they are based on consideration of all of the scientific evidence available. The factors relate to the possible difference between laboratory animals and man, interspecies variation, intraspecies variation to reflect possible variation within the human population, the adequacy of the database and the amount of available data, and the severity of the effect observed. The factors applied for each item vary between 1 and 10 so that the maximum factor would be 10,000, although it would not normally exceed 1000 because above this the level of uncertainty is very great and it would usually be considered that the data were inadequate to set a sufficiently robust value. There are some exceptions and these are considered below in relation to individual substances for which standards have been set.

The TDI is then considered in relation to drinking water. This includes the weight of an average person, the average amount drunk and also the potential exposure from other sources, particularly food. The approach used by WHO and accepted by most countries, including the EU, is to assume a 60 kg adult drinking 2 litres of water per day. This is somewhat conservative for temperate countries but for hot countries with higher water intakes, WHO recommends that standards should be tailored to local conditions taking into account the extent of increased water consumption. For some substances the guideline value is based on a special group and WHO has used a 10 kg child drinking 1 litre of water per day or a 5 kg bottle-fed infant drinking 0.75 litre per day where these groups are the primary concern, usually for substances that would act over a much shorter period than a lifetime and where these groups are considered to be much more vulnerable. Where good

quality data on the exposure of a particular substance from other sources than drinking water are available, particularly food, it is appropriate to use these as a basis for determining how much of the TDI should be allowed to come from drinking water. Where the intake from food is low then a higher proportion of the TDI could be allowed to come from drinking water but where exposure from food is high a smaller allocation might be made to drinking water. Much will depend on where the most appropriate means of control lies but in most cases the total exposure will, in any case, be well below the TDI. Where there are insufficient data to determine a specific allocation to drinking water WHO has used default allocations of 1%, 10% or 20%. This last value is now the standard default value used by WHO.
Some substances have been shown to cause cancer in laboratory animals given high doses, usually for their lifetime. Some of these substances can cause damage to DNA and where this is considered to be the way in which the substance causes cancer it was widely accepted that, theoretically, there would be no threshold to this effect. Under these circumstances it was not thought to be appropriate to determine a safe level using a TDI approach and so mathematical models were developed that were used to extrapolate the risks of tumours at high doses in animal studies to the risks associated with environmental exposure to small amounts. These models generally assume that extrapolating in a straight line from high doses to extremely low doses is valid, with the most extreme position being that one molecule of the substance poses a risk of cancer, albeit minute. The models also make a number of other conservative assumptions. Most do not take into account the absorption, metabolism and detoxification of the substance, the death and removal of affected cells and repair of the damage to DNA. In addition, standards based on these models usually use the upper 95% confidence interval on the calculated risk, so the actual risk is almost certainly much lower than the value given and may even be zero. Where WHO has used such an approach, the guideline value is the concentration per litre associated with one additional cancer per 100,000 of population exposed for a lifetime; this is referred to as a reference risk. However, as indicated, the risk is almost certainly much less than this value and potentially zero. The WHO reference risk is considered to be a negligible risk but the EU has used an even smaller reference risk of 1 additional cancer per million of population resulting in a lowering of the WHO guideline value by a factor of 10. Such decisions regarding acceptable risk are not based on science but have a significant social and political dimension, although cost and achievability are often taken into account in setting the final standard.

An additional consideration is that many of the substances are dosed to the animals in a daily single dose in corn oil. However, in many cases where there are studies available using drinking water to supply the substance to the experimental animals, the data show that either the substance is a much less potent carcinogen or not carcinogenic. Where studies using corn oil have been used as the basis for standards or guidelines, there is a strong chance that these will also overestimate the toxicity/carcinogenicity of the substance under consideration.

Not all substances cause cancer by directly interacting with DNA. A number of substances have also been shown to cause cancer by an indirect mechanism in which tissue damage or hormonal disruption result in changes in cell turnover in a particular tissue. This, in turn, results in an increased chance of a tumour developing. However, such mechanisms do have a threshold that it is possible to demonstrate experimentally. It is, therefore, appropriate to develop a TDI for such substances and to proceed in the same way as other chemicals with a threshold of toxicity.

The development of standards for carcinogens causes most contention between different authorities, primarily because of policy differences in different countries. In North America there is a presumption that the linear no threshold approach should be used in all but very rare cases. In addition while the US uses the same model as that used by WHO, the US model includes an even more conservative assumption that the dose should be measured in terms of body surface area rather than body weight. This can result in the calculated risks being up to 10 times greater than those associated with the WHO Guideline values. However, international agencies are increasingly moving away from the linear mathematical models on the grounds that the scientific basis is limited and the values derived give a spurious impression of precision (Lovell and Thomas, 1996). The approach that is increasingly favoured is the determination of a virtually safe dose by using a large uncertainty factor of up to 50,000 applied to the lower 95% confidence interval on a benchmark dose associated with a fixed tumour incidence such as 1% or 5%. The values derived by this methodology are generally of the same order as those derived using theoretical models but the derivation is much more transparent.

Standards for chemicals that are covered by the EU Drinking Water Directive are presented in Table 2 compared with United States Environmental Protection Agency Standards and WHO Guidelines. It should be noted that some of the differences are entirely due to policy differences and these are highlighted in a more detailed discussion of individual parameters in Annex 1.

6.3 What are the consequences of exceeding the standard?

The situation with chemicals is somewhat different from microbiological standards since there is a significant margin of safety built into standards for chemicals and the potential for an effect on health usually only follows extended exposure to elevated concentrations. The consequences of exceeding a standard will depend on the extent to which the standard is exceeded and the period of time for which the exceedence continues. The implications of an exceedence can be assessed by comparison with WHO guideline values, which are health based. If the concentration is greater than the WHO guideline value then further assessments will be made. The approach suggested in the WHO Guidelines is to consider whether the overall exposure from all sources, but usually food and water, results in the ADI or TDI being exceeded. If not then there is by definition no threat to health. If it is then consideration needs to be given to the margin of safety built into the ADI/TDI. Some erosion of the margin of safety would not result in a threat to health following short-term exposure. Where there is an exceedence of a chemical parameter, consideration also needs to be given as to how this can be brought back into compliance and how quickly this can be achieved.

Should the standard be derived from a theoretical mathematical model for cancer risk then the level that would be considered acceptable requires some expert judgement but WHO suggests that a value associated with a risk of 1 additional cancer in 10,000 population over a lifetime would be a negligible increase in risk for short-term exposure, particularly in view of the conservative nature of the models.

Should the concentration be such that it is deemed to be a threat to health then one of the options open is to issue a ‘do not drink’ advisory. Stopping the supply is not usually a consideration since the risks associated with the loss of a water supply with regard to hygiene are significant. Even advice not to drink the water has significant implications because a source of water for drinking and cooking has to be provided. Delivering water in bottles is a major logistical problem and delivery of water in tankers introduces problems of security, such as preventing vandalism, and the requirement to boil the water since the potential for microbial contamination of water after it has been collected is significant.

In some cases it may not be possible to immediately meet the standard for a substance until appropriate treatment has been installed, which will take time. In such a case, if the problem is not associated with microbial contamination, the approach taken is normally for the regulatory authority to issue an authorised departure. This notice requires the water supplier to meet a value that is higher than the standard but which has been deemed by health authorities to be of no significant risk to health. However, the authorised departure will always have a time limit by which time the standard must be met in full. This is usually a sufficient period to allow the installation of suitable treatment or other infrastructure.

Occasionally, there will be significant difficulty in meeting the standard for naturally occurring chemicals because of the nature of the geology affecting the source from which the drinking water is drawn. In this case if there is deemed to be no significant threat to health and the difficulty in achieving the standard is considered to be too great then a derogation may be issued that will allow the supplier to continue to supply water that is above the standard but there will always be an upper limit set on the concentration of the substance concerned. Under EU legislation derogations may be granted for periods of three years and are subject to programmes of remedial work being completed.

More detailed information on the derivation of the standards for specific chemicals is provided in Annex 1.

Table 2 Comparison of EU, United States and WHO standards or guidelines for chemicals

	EU	USA	WHO
	All numeric values are expressed as µg/l		
Acrylamide	0.1	Product control	0.5
Antimony	5	6	20
Arsenic	10	10	10 (P)[2]
Barium	No standard	2000	700
Benzene	1	5	10
Benzo(a)pyrene	0.01	0.2	0.7
Boron	1000	No standard	2400[1]
Bromate	10	10	10
Cadmium	5	5	3
Chromium	50	100	50 (P)[2]
Copper	2000	1300 [4]	2000
Cyanide	50	200	no value set
1,2-dichloroethane	3	5	30
Epichlorohydrin	0.1 [6]	Product Control	0.4 (P)[2]
Fluoride	1500	4000	1500
Lead	10 [7]	15 [4]	10(P)[2]
Mercury	1	2	6 [1]
Nickel	20	No standard	70 [1]
Nitrate	50000 [3]as nitrate	10000 as nitrate N	50000 [3]as nitrate
Nitrite	500 [3]as nitrite	1000 as nitrite N	3000 [3]as nitrite
Pesticides			
Individual	0.1	Individual	Individual
Total	0.5	pesticides	pesticides
Polycyclic aromatic hydrocarbons	0.1	Individual substances	No value
Trihalomethanes	100 [5]	80 [5]	Individual substances[9]
Selenium	10	50	40(P)[1,2]
Tetrachloroethene plus trichloroethene	10	5 each	40 and 70(P)[1,2]
Tetrachloromethane	3 [8]	5	4
Vinyl chloride	0.5 [6]	2.0	0.3

1 Revised or added in 4th edition.
2 Provisional, will be reconsidered.
3 The ratio of the sum of the concentration divided by the standard must be 1 or less.
4 Action level for steps taken to reduce corrosivity.
5 EU is as a maximum, USA as a 3 monthly average.
6 Calculated based on release of residual monomer from maximum polymer dose.

7 A standard of 25 μg/l applies for the first 15 years of the Directive. No sampling method has yet been defined but the standard relates to weekly average intake. An official EC guidance has been published.

8 UK only.

9 Chloroform revised from 200 to 300 in 4th edition.

7.0 Radioactivity

7.1 Background

Occasionally low levels of radioactive substances may be found in drinking water. Some arise as a consequence of naturally occurring radionuclides, others arise as a consequence of background contamination from events such as the Chernobyl accident and some can arise as a consequence of discharges into water sources. The greatest source of exposure to radiation is natural with exposure through food and drinking water a minor source. The most common radioactive substances found in drinking water are radon and its daughters resulting from the disintegration of the radon nucleus. However, the greatest exposure to radon is through inhalation, since it is a gas, and the amounts in public water supplies are extremely small, although some private wells may have higher levels in areas with the typical geology. Another naturally occurring radioactive substance is tritium, the radioactive form of hydrogen, which is present in very small amounts but which may also be present as a consequence of the discharge of cooling water from nuclear power stations to fresh water.

Radioactivity in drinking water is determined by measuring radioactive emissions in the form of alpha or beta activity but this is of little help in determining the risks associated with particular radionuclides. This requires that the individual substances responsible be identified because it is the absorbed dose of radioactivity that is important. This is related to the nature of the radiation emitted and the persistence of the radioactive substance in the body. Once a radionuclide has been ingested, the risk will depend on the period of time over which the substance is lodged in the body and the ionising strength of the radiation. For example, substances that are incorporated into the bone are generally retained for much longer periods than those in soft tissues. The risk for ingested radioactive sources also usually follows the following order of risk with alpha particles causing most damage followed by beta particles and then gamma radiation.

The activity of a substance is measured in Becquerels (Bq) and a Becquerel is 1 disintegration of an unstable nucleus per second; the potential for harm is measured as the dose equivalent and this is in Sieverts (Sv). Older units are still in use in the USA; these are the curie (Ci) measuring the activity of a substance (3.7×10^{10} disintegrations per second) and Roentgen Equivalent in Man (rem), which measures dose equivalents. In comparison 1 Sv = 100 rem.

7.2 Standards for radioactivity in drinking water

The dose considered to result in a very low additional risk from exposure to radionuclides through drinking water is 0.1 mSv. This represents less than 5% of the average effective dose attributable to natural background radiation (ICRP, 1999, 2007, IAEA, 1996). It also represents only 10% of the lowest value in the range of worldwide average radiation dose from natural sources. This standard has been adopted by the EU as an indicator parameter for drinking water and is the basis for the WHO Guidelines for Drinking-water Quality.

However, it is not possible to directly measure the committed effective dose and a different approach is required. This involves measuring alpha and beta particles against screening values. Draft EU legislation (EC 2011) proposes screening values of 0.1 Bq/litre for gross alpha radiation and 1.0 Bq/litre for gross beta radiation (WHO 0.5 and 1.0 respectively). If these screening values are exceeded then the water must undergo further examination to identify the specific radionuclides responsible for the radiation and the effective dose can be determined using a dose coefficient and the average consumption of water. The guidance values associated with an effective dose of 0.1 mSv for a wide range of radionuclides is given in the WHO Guidelines. These show that for the great majority of radionuclides, exceeding the screening value will not result in the standard being exceeded. The standard also excludes the naturally occurring radionuclides, tritium, potassium-40, radon and radon decay products. However, there is a separate standard for tritium of 100 Bq/litre, which is significantly more stringent than the 0.1 mSv committed dose. The basis for this separate standard is unclear but it may reflect a political desire to minimise discharges from nuclear power stations. Monitoring for radioactivity is relatively difficult and the analysis of specific radionuclides requires highly specialised analysis that is carried out by specialised laboratories and so monitoring strategies are usually developed using a risk based approach. The risks from both natural and anthropogenic sources of radionuclides in a catchment are assessed and the monitoring strategy is built around this. However, the major risks, such as the Chernobyl accident, are monitored by international authorities and water becomes one of a wider range of environmental compartments that are subject to increased monitoring in the event of an incident.

The approach in the USA is similar but uses different units, a dose of 4 mrem (millirems) per year for beta particles and photon activity with a maximum contaminant limit of 15 pCi/litre (picocuries) for gross alpha activity. The USA has also set a maximum contaminant limit of 300 pCi/litre for radon with an alternative maximum contaminant level of 4000 pCi/litre for small systems with a small population. There is also an MCL of 5 pCi/litre for combined radium 226 and radium 228. The standards reflect the specific geology of parts of the USA where elevated level of naturally occurring radionuclides can be found. However, although older units are used they reflect similar doses of radiation to those used by WHO.

8.0 Acceptability

Drinking water should not only be safe but also acceptable to consumers. Should water be unacceptable there is a danger that consumers will turn to less safe but aesthetically more acceptable supplies or turn to much more expensive alternative sources such as bottled water. The water should, therefore, be clear, colourless and have an acceptable taste. However, acceptability cannot be measured precisely since what might be considered acceptable by one person, or in a particular area or region, might not be considered acceptable to another. This is often observed when individuals move between regions of hard and soft water. In the past WHO set a number of standards, and later guideline values for chemicals related to acceptability. However, it was recognised that these guideline values were different from health-based guideline values but there was confusion over their adoption and WHO decided that only health-based guideline values would be set to avoid the misinterpretation of such values. However, the EU Directive includes a number of indicator parameters that are related to acceptability. Details of these EU indicator parameters are provided in Annex 2. Member States are able to adopt these standards in a flexible way and the standards are similar to the non-enforceable secondary standards set by the USEPA. In the England & Wales most of these standards have been made mandatory and national standards for quantitative taste and odour have been defined. However, it is made clear in the regulations that an exceedence of one of these standards requires a different and lower level of response to that for an exceedence of a health-based parameter.

It must be stressed that these standards are based on much softer science than for the health-based standards, and are primarily based on practical experience and observation. This is particularly true for parameters that relate to turbidity or colour, while taste or odour measurements are relatively imprecise and taste or odour detection will depend on a range of specific circumstances that can change quite quickly, for example with changes in temperature or the presence of other unrelated flavours or odours.

A wide range of substances may affect the acceptability of drinking water. Many of these are covered by health-based guideline values that are much higher than the levels that can give rise to taste or odour. This may not appear to be logical but the health-based guidelines can provide reassurance that in some cases where there has been a bad taste or odour, such as might arise from some of the small hydrocarbon molecules in diesel, there is no significant threat to health. Others are not covered by specific standards or guidelines and can cause problems at very low concentrations that are well below a concentration that could conceivably be a risk to health, sometimes a few nanograms per litre (a trillionth or 0.000,000,001 of a gram). One example of such a substance is geosmin, which can be produced by certain algae and fungi, and is responsible for the earthy smell sometimes encountered when rain follows a dry spell. The European Directive does not set any specific standards for either taste or odour but specifies that these should be acceptable to consumers with no abnormal change. The National requirements in England and Wales are different in that values are specified based on laboratory methods for measuring taste and odour, respectively, using a taste panel.

Discolouration is also of importance. In the past, in some parts of the country supplied by water from soft, peaty upland reservoirs, the water supplied could be seen as brown against white sanitary ware. The EU standard for colour simply states that the colour should be acceptable to consumers and there should be no abnormal change, whereas the National requirements for colour in England and Wales specify a value of 20mg/l Pt/Co. This standard means that colour is no longer visible and that is the basis for the standard. Discolouration can also arise in distribution as a consequence of corrosion products from cast-iron pipes, but this is normally only seen after a disturbance of sediment in the mains following an event such as a burst main or accidental initiation of excessive flow in the mains. This too is covered by the standard for colour, although it may also be covered by the standard for turbidity if high levels of sediment are re-suspended.

Turbidity reflects the presence of particles in the water that block the transmission of light and is important in two different ways. The standard in the EU Directive requires that turbidity is acceptable to consumers and shows no abnormal change and suppliers using surface water should strive to provide water below 1 NTU (nephelometric turbidity units originally measured by a comparator) because this is considered, through experience, the minimum to ensure good disinfection. In England & Wales the value of 1 NTU is incorporated as an indicator standard at treatment works along with a national mandatory standard of 4 NTU for water at consumers' taps, which is just below the level of turbidity that is visible to the naked eye. There are a number of potential causes for turbidity at the tap, including air in the water or the precipitation of calcium carbonate in some very hard waters. While these last two items are of no concern for health, the presence of turbidity at the tap can indicate a problem that should not be ignored because it could be an indicator of a serious contamination. Turbidity at the treatment works is also important because high turbidity can seriously interfere with the efficiency of disinfection. It is also an indication that coagulation and filtration are not working properly. Currently there is no formal standard for turbidity at the treatment works in the EU but in North America treatment rules specify turbidity of less than 1 NTU in water leaving the treatment works with 95% of samples being ≤ 0.3 in order to ensure that coagulation and filtration are operating efficiently and that the efficiency of chlorination will not be compromised.

9.0 How standards are measured

The requirements for measuring parameters against statutory standards are normally laid out in terms of the point of sampling, the number of samples, and frequency of sampling which often relates to the size of the water supply or the number of consumers, and the methods that must be used. This last point requires care because while it is necessary to specify minimum standards for microbiological and chemical analysis it is also important to allow sufficient flexibility to allow for the adoption of new and improved methods. While analytical performance criteria can be set for physical and chemical parameters, based on measurement of accurately measured standard solutions it is not possible to do this with microbiological parameters and reference methods have to be prescribed against which alternative methods must be validated. The frequency of sampling will depend on the nature of the parameter under consideration. Parameters that can vary rapidly in both time and quantity, such as the faecal indicators for pathogens, need to be measured much more frequently than many, but not all, chemicals, which are quite stable and change only slowly over time. Some parameters are, therefore, measured relatively infrequently and still accurately reflect whether the standard is being met over an extended period.

The standards usually apply at the tap. However, some chemical parameters will not change between leaving the water treatment works and reaching the tap and so one sample taken at the treatment works is much more efficient than many samples taken at the tap and just as effective. For example, arsenic is a raw water contaminant and will not change in distribution; it is, therefore, appropriate to accept that monitoring at the water treatment works will provide a more efficient but acceptable way of demonstrating that a supply meets the standard. However, lead is not usually found in raw water at other than trace concentrations and the main sources are older service connections and plumbing within buildings and so measurement at the tap is essential. Because lead and other plumbing related substances, copper and nickel, can and do vary from building to building, it is important to specify a sampling programme that will provide sufficient information to make a judgement regarding the area that is supplied. While the water suppliers' responsibility ends at the boundary of the property or the meter, if one is fitted, there is a responsibility to ensure that the water is not corrosive to plumbing.

There are some chemical parameters that may not be present in a particular supply or in the catchment for the water source. In this case monitoring may be reduced to an occasional sample. In Europe the political standard of 0.1 μg/litre is the same for any pesticide except for four named pesticides for which the standards are even lower (aldrin, dieldrin, heptachlor and heptachlor epoxide for which the standard for each is 0.03 μg/litre.) Unlike the USA and Canada the EU standard does not specify which pesticides need to be monitored and since there are many potential pesticides, water suppliers carry out an assessment of the pesticides that are used in the catchment and only monitor for those that are likely to be present. This again introduces a risk-based approach to drinking water quality and is similar to the approach used in the WSPs. WHO has published guideline values for many individual pesticides.

Some substances for which there are standards arise from materials or chemicals that are used in contact with drinking water. The three of greatest note are acrylamide, epichlorohydrin and vinyl chloride. These are not normally measured in drinking water because of the difficulty of measuring such small quantities. However, the proactive approach used is to prevent their entering drinking water at concentrations above the standard in the first place by specifying the maximum residual concentrations in the products used in contact with drinking water. In the case of vinyl chloride this is PVC pipe and the maximum of residual monomer is much more easily determined and controlled at this point. Acrylamide and epichlorohydrin, only occur if present in polymers used to aid coagulation in water treatment. By controlling the level of residual chemical in the product and the amount of the product that can be added to drinking water, unacceptable contamination can be prevented.

One of the major considerations is the way in which compliance with a standard is measured. In the case of the faecal indicators, any detection of an indicator organism would imply that the water is out of compliance with the standard unless it is shown to be due to consumers' plumbing, sampling or other subsequent contamination. However, for chemicals there may be a requirement that the standard is met at any point in time the same as for faecal indicators, as in the EU, or the standard may be considered as an average over a period of time as in the USA. For many chemicals it will make little difference but for some, such as the trihalomethanes (THMs) that will vary over time and which will usually be measured frequently, this will be important. As a consequence the EU standard of 100 μg/litre for total THMs is roughly equivalent to the USEPA standard of 80 μg/litre. In terms of health protection there is no real difference.

10.0 Private supplies

Private drinking water supplies, as opposed to public supplies, are usually regulated separately because the quantity of water is limited, the numbers of consumers are normally very small and the resources available are also small. In most countries, therefore, there is usually an incremental implementation of standards for public supplies and separate standards for private supply. The EU Drinking Water Directive, for example, does not apply to water supplies providing an average of less than 10 cubic metres of water per day or supplying fewer than 50 persons, unless the water supply is associated with a commercial or public activity such as holiday accommodation or a restaurant. The Private Water Supplies Regulations 2009 assigned responsibility for the monitoring and control of private supplies to local authorities.

While the need to ensure that microbiological quality is maintained is still very important, this may be achieved in a number of ways, including boiling water used for drinking, washing foods eaten without cooking and for ice making and activities such as tooth brushing. A number of simple point-of-use treatments are also available. However, chemical contaminants may be much more difficult to remove and where there is no simple preventive action, the assessment of risk described in section 6.3 will allow regulators and users of private supplies to determine whether there is any significant risk to health.

11.0 Future directions

As indicated above, standards do not remain static but evolve in the light of new knowledge and new approaches that are developed to assure the safety of drinking water. Developments can include changing approaches, such as Water Safety Plans, that introduce a more holistic approach to the management of drinking water quality, or changes in scientific knowledge that result in new approaches to the assessment of risks from both pathogens and from chemical contaminants. Such changes are usually introduced only after careful consideration because frequent changes in standards can lead to considerable difficulties for water suppliers and communities. For example, changing water treatment infrastructure is not only expensive but cannot necessarily be achieved quickly. Water treatment processes are often quite complex and the interrelation between different treatment stages must be carefully balanced.

WSPs have been briefly discussed above but this is the change of approach which will certainly become much more apparent in future revisions of drinking water standards. This is a management system that helps to bring together all parts of the water supply and to consider them as a whole. It focuses on controlling and eliminating the potential sources of pollution rather than the detection of pollution when it has occured. As a consequence there is a requirement to assess any change in the light of its impact on other parts of the supply so if a change was proposed in water treatment in order to mitigate the risks associated with one hazard, there would be a requirement to make sure that the proposed change would not increase other risks before it was introduced. However, because WSPs are a management system it is more difficult to incorporate them into the traditional standards without making the process too prescriptive and losing much of the benefits of the inherent flexibility of WSPs, allowing them to be tailored to a specific supply.

There is also considerable activity with regard to the approaches to assessing risks from contaminants. Since the microbiological standards are based on faecal indicators it is also useful to make some estimate of the levels of protection that will be afforded by different treatment combinations. The risks associated with different pathogens will vary according to the pathogen and the levels of removal may also vary. Methods for quantifying risks associated with particular pathogens are now being developed and these can be used to determine the theoretical risks associated with different levels of removal in treatment (Haas et al., 1999). However, just as with the mathematical models for extrapolating the risks of carcinogenicity from high doses in animal studies to the risks at low intakes from drinking water, there are a number of assumptions built into the models and much will depend on the level of immunity in any exposed population. Such approaches may result in the introduction of health-based standards for specific waterborne pathogens or the introduction of better indicators; however, they may also lead to the introduction of treatment-based standards, which are already being used in the USA. They would also provide support for the WSP approach. A number of alternative indicators and approaches to assessing microbial risk are being investigated.

However, much will also depend on the development of more efficient methods for detecting micro-organisms, especially specific pathogens, in drinking water and it remains to be seen how standards and guidelines for protection from waterborne microbial disease will evolve.

There are already changes in the approaches to the regulation of chemicals in drinking water and a more selective and risk-based approach is already being introduced in order to optimise the efficiency of monitoring and directing resources where they will most benefit water quality. This is in line with the introduction of WSPs.

However, there is also a move towards treatment-based guidelines for some groups of chemicals for which analytical methods are extremely difficult. This too is inspired by WSPs and would consist of a demonstration of what treatments would remove the range of substances of concern and then installation of the treatment and ensuring that the treatment is optimised by operational monitoring. Such an approach lacks the simplicity of the current pass/fail approach but it provides a much greater assurance of safety at all times. The additional advantage of such an approach is that it provides a more elegant means of addressing the problem of mixtures of contaminants. While mixtures are currently dealt with on ad hoc basis, e.g. nitrate and nitrite, there is a need to determine which mixtures are really important and at what concentrations they become important. Just as with individual chemicals the potential toxicity is dependent on both the concentration and period of exposure, and interactions are almost invariably additive between substances with a similar mechanism of toxicity, except for a very small number of exceptions.

One of the issues that is also under discussion is how can different risks be compared? Quantitative risk assessment (QRA) has contributed to this question and has demonstrated that the risks from pathogens are greater than the risks from disinfection by-products (Craun et al., 2001). QMRA is being actively developed for microbiological risks. However the subject needs to be considered much more widely in order to provide a transparent presentation of the costs and benefits of particular standards since not only will there be a point of diminishing returns, but the increasing pressures on water resources will certainly force a reappraisal of which water sources can be used to provide drinking water.

12.0 Summary

The importance of clean drinking water has been recognised for thousands of years, even though the actual causes of waterborne diseases were not identified until the late nineteenth century. Standards and guidelines for drinking water have evolved over the past 100+ years and are continuing to evolve as knowledge increases. Standards are important in providing a basis for judging the safety of water supplies but they are also important in ensuring the acceptability of drinking water, providing a benchmark for water treatment and in some cases a means of reassuring consumers. There are many influences on standards and not all standards are based on health, so care must be taken in interpreting any exceedence of a standard. The most important standards relate to the prevention of waterborne disease caused by pathogens that reach water sources in faecal matter from humans and animals. The current standards are for microbial indicators of faecal contamination but these are insufficient on their own and operational monitoring of treatment processes to ensure that they are working efficiently is also important. Any exceedence of a faecal indicator requires urgent investigation to assess whether there is a risk to public health. Many chemical contaminants can be found in water from natural sources and as a consequence of human activities. Standards for these are mostly based on health, although some are political. WHO in its Guidelines for Drinking-water Quality provides information on a wide range of potential chemical contaminants but it would not be appropriate to simply incorporate all of these into national standards, which should take into account local issues. Standards for chemicals usually incorporate a significant margin of safety and an exceedence of a standard does not necessarily mean that the water is unsafe. Some of these standards also relate to the acceptability of drinking water, particularly in terms of taste, odour or discolouration. New approaches to assuring drinking water safety and quality are being introduced, particularly Water Safety Plans, which provide a holistic management tool to prevent problems arising.

Annex 1 Description & discussion of standards for chemical contaminants

Introduction

This annex considers all of the mandatory chemical parameters in the European Directive 98/83/EC on the quality of water intended for human consumption and the additional parameters considered in the Water Supply (Water Quality) Regulations 2000 in England. This information should be considered as illustrative because standards do change. and the Directive may also be revised at some stage within the foreseeable future. However, the values and basis for the values for most substances are likely to remain unchanged for a considerable time. The WHO Guidelines contain many more substances but as indicated in the text, it is neither necessary nor appropriate to include all of these substances in the standards. The values are given in micrograms (µg) per litre or milligrams (mg) per litre. A milligram is one thousandth of a gram and a microgram is one thousandth of a milligram or one millionth of a gram.

Acrylamide – 0.1 µg/litre

Acrylamide is found widely in cooked food where it is formed in the cooking process. It is also a widely used industrial chemical but its primary route into drinking water is as a consequence of its presence as residual monomer in polyacrylamide polymers that are used as aids in the coagulation process for drinking water purification. Coagulation is an important treatment process and is one of the significant barriers to pathogenic microorganisms and to many chemicals that can adsorb onto particles in the water. The standard for acrylamide is modified from the WHO Guideline value of 0.5 µg/l because the lower value is readily achievable. The Guideline value was derived by a theoretical mathematical model applied to data on a range of tumours in rats associated with a cancer risk of 1 additional cancer per 100,000 population. However, the carcinogenic risk from acrylamide remains uncertain and there is continuing research into the toxicity and carcinogenicity, although it seems unlikely that this will impact on regulatory values in the near future. The approach to controlling acrylamide, more properly called acrylamide monomer in this instance, is by specifying the maximum level of monomer in the polymer and also specifying the maximum amount of polymer that can be added. The USA does not specify a value for acrylamide but it is controlled by restricting the level of acrylamide monomer in acrylamide. Different regulatory authorities set product specifications and water suppliers can use only approved products that meet those specifications.

Antimony – 5.0 µg/litre

Antimony is in alloys with copper, lead and tin that may be used in fittings in the drinking water distribution system. It is unusual to find antimony concentrations above the standard, which was based on the WHO Guideline value. An exceedence would be unlikely to be of concern for health since WHO has revised the Guideline value to 20 µg/l in the light of new scientific data. The WHO TDI was derived by the application of an uncertainty factor of 1000 to a 90 day study in rats in which the NOAEL was 6.0 mg/kg body weight per day. The uncertainty factor reflects inter and intraspecies variation and the relatively short duration of the study although the toxic endpoints were not severe. The Guideline value is based on an allocation of 10% of the TDI to drinking water.

Arsenic – 10 µg/litre
Arsenic occurs naturally in drinking water sources but not all sources are affected. Arsenic contamination in groundwater sources is a significant problem for many countries around the world, although the problem in Europe is relatively small. Arsenic is the only substance that has been classified as carcinogenic in man as a consequence of exposure through drinking water. There is considerable debate about the mechanism of carcinogenicity and the actual risks associated with low concentrations in water. The standard and WHO provisional Guideline value was based on reducing the exposure to this substance compared to the previous value of 50 µg/l. This reduction was also based on an allocation of 20% of the 1988 TDI for inorganic arsenic in food (2 µg/kg body weight per day). The PTWI has now been withdrawn but the guideline value was maintained. There is intensive and continuing research activity aimed at trying to clarify the actual risks from arsenic in drinking water at low concentrations and this may have an impact on the regulatory value for arsenic in the future. The USA has adopted the same standard of 10 µg/litre but Health Canada has recommended a guideline value of 5 µg/litre based on their view of the practical achievability by treatment in Canada.

Benzene – 1.0 µg/litre
Benzene is a hydrocarbon present in petrol and is used as a solvent. It reaches drinking water as a consequence of leakage and spills but concentrations are usually very small. The WHO Guideline value is 10 µg/l based on a linear extrapolation model applied to cancer in mice and rats, which is similar to the estimate obtained when extrapolating from epidemiological data on occupationally exposed humans. The guideline value is based on a risk of one additional cancer per 100,000 population exposed for 70 years while the EU standard is based on a risk of one additional cancer per million population. Exposure from drinking water is minor compared with exposure by inhalation and any exceedence of the European standard is still likely to be below the WHO Guideline value. The standard in the USA is 5 µg/litre and this based on technical achievability.

Benzo(a)pyrene – 0.01 µg/litre
Benzo(a)pyrene is a polycyclic aromatic hydrocarbon (PAH) that can occur in drinking water as a consequence of the past use of coal tar to line cast iron water mains. This practice ceased several decades ago but some such pipes are still in service. Occasionally disturbed sediment will give rise to elevated benzo(a)pyrene in water but these incidents are always associated with discoloured water since benzo(a)pyrene is of very low water solubility and is found largely associated with particles. The standard is based on a previous WHO Guideline value derived using a mathematical model for extrapolation of cancer risk. The current WHO guideline value of 0.7 µg/l was also based on a mathematical model applied to the same study in mice but was modified to take account of the unusual experimental design. The USA standard of 0.2 µg/litre is of a similar order.

Boron – 1.0 mg/litre
Boron occurs naturally in some groundwater sources but is also present in surface water that receives treated sewage effluent as a consequence of its use in detergent formulations. It is not easily removed in wastewater treatment or by drinking water treatment. The WHO Guideline value was revised from 0.5 mg/l to 2.4 mg/l after a review in 2009. The WHO Guideline value is based on an uncertainty factor of 60 applied to the NOAEL for decreased foetal body weight in a reproductive study in rats. The USA has no standard for boron, although it does have a non-enforceable lifetime health advisory value of 1 mg/litre. Boron is unlikely to be found at concentrations in excess of the standard.

Bromate – 10 µg/litre
Bromate is occasionally found in groundwater as a contaminant from past industrial activity. However, it is more usually found as a by-product of the use of ozone in water treatment or the electrolytic generation of hypochlorite, which is used as a disinfectant in water treatment, from brine containing high levels of bromide. The WHO provisional Guideline value is also 10 µg/l and is based on the level that is practically achievable while maintaining adequate disinfection with ozone. This is the same as the standard in the USA. Bromate is carcinogenic in laboratory animals given high doses. The most up to date data on the toxicology of bromate indicates that it is reduced in the gastrointestinal tract and is detoxified by antioxidants in the blood (Ballmeier and Epe, 2006, Chipman et al., 2006, Keith et al., 2006). Low concentrations in drinking water do not, therefore, constitute a significant threat to health. This information may result in a re-evaluation of the standard for bromate.

Cadmium – 5.0 µg/litre
Cadmium reaches the water environment in wastewater discharges and from diffuse pollution as a consequence of aerial deposition and fertilizer application. Levels in drinking water are normally very low and the standard is based on rounding the WHO Guideline value of 3.0 µg/l. The Guideline in turn is based on an allocation of 10% of the provisional tolerable monthly intake (PTMI -equivalent to the TDI spread over a month) to drinking water (JECFA 2010). Cadmium accumulates in the kidney and is toxic to the kidney and the PTMI is based on preventing the maximum level of cadmium in the renal cortex reaching more than 50 mg/kg. The Standard in the USA is also 5 µg/litre.

Chromium – 50 µg/litre
Chromium can be found in water sources as a consequence of both natural sources and industrial pollution. The chemical form is important since chromium (6^+) is of much greater concern than chromium (3^+). Although chromium (6^+) is known to be an occupational carcinogen by inhalation, the evidence indicates that it will not be a carcinogen by oral exposure. Chromium is an essential trace element and the recommended minimum intakes are 25 µg per day for women and 35 µg per day for men. The standard is based on the WHO provisional Guideline value, which was first proposed in the WHO European Standards of Drinking Water in 1973. The Guideline value is considered to be provisional because of uncertainties regarding its toxicity, although evidence supports the view that the Guideline value is likely to be conservative because chromium 6^+ is reduced to the poorly absorbed chromium 3^+ in the gastrointestinal tract. The original value in the European

Standards was based on the fact that a concentration of 50 µg/litre in drinking water would contribute less than half of the total daily uptake. In the USA the standard is 100 µg/litre for total chromium, which reflects the uncertainty surrounding the actual toxicity of chromium from drinking water.

Copper – 2 mg/litre

The main source of copper in drinking water is from copper piping in buildings. The concentration can vary from building to building depending on a range of factors but the concentrations are usually highest after a period of extended contact with the pipes, such as overnight. The standard is the same as the WHO Guideline value, which is based on human data and is intended to protect against acute gastric discomfort, such as nausea, in susceptible individuals. This is a concentration effect and occurs at concentrations greater than 2 to 3 mg/l (IPCS, 1998). However, copper is an essential element and the standard is also considered to be protective for long-term exposure, except for individuals suffering from well-recognised deficiencies in copper metabolism, e.g. Wilson's Disease. The USA does not specify a standard for copper at the tap but requires that water suppliers minimise the concentrations by treating the water where appropriate. This is encompassed by a separate rule, the Lead and Copper Rule. The action level for copper is 1.3 mg/litre and is exceeded when 10% of the sites sampled during a monitoring period are greater than this value and this triggers the requirement for remedial action usually by water treatment to reduce the ability of the water to dissolve copper.

Cyanide – 50 µg/litre

Cyanide can cause both acute and chronic toxicity. It can occur in drinking water as a consequence of its presence in raw water, particularly surface water and from the breakdown of a by-product of chloramine formation, cyanogen chloride. The standard is based on a modification of the WHO Guideline value in the Third Edition of 70 µg/l reflecting what is easily achievable with drinking water treatment. The WHO Guideline value was based on a TDI of 12 µg/kg body weight derived from a lowest observed effect level (LOAEL) of 1.2 mg/kg body weight in studies in pigs, which is considered to be conservative because there are uncertainties over the biological significance of the changes observed. Only 20% of the TDI was allocated to drinking water. WHO in the Fourth Edition determined that it was no longer appropriate to set a guideline value. The standard for cyanide in the USA is 200 µg/litre based on short-term exposure.

1,2-Dichloroethane – 3.0 µg/litre

1,2-dichloroethane is used as an industrial intermediate and occasionally as a solvent. It can reach surface water through discharges but when it percolates from the surface into groundwater it can remain for a very long time. The standard is based on the WHO Guideline value of 30 µg/l that is based on the use of a theoretical mathematical model for cancer risk applied to laboratory animal studies in which male rats developed haemangiosarcomas. The standard assumes a risk of 1 additional cancer per million population exposed for a lifetime, a risk 10 times lower than that used in the WHO Guideline value and which is, therefore, highly conservative. The standard in the USA is 5 µg/litre based on technical achievability.

Epichlorohydrin – 0.1 µg/litre
Epichlorohydrin is an industrial intermediate used in the manufacture of some epoxy resins and ion exchange resins used in water treatment. It is highly reactive and is relatively easily hydrolysed in water. It is not monitored in treated drinking water but the standard reflects what can be readily achieved by control of the residual epichlorohydrin in the resins used in drinking water treatment. These resins are regulated to achieve the standard. The WHO provisional Guideline value of 0.4 µg/litre is based on a TDI derived from studies in mice in which there was hyperplasia in the forestomach, an organ which is not found in humans, but which would be more closely identified with the lower oesophagus. An uncertainty factor of 10,000 was applied to an LOAEL of 2 mg/kg body weight but this was adjusted to account for the fact that the animals were dosed for 5 days per week and exposure from drinking water would be for 7 days. There is no numerical standard in the USA but, like acrylamide, it is indicated that it should be controlled by product specification.

Fluoride – 1.5 mg/litre
Fluoride occurs naturally in most waters but is also added to some supplies to prevent dental caries. In some parts of the world there are very high concentrations in drinking water and this can result in adverse effects on the skeleton. However, fluoride is considered to be beneficial at low concentrations. The standard is the same as the WHO Guideline value, which is based on epidemiological data on dental fluorosis and reflects a concentration at which there would be minimal dental fluorosis. However, the occurrence of fluorosis also depends on the intake of fluoride from other sources and, where there is an abnormally high intake from sources other than water, concentrations of fluoride added in artificial fluoridation should take this into account. This standard has been supported by an in-depth study of the effects of fluoride on the skeleton by the US National Academy of Sciences (USNAS, 2006). The standard in the USA is 4 mg/litre with a secondary standard of 2.0 mg/litre on the basis that dental fluorosis was considered to be a cosmetic effect rather than a health effect.

Lead – 10 µg/litre from 2013, 25 µg/litre until 2013
Lead occurs in drinking water almost exclusively as a consequence of the use of lead pipes as service connections, in the distribution systems of buildings and lead solders in connecting lead or copper pipes. Concentrations are usually higher after an extended period in contact with the pipes but the most important consideration is the ability of the water to dissolve lead, which can vary significantly. Lead piping and lead solder are no longer approved for use so problems relate to older installations. Where there is a problem with lead, drinking water is treated to reduce its corrosive properties and this is usually supported by a programme of lead pipe replacement. However, replacement of pipes within houses and buildings is the responsibility of the owner. The 10 µg/litre standard is the same as the WHO Guideline value and is based on the provisional tolerable weekly intake (PTWI) for infants and children to prevent accumulation of lead. The Guideline is conservative since it reflects an allocation of 50% of the PTWI for a bottle-fed infant receiving 0.75 l of water per day and is, therefore protective of all sectors of the population. The USA does not specify a standard for lead at the tap but requires that water suppliers minimise the concentrations by treating the water where appropriate. This is encompassed by a separate rule, the Lead and Copper Rule (USEPA, 2000). The

action level for lead is 15 µg/litre and is exceeded when 10% of the sites sampled during a monitoring period are greater than this value and this triggers the requirement for remedial action usually by water treatment to reduce the ability of the water to dissolve lead.

Mercury – 1.0 µg/litre

Mercury is rarely found in drinking water at more than trace levels, well below the standard, and the mercury found is in the form of mercuric ions, not the highly toxic organic mercury compounds found in some foods. The standard is the same as the previous WHO Guideline value based on an earlier JECFA PTWI for total mercury and was, therefore considered to be highly conservative because the much more toxic methyl mercury does not occur in drinking water. The WHO Guideline value was revised in the Fourth Edition to 6.0 µg/l based on new data on inorganic mercury and an evaluation by IPCS (2003). A TDI of 2 µg/kg body weight was derived from a study in rats and an uncertainty factor of 100 applied to the NOAEL of 0.23 mg/kg body weight. The standard for inorganic mercury in the USA is 2 µg/litre and is similar to the original WHO Guideline value but with a source allocation of 20% of the TDI to water.

Nickel – 20 µg/litre

Nickel occurs naturally in aquatic environments but can be present at higher concentrations in some ground waters associated with nickel rich rocks. It also arises as a consequence of nickel-plating of some fittings, particularly taps, and is also used as the base for plating chromium onto some metal fittings. The Standard is based on the previous WHO Guideline value, which was based on a NOAEL of 5 mg/kg body weight from a study in rats and an uncertainty factor of 1000. New data from animal studies and on humans on the potential for eliciting an allergic response in individuals who are sensitive to nickel, largely as a consequence of nickel jewellery, has resulted in a reduction in the uncertainty and the Guideline value has been increased in the Fourth Edition to 70 µg/litre. The USA does not have a value for nickel.

Nitrate – 50 mg/litre and Nitrite – 0.5 mg/litre

Both nitrate and nitrite occur naturally in the environment as part of the nitrogen cycle. Nitrate is also added to land either as inorganic fertilizer or as organic fertilizer in the form of manures and slurry. When there is insufficient plant growth to take up the nitrate, as at the end of the growing season, then excess nitrate can migrate down to ground water. Nitrite is formed under anaerobic conditions and can sometimes be formed intermittently in distribution when chloramine is used as a residual disinfectant to maintain hygienic conditions in the distribution system. The concern for both nitrate and nitrite is the potential for methaemoglobin formation in bottle-fed infants. Infants are much more susceptible to methaemoglobinaemia, or blue-baby syndrome, and any standards set to protect this group will protect all other groups in the population. More recent data has indicated that the simultaneous presence of faecal pathogens in the supply is also very important as a risk factor in the formation of methaemoglobinaemia. The standard for nitrate, which is the same as the WHO Guideline value, is based on epidemiological evidence, which indicates that methaemoglobinaemia is rarely found at water concentrations below 50 mg/l. Nitrite is a much more potent methaemoglobinaemic agent than nitrate and the Guideline value is based on the fact that it is approximately 10 times more potent than nitrate on a molar basis. However, because of the identical mechanism of action, the two must be considered together and so the standard is met if the ratio of the sum of the concentration of each divided by the standard is less than 1. The standard for nitrite is, therefore, probably conservative. The standards in the USA are 10 mg/litre and 1 mg/litre for nitrate and nitrite respectively but measured as nitrate and nitrite nitrogen. This is broadly equivalent to the WHO values.

Pesticides – 0.1 µg/litre individual substances. (0.03 µg/litre, aldrin, dieldrin, heptachlor and heptachlor epoxide) and 0.5 µg/litre total pesticides.
Except for the four named pesticides for which the standard is the same as the WHO Guideline value, the pesticide standard is not health-based but reflects a political aim to minimise pesticide contamination of drinking water. The standard includes organic insecticides, herbicides, fungicides, nematocides, acaricides, algicides, rodenticides, slimicides, and related products, including relevant metabolites, degradation and reaction products. Although the meaning of the latter group has not been formally defined, in the UK 'relevant' is taken to mean any such products that have similar pesticidal properties to their parent pesticide or possess similar toxicity. Not all pesticides will be found in water, since not all are water soluble, for example aldrin, dieldrin, heptachlor and heptachlor epoxide are of very low water solubility and are no longer used in Europe. In the case of surface waters the occurrence of pesticides will also be intermittent relating to when the pesticides are in use. In order to monitor for pesticides, water suppliers determine which pesticides are used in the catchment and carry out monitoring for those pesticides. WHO has set guideline values for a range of individual pesticides, which is the same approach as in North America, however, for pesticides that have similar mechanisms of action then WHO suggests that they are considered together, if present in significant concentrations.

Polycyclic aromatic hydrocarbons – 0.1 µg/litre (sum of concentrations of benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene)
As indicated for benzo(a)pyrene above, polycyclic aromatic hydrocarbons derive from the past use of coal tar linings for cast iron water mains. This standard is not based on health but derives from a past standard and WHO Guideline of 0.2 µg/l for six named PAH that was, in turn, based on the levels of PAH associated with relatively unpolluted river waters. Although these compounds are removed by conventional drinking water treatment, the past use of coal tar linings means that there is continued relevance for drinking water and they are indicators that the distribution system probably requires rehabilitation. No Guideline values are set in the Fourth Edition of the WHO Guidelines nor by the USEPA.

Selenium – 10 µg/litre
Selenium is an essential trace element and occurs naturally in drinking water derived from selenium rich strata, although the most important source is usually food. The standard is the same as the WHO Third edition Guideline value, which was based on an estimated NOAEL of 4 µg/kg body weight from studies in humans, although this value may be excessively conservative. The provisional Guideline value was increased to 40µg/l in the Fourth Edition but WHO states that it is important to determine the overall intake from all sources when setting

standards for drinking water. The recommended intakes of selenium vary from 6 µg/day in infants (0-6 months) to 35 µg/day in adult males but there is uncertainty regarding the intakes that could induce adverse effects. This is reflected in the USA standard of 50 µg/litre.

Tetrachloroethene and Trichloroethene – 10 µg/litre.
Tetrachloroethene and trichloroethene (tetrachloro- and trichloroethylene) are used as solvents and degreasing agents in industry and dry cleaning. They can be found in groundwater as a consequence of poor handling or disposal, although they are rapidly lost from surface water by volatilisation. The WHO Guideline values are 40 µg/litre and 20 µg/litre for tetrachloroethene and trichloroethene respectively. The Guideline value for tetrachloroethene is based on a TDI of 14 µg/kg body weight from studies in male mice for liver toxicity with an uncertainty factor of 1000. The provisional Guideline value for trichloroethene is also based on a TDI from a study in rats with an uncertainty factor of 100 applied to a benchmark dose for foetal heart defects.
By contrast the European standard is a precautionary value based on public perception of groundwater quality in some parts of Europe. However, the key to dealing with these substances is prevention of contamination by appropriate handling and disposal at source. The standard for each substance in the USA is 5 µg/litre based on what is reasonably achievable by drinking water treatment.

Trihalomethanes – 100 µg/litre (Sum of concentrations of chloroform, bromodichloromethane, chlorodibromomethane, bromoform).
The trihalomethanes (THMs) are by-products of the disinfection with chlorine of water containing natural organic matter. The THM that is usually present in the greatest concentration is chloroform with the others (bromodichloromethane, dibromochloromethane and bromoform) usually present in much smaller concentrations unless the water also contains significant concentrations of bromide ion. The concentration of the THMs is controlled by maximising the removal of precursors and ensuring that chlorine dose is optimised. The standard is based on a concentration that is well below the health-based values, which is achievable by water treatment and allows safe disinfection. It is therefore a balance between achieving water that is safe from pathogens and minimising the levels of unwanted by-products. The USEPA standard of 80 µg/l total trihalomethanes is similar to the European standard of 100 µg/l because the European standard is measured as a maximum and the USEPA standard is measured as an average. The WHO Guideline values for the THMs are chloroform, 300 µg/l. bromodichloromethane, 60 µg/l, chlorodibromomethane, 100 µg/l and bromoform, 100 µg/l. The Guidelines for chloroform, chlorodibromomethane and bromoform are based on TDIs while the Guideline value for bromodichloromethane is based on a theoretical mathematical model for cancer risk. However, the initial studies were carried out using corn oil and newer studies using drinking water have resulted in much reduced toxicity and no sign of carcinogenicity (NTP, 2006). This may result in a future revision of the Guideline value.

Vinyl chloride – 0.5 µg/litre
Vinyl chloride is used in the manufacture of polyvinyl chloride, which is used in the manufacture of some water pipes. This is the main source of vinyl chloride in drinking water. It is not intended that vinyl chloride be monitored in drinking water

but the standard should be achieved by control of vinyl chloride monomer in PVC pipe. The standard is a rounding of the WHO Guideline value of 0.3 µg/litre, which is based on a linear mathematical model for cancer risk, incorporating a modification to take into account pharmacokinetics, in a laboratory animal study. The standard for vinyl chloride in the USA is 2.0 µg/litre, which is of a similar order.

Annex 2 Description & discussion of standards for indicator parameters

The indicator parameters that are listed in the EU Directive on the quality of water intended for human consumption primarily relate to consumer acceptability and operational issues. While monitoring for these parameters is mandatory, exceedence of the standard does not make the supply unwholesome unless the exceedence is considered to present a risk to human health.

Aluminium – 200 µg/litre

Aluminium occurs naturally in many waters and aluminium salts, particularly aluminium sulphate, are used in water treatment as coagulants. Coagulation is one of the major barriers to microbial pathogens and some chemical contaminants, and reduces organic matter in water. Aluminium is not very soluble in neutral waters and forms complex hydroxides that, in turn, form floc. High residual levels can give rise to discolouration and turbidity in treated water. The standard is based on an older WHO guideline value for aluminium that was in turn based on minimising the potential for deposition of aluminium hydroxide floc in the distribution system. WHO no longer sets a guideline value for aluminium. Aluminium at high levels in dialysis fluid was shown to cause dementia in dialysis patients. The identification of aluminium, along with other metals, in the lesions that are characteristic of Alzheimer's Disease and some related conditions led to the suggestion that aluminium in drinking water might be a causal factor in the development of these diseases. However, although some positive associations were identified in some ecological epidemiological studies, analytical studies were generally negative and where positive associations were identified the risks were small. The latest studies have tended to be of higher quality and mostly have not shown positive associations, although a study by Rondeau et al., (2009) concluded that high consumption of aluminum from drinking water may be a risk factor for Alzheimer's disease. Research on other aspects of the aetiology of these diseases has indicated that other potential causes are much more likely than aluminium (Rondeau, 2002, Rondeau et al., 2006, Priest et al., 1998, Stauber et al., 1998). Although an indicator parameter in the EU Directive, the standard is a mandatory National standard in the UK. There is no health-based standard for aluminium in the USA but the secondary standard, which is not enforceable is 50 to 200 µg/litre, depending on the size of the supply and the treatment available.

Ammonium – 0.5 mg/litre

Ammonium is not of direct importance for health but the presence of ammonium in raw water can indicate organic contamination from animal waste or sewage. It may also be an indicator of anaerobic groundwater. Since oxidative water treatment is efficient in its removal, the presence of ammonium in drinking water suggests a failure of treatment. Ammonium combines with chlorine to form chloramine, which is a less efficient primary disinfectant but an efficient secondary disinfectant for maintaining the hygienic status of distribution systems. High concentrations of ammonium in the raw water can lead to a significant reduction in the efficiency of disinfection. The presence of ammonium can also be due to cement-mortar linings of water mains and will reduce or remove residual chlorine in distribution.

Chloride – 250 mg/litre
Chloride is found in raw waters as a consequence of saline intrusion, run-off from de-icing, leaching from soils and discharges of treated sewage or industrial discharges. It can be associated with an increase in the aggressive nature of the water that can result in increased corrosion of metal pipes and fittings. There may also be an associated increase in sodium. While the presence of chloride is not of significance for health, as concentrations increase above the indicator value then the risk of detectable taste also increases and it is taste that is of concern.

Clostridium perfringens – 0/100 ml
& Coliform bacteria – 0/100 ml
& Colony counts – no abnormal change
See section on microbiological standards

Conductivity – 2500 µS/cm at 20^{o}C
Conductivity is a non-specific measure of the concentration of dissolved inorganic ions in the water. It is not of any specific health significance but high concentrations may be noticeable through taste or scaling of pipes and fittings, particularly in hot water systems. A sudden or unusual increase in conductivity is an indicator of contamination and if the measurements are taken from consumer premises then this may indicate that there is back-flow into the water system.

Hydrogen ion – pH maximum of 9.5, minimum 6.5
The pH of the water is a measure of whether it is acid or alkaline but the significance depends on the buffering capacity of the water. This is not generally of health significance but the acceptability of the water may be impaired at high pH while metal solubility may be increased at low or high pH.

Sulphate – 250 mg/litre
Although sulphate is not of particular significance for health, concentrations in excess of 250 mg/l may start to be detectable by taste. At very high concentrations of 500 mg/l it may cause a short-term laxative effect on people who are not used to the water, depending on the associated cations, e.g. magnesium.

Total Organic Carbon (TOC) – no abnormal change
TOC is a non-specific measure of the dissolved organic matter present in the water. High concentrations can lead to the formation of high levels of chlorination by-products such as THMs and so water treatment is designed to remove much of the TOC. An abnormal increase in TOC can be an indicator of treatment failure or of ingress into the system and if it is associated with an increase in assimilable organic carbon (biologically available carbon) then this may give rise to an increase in bacterial growth and the formation of biofilms in distribution.

Total indicative dose – 0.10 mSv/year
& Tritium – 100 Bq/litre
See section on radioactivity.

Turbidity – 1 NTU (Nephelometric Turbidity Units)
Turbidity is due to particles and colloids in the water and these can be due to a range of causes. The indicator value only applies at the treatment works since

WHO considers that turbidity above 1 can compromise disinfection. However, it is very important to optimise the removal of turbidity in order to remove all microorganisms including those that are resistant to chlorine such as *Cryptosporidium*. An increase above the indicator value is, therefore important. Many treatment works install continuous turbidity monitors on the filters and these are used as indicators of an individual filter's efficiency and can indicate when maintenance is required or when a problem arises. Most works operate at much lower turbidity than 1 NTU, below 0.5 and as low as 0.1 or 0.2. The standard in Canada is 0.3 NTU post-filter with a target of 0.1 NTU or less.

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