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WORLDWIDE ASPECTS OF WATER CHLORINATION[1]

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Humanity's need for a safe and healthy environment makes it necessary to think about both the hazards of chlorinated compounds and the dangers posed by water-borne diseases. This article describes the water supply situation in the developing world in terms of these two key considerations.

Water Disinfection and Contamination

Grave concerns have been raised in recent years about the long-term effects on human health of a wide variety of chemical compounds, including many that contain chlorine in their structure. For example, a report prepared a few years ago on health effects relating to re-use of waste water for human consumption stated that chlorine-containing compounds accounted for more than a third of the organic water contaminants showing very toxic carcinogenic effects in subchronic tests.

It is gratifying to know that scientists in the United States of America, as well as in the industrialized countries of Europe and elsewhere, are devoting their efforts to research in this area. It is equally understandable that such work is being done particularly in the industrialized countries, because that is where the problem exists with an intensity that is, at the least, disturbing. Health statistics on morbidity and mortality indicate clearly that diseases associated with the chemical contamination of the environment have reached epidemic proportions. The emergence of these "diseases of the aging" seems to parallel an increase in the frequency with which carcinogenic compounds are detected in the food chain (including water supplies). We must remember, too, the ever-present fear of possible mutagenic and teratogenic effects of some of the halogenated organic compounds.

It is a tribute to science and technology that many of these compounds can be detected and their concentrations measured. Not many years ago the limits of analysis were on the order of milligrams per liter; since then these limits have been reduced by two and often three orders of magnitude. On the other hand, one cannot help but wonder, sometimes, whether the accuracy obtained by sophisticated analytical technology is not far in advance of the significance of the results obtained.

While the halogens in general and chlorine in particular are being placed under scrutiny in many quarters for their

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harmful or potentially harmful long-term effects, let us not forget that these very chemicals have been major contributors to the high standards of living and levels of health enjoyed by most people in the industrialized countries. In fact, the use of chlorine for disinfection of drinking-water supplies was probably the most important public health event in the entire history of water supply technology. Disinfection has virtually eliminated the enteric diseases—cholera, typhoid, and the dysenteries—as causes of disease or death in the industrialized countries. This benefit is accepted matter-of-factly by the approximately one billion residents of the industrialized world.

But let us describe briefly the health and water supply conditions facing the other two-thirds of the population that share this planet Earth. Though there is a great lack of reliable data from countries where the problem is serious, there is almost complete agreement on the fact that diarrheal diseases are one of the most important public health problems, particularly for children, in the developing countries. Mortality due to diarrhea continues to be as high in those countries as it was in the industrialized nations in 1900. In South and Central America, diarrheal diseases have been found responsible for about 28 per cent of all deaths among those 0-4 years of age. And although diarrheas are strikingly more common in children, they also affect adults in developing countries, particularly travellers, a fact that among other things has applications for the development of the tourist industry.

Closely related to the enteric diseases and sometimes overlapping with them are parasitic infections caused by various protozoa and worms. The frequency of these infections in developing countries is often formidable. For instance, a study of schoolchildren in one capital city showed that 78 per cent harbored intestinal parasites and two-thirds of those infected harbored two or more kinds of parasites. The findings are all the more striking because these schoolchildren tended to represent the country's social and economic elite. Among the urban and rural poor the rate of parasitic infection approaches 100 per cent.

These enteric diseases and parasites (except hookworm) have something in common: They are *all* transmitted via the fecal-oral route. This means that the common transmission pathways involve water or food or both; and to interrupt such transmission there is no known alternative to an adequate supply of microbiologically safe water. Mere water supply is not sufficient by itself; the water must be used to achieve improved levels of food sanitation, community cleanliness, and personal hygiene. But sanitation, cleanliness, and hygiene cannot be achieved without safe water, and reliably safe water cannot be achieved without disinfection.

There is a long way to go before all the people in the developing countries have ready access to adequate quantities of safe water. A study carried out by WHO in 1975 (*1*) indicated that more than one billion people then lacked this service. That is not to say they had no water, but rather that they lacked water free of bacteria or parasites and often had to travel long distances merely to get enough water to maintain life.

While this is a sorry picture indeed, we would be remiss if we failed to refer to those situations where public water supplies have been installed. Perhaps the greatest progress has been made in Latin America, but substantial progress has also been made in Asia and Africa. Much of this has resulted from technical and financial assistance provided by organizations in the United Nations system, bilateral assistance agencies, private foundations, and other nongovernmental organizations. Progress has also resulted from tremendous efforts by the governments of developing countries to provide water services for their people.

Appropriate Technology

Many of the systems that have been installed in the past are not, unfortunately, functioning as well as they should. Reports frequently refer to the fact that chlorination equipment at some water treatment plant is not operating. Investigation often shows that no funds are available to purchase chlorine or the parts needed to repair the equipment. In such cases it is hard to tell exactly where the technical problems end and other types of administrative, logistical, and financial problems begin. The logistics of chlorine supply and spare parts procurement are, in a sense, technical problems, because often neither chlorine nor chlorinators are manufactured within the country involved. These problems will eventually be overcome through technical industrial development, but for the moment they remain a constraint on the objective of supplying safe water.

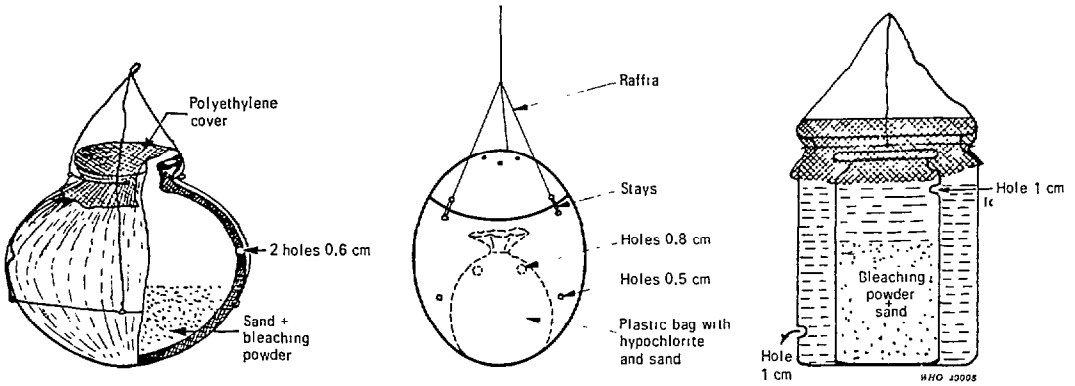
Because of these problems, chlorination technologies in developing countries tend to be simpler than those used in North America and Europe. While large water supply plants in the developing countries usually employ gas chlorination, many smaller facilities use hypochlorite or bleaching powder. Positive-displacement pump chlorinators are quite rare; it is far more common to find drip-feed chlorinators—some of them using ingenious arrangements to add their chlorine solutions to the water at a constant rate. Others, which operate under a falling head, add progressively less chlorine as the container empties. This very common situation causes too much chlorine to be added at one time and too little at another. Too much chlorine results in the water being rejected by users because of its objectionable taste and odor, and this causes them to resort to other sources—many of which are bacterially contaminated and a potential health hazard.

Many millions of people, especially in rural areas, get their water from open wells, streams, ponds, or rain barrels. The chances of disinfecting such supplies by any means are very slim. However, some progress has been made in the chlorination of open wells by using a "pot chlorinator." This is a simple perforated container filled with a mixture of gravel and bleaching powder and suspended in the well. The only restriction on making a pot chlorinator is the imagination, and a wide range of materials (including clay, coconut shell, and plastic) have been used in their construction. These pot chlorinators (see Figure 1) work surprisingly well. Nevertheless, as the bleaching powder slowly dissolves and diffuses through the water, the amount of chlorine dispensed diminishes—a problem similar to that of the falling head, gravity-feed hypochlorinator.

An ingenious device that recently came to our attention is a well chlorinator made from a length of plastic pipe with one end sealed except for a small orifice. This pipe, filled with hypochlorite solution, is installed vertically in the well. The buoyancy of the plastic pipe causes it to float; and, if proper dimensions are chosen, the level of the liquid in the pipe will be the same as the level of the water in the well. When a bucket of water is withdrawn from the well, the wave action unbalances this equilibrium, causing a small quantity of hypochlorite to be released through the orifice. The overall effect is chlorination of the water at a rate approximately proportional to the rate of water withdrawal from the well. Field trials of this device in Tunisia indicate it can effectively disinfect an open well for periods of 25-50 days, depending on the amount of water withdrawn. Its greatest advantage is that it requires no active maintenance other than periodic refilling with hypochlorite solution.

Another point about water disinfection in developing countries is that chlorination of water supplies should be intensified during emergency situations or epidemics. This response provides an essential "first

Figure 1. A few of the many possible designs for "pot chlorinators" used to chlorinate open wells.



[a] Fig. 18 A and C reproduced, by permission, from India, Central Public Health Engineering Research Institute (1970). Fig. 18 B reproduced, by permission, from Talib et al. (1972).

line of defence" for controlling communicable enteric disease and should be applied routinely whenever outbreaks of epidemic or subepidemic proportions occur. We rarely hear of most minor outbreaks because they are brought under control so quickly, thanks largely to disinfection of water supplies with chlorine or sometimes with iodine. Larger outbreaks of cholera, such as those in Malawi in 1974 and Syria in 1977, are not so easy to overcome, but the evidence shows indisputably that the incidence of disease is much greater in areas that do not have water supplies protected by disinfection.

Role of International Agencies

Environmental Considerations

Chlorination of water supplies in developing countries is extremely important because biological pollution, namely the pollution of natural waters by excreta, presents both the greatest single obstacle to controlling water quality and a tremendous threat to human health. While this fact can hardly be overemphasized, it is also necessary to point out that many developing countries are experiencing rapid industrialization and an agricultural revolution. It can be expected that many of the present basic health and environmental problems of the developing countries—e.g., nutrition, income, housing—will be overcome by benefits from industrialization and increased agricultural production. But without substantially improved water and waste-water treatment, there will be concurrent disbenefits from the appearance of industrial and agricultural chemicals and wastes in the water supplies.

At the present time the World Health Organization (WHO), in collaboration with other international bodies and national health authorities, is making a significant contribution to management of this worldwide program through its Environmental Health Criteria Program. The Program, established in 1973, has the following objectives (*2*):

1) to assess existing information on the relationship between exposure to environmental pollutants (or other physical and chemical factors) and man's health, and to provide guidelines for setting exposure limits consistent with

health protection, i.e., to compile environmental health criteria documents;

2) to identify new or potential pollutants by preparing preliminary reviews on the health effects of agents likely to be increasingly used in industry, in agriculture, in the home, or elsewhere;

3) to identify gaps in knowledge concerning the health effects of recognized or potential pollutants or other environmental factors, to stimulate and promote research in areas where information is inadequate, and

4) to promote the harmonization of toxicological and epidemiological methods in order to obtain research results that are internationally comparable.

As part of this work, 10 environmental health criteria documents dealing with major pollutants[5] have been published or are in press, and work on 22 other criteria documents is underway. These documents are specifically designed for use by national governments engaged in setting standards, administering water supply and pollution control programs, and conducting toxicologic and epidemiologic research.

The Water Supply Problem

Although reports furnished by Member Governments vary in terms of accuracy and reliability, the results of a global survey[6] conducted by WHO in late 1975 (*1*) can be summarized as follows:

- Seventy-seven per cent of the urban population had access to a piped water supply. Fifty-seven per cent had house connections, and the remaining 20 per cent had reasonable access to public standposts.
- Seventy-five per cent of the urban population had reasonable sanitation facilities, 25 per cent being served by public sewer connections and the remaining 50 per cent by household systems.
- The contrasting backlog of work to be carried out in the rural areas was quite apparent. There 78 per cent of the population lacked adequate water supply and 85 per cent lacked satisfactory sanitation services.
- It should be noted, however, that these global averages mask considerable differences between regions and countries. Nor should it be forgotten that many urban water supply systems are overloaded to the extent that intermittent supply is required to ensure water for all the metropolitan areas served. In 1970, as much as 54 per cent of the population served by piped public water received it on only an intermittent basis. A considerable quantity of water is also unaccounted for because of undetected leakages, unauthorized use, unmetered supplies, and underregistration of meters. While no firm data are available, enlightened guesses put this "vanishing" water at between 20 to 50 per cent of all the treated water leaving the plant. Many city authorities are unaware of the extent of the problem and are shocked when detailed survey results first reveal the facts.

In addition, there are major constraints on the accelerated provision of safe water and hygienic means of waste disposal. These constraints, identified in the course of WHO's many years of work on all aspects of the water supply problem, can be summarized as follows:

1) *Government commitment.* Without a national commitment to improve the water supply situation by stages in a foreseeable period, and without a definite plan, program, and allocation of resources, there is no hope of achieving any worthwhile results.

2) *Manpower.* High priority must be given to developing the various categories of manpower needed to implement community water supply programs. The progress made in Latin America could not have been achieved without the manpower build-up that has occurred over the last 30 years. Given the present acute shortage of highly skilled professional personnel, attention should now be focused on making the maximum use of auxiliary personnel, and on training the various categories of auxiliaries to do specific jobs. This new focus should go hand in hand with corresponding delegation of authority to the local level and possible regionalization of planning.

3) *Water quality and surveillance.* A great deal of work needs to be done to strengthen national drinking-water surveillance capabili-

[5] Cadmium; lead; manganese; nitrates, nitrites, and N-nitroso compounds; oxides of nitrogen; PCBs; photochemical oxidants; sulphur oxides and SPM; and tin.

[6] Mainland China is not included in this discussion, nor does the "two-thirds" figure referred to include its population.

ties and to maintain the safety of water in distribution systems. At the same time, it should be remembered that the standards of drinking-water quality set forth in the *International Standards for Drinking Water* (*3*) are recommendations; they are not mandatory. As a minimum, bacteriologically safe water that is free of the better-known toxic substances is not difficult to obtain.

4) *Design criteria and technology*. One of the curses of high specialization has been that professional personnel from developing countries have used highly sophisticated design criteria currently used in industrialized countries, without any modification or adaptation. Nor have consultants from industrialized countries, invited to advise the developing countries, been immune from such mistakes. The common result has been construction of massive sophisticated works that soon break down for lack of the skilled personnel needed to operate them, while the funds needed to invest in works serving many more people with a simplified technology have been lost. What is actually required is careful assessment of the real needs of the people, taking into account their way of life, their capacity to pay, and other factors—including the numbers of skilled workers available—so as to design a system that will operate under the conditions at hand.

5) *Community participation*. No public service for a community can be expected to succeed without the participation of that community. A community that is supplied with water is an essential element of the water supply system, just as much as the installed pump or pipe. There is ample evidence that where communities have been ignored the water supply system has failed, and where communities have been taken into confidence and have played an active role, the system has succeeded.

6) *Institutional development*. No program can be implemented successfully without proper organizational arrangements. However, in any given country it should be possible to use local institutions—and to build upon them, modify them, and adapt them as needed—so as to create a viable institutional structure that will permit the program to succeed.

7) *Management*. The importance of competent management—including competent planning and programming, personnel policies, financial policies, etc.—need hardly be emphasized. However, such management skills are not usually developed merely as one gains experience on a job; they have to be acquired. National administrations embarking on community water supply programs must seek early advice from management specialists competent in program formulation and implementation.

In sum, it is only through a concerted effort, including a proper mix of all the activities outlined, that the health aspects of community water supplies in developing countries can truly be improved.

Fortunately, the severe and pervasive water supply deficiencies that exist are beginning to receive attention commensurate to their importance at both national and international levels of government. The United Nations Conference on Human Settlements, convened in Vancouver in 1976, made a clear-cut recommendation to accelerate efforts to provide safe water supply and hygienic waste disposal in all the countries by 1990. The United Nations Water Conference, held at Mar del Plata, Argentina, on 14-25 March 1977, endorsed this recommendation, as well as a series of other community water supply recommendations made by WHO in collaboration with the World Bank (*4*). The final resolution of this latter conference also recommended that the period 1981-1990 be designated "The International Drinking-Water Supply and Sanitation Decade."

Implementing these Water Conference recommendations (*5*), which deal with all significant aspects of the work to be done, will require extraordinary local, national, and international effort. Some idea of the actions required can be gleaned from the following recommendations to Member States contained in World Health Assembly resolution WHA30.33. This resolution (*6*), enacted after consideration of the Water Conference recommendations, builds upon previous World Health Assembly resolutions and WHO activities in this field. The resolution states, in part, that the Assembly:

URGES Member States:

1) to appraise as a matter of urgency the status of their community water supply, sanitation facilities and services, and their control;

2) to formulate within the context of national development policies and plans by 1980 pro-

grams with the objectives of improving and extending those facilities and services to all people by 1990 with particular attention to specific elements such as:

a) the elaboration of sector development policies and plans through comprehensive studies of the national water supply sector;
b) the development of alternative approaches and materials so as to suit best the particular conditions of the country;
c) the identification and preparation of investment projects;
d) the improvement of the operation and maintenance of facilities, including the surveillance of drinking water quality;
e) the assessment of water resources, and their conservation;
f) the prevention of pollution of water resources and spread of disease resulting from water resources exploitation;
g) the improvement of manpower and management capabilities;

3) to implement the programs formulated in the preparatory period 1977-1980 during the decade 1981-1990 recommended by the United Nations Water Conference to be designated as the International Drinking-Water Supply and Sanitation Decade;
4) to ensure that people consume water of good quality by periodic inspections of water sources and treatment and distribution facilities, by improving public education programs in the hygiene of water and wastes, and by strengthening the role of health agencies in this respect. . . .

As an initial step in the implementation of these recommended actions, in late 1977 the Organization provided special assistance to Member States for the conduct of a "rapid assessment" of their water supply situation. These assessments are considered as a necessary precursor to the preparation, before 1980, of national plans for the International Drinking-Water Supply and Sanitation Decade. More than 100 rapid assessments have now been completed and in 35 countries this initial work has been followed by missions to identify projects which will be components of the national plans and which can be quickly developed to the operational stage.

Despite the urgent need for action, neither the World Health Assembly resolution nor WHO's work on rapid assessments should be interpreted to mean that WHO could undertake the accomplishment of these tasks on its own. On the contrary, it is imperative to emphasize that concerted action by all governments and relevant international bodies will be needed if this great objective—to improve the well-being of mankind by providing safe and ample water—is to be achieved.

To conclude, concern for and research into the effects of chlorine and other disinfectants on man and his environment are matters of great importance to the people of the industrialized societies. Those who are involved must continue to display this concern and must continue to conduct research in their efforts to advance the boundaries of human knowledge and understanding. But as these things are done the millions of disadvantaged people in developing countries whose lives and well-being are in daily danger for lack of ample supplies of safe water must also be remembered.

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SUMMARY

Grave concerns have been voiced in recent years about the long-term effects on human health of many chlorine-containing compounds, and researchers are now devoting significant efforts to this subject. It is of course desirable that these harmful or potentially harmful long-term effects be scrutinized this way; but it is likewise important not to forget that chlorine has been a major contributor to the high standards of living and levels of health enjoyed by most people in the industrialized countries. Specifically, the use of chlorine for disinfection of drinking-water supplies was probably the most important public health event in the entire history of water supply technology. In fact, disinfection has virtually eliminated the enteric diseases—cholera, typhoid, and the dysenteries—as causes of disease and death in the industrialized world.

On the other hand, the large part of humanity that lives in developing countries faces quite different conditions. Despite a lack of reliable data, there is general agreement that diarrheal diseases are one of the most important public health problems, particularly for children, and that to interrupt transmission of diarrheal diseases, among others, there is no known alternative to a service providing an adequate supply of disinfected, safe water. A study carried out by WHO in 1975 indicated that more than one billion people then lacked this service.

A major problem facing the developing countries is overuse and misuse of sophisticated water supply technologies brought in from industrialized nations that simply do not conform to local resources or local needs. Another problem is that many people, especially in rural areas, get their water from open wells, ponds, streams, or rain barrels that are difficult to disinfect. Among other activities in this field, WHO is currently seeking to encourage simple technologies that can be adapted to local conditions, and to promote development of devices that can disinfect small, isolated sources of fresh water.

In general, WHO's many years of work on all aspects of the world water supply problem indicate that the following are essential features of any successful program: (1) a firm government commitment to improve the water supply situation; (2) competent management and early procurement of expert outside advice; (3) development of proper organizational arrangements; (4) assignment of high priority to developing needed manpower; (5) strengthening of resources for water surveillance and for maintaining the safety of water in the distribution system; (6) use of appropriate design criteria and technology; and (7) active community participation.

In March 1977 the United Nations Water Conference endorsed a clear-cut recommendation to accelerate efforts to provide safe water supply and hygienic waste disposal in all the countries by 1990. It also recommended that the period 1981-1990 be designated "The International Drinking-Water Supply and Sanitation Decade" and endorsed a number of other community water supply recommendations made by WHO in collaboration with the World Bank.

These and other significant international actions should not be thought to imply that WHO or other international agencies can somehow undertake to solve mankind's water supply problem themselves. On the contrary, it is essential to emphasize that concerted action by all governments, acting together with relevant international bodies, will be needed if the great objective of improving humanity's well-being by providing safe and ample water supplies is to be achieved.

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